Project MADE

High Level Design

Revision history

Version	Change Description	Initials	Release Date
v1	Pre-Technical Trial Final	CT/EC	19/08/2019

1 INTRODUCTION

The MADE project sets out to make an exploration of the impact of multiple low carbon assets in the home on the electricity distribution network, and the initial potential for reducing this impact by coordinating the assets.

We believe that as we transition to our 2050 goals a large proportion of UK homes will be heated by hybrid heat pumps, have solar PV panels generating electricity to use at home and export to the grid, have a battery installed to store the solar generation and also take advantage of cheap renewably-generated electricity from the grid, and the occupants will drive an electric car which can be charged at home. The project aims to replicate this combination of technologies for the first time as a deployment which is coordinated within the home to make the most of the combined flexibility, and also can be orchestrated between homes to offer grid services and honour local grid constraints.

The project consists of carrying out a small field trial of the technologies, and a parallel stream of modelling work that aims to extrapolate to the wider population of homes and assess the value of flexibility, and also a stream of customer engagement work. This document is focused on the pilot trial: what technologies are being deployed, what use cases are being considered for the field trial design, and what software systems need to be developed to support them.

2 FIELD TRIAL

2.1 Overview

The project will deploy the following low carbon technologies to a set of five trial homes over winter 2019-2020:

- Hybrid heat pump, consisting of an electrically-powered heat pump (either air source or ground source) together with a fossil-fuel boiler (oil or gas), which together provide the heating and hot water requirements of the home
- Electric vehicle and smart charge point
- Solar PV panels
- Domestic battery for electricity storage

In addition, we will install a PassivSystems hub which will collect monitoring data, run the smart home energy management system and connect to PassivSystems' cloud platform for trialling demand flexibility services.

The following pilot trial homes have been recruited:

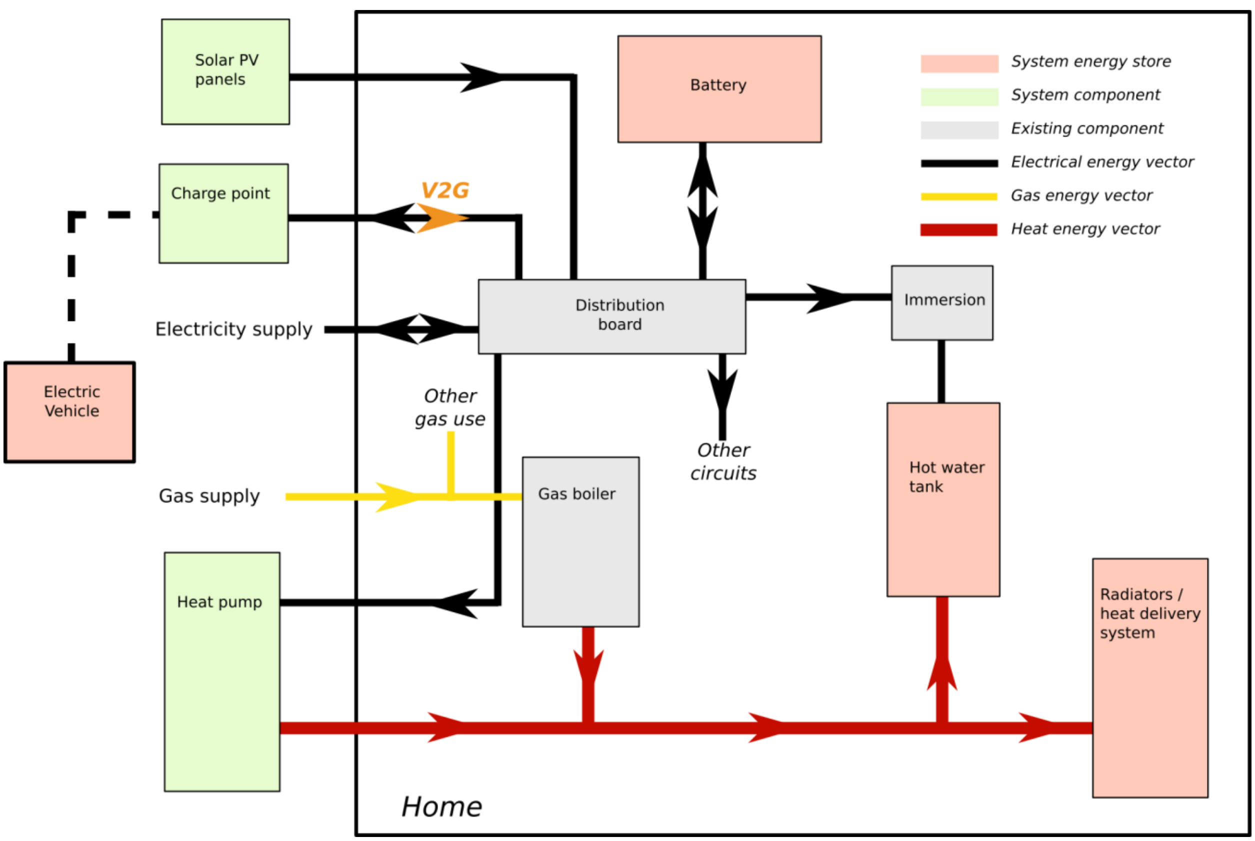
1. Home in South Wales with an existing Samsung 5kW air source heat pump and LPG combination boiler, and existing PassivLiving heating controls

2. Home in South Wales with an existing MasterTherm 8kW air source heat pump and gas system boiler with hot water tank, and existing PassivLiving heating controls
3. Home in Devon with an existing MasterTherm 22kW ground source heat pump and oil system boiler with hot water tank, and existing PassivLiving heating controls
4. Home in South East, with an existing Samsung 9kW air source heat pump and combination boiler, and existing PassivLiving heating controls
5. Home in Cornwall, with an existing Samsung 9kW air source heat pump and a system boiler, and existing PassivLiving heating controls

The project will install Samsung air source heat pumps with PassivLiving heating controls in the last two homes. All homes will have installed in addition solar photovoltaic (PV) panels, a Sonnen battery, an electric vehicle charge point (either Alfen or Wallbox), and an immersion heater remote switch (where there is a hot water tank). Householders will be provided with an electric vehicle (EV) on lease for the duration of the project.

The sections below provide more details of the physical installation and the plan for the field trial (the use cases that will be considered).

2.2 System components



2.2.1 Heat provision

Our assumption is that in the future heating will be substantially decarbonised, which means moving away from fossil fuel boilers and introducing heat pumps. In many cases it will make sense to retain the fossil fuel boiler and add on a heat pump, thus becoming a **hybrid heat pump**.

Trial homes will be heated by a combination of an electrically powered heat pump and a gas boiler. Space heating is provided wherever possible by the heat pump, which is sized so that it can provide the majority of the home's heating needs, but there is no need to upgrade radiators. The gas boiler is used for heating in three circumstances: firstly when it is too cold outside for the heat pump to keep the house warm; secondly when it is cheaper to run than the heat pump; and thirdly when grid constraints or grid services require a reduction in electricity demand to the house. **A hybrid heat pump has 100% electrical demand flexibility** as heating needs can be met by the gas boiler, instantaneously, at any point in time. The heat pump also has the potential to provide upwards demand flexibility although the response is slower.

The field trial will test a variety of types of heat pump, including both Samsung and Mastertherm units, and both air- and ground-sources. The MasterTherm unit is larger and more expensive, but is more highly tunable so we will explore whether this is an advantage within the multi-asset deployment.

2.2.2 Hot water provision

Domestic hot water is usually provided by the fossil-fuel boiler, either instantaneously (combination boiler) or by heating a hot water tank (system boiler). In the latter case it may be possible for the heat pump to provide some contribution to hot water production, which is something we hope to explore in the project.

On homes with a hot water tank we will also install a switch on the **immersion heater** that will be controlled by the HEMS. This will provide additional demand response turn-up services, as well as the potential to directly utilise cheap rate electricity or that stored in the battery.

2.2.3 Solar PV panels

Houses will be installed with solar panels providing the only local generation input within the project. There are over a million solar panel installations in the UK and they are significantly impacting the grid in places; managing the solar generation is a key part of the project: for example finding local sinks for the solar-generated electricity, whether within the same house (e.g. hot water tank) or nearby houses (to avoid the need to stress the wider distribution network). The key consideration with solar generation is its time variability -- over the course of a day and a year, solar generation varies immensely.

The project could consider controllability of solar generation - the possibility of instructing the inverter to turn off or turn down.

The project will also include work to **improve forecasting of solar generation** on short timescales, which we believe has the potential to increase the ability to utilise it (e.g. confidence to turn on the heat pump compressor if there is a good sunny period). We hope to test this hypothesis within the field trial.

The key decision for field trial planning is the **sizing of the solar panels** (kWp, total area). In practice, the size will be limited by the amount of roof space at the trial homes, but our approach is to size them consistently with the household size and our expectation of typical affordable sizing in the future.

2.2.4 Domestic battery

A battery installed in the home is a necessity for balancing the grid. It is strongly connected to the solar panels as it provides the ability to store generated solar until it is needed, but we also expect it to be used significantly for grid arbitrage (storing electricity when it is cheap, preventing grid import when it is expensive, and even discharging to the grid when advantageous) and to respond to grid constraints from a centralised coordination system. A key control decision is balancing all these factors as the trade-offs are not obvious: Passiv's optimisation technology is required.

The field trial will use Sonnen batteries as these are a leading product which has a full interface for third party monitoring and control.

The key decision for field trial planning is the **sizing of the battery system** (kWh). Our approach is to err on the side of oversizing as we can always use software in the field trial to emulate smaller sized batteries; realistic future sizing will be driven by economic factors and space available in the home that are hard to predict (batteries are still very expensive but have reduced in price much faster than anyone predicted in the last 10 years). Important comparisons are the total amount (kWh) of solar energy generated on a summer's day, and the total amount (kWh) of heat pump electrical energy consumption during peak electricity prices on a winter's day.

To give a feel for the high end of sizing, the largest solar panels (kWp=4) generating power for the best summer's day is likely to produce ~20kWh. The largest heat pump on the project can consume 5kW of electricity, so avoiding three hours of peak in the depths of winter would require a 15kWh battery. Sonnen batteries are available in 5 kWh – 15 kWh sizes (2.5kWh increments). We would recommend at least a 10kWh battery.

2.2.5 Electric vehicle and charge point

Our assumption is that in the future transport is significantly decarbonised by the majority of people owning or leasing electric vehicles (EVs), and thence also have an ability to charge these vehicles at home. The trial will thus include electric vehicles and charge points as these are expected to have a large contribution to electrical grid demand.

Charge points need to have a capability for third party monitoring and control, so that for example the Passiv coordination system can delay the EV charging until later in the night when the grid is quieter. We also hope to trial vehicle-to-grid (V2G) and vehicle-to-home (V2H) capability where the EV battery can discharge and provide power to the home or back to the electricity grid; this requires special capability in both the vehicle and the charger. Another key consideration is the ability for the vehicle to communicate its state of charge to the charger and thence HEMS system, so that a considered decision can be made about when to start charging (e.g. to achieve a full charge by the end of the night) or whether it is acceptable to discharge the EV battery.

It is expected that the field trial will use Alfen and Wallbox charge points, and an EV with V2G/V2H and comms capability such as the Nissan Leaf. The project will also explore integration with Newmotion EV Chargers as these are interesting for other projects that Passiv are involved with.

2.2.6 HEMS: control system

Controlling multiple assets in a coordinated way is difficult: there are multiple trade-offs and decisions to be made. PassivSystems optimisation technology can solve this challenge in a quantitative way, so at the core of the physical deployment will be a Passiv hub which runs optimisation algorithms to control the assets, as well as gathering monitoring data to send to the Passiv servers.

2.3 Use cases

Intra-home coordination. There are a large number of possible system operation modes and we consider some of the possible use cases as examples of the advantages of coordinating assets within the home:

- Decide whether to charge the battery using cheap rate electricity or to wait for solar generation
- Decide whether to store solar generated electricity in the battery, in the fabric of the home as heat, in the hot water tank or in the electric vehicle battery
- Decide whether to discharge the domestic battery into to power the heat pump to warm the fabric of the home, hot water tank, or electric vehicle battery, in advance of solar generation or cheap tariff periods
- Decide how best to avoid high import tariff periods and exploit high export tariff periods
- Decide when to heat the hot water tank, so that it provides enough hot water when the occupant needs it, but taking advantage of the flexibility of energy storage

Inter-home coordination. From a network perspective, the important metric is the load profile from each home (especially the peak load), hence the focus above on understanding factors that affect the baseline load profile. The network may want to influence the load profile, particularly if peak load may be exceeded on particular parts of the network topology. Potential use cases are as follows:

- **Early evening peak load** when people return from work they will need heat, they will turn on appliances and lighting, and they will plug in their EV, thus causing an exacerbated peak load. The system needs to decide which assets to use to mitigate this peak load:
    - Discharging the domestic battery
    - Pre-heating the house before peak periods, or switching to the fossil-fuel boiler for heating
    - Delaying EV charging until overnight if it is not needed in the evening, or even discharging it if V2G capability is available
- **Peak created by the onset of cheap electricity.** The introduction of variable electricity tariffs is likely to make things worse in some circumstances as homes react and make the most of cheap periods: for example, shortly after midnight with an Economy 7 tariff. In this case the system needs to decide fairly which homes would get the most cheap electricity given network capacity. This could be done either in an auction-like process or by applying equal restrictions to each competing home in the system.
- **Excess generation.** In summer months PV generation at high penetration is likely to stress network capacity. The system needs to decide whether to:
    - Get individual houses to store the generated PV even if this is more expensive for the consumer (e.g. utilise immersion heater)
    - Identify nearby homes that have a need for electricity at times when there is excess PV generation at a topology layer “beneath” the restricted network components
    - Restrict PV generation (turn off the inverter) - likely to be a last resort as we would aim to maximise renewable utilisation rather than curtail

On a small scale field trial with five homes we will be unable to demonstrate meaningful network-scale interventions but we hope to identify scenarios that would enable us to demonstrate some of these use cases.

2.4 Field trial design

This section provides an initial design for the field trial and the use cases that will be explored over winter 2019-2020 using the deployed physical assets. Our general approach is to explore *in-home* factors for the multi-asset multi-vector scenario, rather than factors that affect multiple homes, as a small scale field trial is unlikely to provide definitive answers to the latter.

2.4.1 Phase 1: Baseline operation

For the first part of the field trial, assets will operate somewhat independently and this will provide baseline data for later comparison.

- **Flat electricity tariff**. We propose that trialists are initially on a flat electricity tariff as this provides no incentives to shift electricity from peak times and operation will illustrate how demand all coincides in the early evening. An alternative would be to have some trialists on an Economy 7 tariff to explore the problem of demand peaking shortly after midnight. "Virtual tariffs" are likely to be utilised (where the system optimises for the tariffs but the householder is not actually paying these rates).

- **High fossil fuel price**. The hybrid heat pump controls will be configured with a high price for the fossil fuel boiler to reflect the future scenario of substantial decarbonisation (so that as high as possible a proportion of the heat demand is provided by the heat pump). Against this pricing, hybrid heat pump operation will be optimised by the system to minimise running costs for the user and maximise heat pump efficiency.
- **Solar optimisation.** The heat pump will be optimised to utilise available solar generation (and recognise that it is free) but will not otherwise be coordinated with the battery. An alternative baseline scenario we might consider is no solar awareness for the heat pump (i.e. it assumes electricity it consumes is a fixed price).
- **Simple automatic battery control.** The batteries will be controlled by Sonnen's internal "automatic" control algorithm which charges the battery when there is net household production (i.e. excess PV generation that would have been exported) and discharges when there is net consumption. The battery will thus react to heat pump operation, and in effect the heat pump will have priority on the solar generation.
- **Default EV charger behaviour.** The EV charger will be used "out of the box" however the consumer decides, and the consequences will be monitored.

Monitored data will be collected from this phase and analysed to produce conclusions as to likely load profiles in the baseline scenario. These results will be compared with modelling, and further modelling work used to extrapolate these results to the country as a whole (i.e. used to refine previous models).

2.4.2 Phase 2: National-scale grid drivers

The next step is to construct a scenario where assets in the home react to national-scale grid drivers (but assets within the home are largely uncoordinated with each other). This will explore the impact of "selfish algorithms" where multiple assets take advantage of cheap electricity prices (for example) causing stress on the local distribution network.

- **Variable ToU electricity tariff**. We propose that all trialists are placed on the Octopus Agile tariff as this is the most advanced tariff in the market today and most representative of future price variations (as prices are determined by the day-ahead electricity wholesale market). This would require all trialists to have a (electricity) **smart meter installed**.
- **Export tariff.** If possible we will suggest that trialists sign up to the "Outgoing Octopus" tariff which pays a variable rate for electricity exported to the grid. We believe that export tariffs are going to become more widespread with the Smart Export Guarantee coming in from 2020.
- **Hybrid heat pump optimisation.** Heat pump operation will be optimised against the variable rate tariff, so that heat will be stored in the fabric of the house during low tariff

periods, and perhaps the fossil fuel boiler will be used during high tariff periods; the strategy will be determined by optimisation calculation.

- **Simple battery control.** On top of the "automatic" behaviour, we will inject commands to charge if the grid import price is below a certain threshold or discharge when the export price is below a threshold.
- **Immersion control.** We will inject simple commands to turn on the immersion heater if the grid import price is below an appropriate threshold such that it is the cheapest way of producing hot water.
- **Electric vehicle charge control**. The occupiers will be encouraged to set up rules on their smart charger to take advantage of the ToU tariff in a relatively simple way.

We hope to demonstrate from analysis of the monitored data some of the consequences of cheap rate electricity causing simultaneous asset activity which results in higher grid stresses than the baseline case.

2.4.3 Phase 3: In-home asset coordination

PassivSystems will develop algorithms which coordinate assets within the home to make best advantage of the variable availability of cheap electricity, the different storage potential of the assets, and the various patterns of consumption needed by the occupiers. These will calculate the best strategy for the householder in terms of minimising running costs against the variable tariffs. The battery will be put into "manual" mode in circumstances when the algorithm determines that it can do better than the default "automatic" mode.

We do not envisage full interoperability with the EV charger at this stage, but will instead use the trial primarily to understand the human interaction and user interface questions than need to be addressed (such as the acceptability of delaying an evening charge). As much as possible we will demonstrate practical interventions where the EV charge is delayed (for example) in line with user preferences. Similarly we will demonstrate V2G scenarios on a case by case basis.

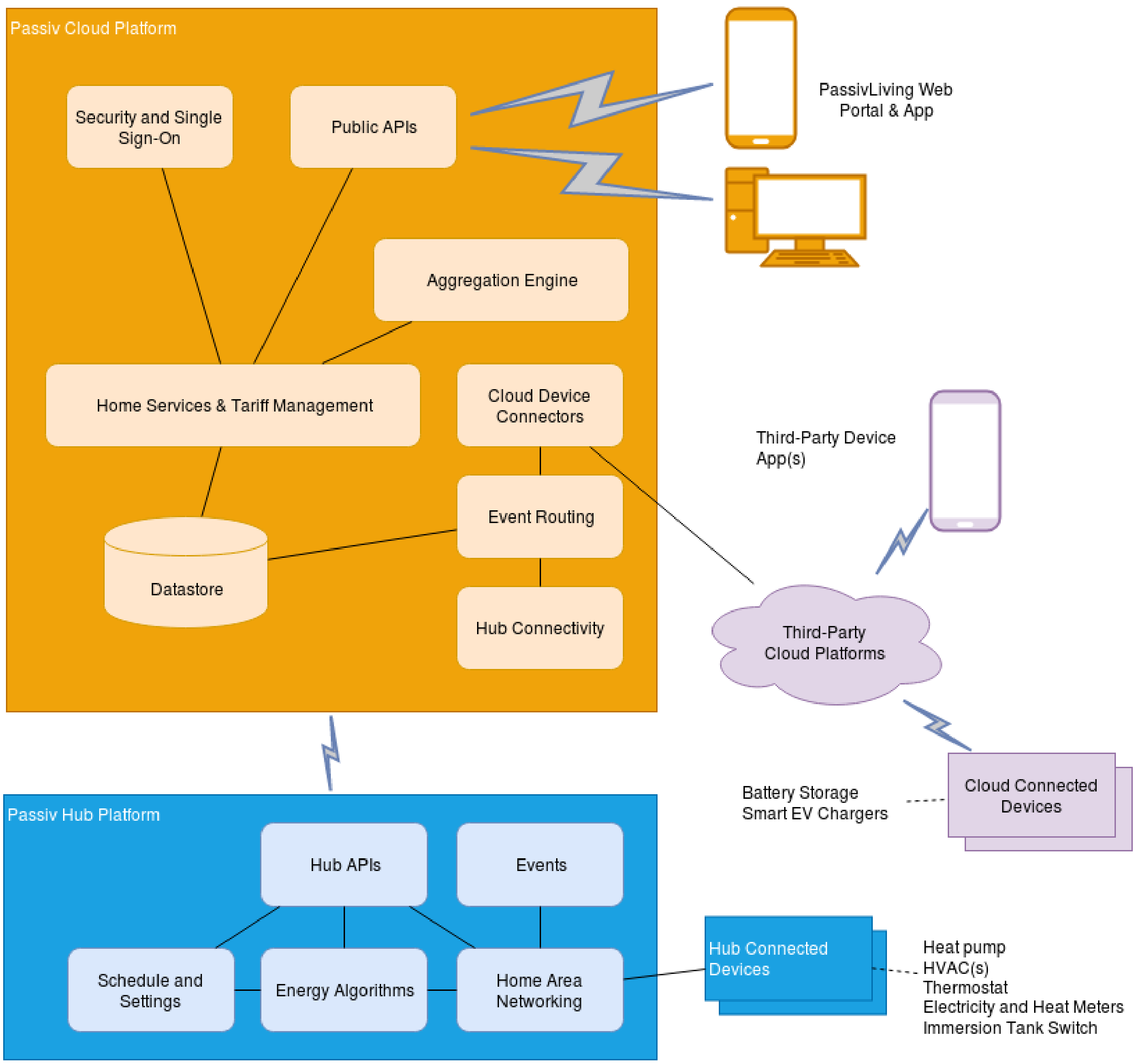
The purpose of this phase will be to find out how the patterns of asset operation change when they move from uncoordinated to coordinated control within the home, and whether this makes the impact on the local grid bigger or smaller.

2.4.4 Phase 4: Local grid interventions

In this final phase we will identify some key grid problems (for example, times of peak load) and will design some interventions that demonstrate that a inter-home coordination system could mitigate some of the problems. This could for example involve pushing down to the control algorithms a whole-house maximum power constraint which is applied across the set of flexible assets, and might for example result in more pre-heating by the heat pump and a transition to gas heating at the time that the EV is plugged in and the sun has gone down.

3 ARCHITECTURE

The project will utilise PasivSystems's existing energy management platform, with the addition of new components for integration with assets that are new for this project. A logical view of the system architecture is shown below:



3.1 Passiv Hub Platform

The Passiv Hub Platform is installed in the trialist's home. It consists of a physical hub connected to various devices and sensors. These connections may be wireless (e.g. Z-Wave) or a wired connection (usually via a smart USB cable).

The hub contains software that runs the trialist's schedule for their heating, hot water and other requirements. It also contains the energy algorithms that provide the core HEMS functionality, including:

- Determining when and how to operate the heat pump and boiler to ensure the home's comfort constraints are met
- Determining when to heat hot water to ensure the home's water needs are met
- Predicting how much solar energy will be generated and how best to use this to meet heating and hot water requirements
- Taking control of the battery storage to force charging or discharging in order to optimise energy usage of the other assets
- Adjusting asset energy consumption around DSR constraints

An outcome from the project will be to determine how control of EV assets can be included into the optimisations undertaken by the energy algorithms.

Functionality of the hub platform is exposed to the Pasiv Cloud Platform via a set of APIs. It also generates a stream of events that are sent to the cloud for reporting and analysis purposes.

Additionally, DSR constraints can be passed from the cloud platform to the hub in order to request it to change its energy consumption profile.

3.2 Passiv Cloud Platform

The Passiv Cloud Platform manages the connection to the hubs in each of the homes. It routes events coming from those hubs to the various components and into the database. It also provides all of the functionality around managing homes and the services that they support.

Tariffs are also managed via the cloud platform, with tariff data being automatically distributed to all of hubs on each tariff.

The cloud platform also exposes public APIs and Single Sign-On that are used by clients to integrate with the platform. The PassivLiving Web Portal and Android/iOS Apps connect via these APIs.

Most of the Passiv Cloud Platform already exists and will just be utilised 'as is' for the trials.

3.2.1 Cloud Device Connectors

One aspect of the MADE project that is new is the connection to EV Chargers to explore how these can be optimised for energy usage and utilised for DSR. It is planned that this connectivity will be achieved using a cloud-to-cloud approach rather than connecting directly to the physical charger. Reasons for this architectural decision are:

- Most smart EV chargers have an App for control, so they are already cloud connected and probably have a public API
- Many EV chargers are unlikely to support a local connection option
- The location of the physical EV charger in the home may not be convenient for connecting to from a Passiv hub
- A significant portion of the EV charger control logic may exist in the cloud, so it would not be viable to connect other than through this cloud approach
- It is much easier to enforce secure access between Passiv and the EV charger using cloud-to-cloud connectivity

Passiv already use this cloud connected device approach to work with Sonnen batteries. A Sonnen device connector regularly polls the Sonnen API to retrieve the battery status information. It passes this down to the hub for use in the home optimisation. The hub then requests the Sonnen device connector to either put the battery in automatic or manual mode. Once in manual mode the hub can also then instruct the battery to charge or discharge.

We would expect to implement exactly the same connectivity approach for EV chargers. However, for initial experimentation we would not complete the link between our cloud connector and hub. Instead the status from the EV charger would be captured for monitoring and the connector will provide an API that allows the R&D team to test different EV charger control approaches.

The required behavior from the third-party EV charger cloud interface will ideally include the following information:

- The current state of charge of the EV battery (may not be available as a communication link is required to the EV itself)
- The expected available distance the EV can travel on its current charge (may not be available as a communication link is required to the EV itself)
- The operating status of the EV charger
    - Automatic or manual mode
    - Whether it is charging or discharging (if V2G supported)
    - Current power consumption / rate of charge or discharge
    - Estimated time until full charge/discharge (if available)
- It would also be necessary for the API to allow the EV charger to be instructed to charge, discharge or do nothing, and also to limit the charging power consumption

Each EV charger to be tested by the project will need its own Cloud Device Connector implementation.

3.2.2 User interfaces

We will prototype some user interface concepts for the EV use cases, such as giving a push notification when the EV is plugged in to ask for additional information (charging state, when it is next needed and permission to delay charge or discharge).

3.2.3 Aggregation

The Aggregation Engine collects the forward power consumption plans from each home and aggregated them together to produce a plan for the entire population of homes. It then provides functionality to calculate how much flexibility can be achieved from the set of assets for a given requested DSR scenario. It then has a way to dispatch flexibility constraints to the hubs in each of the homes so that they can adjust their energy consumption to deliver the DSR.

As part of the MADE project it is not envisaged to make significant changes to the existing aggregation solution. However, there will be some algorithmic changes to include the provision of batteries in delivering flexibility.

The Aggregation Engine will be used as a means to experiment with dispatching flexibility rather than trying to provide an integrated DSR solution.

4 DEVELOPMENT WORK

The following is a list of potential areas of development work required to support the project. These areas will be further refined during detailed design.

- Cloud Device Connectors for EV Chargers
    - Investigation and prototype of API for Alfen solution
    - Investigation and prototype of API for Wallbox solution
    - Connector API for managing cloud connected batteries and EV chargers
    - Driver for Alfen API
    - Driver for Wallbox API
- User Interface prototypes for householder interaction
- Energy Algorithms
    - Develop simple battery controller for ToU import+export tariffs
    - Develop simple immersion heater controller for ToU tariffs
    - Support for using the heat pump to store heat in the hot water tank
    - Expand tariff support to encompass export tariffs
    - Develop multi-asset optimisation algorithm for HHP+PV+Battery