July 2022

DSR flexibility for domestic heat pumps

PART 3

Smart home protocols and DSR

Vaillant and geo white paper

Comfort for your home

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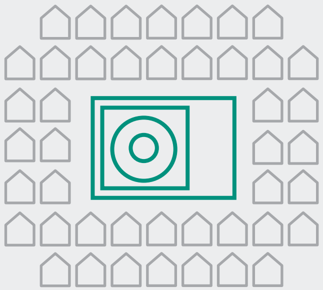
Executive summary

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.

Key findings

#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 white paper is the third in the 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 – 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 – (this paper) 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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Introduction

In earlier white papers, we covered the market situation and the thermal modelling of heat pumps, which at scale can be used flexibly to avoid overloading the low voltage (LV) networks at peak times of day.

In this paper, we discuss the technical in home architectures and protocols that can be adapted to control heat pumps, as well as other energy smart appliances (ESAs) – i.e. EV, solar PV, battery energy storage.

In particular, we discuss how smart thermostats used to control heat pumps will need to be more capable than many existing solutions used to control gas boilers, since heat pump systems are already smart in their own right.

We will also examine the use of the new Connectivity Standards Alliance (CSA) **Matter** standard as a potential smart home control protocol that is likely to gain mass adoption in the home in the next few years.

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.

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.

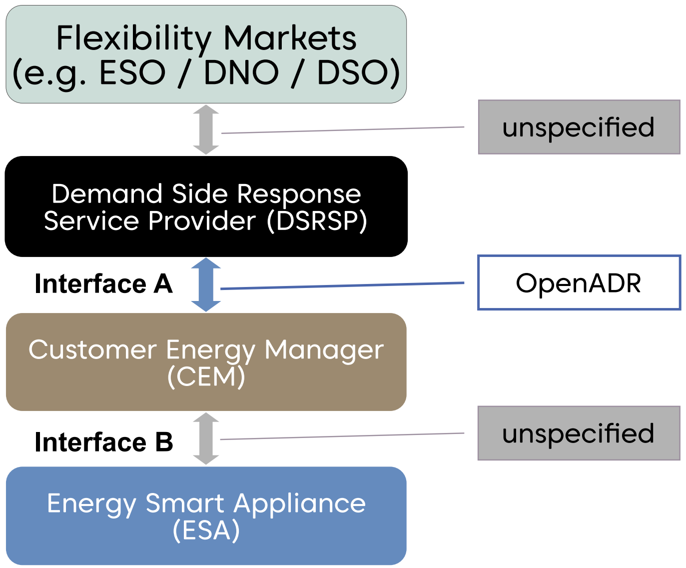


Figure 1 - PAS1878 high-level components and interfaces

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

The PAS1878 architecture is shown in Figure 2, 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 DSRSPs 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.

Energy smart protocols

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).

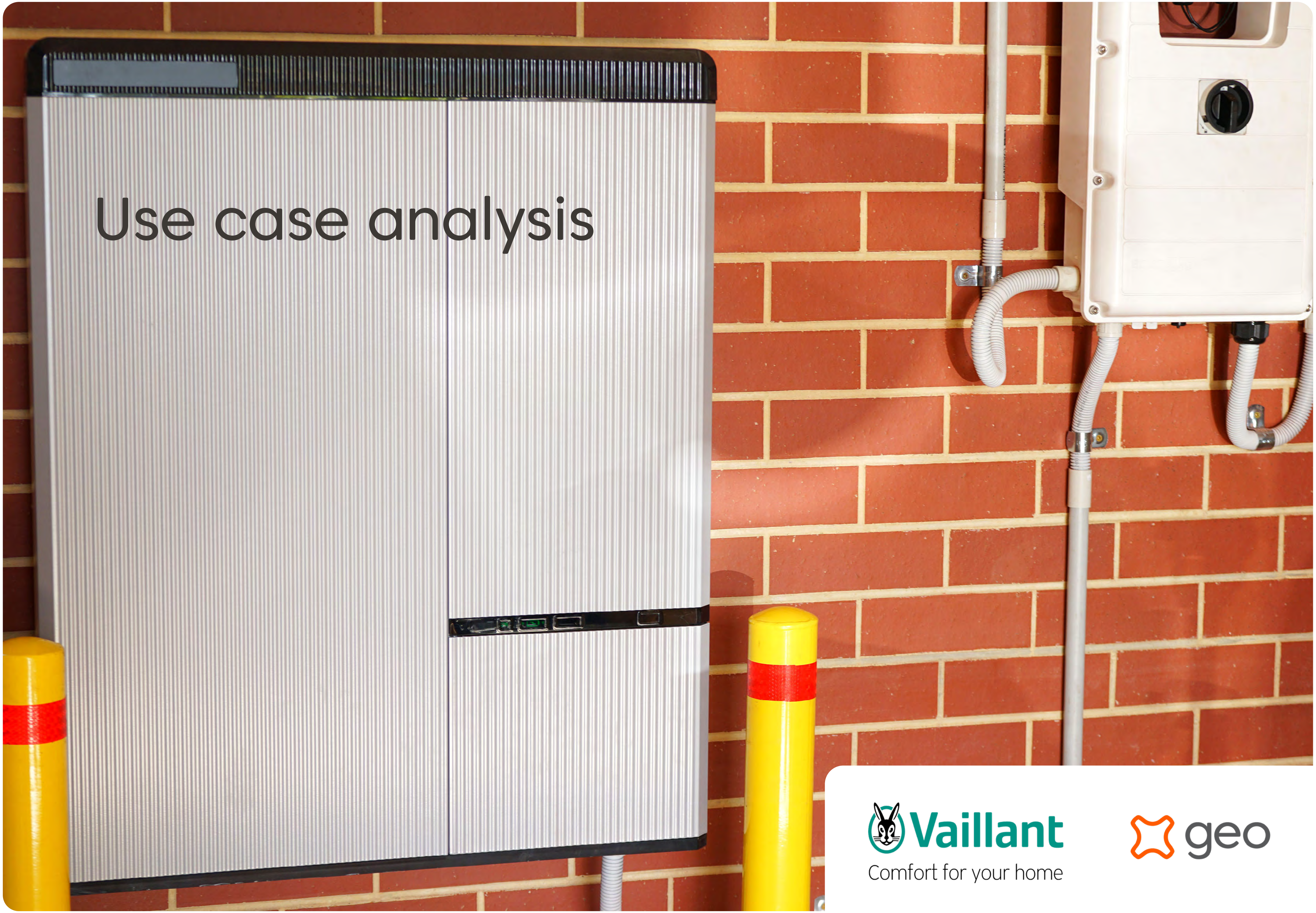
The primary focus of this document is heat pump systems, but many of the principles discussed can also apply to storage, immersion and panel heaters.

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

Use case analysis



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Use case analysis

This document considers some of the use cases for how energy smart heating systems would interact in different modes.

In one scenario, DSR Flexibility provides a potential financial benefit for aggregators, energy retailers and DNO/DSO as part of local grid management. However, these may or may not be passed onto the consumer, who will be directly impacted by these grid driven actions.

Another DSR impacting scenario is the situation in which consumers themselves may wish to save money and reduce their CO_2 impact, and may be utilising other appliances (e.g., battery storage, solar and EV) to run their home efficiently and cheaply. If all homes were to do this, then arguably there is less need for the grid-side management from DSR.

Therefore, two high level use cases are explored:

- UC1 - Enable heating appliances to provide DSR flexibility to grid.
- UC2 - Enable in-home HEMS (Home Energy Management System) cost & CO_2 reduction and self-consumption optimisation in 'routine mode' to achieve comfort levels set by consumer.

Note that the in-home HEMS may or may not be controlled from a physical device in the home (it may well use cloud based services to provide this).

UC1.x : DSR Flexibility

At a high level, DSR is typically is about shifting energy use out of one period and into another, but in practice DSR really involves reducing or increasing instantaneous power for a period of time, with the expectation that the total energy requirements remain constant.

Note that where there are opportunities to store energy (e.g. because there is excess generation on the grid), consumers may be encouraged to switch on and use additional energy rather than letting it go to waste. In such cases this may reduce the demand on subsequent days (e.g. if an EV was charged up more on one day, then it would need less charging on the next day, or if hot water was heated up earlier, then it may need less energy on the next day, assuming the tank insulation is good enough).

These use cases are focused on DSR (grid side) control. There are potential DSR service providers (DSRSPs) which may take advantage of these use cases:

- DNO/DSO – optimising local sub-station level.
- DNO/DSO – optimising for the primary distribution network.
- National Grid/ESO – balancing supply and demand.
- Wholesale energy trading – (e.g. energy retailers) purchasing energy, balancing mechanism & cash-out markets.

The concept of delaying energy demand or limiting instantaneous power demand can be considered as a temporary reduction in power for a period of time. Equally, advancing the energy demand can be considered as a temporary increase in power for a period of time.

The following sub-use cases are considered:

- UC1.1 - heat pump flexibility (reducing power demand)
- UC1.2 - heat pump flexibility (increasing power demand)
- UC1.3 - domestic hot water (reducing power demand)
- UC1.4 - domestic hot water (increasing power demand)
- UC1.5 - power demand forecast to enable prediction of energy demands

These use cases implicitly require an internet connection to allow the DSRSP to make the demands on behalf of the grid actor.

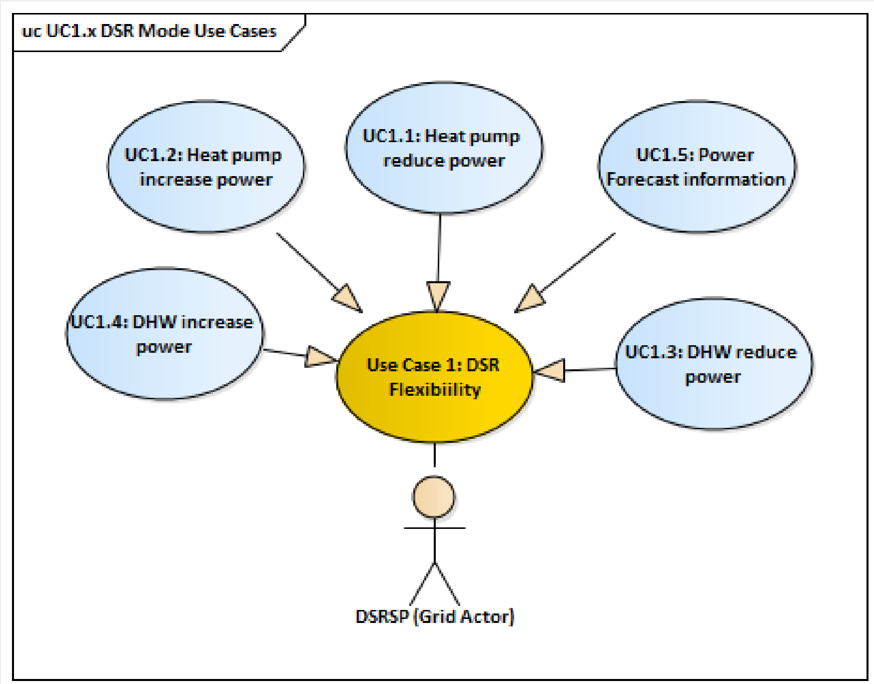

Figure 2 - Use case 1.x DSR Grid control

UC2.x : HEMS (Routine mode)

In addition, there are use cases for home energy management which do not necessarily require an active internet connection to control the electrical loads within the home:

- UC2.1 - As a consumer, I want to limit my peak load import power to avoid blowing my main fuse (this implies curtailing multiple appliances to limit the total home load at any given instant of time).
- UC2.2 - As a consumer, I want to minimise my energy costs (using Time of Use tariffs) across all of my energy smart appliances (EV, heat pump and DHW).
- UC2.3 - As a consumer, I want to minimise my CO_2 impact (using grid carbon intensity data) across all of my energy smart appliances (EV, heat pump and DHW).
- UC2.4 - As a consumer, I want to minimise my cost and CO_2 impact using my local (PV) generation.
- UC2.5 - As a consumer, I want to minimise my cost and CO_2 impact using my local Battery Energy Storage System (BESS) to take advantage of buying energy at cheap rate/low CO_2 and use it later.
- UC2.6 - As a consumer, I want to understand the impact of weather changes tomorrow so I can pre-heat or store energy for later using cheaper tariff / lower CO_2 impact.

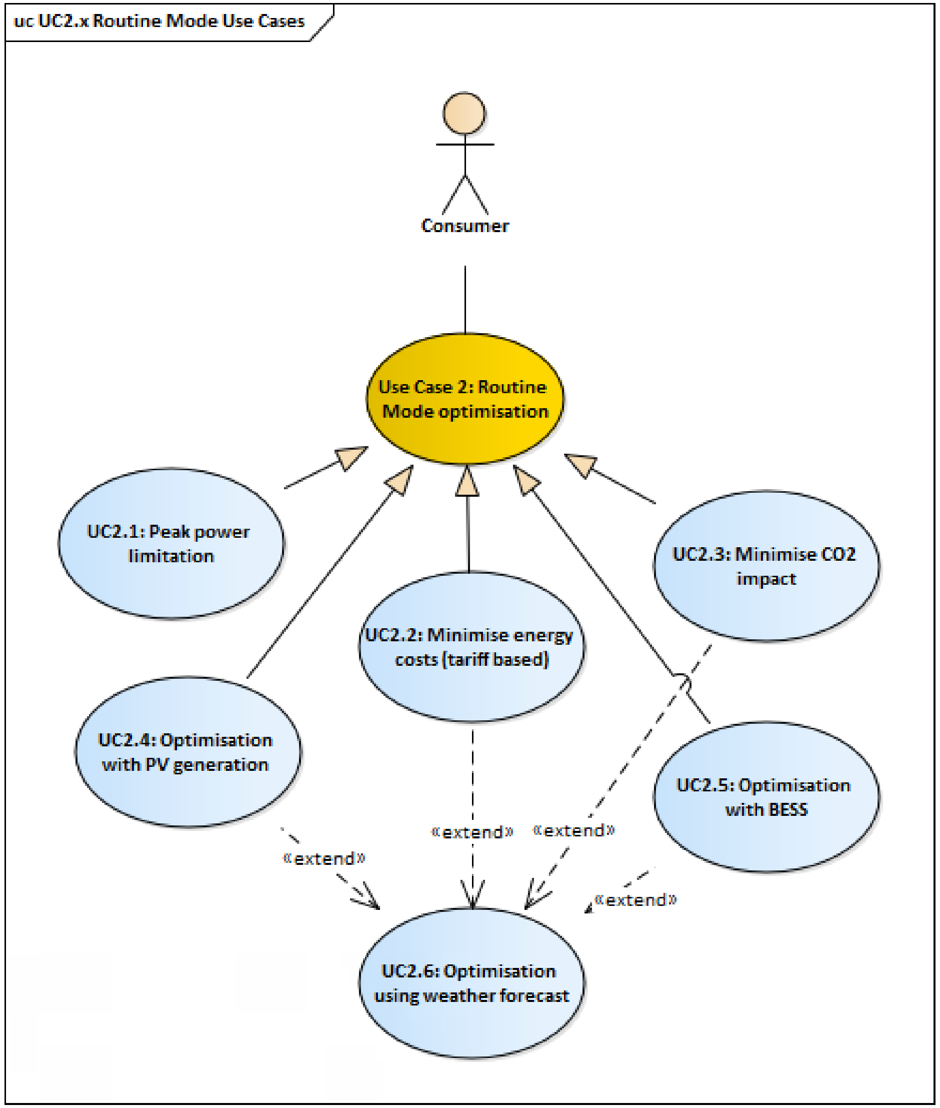

Figure 3 - Use case 2.x routine mode optimisation

Communication architectures

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Typical communication architectures today

In the UK and in some other countries, HVAC communication architectures utilise a mix of wired and wireless heating controls. Wireless heating controls have become popular in the last few years and typically communicate via a radio link (868MHz or 433MHz) to transfer data back to a receiver which will then communicate to the heating appliance via a 230V relay or communication protocol.

Wired heating controls typically utilise a communication protocol or more commonly either a high or low voltage relay to provide an On/Off signal to the heating appliance to call for heat.

Future communication architectures and smart thermostats

In recent years, manufacturers of smart self-learning thermostats have produced several generations of devices which can learn the building's thermal model and then use weather forecast data to predict the building's heat losses. In turn, they can then advance the heating schedule to ensure the home is warm at the right time to meet the consumer's desired heating schedule, or determine that less heat will be needed on warmer days.

Moreover, they encourage users to be green and save energy with features like automatic away mode and remote control of the heating via mobile apps. These features encourage people to ensure that they turn off the heating when they are not at home and in turn save energy and reduce their carbon footprint.

In order to remain compatible with older style thermostats, they too have a simple On/Off control to the gas heater or immersion heater – using a relay type control for the call for heat signal. This allows them to simply replace the old thermostat by connecting into the wiring of the existing heating system.

Wi-Fi and cloud connected

These smart thermostats typically use Wi-Fi to connect to internet-based cloud servers which enable some of the thermal model learning and prediction of heating needs using weather forecasts, as well as allowing the user to remotely control the system when they are away from home and may have forgotten to put the system into vacation mode.

Wireless boiler controls

In order to control the heating system, some smart thermostats require connection via a live / switch-live control of a relay in the thermostat itself. More typically, this control signal is sent via a proprietary 868 MHz or ZigBee based radio link to a mains powered control board located near to the boiler, potentially creating additional complexity for the installer.

It should be noted that with many UK homes, the simplistic live / switch-live wiring does not allow the smart thermostat to power itself from the mains since there is no neutral. Such devices may need to be battery powered or powered from a USB adaptor, or may need to utilise the boiler-sited powered control solution noted above.

This means that in retrofit buildings, smart thermostats are often hard to install where the existing old fashioned wall thermostat used to be. Instead, manufacturers often design the display and temperature measuring component to be a portable device which can be powered using a mains socket, whilst the boiler control box that controls the call for heat signal is radio controlled and mounted near the boiler.

Matter (Connectivity Standards Alliance)

In May 2021, the Connectivity Standards Alliance (https://csa-iot.org/), formerly known as the ZigBee Alliance, announced that the open source Project CHIP (Connected Home over IP) would be rebranded as 'Matter' (see https://buildwithmatter.com).

> Google, Amazon and Apple.. have collaborated to develop an open source... standard

Notably, Amazon, Apple, Google, Samsung and many more global organisations have collaborated since 2019 to develop an open source secure connectivity standard for smart homes using IP.

The Matter standard includes data models (known as clusters) that can be used to read and control 3rd party devices such as smart thermostats and HVAC systems (as well as TVs, door locks, smart plugs, smart light bulbs, blinds, infrared sensors and other home automation devices). These can communicate over 802.15.14 (Thread) or Wi-Fi in a standardised and secure way.

One key element of the Matter protocol is the automatic discovery of new Matter-enabled devices, making it easy for users to add them to their home network.

The Matter standard is intended to enable smart home technology providers to offer their customers native voice control of smart home solutions and a wide range of novel applications. In the smart heating space, Matter will allow consumers to access a wide range of smart thermostats that can work with any smart home system.

Device manufacturers simply need to build and certify their products to work against standardised Matter cluster definitions.

This could, for example, allow HVAC systems to be seamlessly controlled by any smart thermostat as long as they were both certified Matter devices.

> To date, the primary focus of the Matter developers has not been on energy optimisation or whole home energy management.

Matter is an emerging standard and development efforts are focused on ensuring the core capabilities for smart home control are in place prior to its launch in 2022.

So, whilst there are data models for HVAC and smart thermostats in Matter 1.0, there is not yet, for example, a data model for controlling battery storage, solar PV, or tariff data. These may be introduced in a future Matter 1.x roadmap.

How do smart thermostats and heat pump control systems interoperate?

Smart thermostats that support pre-heating compensation capabilities can work well with domestic gas boilers.

However, heat pumps often have a lot of intelligence built into them so that they can operate with peak efficiency. They too can have features that take advantage of the variable pricing in Time of Use (ToU) tariffs, weather forecast as well as the more typical indoor and outdoor temperature sensors. As such, a heat pump system is already smart compared with a traditional gas boiler.

> A heat pump system is already smart compared with a traditional gas boiler

Many heat pump manufacturers have developed their own thermostats, which instead of just having a call for heat, allow the heat pump to know the schedule and temperature set point in advance, so that the heat pump can plan how to get the home to the right temperature at the right time.

> Smart thermostats which are also trying to optimise the home using pre-heating algorithms may actually upset the heat pump's optimisation control algorithms.

Smart thermostat vendors and heat pump vendors should ideally work together to enable consumer choice of a smart thermostat.

There are two key benefits of an open approach:

- Heat pump vendors would not have to develop a custom UI control point, instead relying on partner organisations to develop the voice control, app and user experience of an elegant and low-cost smart thermostat.
- Consumers will not be forced to change their existing smart thermostat if they change their heating system.

Using Matter for heat pumps & smart thermostats

Using Matter as a standardised protocol and data model would potentially allow the smart thermostat and heat pump to work together.

The smart thermostat would:

- Allow the consumer to set the desired temperature (and comfort range around this) against a pre-set weekly schedule in advance.
- Boost (nudge) the temperature up or down for a period of time.
- Allow the user to remotely (via a cloud & mobile app) to set the away mode.
- Automatically determine home occupancy (e.g. with additional Infrared sensors).
- Report the room/zone temperature & humidity.

The heat pump would then be able to use Matter to:

- Know the room temperature and desired schedule & set point (from the smart thermostat).
- Decide how best to achieve this outcome (using other data it may have access to, such as weather forecast and tariff information, either using its own cloud or from local sources via Matter).
- Report back the status and energy consumption to the smart thermostat so the thermostat UI can show the user how efficiently the system has been performing overall.

The authors expect that when using smart thermostats that conform to the Matter standard, it should be possible to enable heat pump control if the two devices 'agree' to disable relevant parts of their more advanced pre-heating algorithms and allow the heat pump to perform this role via a HEMS.

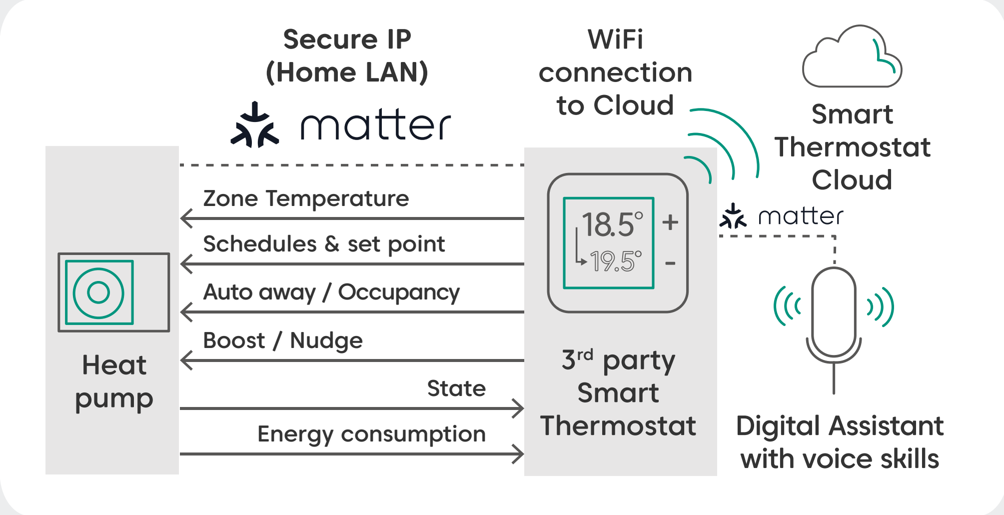


Figure 4 - HVAC and smart thermostat data flows using Matter

A HEMS solution should be aware of all of the appliances in the home (including PV, DHW, battery storage and EV). Most smart thermostat vendors will not want to develop these capabilities as standard.

Whole home energy optimisation architectures

Earlier in this paper we discussed use cases for a more advanced HEMS solution.

Here we discuss possible in-home architectures and outline their respective benefits.

There are three distinct architectures:

- locally controlled within the home
- cloud-2-cloud control
- hybrid approach (both locally connected and cloud-connected)

Local control within the home

In this architecture, the CEM and all ESAs only communicate over in-home networks using standardised protocols (e.g. Wi-Fi / ZigBee).

Note that it is possible that one ESA vendor could host the CEM function in their appliance. E.g. a PV vendor could instruct a heat pump to turn on when there was excess solar.

It should be noted that proprietary protocols and bespoke integrations already exist today. These implementations lack interoperability with other systems, meaning that if a customer has a slightly different requirement or if part of the system fails and needs replacing, then it can be difficult to replace just the single component. Such changes or replacements may mean the entire solution needs to be replaced.

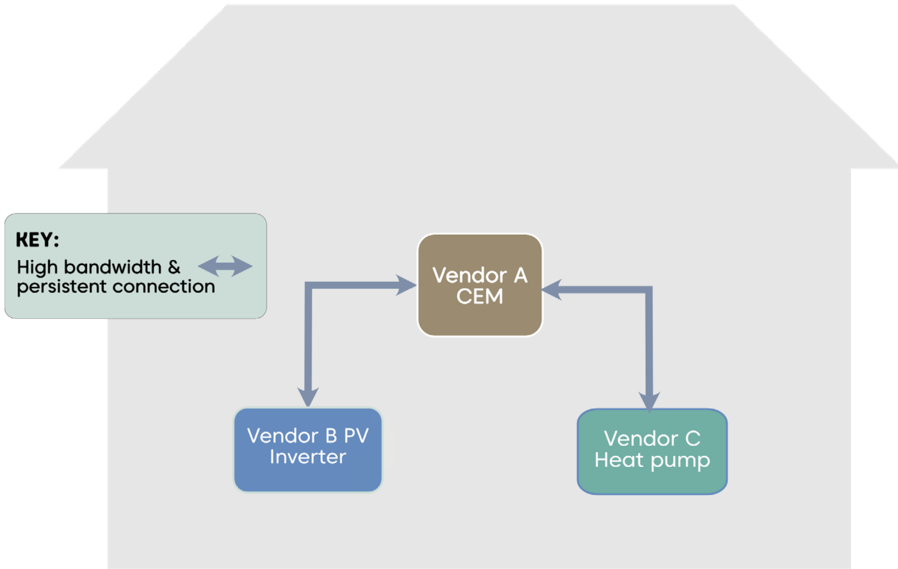


Figure 5 - Local control within the home

Local CEM control (no cloud)

In a local CEM (only) control architecture, the system can continue to operate without needing internet access:

- House builders can build new homes without needing internet installed to commission the system.
- Closed-loop control systems would not be affected if the internet went down (e.g. consider a battery storage system that responds to match home loads).

Data latency in the home LAN is minimised (typically <10ms). However in most modern broadband connections the latency is <100ms, whereas meter readings may be sampled at the order of 1s and inverters and appliances often have much longer response times. As such, this is not a real benefit over internet connected devices in practice.

The volume of data sent to internet cloud services is reduced by keeping the CEM locally in the home:

- Depending on the nature of how the home connects to the internet, this may be an issue (e.g. some rural homes may rely on mobile networks). Where monthly usage is high and the routine operation requires small packets to be sent every few seconds. This could cost consumers more.
- Cloud connection charges – these also cost the manufacturer hosting the cloud service. E.g. some cloud platforms charge for MQTT based services based on the number of packets sent by a device as well as a lower monthly charge for having a device permanently connected that does not send any data.

By having a local controlling CEM, device manufacturers do not need to pay to maintain a cloud service:

- If the entire solution worked over Wi-Fi or ZigBee (or other home networks) then there is no additional cost to build and operate a cloud service.

Many solutions today use this model for relatively simple controls, but equally they have some drawbacks:

- Customer support – may require a site visit to rectify a problem (e.g. to upgrade firmware for new functionality or to fix bugs).
- Maintenance – service engineers cannot remotely obtain diagnostics data to pre-empt and pre-order components that may need routine maintenance.
- Away from home - users cannot interact or monitor their systems away from home using smart phone apps.

Many vendors now have some limited cloud connectivity to their appliances to help support their customers (via diagnostics) and to provide what is expected in terms of an app.

Additionally, some vendors are using their clouds to provide weather and tariff information to their assets directly to help them perform more efficiently and reduce running costs for their customers.

However, the key purpose of this white paper (namely DSR) would be impossible if there was no ability to allow the UC1.x (DSR grid event scenarios) to be controlled remotely. It should be noted that UC2.x scenarios could potentially operate in a standalone fashion without constant internet connections, perhaps connecting to the internet a few times per day to download weather or tariff data.

Cloud-2-Cloud control

As discussed, there are some potential costs for using a cloud connection as well as practical considerations of the fact that the system may fail to operate at all if the internet goes down.

> the system may fail to operate at all if the consumer's internet goes down

In order to allow for a Cloud-2-Cloud architecture, each device in the home that needs to be controlled, must now be internet connected using a secure link.

It should be noted that cloud-based architectures that can turn on or off many thousands of systems in homes simultaneously, presents a cyber security threat as well as a grid stability threat. Governments are naturally looking to add regulations and best practice to minimise such threats (notably the UK PAS1879).

However, there are other advantages of using cloud computing (vs. in home control), namely that in-home devices need to be low cost and easy to replace:

- Whilst they need to have basic communications capabilities (e.g. Wi-Fi connectivity), they may not always have the CPU and memory capabilities that enable them to perform advanced machine learning etc.
- Cloud computing capabilities are inherently more powerful.

It is also important to consider upgrade and security risks:

- Once a device has been deployed to the field, it needs to have security patches and software upgrades with fleet management solutions.
- Ultimately, a device may become so old that it becomes more cost effective to replace it with a newer version.
- If, however more of the logic and algorithms are hosted in the cloud, then there are fewer demands on the embedded firmware teams and so software maintenance could be minimised, trading this for a centralised cloud deployment which is more easily upgraded.

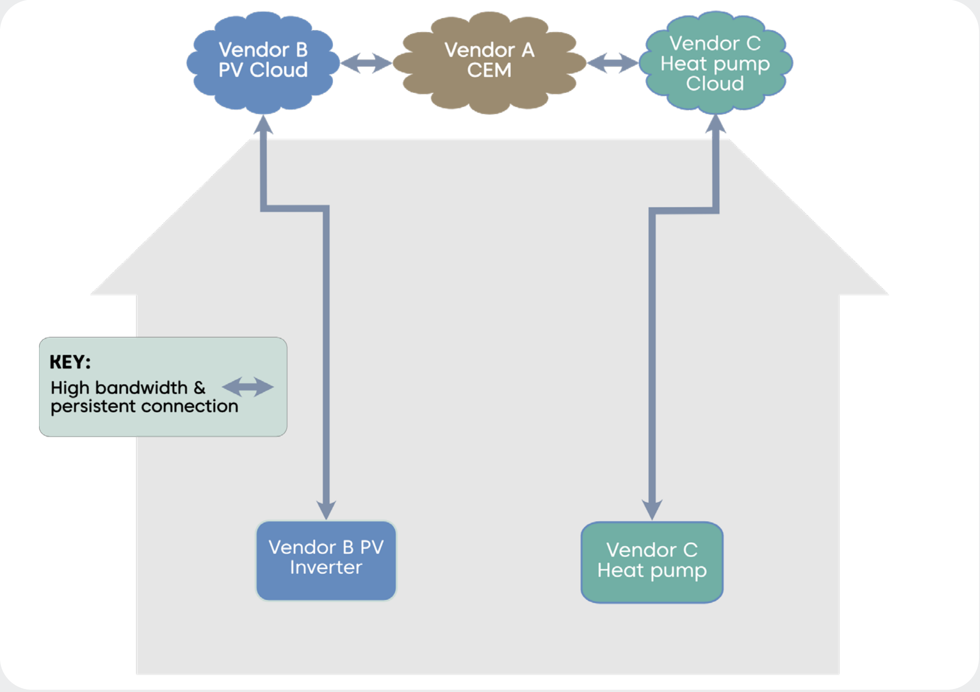


Figure 6 - Control via cloud-to-cloud

Hybrid approach (locally connected and cloud-2-cloud)

The hybrid approach combines the best features of the two earlier architectures (local CEM only and Cloud-2-Cloud only) which can help reduce the amount of data exchanged to the cloud:

- This keeps the cloud and user bandwidth costs down.
- The system stays operational (to some basic level) in the event of an internet connection failure or Cloud-2-Cloud interface failure.

Additionally, the local CEM component can operate in routine mode (UC2.x), with a cloud backed optimisation engine running deep learning AI models to improve performance.

The local CEM can also act as a DSR gateway to allow UC1.x scenarios when required, meaning that the overall solution can ultimately make more informed decisions about which assets in the home can be flexed without impacting user comfort.

The disadvantages of this approach are similar to those already discussed in the cloud-2-cloud only approach: namely that it is still necessary for vendors to maintain a cloud service with the associated costs and that cloud connected controllers could present a potential security risk to grid stability.

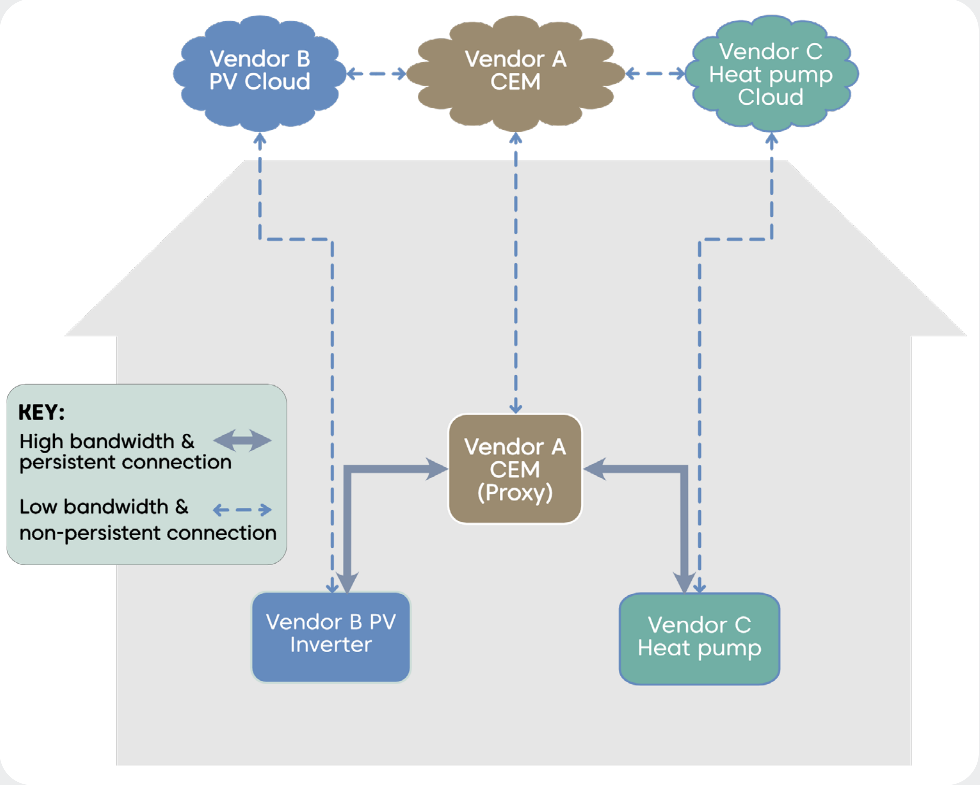


Figure 7 - Hybrid control (locally control with cloud-2-cloud)

Example communication flows between components in the system

Figure 8 shows the components and interfaces in a future home containing PV, BESS, smart heating, EV and other Energy Smart Appliances (ESA) and how these may use the hybrid architecture outlined above.

Here we show the PAS1878 architecture overlaid with a split CEM (a cloud-based CEM) to enable UC1 (DSR flexibility) and local CEM to provide the UC2 (routine optimisation).

The cloud based CEM importantly provides the ability for CPU and data intense optimisation functions to be performed centrally, and also provides the ability to optimise over many homes in a local area, perhaps considering the load across a single sub-station.

The local CEM in the home can focus on doing simpler real-time power flow optimisation between, for example, a local PV or battery storage and the energy consumers in the home.

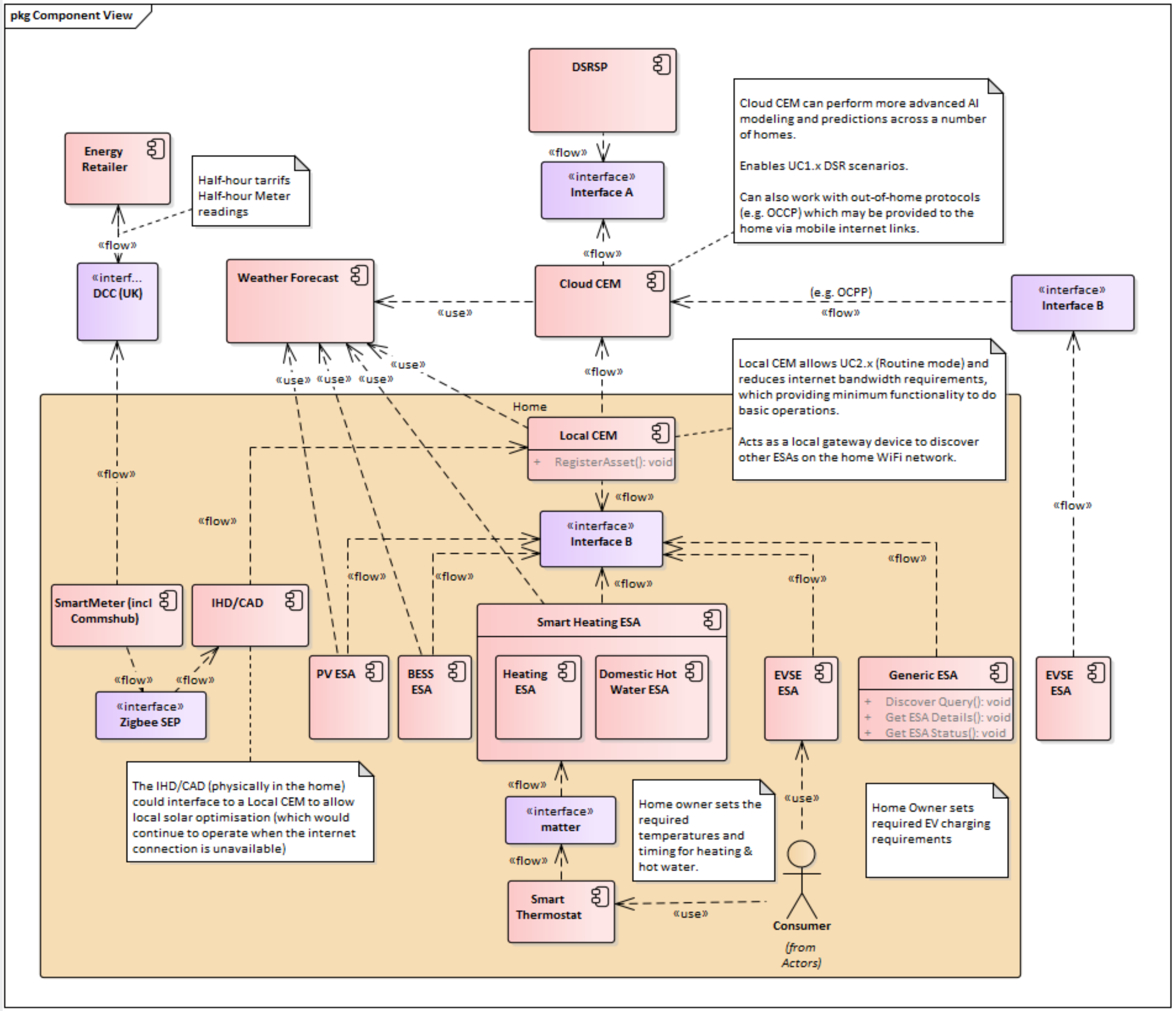


Figure 8 - UML diagram of communication flow between ESAs, CEM & DSRSP

The role of IHDs & CADs

In Great Britain, near real-time smart meter data (with live power readings and tariff information) is accessible via a secure CAD (Consumer Access Device) or IHD (In-Home Display).

The IHD or CAD must be close to the smart meter in order to connect over the ZigBee radio link to the smart meter.

IHDs and CADs can be paired with the smart meter by entities other than the energy retailers by issuing commands from the Data Communications Company (DCC), however the smart meter installers do this routinely when fitting a new smart meter.

Newer generation IHD/CAD devices often contain Wi-Fi radios which allow them to be connected to a Cloud and on the home LAN.

Energy retailers are mandated to supply an IHD to their customer in order to provide visibility of the amount of energy they are using, helping them to reduce their energy requirements.

> **The IHD/CAD with access to meter readings and tariff data offers an opportunity to … act as a local CEM**

The IHD/CAD, with its secure access to live power readings and tariff data, offers an opportunity to provide a secured device which can act as a local CEM (when there is no need for internet) and this can perform the control in routine mode (UC2.x scenarios) where Interface B is in the home.

When the IHD/CAD is also connected to the internet via Wi-Fi and the home broadband router, then it can also connect to its peer cloud based CEM and via Interface A to the DSRSP to perform the DSR services.

Cellular connections to EV Chargers

It should also be recognised that specifically around EVSE (EV chargers), there are a growing number of smart EV chargers which utilise a mobile internet connection, since they cannot rely on a good Wi-Fi signal outdoors where the car charger is located.

> cellular connected EV chargers will not be visible on the local Wi-Fi LAN...

These cellular connected EV chargers will therefore not be visible on the local Wi-Fi LAN to the local CEM, and so may use an additional interface B to connect to the Cloud CEM.

However, electricity is still provided through the customer's energy supply and metered via the smart meter.

It is vital that when performing UC1.x or UC2.x scenarios the local CEM and cloud CEM exchange data relatively frequently.

In practice the load from an EV is relatively slow in its adjustment rate, but other non-ESA loads in the home which could switch on more quickly means that some power headroom must be maintained in peak load management scenarios (e.g. before the fuse blows or MCB trips).

Our proposal

Where possible, the EV charger should be connected over local Wi-Fi (or CAT-5 Ethernet to the home) to reduce complexity with communication latency and intermittent connectivity issues.

EEBUS, Matter and ZigBee could all support this function.

For scenarios where this is not possible and the EV charger would appear outside of the home LAN. In this instance, the CEM needs to communicate with the partner's EV charger cloud.

This can be accomplished via:

- the user manually registering their EV charger with the CEM provider
- the local CEM communicating real-time power reading to its cloud
- the cloud CEM connecting to the EV charger's cloud to read the EV charger state and allowing control of the power limit to the EV charger (ultimately, with the ability to turn it off completely).

Consideration of the EV charger's cellular connection data needs to be factored in (e.g. 30s updates).

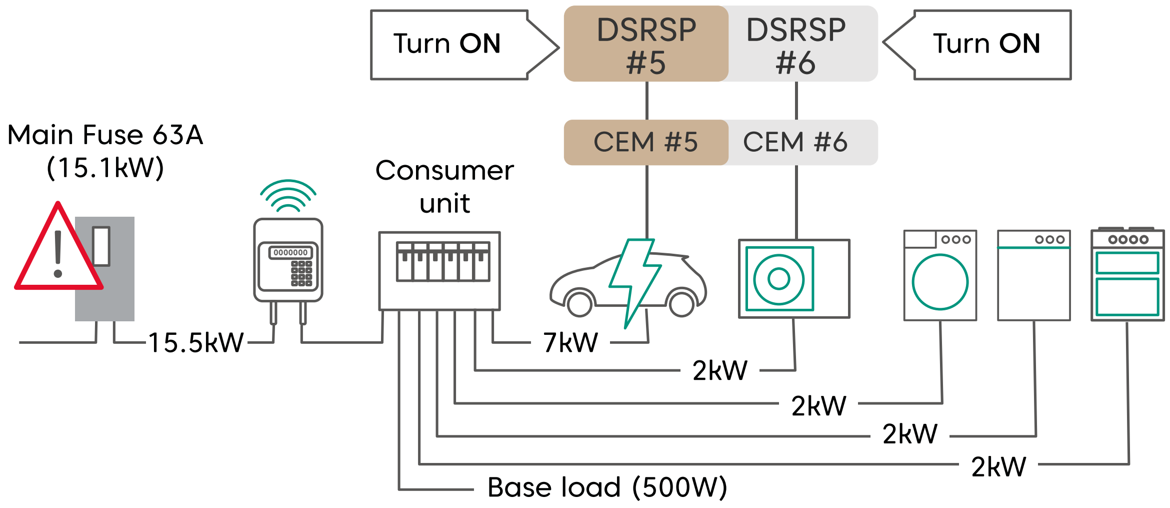
Multiple CEMs may cause issues

It is important to note that whilst PAS1878 allows for multiple CEMs to be operated independently from each other in the same home, this strategy is not recommended.

Consider if there was a grid turn up event, it would be possible for one CEM controlling just an EV charger to turn on the EV charger, and a second CEM controlling a heat pump to also turn on.

When this occurs, it may change the diversity factors that were assumed by the electrician at the time of installation and could result in a secondary switch fuse blowing.

A single CEM could manage peak loads across the home to avoid these scenarios more easily than multiple CEMs.



The multiple CEM problem scenarios are covered in more detail in Paper 1.

Figure 9 - Multiple CEM considerations

Our proposal

It is inevitable that CEMs will evolve and better versions will be produced. More research into solutions that make it easy for consumers to upgrade or switch CEM providers and promote market competition will be needed. Such research should seek to minimise potential safety concerns as well as other undesirable outcomes for the consumer and grid operators.

It should be noted that PAS1878 proposes a new interface C between CEMs and HEMS devices. This does not fall into current international standards and adds costs and unnecessary complexity.

We recommend that EV charger, heat pump, battery and solar PV installers should be trained in how to set up CEM devices, since their operation may be too complex for most consumers.

The importance of metering data in DSR

DSR baselining & asset metering

Baselining

In UC1.x scenarios, there is a need to prove that the DSR request resulted in a change in behaviour.

This can be achieved by either metering the whole home (e.g. using a smart meter) or the individual asset within the home.

Smart meter 10s power readings

The live power meter readings can be read via a CAD or IHD every 10 seconds in GB smart meters. This data set could easily be extended to include a significantly richer set of real-time power quality and voltage information at very little extra cost. Smart meters in many international deployments provide similar data availability, supporting the same DSR-enabling use cases.

Note that, in the GB case, these power readings are not sent to the Data Communications Company (DCC) - only the half-hourly import & export energy readings are sent several hours later for billing purposes.

These power readings can be used to provide baselining data and to monitor that the actual DSR service is performing as requested at the whole home energy monitoring level.

In some DSR scenarios, there may be requirements for separate asset meters (e.g. built into the ESA as well – e.g. heat pump or EV charger).

It is noted that in the GB model, DSR aggregators are currently obliged to provide 1s data to the ESO for some DSR services.

This may be necessary for grid scale industrial and commercial activities. However, in a domestic DSR market, such additional meters would add significant extra cost (and of course carbon emissions) to supply and install.

Further costs and emissions would be incurred to collect and manage the data recorded by the meters.

Finally, it is important to note that every metering device consumes energy in operation and the net financial and carbon cost of that energy must be taken into account in evaluating the efficacy of any such incremental (duplicate) metering activity.

Such additional metering would duplicate the purpose of a smart meter, as well as taking up more space in consumer units or meter cupboards.

The authors note that any requirement for additional asset or grid meters will act as a barrier to competition, effectively forced by current DSR market regulations. Any such barrier should be addressed by industry.

Smart meter power readings in other scenarios

Solar PV self-consumption scenarios using smart meters

When operating in UC2.x scenarios, energy management systems need to know if there is a net import flow or export flow of power. This is especially useful when dealing with solar and battery storage solutions.

For example, many EV charging solutions that implement solar optimisation (which is very popular with EV owners looking to reduce their CO_2 impact) make use of two separate Current Transformer (CT) clamps.

One CT clamp is connected to the PV generation (although in practice this is to help users understand how much total solar is being generated), and the second is connected to the main grid connection to the home.

Ultimately, the decision as to when to turn on the EV charger is dependent on how much unused power is being exported to the grid (via the 2nd CT clamp).

This solution involves running additional wiring to the meter box on the property to understand the export power flow.

Installing these CT clamps can take several hours of a qualified electrician's time and drive a significant incremental cost for the household. However, the data is readily available to the IHD/CAD over the ZigBee connection.

Future homes will have multiple EV chargers - peak load control

Whilst today most consumers do not have an EV, a growing population of EVs will eventually mean that there may be 2 or 3 vehicles at the home which will need charging overnight.

> Smart meters can provide real-time power readings for the entire home to the HEMS.

Clearly, it is not practical to expect consumers to wake up in the middle of the night and swap the cable between their respective vehicles, and so inevitably homes with two or more EV chargers, or chargers with multiple charging cables, will eventually become more common.

These homes will also be limited to a peak import rate (realistically sharing a maximum of 7kW between the EV chargers for single phase homes). The EV chargers will need to communicate with each other to manage the total combined EV charging load to avoid tripping the breaker.

There is therefore a need for peak load management - not just of the EV chargers, but also to consider other high current devices such as heat pumps.

Smart meters can provide real-time power readings for the entire home to the HEMS.

HEMS can dynamically control EV chargers and heat pumps, implementing peak load management using smart meter real-time power readings. This ensures the customer gets their EVs charged and a warm home without overloading their grid connection.

G100 import/export limitation

At present, the UK DNO grid codes require that installers must fit a G100 export limitation device for battery storage and some other devices. These are designed to limit the peak export on the connection to the home.

A G100 limiting solution must ensure that the current exported will not overload the local grid connection (and cut out fuses).

It typically achieves this by using meters (or CT clamps) to monitor and adapt the power of the devices in the home.

For example, a single phase home is limited to a maximum export of 3.68kW. However, a battery inverter and separate PV inverter may each be able to produce 3.68kW. Both devices combined could theoretically export a total of 7.2kW back to the grid (breaching this limit).

To prevent this from happening, the battery and PV inverters must monitor the total export power through the grid connection (each with their own CT clamp and cabling).

However, if their respective meters were to fail (or become disconnected) then they do not know what the actual import or export power is.

The G100 grid codes have type approval test cases that check the behaviour of inverters under this scenario.

Battery storage and PV inverters must act in a fail-safe way (i.e. stop operation) if they lose connection with their respective grid meters and shutdown within 5 seconds.

Our understanding is that the 5 seconds was chosen as an arbitrary value by the ENA which manages the grid codes in the UK. In practice it is understood that the cut-out fuses and cabling will handle longer durations of overload.

The GB smart metering system uses ZigBee, which in order to minimise interference with other devices, has suggested that IHD/CAD devices should only poll the electricity meter once every 10 seconds. As such, many of the smart meters only update their import/export power registers every 10 seconds (even though internally they are sampling the power readings at much higher frequency).

Our proposal to the DNOs (via the ENA) is to review if 10s smart meter data could be used for G100 limitation devices.

This would enable existing smart meters to be used, saving on installation & hardware costs as well as additional space in cramped consumer units and meter boxes.

Alternatively, the GB smart metering specification could be reviewed to see if a shorter poll period (<5s) could be allowed for power readings. However, this change may be difficult to retrospectively implement at scale.

Protocol requirements

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PAS1878 data requirements

Whilst PAS1878[4] is not the sole focus of this document, it provides an example reference model which helps to draw out some specific requirements to be considered.

The typical message flows in the PAS1878 map onto the use case (UC1.x) scenarios as a grid actor (such as a DNO/DSO or energy retailer).

These flows explicitly include requirements for:

- Device registration so the grid operator knows where the asset is on the grid - e.g. using the post code and what type of asset is it.
- Device de-registration (e.g. because of a failure, or user opt-out).
- DSR Offers (intended operation, most delayed, least delayed power profiles)
- DSR events (confirming the start/end of a DSR event from the DSRSP)
- Status reporting e.g. power meter readings.
- Reporting of cyber security breaches.

In the use case (UC2.x) scenarios (routine mode) the HEMS may optimise ESAs by utilising:

- Tariff forecast data (In the UK these may change every 30 minutes, and in some EU countries every 15 minutes).
- Forecast grid CO_2 intensity (CO_2e kg / kWh).
- Optional local generation forecast data (e.g. solar PV prediction derived from weather forecast).
- Optional EV charging energy requirements.
- Optional predicted electrical energy requirement of a domestic hot water tank.
- Optional predicted electrical energy requirement of a heat pump.
- All other (non-smart) home appliances' predicted energy needs.
- Control of the ESA (i.e. limiting or increasing the instantaneous power, or energy utilisation within a set period) to help keep costs low and reduce CO_2 impacts for the consumer's benefit.

Whole home energy optimisation with a single HEMS device

Since the EV and heat pump are independent systems with some varying degrees of flexibility, on their own they cannot produce an optimal low-cost, low CO_2 whole home energy optimisation solution.

Instead, they should ideally be co-optimised by a single HEMS which has overall visibility of the entire home's energy needs. In this model, the HEMS acts as a master control point of all attached systems.

HEMS architecture – where does the control logic sit?

At the time of writing, the HEMS industry is relatively nascent. The need for HEMS is becoming increasingly clear as the need to reduce CO_2 and optimise peak energy demand requires more intelligent optimisation of different and separate energy appliances in the home.

As the ecosystem of ESAs is evolving, some of the intelligence naturally sits within the ESA (where the ESA manufacturer has special expertise of their specific devices) and some of it falls into a more central, agnostic optimisation engine.

For example, a manufacturer of a HEMS system may not be an expert in the internal intricacies of a heating system (e.g. monitoring the flow temperatures of heating circuits) and so could make bad optimisation decisions which impact the user's comfort, which would result in users disabling the HEMS.

However, providing additional data, which is not necessary for the operation of a heat pump, to support HEMS functionality, could add cost and complexity for manufacturers of heating systems. This could lead to fewer manufacturers adopting HEMS standard interfaces.

Ultimately, there needs to be a balance of what information is needed vs. what is desired across the data interfaces.

As such, the authors have focused on exploring the minimum data requirements which will allow the desired functionality of a basic system.

Where data is not exchanged, then it is assumed that the device that produces the data uses it solely for its own needs (and it therefore optimises that part of the system as a standalone decoupled system).

Cyber security requirements

As per the PAS1878 requirements, the main aspects of this are covered by ensuring that data links are:

- encrypted (even in the home)
- authenticated (a trusted device is giving information or controlling another device) i.e. client and server perform mutual authentication

This requires a list of approved trusted devices and management of trust anchors.

Note that other aspects of security are out of scope of this white paper (e.g. firmware meets secure boot requirements, default passwords are not used etc.). These are well defined in PAS1878 and its references to ETSI EN 303 645.

Most modern IoT protocols require SSL (TLS) based on PKI certificates and mutual authentication of both client and server.

The authors are confident that the PAS1878 requirements can be readily met with either EEBUS or Matter.

The management of the trust anchors is something that industry will have to agree on collectively, ensuring that the risks to grid stability as a result of a cyber attack are minimised.

Our proposal

Some standards (e.g. EEBUS) do not have a specific list of trusted device manufacturers, and the users make the decision to join the device to their home.

In other standards (e.g. Matter) the manufacturers must pass stringent conformance testing in order to obtain certification. These devices can automatically be verified via a device attestation check before being allowed to join the network.

Industry will need to jointly decide how best to enable innovation, whilst minimising manufacturer's costs and risk of a cyber attack.

Device discovery & joining

In order to maximise the number of homes and in-home devices made available for DSR, it must be easy for end users to set up (if not semi-automatic).

It must be simple for users to automatically join their ESAs and HEMS together. Equally, users should be able to opt-out of DSR services simply and easily using a UI (e.g. on an App or on the ESA or HEMS itself).

Plug & play

- Users should not need an expert to set up their system.
- Users should be able to switch their broadband provider / home router without impacting their HEMS set-up and any DSR services they are subscribed to.

Discoverable

- Devices using IP connections may be assigned their IP address using the router DHCP service (end users will not want to manually assign their IP addresses).
- Discovery protocols (such as mDNS) allow servers to advertise their services (e.g. a heat pump may advertise itself as an ESA capable device).
- HEMS/CEMs in the home may detect such devices and offer to register and control those ESA assets.

Secure registration

It may be necessary for users to be able to confirm that:

1. They own the asset and have control of it.
2. The asset is physically in their possession and connected to their registered electricity meter (e.g. using its MPAN or post code).

Information flow requirements per use case

Table 1 lists classes of information needed by the CEM and the ESA in order to carry out some of the identified use cases.

This list is not exhaustive but provides a reasonable minimum information set required by a CEM to meet the requirements of UC1.x and UC2.x.

Class of Information	Example	Owner / Flow	Use Case 1.x	Use Case 2.x
Device type	EV / BESS / EVSE / heat pump / PV inverter etc	ESA to CEM	YES	YES
Device manufacturer Info	Manufacturer name, serial number, hardware model, hardware version, software version etc.	ESA to CEM	YES	YES
Security information	X509 certificates, trust anchor (CA certs)	ESA to CEM CEM to ESA	YES	YES
User consent to join devices to CEM	Devices can remember that user has granted permission for HEMS/CEM to control an ESA	Stored in ESA Stored in CEM	YES	YES
Networking configuration	Where devices are not physically on the same network and auto-discovery cannot work (e.g. control via 3rd party cloud) then user credentials may need to be manually set up.	Stored in ESA Stored in CEM	YES	YES
Power source info	Single Phase / 3-Phase (Phase A) grid power limit	ESA to CEM	-	UC2.1
Grid location Info	MPAN, DNO	Stored in CEM	YES	-
Geographic location	Latitude & Longitude for weather forecast	Stored in CEM / Stored in ESA	-	UC2.6
Device power capabilities	Peak power demand, Peak power generation	ESA to CEM	-	YES
Device status	Operational State: Online / Offline / Fault etc	ESA to CEM	YES	YES
DSR service provision	Enrolled for DSR Service? User temporarily opted out?	ESA to CEM	YES	YES
Tariff information	Cost of electricity supply (half-hour data)	CEM to ESA	-	UC2.2
Weather forecast data	Based on geographic location	CEM to ESA (or ESA direct from cloud)	-	UC2.6

Table 1 – High-level Information Flow between CEM and ESA (continues over page)

Class of Information	Example	Owner / Flow	Use Case 1.x	Use Case 2.x
Grid carbon intensity	Based on geographic location	CEM to ESA	-	UC2.3
Device power data	Import/export power, current, voltage, VA, VAR, import/export energy measured by the device	ESA to CEM	YES	YES
Grid connection power data	Import/export power, current, voltage, VA, VAR, import/export energy at the grid supply point	CEM (from Grid meter)	YES	YES
Power demand profiles (ESA forecast)	The expected power consumption by a device over a period of time based on the user requested heating schedule or EV charging requirements that minimise cost / CO_2 and have knowledge of weather information.	ESA to CEM	UC1.5	YES UC2.2, UC2.3
Power production profiles (ESA forecast)	The expected power production by a device (e.g. PV inverter) based on weather forecast information.	ESA to CEM		UC2.4
Demand flexibility profile (ESA Offers)	The range over which power can be adjusted, and how much it can be advanced or delayed without significantly impacting user requirements and system operation as offered by the ESA.	ESA to CEM	YES	UC2.1
Load control information (CEM to ESA)	Explicit requests from the CEM to the ESA to limit its power demand or output power (PV, BESS) for a period of time.	CEM to ESA	-	UC2.1
DSR control information (CEM to ESA)	Explicit request from the CEM to the ESA to charge or turn on (turn up), or discharge or turn off (turn down) at a set power for a set duration.	CEM to ESA	UC1.1 UC1.2 UC1.3 UC1.4	-

Table 1 – High-level Information Flow between CEM and ESA

Example protocol implementation

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We have considered two scenarios:

1. Develop a new standard
2. Re-use an existing standard

In general, for wide-scale adoption and to enable greater interoperability, it is often better to re-use or adapt an existing standard rather than create a new competing standard. Developing a new standard may take several years and risks low adoption if an equivalent competing standard already exists.

It should be noted that PAS1878 considers OpenADR as the standard interface between the DSRSP and the CEM (Interface A).

However, the in home interface between the CEM and the ESA (Interface B) requires additional features such as automatic device discovery and security, as well as sharing of power consumption, power limitation, incentive (tariff) information and power profile forecasting.

> "the in home interface between the CEM and the ESA requires additional features"

The authors have therefore considered exploring if EEBUS is a suitable standard. It already has some adoption in EV charging solutions, heat pumps, solar PV, battery storage and home appliances to unlock home energy management and DSR use cases.

As highlighted earlier, thanks to its adoption by Amazon, Apple, Google, Samsung and others, Matter may in the fullness of time also support the same concepts and capabilities as EEBUS.

In the next section, we discuss Matter and EEBUS features which appear similar in terms of security and auto-discovery in the home. Both are intended to work over secure IP networks.

EEBUS provides a set of defined use cases and an electrical data model. This makes it worth understanding in greater detail to comprehend its capabilities and applicability to the use case requirements outlined above.

Matter is an open source, royalty free home automation connectivity standard. It aims to be the foundation for connected things, simplifying development for manufacturers and increasing compatibility for consumers.

It has four key principles:

- simplicity
- interoperability
- reliability
- security

The standard is combined with an open source SDK (Software Development Kit), test tools and a certification programme. It has already been adopted by over 200 companies including silicon vendors, device manufacturers, smart home controllers and retailers.

Matter has been developed by the Connectivity Standards Alliance (CSA) which was previously known as the ZigBee Alliance that developed the Smart Energy Profile (SEP) used in many smart metering solutions.

Matter stack

The Matter stack is designed for low overhead MCU processors (with small amounts of RAM and FLASH).

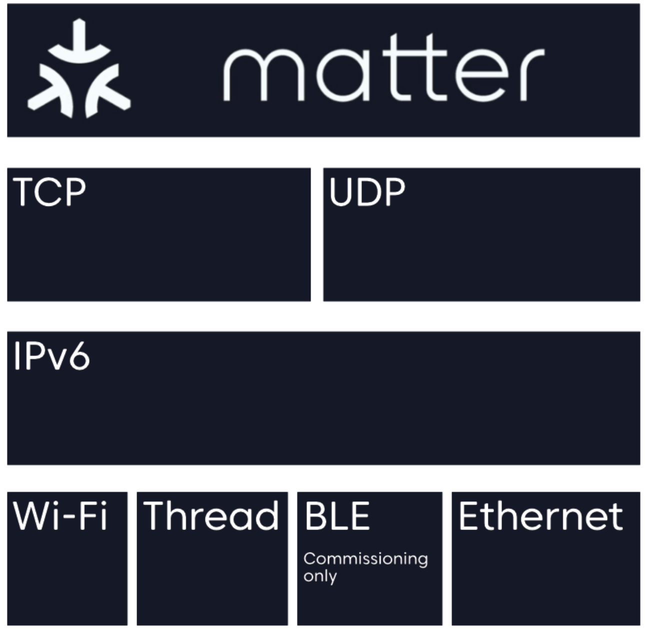
Built upon existing physical layers (Wi-Fi, Thread, Bluetooth Low Energy (BLE) and Ethernet), it can support different operational needs, from radio linked ultra-low powered battery devices, to mains powered devices connected via hard-wired Ethernet cables.

Above the various physical layers sits IPv6 and a combination of TCP and UDP based protocols.

Notably, it uses mDNS-SD for service discovery on a LAN or other IP network. BLE is only used to help commission devices and can make it simpler to join Wi-Fi or Thread networks.

The Matter application layer adds:

- security (AES-128 CCM encryption with 128-bit AES-CBC)
- simplified setup & control
- interoperable data model and interaction framework (commands)



Matter Clusters

Matter builds on ZigBee clusters which allow component functions (such as a temperature sensor) or an actuator (such as an LED light) to have defined attributes and commands.

Devices can be built up from multiple clusters. Controllers can auto-discover the device and its supported capabilities.

Joining and binding

Once a device is joined into a Matter network it can be securely bound to another device by an administrator.

E.g. a wireless light switch device can be bound to a wireless controlled LED lamp device so that operating the switch can turn the LED lamp on or off.

Certification

Products will have to be certified through a testing regime to use Matter branding. This aims to make it simpler for consumers to know that their products will work together.

Security

Security is at the heart of Matter. Several intrinsic features are built into the standard:

- Device attestation - allows consumers to know if the product they have purchased is a real device or fake. It uses a Distributed Compliance Ledger (DCL) built on block-chain technology to allow verification of devices.
- Mutual authentication - all parties are mutually authenticated as part of the secure link establishment.
- Secure communication - all links are encrypted and authenticated.
- Secure storage - especially of private keys.
- Secure firmware updates - with links to the latest OTA firmware listed on the Distributed Compliance Ledger (DCL)

Supported devices in Matter 1.0

Matter 1.0 focuses on core smart home devices such as lighting, electrical (smart plugs and smart light bulbs), door locks, blinds and shades (openings), safety and security sensors and cameras, TVs and HVAC controls (including smart thermostats).

It also allows legacy devices (e.g. those connected via Z-Wave, ZigBee or other proprietary protocols etc.) to appear as standard Matter devices via bridges.

Finally, controllers allow home automation providers or digital assistants and mobile apps to control the devices.

Devices can be grouped together and scenes can be created to control multiple devices with a single command (e.g. a user defined night time scene may turn off all the lights, lock the doors and ensure all the curtains and blinds are closed).

It is expected that beyond Matter 1.0, more capabilities will be added.

EEBUS (see www.eebus.org) is an international communications standard for intelligent networking of applications in a networked home (smart home).

Devices can use EEBUS to exchange information regardless of the manufacturer or technology. HVAC manufacturers can use EEBUS to communicate with connected units from other manufacturers, to automatically enable energy management for the effective use of energy in the home.

For example, the HVAC manufacturer's ESA communication unit establishes a connection between the system and the internet using the end user's internet router and takes over the task of communicating via EEBUS locally. The internet connection is then only required in order to access the system and EEBUS data remotely via an app.

EEBUS Smart Premises Interoperable Neutral message Exchange (SPINE)

The EEBUS Smart Premises Interoperable Neutral Message Exchange (SPINE) protocol includes resources as well as protocol parts. As a transport protocol using IP, the Smart Home IP (SHIP) protocol is recommended (although not mandatory). SPINE resources and the application protocol sit above SHIP transport in the protocol stack, but are not dependent upon a SHIP implementation being present. SPINE resources were also designed to run over a number of different application layer protocols including HTTPS, CoAP and MQTT. In the latter case, only the SPINE resources would be used, and the SPINE protocol part would have to be replaced by a different mechanism. SPINE resources can be accessed over SPINE protocol with SHIP, HTTP(S), secure WebSocket (over TLS/TCP) and MQTT.

EEBUS Smart Home IP (SHIP)

SHIP mandates the use of the WebSocket protocol (RFC 6455) over TLS 1.2 mutual authentication between all SHIP nodes. The use of the WebSocket protocol allows a connection between EEBUS nodes to remain open for full duplex communication.

Key management procedures, including Subject Key Identifier (SKI), SHIP node PIN and QR code, are defined in the SHIP specification.

Two-factor authentication is possible using SHIP, which also supports three different user interaction modes (above the same TLS implementation) for different levels of device sophistication and customer knowledge.

When using SPINE and SHIP, the EEBUS stack provides mechanisms for device discovery, binding and subscription to ensure secure peer-to-peer communication, as shown in the sequence diagram below.

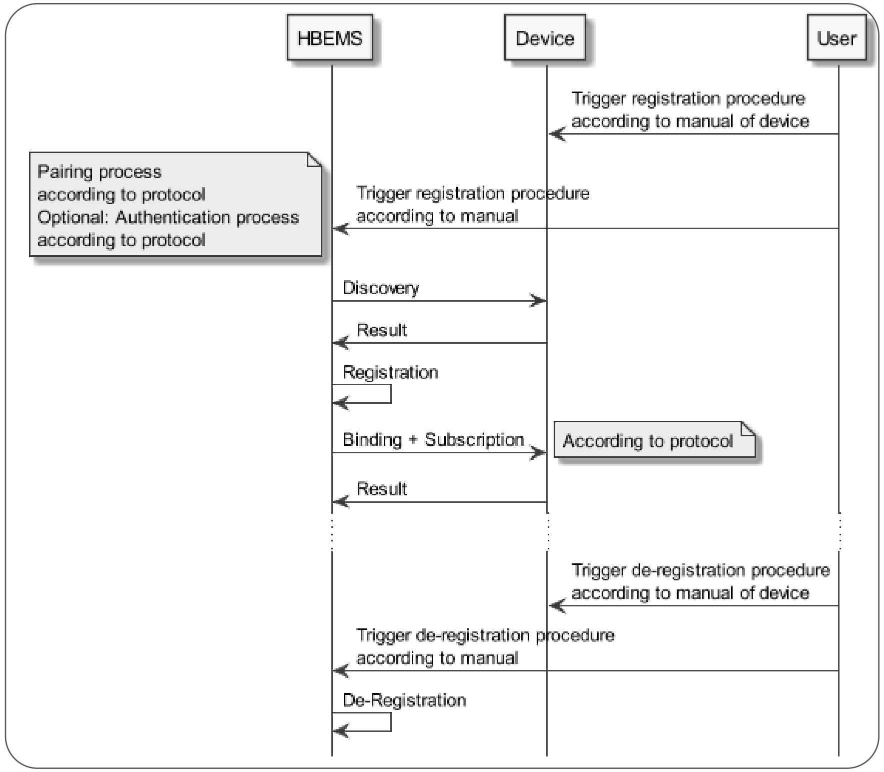


Figure 10 - EEBUS device discovery & registration

The foundation of EEBUS are its well defined use cases. These are designed to support the needs of consumers in automatically managing the energy between devices in the home such as EV chargers, battery, EVs, heat pumps and solar PV.

EEBUS already supports a number of HVAC use cases which complement and build on the use cases outlined in this document.

Such use cases cannot be implemented with Matter at the time of writing, however this situation may change in the fullness of time. As such, we focus the remainder of this section on the analysis of EEBUS use cases which could have a similar role in Matter deployments.

The EEBUS ***Optimisation of self-consumption by Heat Pump Compressor Flexibility (OHPCF)*** use case describes the combination of a PV system and a heat pump. The goal of the use case is to optimise the heat pump's electrical power consumption to match the available PV power output.

This helps reduce the instantaneous power drawn by the home from the grid (helping the grid) and reduces the consumer's energy costs and CO_2 impact.

The system automatically detects whether a compatible heat pump is present and offers a selection of applications for energy management. The CEM controls the heat pump to limit the amount of power it consumes to match the PV power generated.

EEBUS is built around specific EEBUS use cases, and the developers of EEBUS have taken these specific scenarios to ensure that the data model between the energy manager (a client) and the energy appliance (a server) enables the desired behaviour to be achieved.

Use case discovery enables the energy manager to understand the use cases supported by the connected devices.

The EEBUS use case acronyms are explained in Table 2 opposite.

EEBUS Use case	Definition
CEVC	**C**oordinated **EV C**harging
COB	**C**ontrol **o**f **B**attery
ENDF	**En**ergy **D**emand **F**orecast
FLOA	**F**lexible **Loa**d (in preparation)
ISCBC	Increase of **S**elf-**C**onsumption by **B**idirectional EV **C**harging (in preparation)
ITPCM	**I**ncentive **T**able-based **P**ower **C**onsumption **M**anagement
LPC	**L**imitation of **P**ower **C**onsumption
MGCP	**M**onitoring of **G**rid **C**onnection **P**oint
MOB	**M**onitoring **o**f **B**attery
MOI	**M**onitoring **o**f **I**nverter
MPC	**M**onitoring of **P**ower **C**onsumption
OHPCF	**O**ptimization of Self-Consumption by **H**eat-**P**ump **C**ompressor **F**lexibility
OPEV	**O**verload **P**rotection by **EV** Charging Current Curtailment
OSCEV	**O**ptimization of **S**elf-**C**onsumption during **EV** Charging
TOUT	Time of Use Tariff (in preparation)

Table 2 – EEBUS Use cases

In a DSR flexibility scenario, the Home or Customer Energy Manager (HEM or CEM) would need to understand the current state of each of the attached assets

- **user opt-out state** (e.g. is the device opted out from DSR by a local user)
- **current power consumption** (Watts)
- **turn up offer** (how much additional power could the device consume and for how long?)
- **turn down offer** (how much power could the device stop using and for how long?)

It should be noted that in EEBUS, the CEM is a client that discovers and connects to the ESA (a server). This allows the CEM to poll the ESA to request its current power level.

> Heat pumps have similar attributes to that of a Battery Energy Storage System (BESS)

How a heat pump ESA can make DSR Service offers

According to PAS1878, the ESA should make flexibility offers using power profiles with its Intended Operation, Most Delayed and Least Delayed versions. This simplistic model is suitable for devices which have a simple pre-set programme - for example dishwashers, washing machines, EV chargers.

> The flexibility offer model proposed in PAS1878 has some practical complexities for some ESAs which cannot predict their future operation so easily.

Battery storage and heat pump similarities

A heat pump's power consumption will be dependent on a number of factors which could readily fluctuate (such as flow & return temperatures, outside air temperature changes, doors being left open causing additional heat loss, water being drawn to run a bath). This makes it challenging to accurately forecast the power required to operate at optimal levels.

Similarly, other Energy Smart Appliances such as a battery storage system are designed with control loops to respond to dynamic changes in the home electrical load (such as turning on a kettle) which cannot be easily predicted.

Heat pumps have similar attributes to that of a battery storage system, where the current state of charge of the battery is known. In the case of a heating system, the energy stored in the buffer tank or building structure can be derived by measuring the room temperature or water temperature in a buffer tank.

The recent average electrical power consumption of the heat pump can be derived from characterisation (or built-in meter) as well as its average heat output.

Like a battery inverter, the heat pump also knows its minimum (20%) operating electrical power and maximum (100%) operating power.

A battery storage system may have a forecast of typical home load during the course of a normal weekday based on historic user behaviour; in a similar way, the heating schedules from a smart thermostat allow the heat pump to know what its likely operating schedule will be.

Example UC1.x DSR offers

Weather forecast information can be used by solar PV coupled battery storage to understand the likely PV generation - so the battery storage can optimise the amount of pre-charging before a sunny day.

In a similar way, the heat pump can use the weather forecast to understand likely external temperatures which will impact its COP and the heat loss impact through its self-learnt thermal building models.

With tariff and grid carbon intensity forecasts, energy smart devices can determine the cheapest and greenest times to consume energy from the grid.

With these data points, a heat pump can similarly consider its likely heating requirements (between hot water and space heating) over the course of a day and can potentially support turn up events to overheat the home or buffer tank ahead of time.

If a heat pump has the opportunity to pre-charge and store energy earlier in the day (from locally generated PV or cheap grid energy) into a buffer tank or thermal storage, it can make a DSR offer to reduce its electrical load storage during peak times.

During these turn down periods it can extract the stored heat from the buffer or thermal storage by running the circulation pump only (approx 60W) reducing the grid energy demands whilst limiting the impact to user comfort.

We can consider making ***Power x Time*** offers to the energy manager to ensure the total energy gained or lost as well as the electrical power limits are not exceeded.

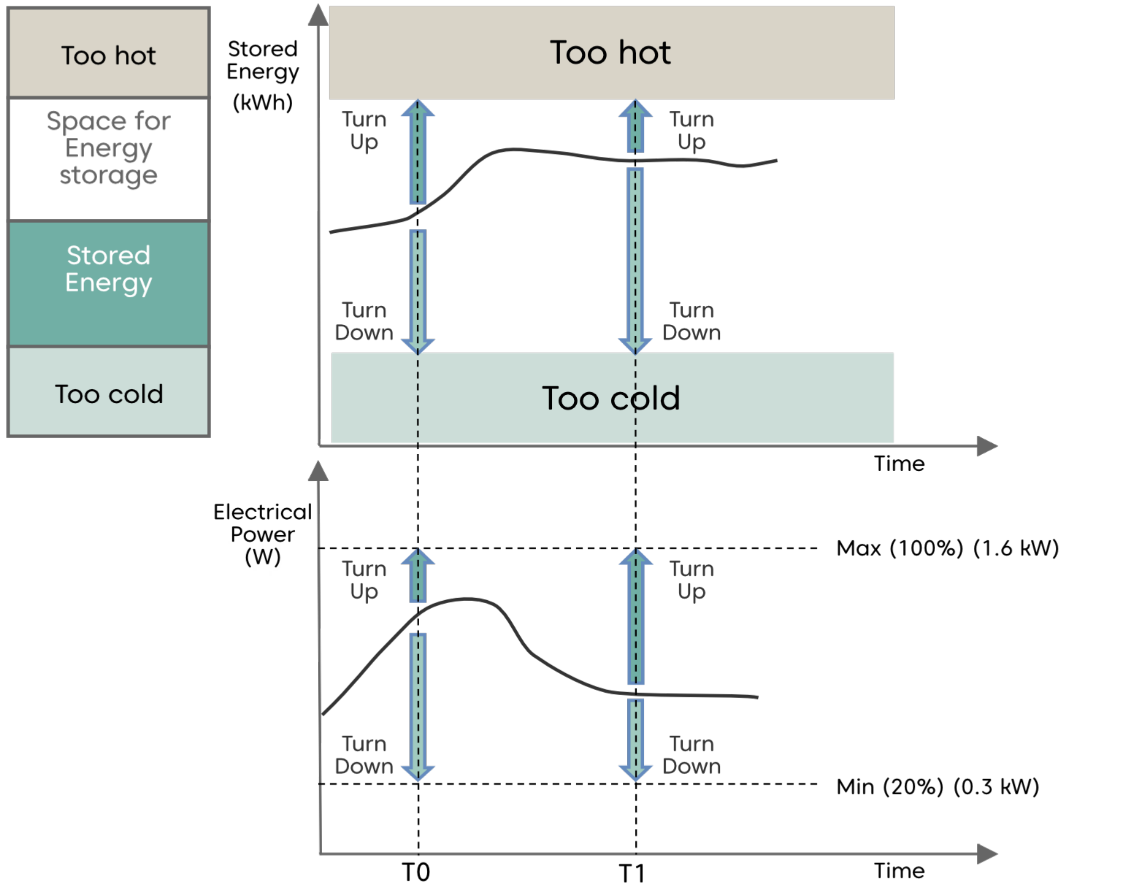


Figure 11 - DSR turn up & turn down offer calculation concepts for energy storage solutions

DSR service offers with EEBUS

EEBUS is defined using SPINE data model, which allows for relatively complex power profiles to be exchanged (more capable than that proposed in PAS1878).

The SPINE function that could be used to model the DSR offers and events, called *SmartEnergyManagementPs*, allows devices to share power profile sequences where power consumption for different time "slots" is defined. Slots can be interruptible or not and start times can be shifted in time.

There is also the concept of "Determined" or "Undetermined" slots for scenarios such as heat pumps and battery storage systems.

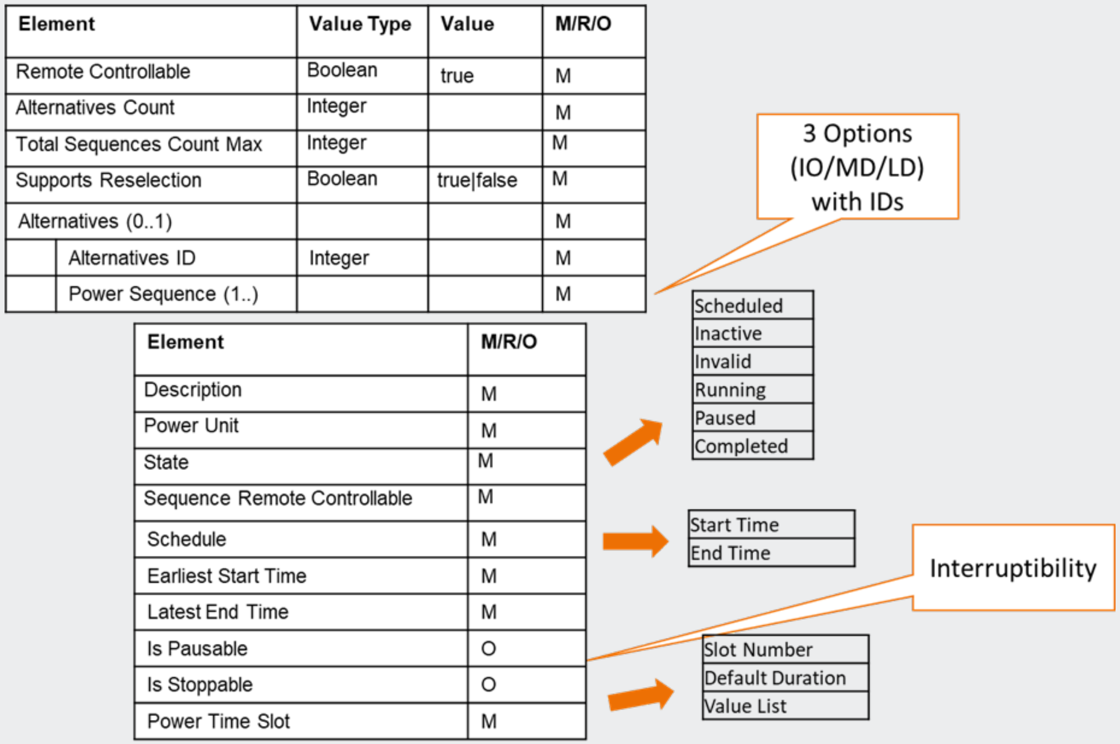
The figure opposite shows a simplified depiction of the corresponding data structure.

Additionally, the ***SmartEnergyManagementPs*** data contains a data element called ***Alternatives*** which represent a series of alternative power sequences. As such the Intended Operation would represent the baseline power profile forecast of what the heat pump plans to do.

- The turn up offer would be computed by adding to the baseline an increase of power as one alternative.
- The turn down offer would be computed again by adding a negative power to the baseline which would result in a second alternative.

This information can be sent by the heat pump to the CEM to allow it to make DSR offers to a DSRSP.

If Matter were to implement DSR offers for UC1.x or UC2.x then it would need to support similar constructs to send offers from the ESA to the CEM.



Element	Value Type	Value	M/R/O
Remote Controllable	Boolean	true	M
Alternatives Count	Integer		M
Total Sequences Count Max	Integer		M
Supports Reselection	Boolean	true|false	M
Alternatives (0..1)			M
Alternatives ID	Integer		M
Power Sequence (1..)			M

Element	M/R/O
Description	M
Power Unit	M
State	M
Sequence Remote Controllable	M
Schedule	M
Earliest Start Time	M
Latest End Time	M
Is Pausable	O
Is Stoppable	O
Power Time Slot	M

Figure 12 - EEBUS SmartEnergyManagePs message structure

DSR service monitoring & peak load control

In the UK, DSR regulations today require that the grid connection point power levels are monitored and the impact of a DSR service can be observed by a change in the baseline power (i.e. what was going to happen before the DSR service was activated) and the actual resulting change in power.

For this reason, it is vital to be able to monitor the grid connection point (or at least the DSR asset itself).

For grid connection point metering, GB SMETS meters can be used which would allow the CAD or IHD to report the real-time power values (at 10s intervals).

The EEBUS *Monitoring of Grid Connection Point* **(MGCP)** use case can provide total home import/export power to other devices over EEBUS as well as to the CEM for reporting to the DSRSP.

Monitoring of an ESA's power consumption can also be performed by the ESA itself. It will need to have a highly efficient and low cost embedded power metering capability to a sufficiently accurate standard.

Note that PAS1878 recommends a 10% metering accuracy, since averaging this across 10,000 systems (assuming unbiased meters) would result in a 1% overall network wide accuracy.

International approach to Domestic DSR using peak load control

It should be noted that in other countries, the approach to domestic DSR is different to the UK (due to the different market structures).

In Germany, the DNOs will likely incentivise consumers to limit their peak demand by reducing their bills if they opt into a scheme which limits their power consumption during peak times.

In the deregulated UK energy market, consumers do not have a direct contract with the DNO, so it is harder for such incentives to be given directly to the consumer. Instead, incentives would likely flow via the energy retailer or DSRSP on an open flexibility market.

In Germany, the DNOs are looking to use the secure Smart Meter Gateway (SMGW) to send a message to the energy manager in the home (using EEBUS as one supported protocol) to actively manage the peak load.

The *"Limitation of Power Consumption"* **(LPC)** use case is designed to manage the supported EEBUS appliances along with the *"Monitoring of Grid Connection Point"* **(MGPC)** to curtail power consumption to a lower limit.

The energy manager would be able to perform peak load management to limit EV charging and other devices to keep the total power under, for example, 6kW between 4pm-7pm.

Minimum requirements

Any protocol (e.g. Matter) would need to support:

- **Monitoring of power consumption** - at appliance level at regular intervals (this could be using a built in meter or based on known state for the type of device).
- **Monitoring of grid connection point power** - reading the smart meter at regular intervals to know if the home was importing or exporting power.
- **The ability to limit the power consumption of appliances** (e.g. set a maximum power limit for a period of time). An EV or EV charger could, for example, be told to increase or reduce the maximum power (or current) to offer to the vehicle, or a washing machine may have to pause its cycle if the heating element would push it over the limit.

Example UC2.x routine mode using EEBUS

There are several EEBUS use case specifications to cover the scenarios given in UC2.x.

These are specifically around routine mode operation (such as optimising of excess PV).

This table maps the UC2.x use cases defined in this document to applicable EEBUS use cases.

Some EEBUS use cases should be used in combination (indicated by a +).

Use cases separated by a semicolon are alternatives.

<table>
<tr><th>UC 2.x</th><th>User story</th><th>EV</th><th>Heat pump</th><th>DHW</th><th>Battery</th></tr>
<tr><td>2.1</td><td>As a consumer I want to limit my peak load import power to avoid blowing my main fuse</td><td>Overload Protection by EV (OPEV); Limitation of Power Consumption (LPC)</td><td>Limitation of Power Consumption (LPC)</td><td>Limitation of Power Consumption (LPC) via Heat pump or direct immersion heater control</td><td rowspan="3">Control of Battery (COB)</td></tr>
<tr><td>2.2</td><td>As a consumer I want to minimise my energy costs (using Time of Use Tariffs) across all of my energy smart appliances (EV, Heat pump and DHW)</td><td>Time of Use Tariff (TOUT) + Coordinated EV Charging (CEVC) + Increase of self-consumption by Bi-directional EV Charging (ISCBC)</td><td colspan="2" rowspan="2">Time of Use Tariff (TOUT) + Incentive Table Power Consumption Management (ITPCM)</td></tr>
<tr><td>2.3</td><td>As a consumer I want to minimise my CO_2 impact (using grid carbon intensity data) across all of my energy smart appliances (EV, heat pump and DHW)</td><td>Time of Use Tariff (TOUT) + Coordinated EV Charging (CEVC)</td></tr>
<tr><td>2.4</td><td>As a consumer I want to minimise my cost and CO_2 impact using my local (PV) generation</td><td>Optimisation of Self-Consumption via EV Charging (OSCEV); Monitoring of Inverter (MOI) + Increase of Self-Consumption by Bi-direction EV Charging (ISCBC)</td><td>Monitoring of Inverter (MOI) + Incentive Table Power Consumption Management (ITPCM); Optimisation of Heat Pump Compressor Flexibility (OHPCF)</td><td>Monitoring of Inverter (MOI) + Incentive Table Power Consumption Management (ITPCM); Flexible Load (FLOA)</td><td>Monitoring of Inverter (MOI) + Control of Battery (COB) + Monitoring of Battery (MOB)</td></tr>
</table>

Table 3 – Mapping of UC2.x to EEBUS use cases (continues on next page)

Example UC2.x routine mode using EEBUS

In addition, the use case "MPC" (Monitoring of Power Consumption) should be used to report momentary active power consumption.

To monitor grid power consumption, use case "MGCP" (Monitoring of Grid Connection Point) is available.

UC 2.x	User story	EV	Heat pump	DHW	Battery
2.5	As a consumer I want to minimise my costs and CO_2 impact using my local Battery Energy Storage System (BESS) to take advantage of buying energy at cheap rate/low CO_2 and use it later	Time of Use Tariff (TOUT) + Increase of Self-Consumption by Bi-direction EV Charging (ISCBC)	n/a	n/a	Time of Use Tariff (TOUT) + Control of Battery (COB) + Monitoring of Battery (MOB)
2.6	As a consumer I want to understand the impact of weather changes tomorrow so I can pre-heat or store energy ahead at cheaper tariff / CO_2 impact	Coordinated EV Charging (CEVC) + Increase of self-consumption by Bi-directional EV Charging (ISCBC)	Incentive Table Power Consumption Management (ITPCM); Optimisation of Heat Pump Compressor Flexibility (OHPCF)	Flexible Load (FLOA)	Control of Battery (COB) + Monitoring of Battery (MOB)

Table 3 – Mapping of UC2.x to EEBUS use cases

Summary architecture using EEBUS or Matter

Both EEBUS & Matter come with several common features:

- security
- automatic device discovery of protocol compatible devices on the home LAN (using mDNS-SD)
- user pairing of the devices

mDNS-SD (multi-cast DNS Service Discovery) protocol can only function on the in-home network:

- The discovery and tracking of the IP addresses of devices in the home must be performed by a device in the home.

Most internet home routers have built-in firewalls which use Network Address Translation (NAT):

- in order for a cloud-based service to communicate with devices in the home, there must be a local gateway or proxy device that acts as a client (typically the energy manager).

The home router will block inbound connection attempts from the internet:

- The device in the home must first establish an out-bound IP connection to the cloud before the cloud's response is allowed back.

The heat pump (which would typically be a server) would wait for an energy manager to connect to it (having discovered it) and that energy manager (or proxy) must be on the home LAN behind the router.

Earlier in this white paper, we presented a hybrid cloud connected architecture, which would be compatible with EEBUS or Matter if there was a local gateway device behind the home router.

This architecture would enable the benefits of cloud based optimisation services (e.g. using ML trained models) as well as reduced data transfers across the home to cloud interfaces and a more resilient solution when the internet fails.

Summary architecture using EEBUS or Matter

In the figure opposite we show an example architecture that enables in-home device discovery via a CEM proxy using mDNS-SD .

The CEM can communicate with a smart meter IHD or CAD providing Time of Use tariffs (ToU) and grid connection point metering.

A PV system can be monitored to understand PV generation by communicating with the PV inverter.

A heat pump can be steered towards low cost tariffs or lower grid CO_2 intensity with incentive tables and optimally controlled via power commands.

Note that the EVSE shown here is connected via a cellular network to a charge point operator (CPO) and can be controlled via a Cloud-2-Cloud interface.

In this setup the EV charger 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) and is therefore a preferred option.

In order to handle UC1.x scenarios and respond to grid events, the CEM is connected to the DSRSP via a cloud connection.

The smart thermostat here is shown to be a Matter enabled device which can communicate the current temperature, user schedules and set points to the heat pump. A digital assistant with voice skills or third-party app can make a seamless consumer experience.

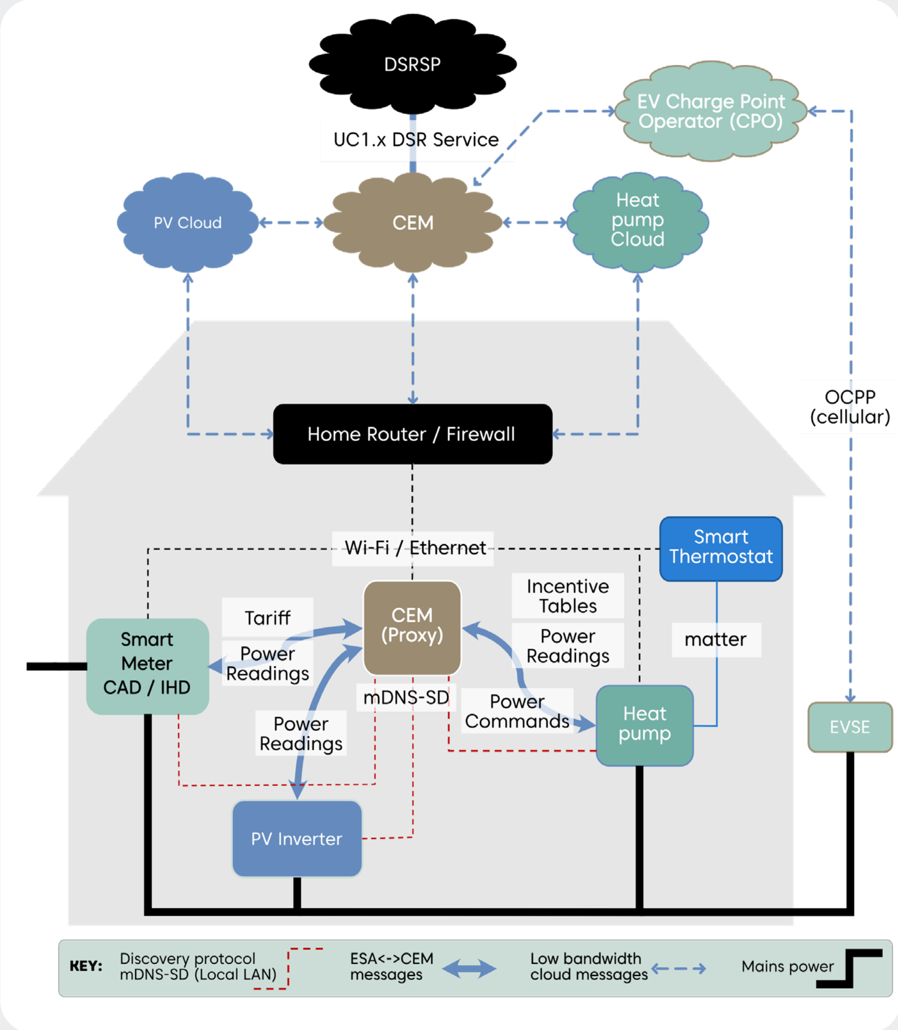


Figure 13 - Example of proposed hybrid architecture

#1

A use case approach should be taken when defining protocols

When defining data models, there needs to be well defined user focused use cases.

EEBUS already has several use cases which can serve as a reference for building home energy management solutions.

#2

Consumer adoption is key to mass market DSR solution

UC2.x use cases (those which benefit the user first) focus on **cost and CO2 reduction**. These will likely bring the initial products to market.

UC1.x solutions (e.g. managing grid stability and load shifting) will only be available once ESAs that are equipped with DSR functions are deployed at scale.

A HEMS coupled with smart plugs can make some simple traditional devices controllable in the near-term.

#3

Early adopters and mass-market consumers have similar needs

Not all consumers will be able to afford EV charging at home, solar PV, or battery storage.

However, white goods appliances also offer cost savings and CO_2 reduction opportunities by shifting away from peak times.

#4

Time of Use (ToU) tariffs and incentive tables will be needed in UC2.x use cases

Protocols will need to support sending ToU tariff and incentive tables (which can steer around high CO_2 intensity on the grid, or constraint issues in the local network).

#5

Peak load control and energy optimisation will need a HEMS

A home energy management system will be needed to optimise and limit the power load at peak times across all devices.

Devices will need to monitor their own power consumption and stay below a pre-set limit.

#6

EEBUS and Matter are the leading contenders for in-home ESA control

Whilst EEBUS is already used in some markets for energy control of appliances, Matter may gain a larger international reach due to the predominance of major brands, the open-source SDK availability and support by major silicon vendors.

Both of these are compatible with the hybrid architecture we presented in this paper.

Annex A - EEBUS use cases

Vaillant
Comfort for your home

geo

EEBUS use cases in detail

CEVC – Coordinated EV Charging

CEVC enables communication of an EV's departure time, minimum energy required and optimal energy (or maximum capacity) to the energy manager.

The energy manager responds with an incentive table and the available energy (maximum power curve).

The EV creates the charging plan at low monetary or ecological costs and sends it to the energy manager.

A renegotiation may be triggered by all devices, e.g. if energy demands of the EV or the energy cost through more available PV energy has changed.

This solution enables lowest cost EV charging from different energy sources at very different costs (e.g. free PV energy, cheaper grid energy).

COB - Control of Battery

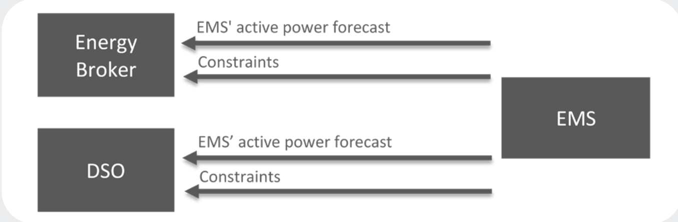
COB enables the system to integrate battery systems by controlling its operating behaviour through 2 control modes.

- Power: The power of the battery is directly controlled (charge/discharge)
- PCC: The battery monitors the grid connection point and aims to reach a configured set-point at the GCP (e.g. 0W)

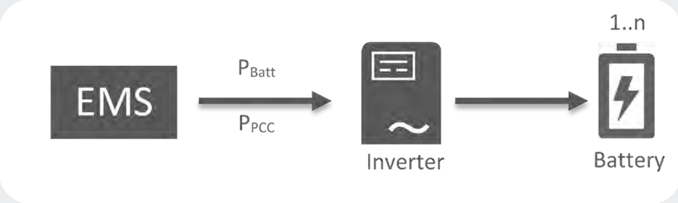
The battery may be controlled by the EMS within its operating limits to store PV energy temporarily and provide energy to the building over the day and even after sunset.

ENDF - Energy Demand Forecast

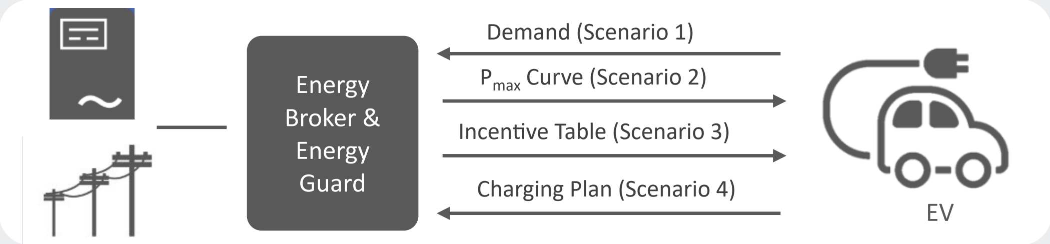
ENDF enables the system to send an energy demand forecast to the grid or DSRSP. The grid/DSRSP will be notified about the energy demand of a zone (e.g. building) and may use this information to optimise the grid supply and demand.



Energy Demand Forecast (ENDF)



Control of Battery (COB)



Coordinated EV Charging (CEVC)

FLOA - Flexible Load

This is a simple use case for closed loop control of a device's optional power consumption.

This use case is applicable for devices that can be controlled with no or minimum delay.

An example is a hot water storage with smart heater which may heat up the domestic hot water (DHW) to the maximum allowed temperature.

This is especially useful for short term use of PV power that otherwise would need to be power curtailed. The use case complements other use cases that enable early scheduling of energy consumption.

ISCBC – Increase of Self-Consumption by Bidirectional EV Charging

This use case enables the system to use the EV battery for vehicle to home (V2H) applications.

- temporarily store PV energy instead of feed-in to increase self-consumption
- make PV energy available after sunset
- peak shaving in terms of power limitation by the DSO

The EV's constraints (departure time, energy demand) will be still be met.

The EV may be used to increase self-consumption at cheap rate.

The EV's battery may be used much like a fixed home battery - to cover PV supply gaps during the day or provide stored cheap PV energy available to the home at night.

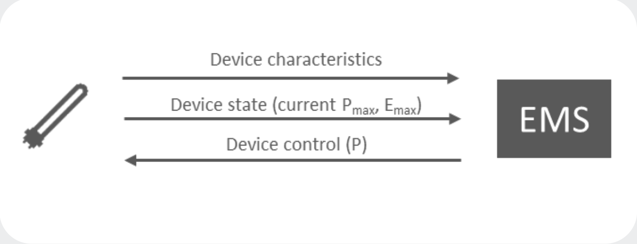
ITPCM - Incentive table-based Power Consumption Management

This use case enables the energy manager to influence the power consumption of a device (e.g. heat pump) through the price of energy (incentive table).

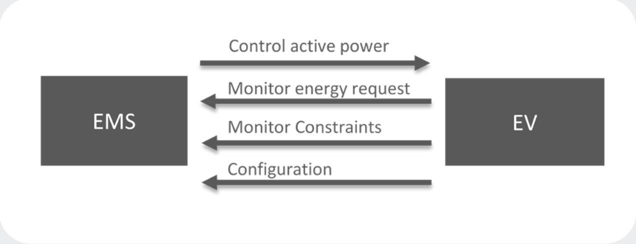
The energy manager may negotiate consumption plans without touching the device's internal process.

Devices know when green, cheap or costless energy is available and can change the operation mode accordingly.

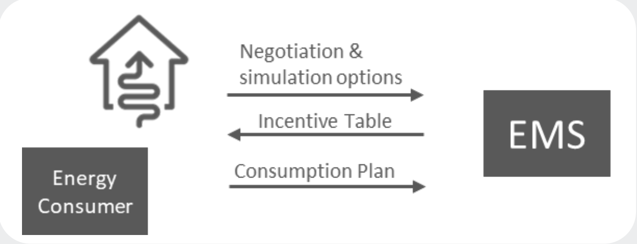
Devices can operate without loss of comfort by accepting the energy price valid at that time.



Flexible Load (FLOA)



Increase of self-consumption by Bidirectional EV Charging(ISCBC)



Incentive table-based Power Consumption Management (ITPCM)

LPC – Limitation of Power Consumption

This use case enables the system to limit the power consumption (e.g. of a building or device).

It avoids overload scenarios in the low voltage distribution network by reducing the power consumption of the connected devices directly or through a local energy manager according to the received limits.

MGCP – Monitoring of Grid Connection Point

This use case enables the system to share data between endpoints:

- power, energy or current which is fed into or taken from the grid
- voltage and frequency as grid stability information
- maximum power that can be fed into the grid

The energy manager may use the total power consumption within its control algorithm or use it for total power consumption calculations or visualisation.

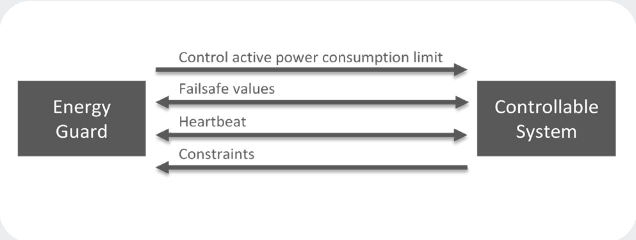
The DSO may read the total power consumption from the control unit to identify hot spots or even check the quality of the grid through voltage or frequency data.

MOB – Monitoring of Battery

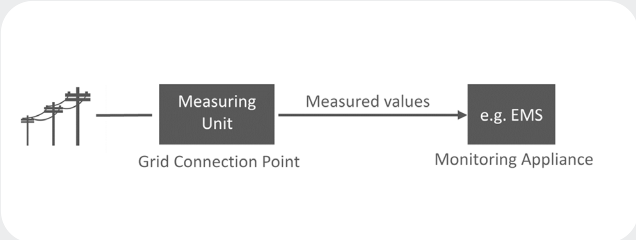
This use case enables the energy manager or user interface to read battery system specific data:

- identification information.
- state of the battery.
- power / current / voltage nominal values.

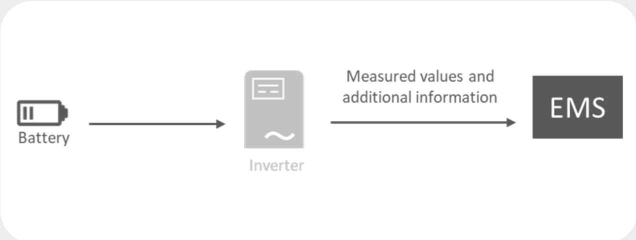
The energy manager may read all energy relevant values from the battery for whole home optimisation (such as turning on a heat pump when grid power is limited).



Limitation of Power Consumption (LPC)



Monitoring of Grid Connection Point (MGCP)



Monitoring of Battery (MOB)

MOI – Monitoring of Inverter

This use case enables the energy manager to monitor data provided by any type of inverter, such as PV, battery, hybrid, etc.

The inverter provides information like identification, state, power production or data points needed for diagnosis or efficiency calculation.

An energy manager may read all energy relevant values from the inverter for energy management purposes or to show detailed status information.

MPC – Monitoring of Power Consumption

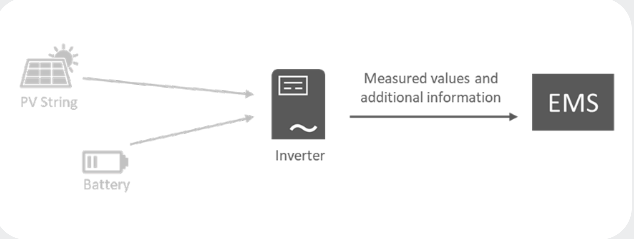
This use case enables the system to measure the power consumption or production of devices.

The energy manager may use the device's power consumption within its control algorithm or use it for power consumption calculations or visualisation.

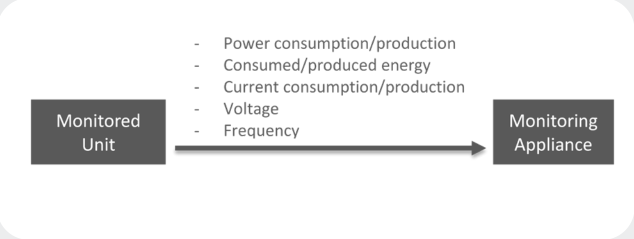
OHPCF - Optimisation of Self-Consumption by Heat-Pump Compressor Flexibility

This use case explicitly describes the combination of a PV system and an electrical heat pump system with the goal of optimising the electrical power consumption of the heating system according to the available PV power in order to reach economic or ecological goals.

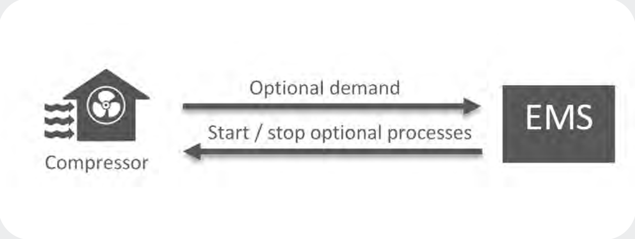
To make sure the heat pump is running at the lowest costs, it should be integrated into the energy management.



Monitoring of Inverter (MOI)



Monitoring of Power Consumption (MPC)



Optimisation of Self-consumption by Heat pump compressor flexibility (OHPCF)

OPEV - Overload Protection by EV Charging Current Curtailment

This use case enables the system to limit the maximum charging current of the EV on each phase depending on the electrical connection.

In addition, the connection itself is monitored. In case there is no connectivity, the EV will only operate within defined safety parameters typically set by the charging station (EVSE).

The power consumption of the EV may be reduced to prevent grid issues or even fuse break through limiting the maximum current. The hard requirement to react within 4s will be fulfilled.

OSCEV - Optimisation of Self-Consumption during EV Charging

This use case enables communication of optimal power level to indicate how much self-produced power is available on each phase depending on the electrical connection.

In addition, the connection itself is monitored and the EV can adjust its consumption to the actual self-produced PV (to ensure that it does not cause any import from the grid when PV power fluctuates).

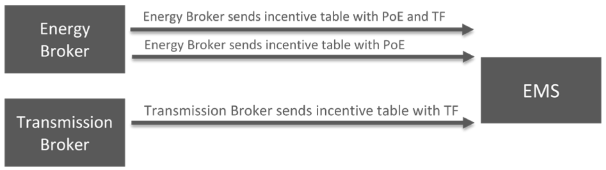
TOUT – Time of Use Tariff

This use case enables market participants to send flexible tariff tables to the premises, based on price, CO_2 grid intensity based on the amount of renewable generation sources.

It enables optimisation of cost and carbon.

Overload protection by EV charging current curtailment (OPEV)

Optimisation of Self-consumption during EV charging (OSCEV)



Time of use Tariff (TOUT)

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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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