NEA Action for Warm Homes
TECHNICAL INNOVATION FUND

CP776b
Powervault G200 domestic battery storage
Cheshire East Council

Technical Evaluation Report

Paul Rogers and Michael Hamer
March 2019

Background

About National Energy Action

National Energy Action is the national fuel poverty charity working across England, Wales and Northern Ireland, and with sister charity Energy Action Scotland (EAS), to ensure that everyone can afford to live in a warm, dry home. In partnership with central and local government, fuel utilities, housing providers, consumer groups and voluntary organisations, NEA undertakes a range of activities to address the causes and treat the symptoms of fuel poverty. Its work encompasses all aspects of fuel poverty, but in particular emphasises the importance of greater investment in domestic energy efficiency.

About the Technical Innovation Fund

NEA believes that there is huge potential for new technologies to provide solutions for some of the 4 million UK households currently living in fuel poverty, particularly those residing in properties which have traditionally been considered too difficult or expensive to improve through mandated fuel poverty and energy efficiency schemes. However, more robust monitoring and evaluation is needed to understand the application of these technologies and assess their suitability for inclusion in future schemes.

The Technical Innovation Fund (TIF) which was designed and administered by NEA, formed part of the larger £26.2m Health and Innovation Programme along with the Warm Zone Fund and Warm and Healthy Homes Fund.

TIF facilitated a number of trials to identify the suitability of a range of technologies in different household and property types and had two strands: a large measures programme to fund contributing towards the installation and evaluation of technologies up to a maximum £7,400 per household, and a smaller measures programme contributing up to the value of £1,000 per household. The fund launched in May 2015, with expressions of interest sought from local authorities, housing associations, community organisations and charities wishing to deliver projects in England and Wales.

Over 200 initial expressions of interest were received, and NEA invited 75 organisations to submit full proposals. Applications were assessed by a Technical Oversight Group, chaired by Chris Underwood, Professor of Energy Modelling in the Mechanical and Construction Engineering Department at Northumbria University who is also a trustee of NEA. In total, 44 projects were awarded funding to trial 19 different types of technologies and around 70 products (although this number reduced slightly as some products proved not to be suitable and were withdrawn).

More than 2,100 households have received an intervention under this programme. Of course, the amount of benefit varies depending on the household make up and the measures installed. In a small number of instances, we removed the measures and took remedial action to ensure residents were not detrimentally affected.

Technical monitoring and evaluation

NEA has been working with grant recipients to monitor the application of these technologies and assess performance, as well as understand householder experiences and impacts.

A sample of households from each TIF project was selected for monitoring and evaluation purposes. Participation was entirely voluntary, and householders were free to withdraw at any time. This involved the installation of various monitoring devices within the home which collected data for analysis by NEA's technical team. Some residents were also asked to take regular meter readings. In some instances, a control group of properties that had not received interventions under TIF were also recruited and monitored for comparison purposes.

The technical product evaluation was conducted alongside a social impact evaluation to inform our understanding of actual energy behaviour changes, perceived comfort levels and energy bill savings, as well as any other reported benefits. Householders were asked to complete a questionnaire both before and after the installation of the measures which captured resident demographic data including any health conditions. Small incentives in the form of shopping vouchers were offered to maintain engagement over the course of the evaluation period.

The HIP fund was principally designed to fund capital measures to be installed into fuel poor households. A small proportion of the funding enabled NEA to conduct limited research and monitoring of products installed and was restricted to ensure that the majority of funds were spent on the products. All products included in the trials were deemed to offer costs savings and energy efficient solutions as proposed by the delivery partners. The research and monitoring aimed to provide insights to inform future programme design and interested parties of the applicability of the product to a fuel poor household. We recognise that due to the limited number of households involved in the monitoring exercises and the limited period we were able to monitor a product's performance, we may recommend that further research is needed to better understand the application of these products in a wider range of circumstances over a longer period of time.

The research was conducted according to NEA's ethics policy, which adopts best practice as recommended by the Social Research Association (SRA) Ethical Guidelines 2002.

An accompanying programme of training and outreach work was also delivered to 292 frontline workers to increase local skills and capacity.

Individual project reports are being compiled and will be made available publicly on NEA's website from September 2017, along with a full Technical Innovation Fund Impact Report.

Acknowledgements

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Sarah McClelland, Environmental Manager, Great Places Housing Group

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Legal limitations and disclaimer

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Executive summary

Project overview

The project was led by Cheshire East Council and had the following aims:

- Install domestic battery systems in 22 socially rented homes with solar PV in Macclesfield and Knutsford.
- Assess the performance of the Powervault G200 system with 4kWh lead acid batteries
- Assess levels of resident satisfaction with the technology
- Determine the battery performance over about 2 years, quantifying the savings for the residents from the batteries and the associated solar PV systems
- Consider any challenges associated with deployment and operation of the technology

Context

There were estimated to be 163,566 households in Cheshire East in 2015[1] and the number in the district who were socially renting was 18,141[2]. The fuel poverty rate in Cheshire East in 2016 was 10.8%, which corresponded to 17,895 households[3].

By the end of September 2018, there were 4,413 domestic solar PV installations in Cheshire East. In the last few years, homeowners who have funded their own solar PV systems have benefited from feed-in tariff payments, export tariff payments and electricity savings from these systems. Those living in socially rented homes with solar PV installations only benefit from electricity savings. Such households need to maximise their self-consumption to increase the benefit from the solar PV system. One way of doing this is to add a domestic battery to store electricity which would otherwise be exported to the grid for use later in the day.

The market for domestic battery storage is still in the early stages of development in the UK. Battery storage is not covered by the Microgeneration Certification Scheme (MCS) which provides quality assurance for renewable installations. While renewable energy installers are very familiar with solar PV and the benefits can be easily estimated, experience with battery storage is more limited. The BRE National Solar Centre in collaboration with the Renewable Energy Consumer Code (RECC) has produced guidance for those considering purchasing battery storage systems[4]. Although solar PV installations can significantly increase SAP ratings, battery storage currently has no impact.

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[1] Table 406, 2014-based Household Projects for 2015, Department for Communities and Local Government, https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections (Accessed 31 Oct 2018)
[2] LSOA Community Data, Cheshire East Council, https://opendata.cheshireeast.gov.uk/Community/LSOA-Community-Data/m4t6-cppc (Accessed 31 Oct 2018)
[3] Sub-regional fuel poverty data 2018, Department of Business, Energy and Industrial Strategy (BEIS), https://www.gov.uk/government/statistics/sub-regional-fuel-poverty-data-2018 (Accessed 8 Aug 2018)
[4] Batteries and Solar Power: Guidance for domestic and small commercial consumers, BRE/RECC (2016) https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/NSC%20Publications/88031-BRE_Solar-Consumer-Guide-A4-12pp.pdf (6 Dec 2018)

The feed-in tariff led to a dramatic increase in the number of solar PV installations from 2010 to 2016 and played a role in the significant decrease in installation costs. There has been no such financial incentive for domestic battery storage to date. Most recent domestic battery installations have been by early adopters, specialist users or as part of research trials. Organisations which have been running research trials include NEA, the Distribution Network Operators (DNOs) and electricity suppliers. Typically, these have included between 20 and 60 batteries which have often been provided to households for free[5] [6]. Installation numbers for domestic battery storage in the UK have so far been modest, but strong growth has been predicted by the manufacturers. Powervault had plans to sell 50,000 units by 2020[7].

As manufacturers develop new products, there is a trend towards larger capacity batteries with greater output power. Prices per kWh of storage are predicted to fall. The economics for domestic battery storage will be further improved by batteries allowing residents to minimise their electricity costs on time-of-use tariffs and receive income for offering grid services.

The technology - *Powervault G200 battery storage system*

The Powervault G200 system is about the size of a fridge. The system is agnostic about the type of battery used and either AGM lead acid, tubular gel lead acid or lithium-ion batteries can be fitted with the system. The sizes of batteries available range from 2.5 kWh to 4 kWh for the lead acid batteries and 2.0 to 6.0 for the Lithium-ion. A Powervault G200 system with lead acid batteries and a 4 kWh usable capacity contains 6 lead acid batteries fitted in the G200 cabinet.

The Powervault G200 can provide a maximum continuous output of 0.8 kW, but for short periods can discharge about 1.15 kW. The system can charge at up to about 0.8 kW. The G200 system has LED colour bars to show when the battery is charging and discharging, however there is no meter to show the cumulative level of battery discharge on the system. It is only possible to monitor the performance of the G200 system when it is online. There is no built-in memory to store performance data when the WiFi connection is lost.

The project

Households that received the batteries were recruited from the customers of social landlords Peaks & Plains Housing Trust and Great Places Housing Group. Environmental social enterprises Energy Projects Plus and Go-Lo Macclesfield were engaged by Cheshire East Council to assist in household recruitment and support of residents during the project. All properties where batteries were installed had pre-existing solar PV systems and residents met eligibility criteria for low income and/or benefits.

A total of 17 Powervault G200 battery systems were installed in bungalows owned by Peaks & Plains Housing Trust in Macclesfield. A further 5 Powervault G200 battery systems were fitted in

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[5] Solar energy and battery storage trial, Mayor of London, https://www.london.gov.uk/sites/default/files/renew_solar_energy_case_study2.pdf (Accessed 31 Oct 18)

[6] Domestic Energy Storage and Control (DESC), UK Power Networks, https://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-1-projects/domestic-energy-storage-and-control/ (Accessed 6 Dec 18)

[7] UK solar start-up powers up to take on Tesla's home battery, Financial Times, 23 Jun 15 https://www.ft.com/content/6872b6fe-18e3-11e5-8201-cbdb03d71480 (Accessed 31 Oct 18)

houses in Knutsford owned by Great Places Housing Trust. The version of the Powervault G200 initially deployed on the project used AGM lead acid batteries with a total usable capacity of 4 kWh. The systems were installed between the beginning of July 2016 and the end of September 2016.

A number of the households were recruited to be part of the project evaluation carried out by NEA. This included interviews with the residents and technical monitoring of the battery and solar systems. There were 10 households recruited in Macclesfield and 1 in Knutsford. A further 4 households in Macclesfield which only had solar PV installations were recruited as control properties for comparison purposes. Over the course of the project 1 household with a battery and 1 in the control group withdrew from the monitored group due to health issues. It was not possible to recover monitoring equipment from 2 monitored sites.

Initial questionnaires were completed in June and September 2016. Intermediate visits were carried out in July 2017 to maintain contact with households, replace logging equipment and check for any changes to the household. Final visits were carried out in October 2018 and logging equipment was collected. The final questionnaire assessed the benefit of the battery, any reliability issues along with the appliances in the home and when they were used to assist with analysis of the electricity consumption.

Summary of findings

Resident satisfaction

- All the residents in the monitored group agreed or strongly agreed that the batteries didn't need any active input to work and found the systems easy to use.
- Out of the 9 households interviewed, 7 felt they knew enough about how the battery worked, while 6 agreed that they understood how best to use the battery.
- There were 6 out of 9 households who felt they had seen a reduction in their energy bills, with the other 3 saying their bills were about the same.

Installation and reliability issues

- When the monitored group was interviewed, 7 households thought the installation was neat and tidy with no loose wires or connections, but 2 disagreed.
- The initial Powervault G200 system at 1 site failed and when a replacement system was installed, the current clamp was fitted the wrong way around. This resulted in higher bills for the household rather than savings and compensation was paid to the residents as a result.
- Powervault discovered there had been issues with the batch of AGM lead acid batteries that had been supplied with the G200 systems. As a result, they advised switching off the battery systems on 23 Aug 17.
- After the batteries were switched off, it was discovered that some of the batteries had swelled and some had cracked in places due to a manufacturing defect. The batteries were replaced to overcome this issue and the component supplier was changed. A firmware update for the systems was also carried out to detect and mitigate further risks from over/undercharging batteries. The importance of an online connection was also highlighted to allow remote monitoring of battery health as well as system performance.
- New tubular gel batteries were fitted at the end of October 2017 and the battery systems were turned on again and provided with a charge from the grid.

- On the evening of 2 Nov 2017, a carbon monoxide alarm was set off when the faulty batteries were replaced. This was caused by incorrect setting of an initial commission charge causing over-charging of the batteries leading to release of hydrogen and oxygen through the 1-way valve on the batteries. The sensor on the carbon monoxide alarm was unable to differentiate between hydrogen and carbon monoxide. The household where the alarm was set off requested that the battery was permanently removed from the property.
- There was a battery system where there was little, or no electricity import or battery discharge and this was likely to be due to issues with the current clamp. The battery was serviced in October 2018 and was seen to discharge although it went offline shortly after.
- The last of the installations had the tubular gel battery replacements fitted in August 2018. The batteries had been stored on site, stolen and recovered by the police. When these batteries were installed, the insulation on some wiring in the G200 unit melted due to a damaged battery connector. Powervault has incorporated design changes to prevent problems with damaged battery connectors in future.
- The solar PV systems for the properties in Macclesfield were installed in 2011. Unrelated to the Powervault system, there have been a number of solar PV inverter failures among the systems in recent years. This included 3 households with batteries and a control household during the study period. There was a household where the PV system was off for over a year. The battery system was switched on for much of this time and with no solar generation, it provided no benefit and was consuming about 35W of power.
- Most of the households that received installations had elderly residents and few had internet connections. Initially it was mainly the households in the monitored group where the battery systems were connected online. From November 2017, there was an aim to connect all the systems online to allow monitoring of system performance and battery health. However, there were challenges in maintaining a good internet connection.

Methods of analysing battery performance

- System performance was recorded every 30 seconds by the Powervault G200 system while it was online. Data that was averaged every 5 minutes was provided by Powervault for analysis.
- Verv data loggers were used to measure charge and discharge of the batteries at 3 households. The loggers recorded data every second. Typically values of charge and discharge calculated were about 20% lower than those derived from the 5-minute aggregate Powervault data. Other trials where Powervault and Verv equipment have been used have not identified a similar difference. This was likely to be at least partly caused by the use of 5-minute aggregate data with these calculations rather than the raw 30 second Powervault data.

Overview of the performance of the Powervault G200 battery systems

- 11 of the batteries recorded performance for between 164 and 333 days, with periods online varying from 60.4 to 99.6%.
- The battery discharge derived from the 5-minute aggregate Powervault data ranged from 190.4 to 618.6 kWh.

Better performing Powervault G200 systems

- Calculations from the Powervault data showed the best 2 performing batteries in the monitored group discharged 0.31 to 0.35 kWh/day in December 2017 with the tubular gel batteries and 3.03 to 3.63 kWh/day in May 2018.
- For 1 of these installations with tubular gel batteries, between 1 Nov 17 and 1 Nov 18, the system recorded a battery discharge of 656 kWh. This averaged out at 1.83 kWh/day once the period online was taken into account.
- The battery round trip efficiency was 24.2 to 26.7% in December 2017 and 70.5 to 72.4% in May 2018
- All the sites had an excess of solar PV generation. The level of PV generation between sites was not a significant factor in the better performance as 1 of these sites had about the lowest PV generation among the installations due to shading from bushes and trees.
- The battery system was able to supply much of the power to these households in the early evening on days when the batteries were able to charge from the solar PV.
- Both these battery installations recorded higher levels of electricity import of 904 – 989kWh over 333 days. The values of electricity consumption recorded by the Powervault system did not show major differences from the utility meter readings.

Low values of battery discharge at some sites may have been influenced by low readings for household electricity import

- There were particularly low values of battery discharge for 1 of the monitored systems and the resident felt that there was no change in the electricity consumption after the batteries were installed.
- For the months between May and September 2018, the battery discharge determined from the Powervault data was in the range 1.14 to 1.17 kWh/day. Values measured using a Verv data logger ranged from 0.87 to 0.96 kWh/day between June and August.
- There was a significant difference between the import recorded by the Powervault system and that recorded by the utility meter. Electricity meter readings were 3.6 to 5.3 times the values derived from the Powervault data between June and September 2018.
- It is possible that the low readings of electricity import were due to a problem with readings from the current clamp for the G200 system. The cable between the electricity meter (where the current clamp was fitted) and the battery was longer on the poorest performing system than on the sites with better performance which may be a contributing factor. Had the G200 system more accurately measured the household demand, it is likely the system would have supplied greater power to the household.
- Similar issues seemed to occur in 2 other households where levels of battery discharge were not particularly high. Again, the import power recorded by the G200 system was significantly lower than the consumption measured by the utility meter.

Comparison with other battery systems

- 2 of the Powervault G200 battery systems with 4 kWh tubular gel batteries recorded good quality data over a period of a year.
- The battery discharge determined from the Powervault system was 553 kWh and 656 kWh. This equates to savings of £85 and £105 per year using an electricity price of 16p/kWh.

- Other battery systems have been tested on another NEA trial in Thurrock[8].
- The best performing Maslow lithium-ion battery with a 2kWh nominal capacity (1.6kWh usable) discharged 341 kWh in a year.
- The best performing PowerFlow Sundial battery of the same size discharged 422 kWh.
- A Victron charger/inverter with a Leoch AGM lead acid battery with a 1.56 kWh usable capacity had a net battery discharge of 288 kWh in the year.

Conclusions and recommendations

- Domestic solar PV is an effective technology for reducing electricity bills for residents as well as for increasing the SAP-rating of a building. Battery storage can help households maximise savings by increasing the level of self-consumption of the generated electricity.
- At present there is no financial payback for a battery by solar time-shifting alone.
- When developing a project with multiple battery storage installations, sufficient time and resource should be allocated for recruiting suitable households
- Full surveys of properties are required to determine if there is a suitable location for the battery and a sensible cable run to the consumer unit. An assessment should be made of household energy consumption and PV generation. If there is little excess solar generation there would be little available to charge the battery.
- In order to monitor the battery performance and follow warranty requirements, the battery system must have a good online connection.
- While selecting households, it must be confirmed there is currently an internet connection and the residents are willing to allow the battery system to be connected to this.
- Certain groups (particularly some elderly households) are less likely to have a broadband connection. It is possible to set up dedicated broadband connections for the battery and piggyback other battery systems onto this, but such an approach has been challenging on this project.
- A 3G connection on the battery alone is rarely good enough to provide the required communications. TP Links can connect the battery system to a WiFi router, but a hard-wired connection is more reliable.
- Lead acid batteries should be installed in a ventilated area in accordance to the manufacturer's recommendations.
- CT clamps can be fitted the wrong way around at installation or after a smart meter is installed. Some battery systems are now using directly connected MID approved meter modules to improve accuracy and reliability.
- In this and other projects where there has been battery storage and solar PV in social housing, there have been some systems which have broken down for a number of months. Landlords and manufacturers need to develop better systems to avoid this in future. This should include automated alerts, regular analysis of performance data and the ability to respond rapidly over repairs. Another issue to regularly address is shading of PV systems by trees and bushes.
- Some battery systems on projects have not performed correctly from the time of installation and there is a greater risk of this occurring in socially rented properties. The installer or manufacturer needs to check the battery system is performing as expected at least a month

[8] Paul Rogers and Michael Hamer, SunGain Battery Bank, Thurrock, Nottingham Energy Partnership, (NEA, in press)

after installation. This should include checking the battery discharge, household import and PV generation and comparing with other data, derived from electricity and generation meters, and pre-install predictions.

- Residents should be provided with advice at the time of installation and be provided with documentation which advises on how the system works, how to maximise savings and the impact of different patterns of use.
- The battery system should allow residents to check the unit is working correctly along with a monitoring system, with either a display on the battery, an App or an online portal. These should have an easy way to see what savings the battery has produced and more detailed information which would allow the resident to determine how to improve savings.
- Social landlords or other agencies should be engaged to offer advice on how to maximise benefits from the battery and solar PV systems through internal staff or external energy advisors.

1. Project overview

1.1 Introduction

Many social landlords took advantage of the feed-in tariff and installed significant numbers of solar PV systems on their properties. Residents of these properties are typically able to consume the solar generated electricity for free. However, much of the electricity generated is exported to the grid if the residents are out during the day or during the summer when the PV generation is greater than the household consumption. Adding battery storage enables some of the electricity that would be otherwise exported to be stored for later use in the evening, saving the residents money (figure 1.1). Installation of battery storage also benefits the electricity network overall by facilitating greater integration of renewable energy and reducing the resident's dependency on grid power during peak hours of consumption.

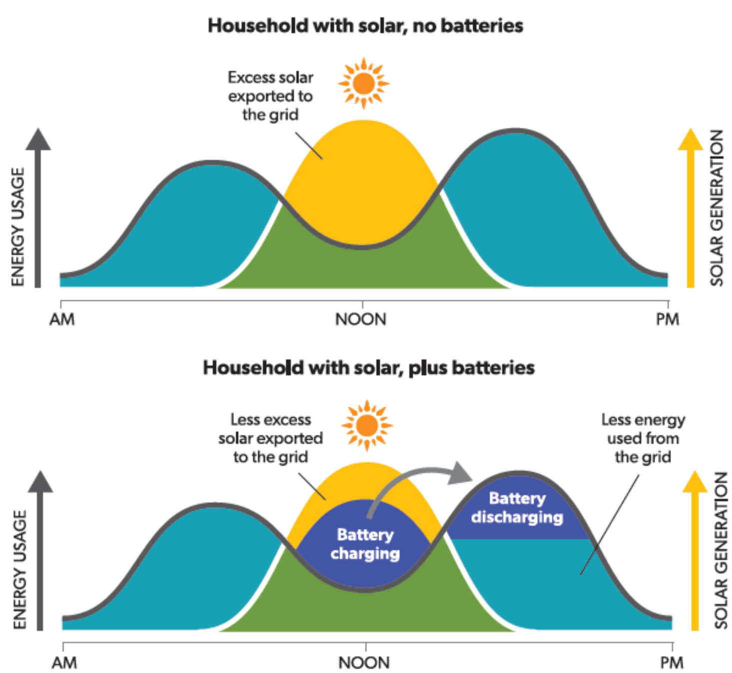

Figure 1.1 Illustration of the benefits of energy storage on a solar PV system[9]

Cheshire East Council were keen to develop a project installing domestic battery storage in socially rented properties as a means of reducing fuel poverty. They were assisted in the project by Go-Lo Macclesfield and Energy Projects Plus (EPP) and the social landlord partners were Peak & Plains Housing Trust and Great Places Housing Group.

The battery system selected for the project was produced by UK battery system company, Powervault Ltd. A total of 22 Powervault G200 systems using lead acid batteries were installed, with 17 fitted in bungalows in Macclesfield and 5 in houses in Knutsford.

[9] NSW Home Solar Battery Guide (2017), https://energy.nsw.gov.au/sites/default/files/2018-09/NSW-Home-Solar-Battery-Guide_WEB.pdf (Accessed 6 Dec 2018)

1.2 Aims

The project had the following aims;

- Install domestic battery systems in 22 socially rented homes with solar PV in the area of Cheshire East Council.
- Assess the performance of the Powervault G200 system with 4kWh lead acid batteries
- Assess levels of resident satisfaction with the technology
- Determine the battery performance over about 2 years and the savings for the residents from the batteries and the solar PV systems
- Consider any challenges associated with further large-scale deployment of the technologies

1.3 Context

There were estimated to be 163,566 households in Cheshire East in 2015[10] and the number in the district who were socially renting was 18,141[11]. Peaks & Plains Housing Trust has over 5000 properties across Cheshire and the High Peak and within Macclesfield has 3,256 properties. Great Places Housing Group has customers living in 19,000 homes across the North West and Yorkshire.

The fuel poverty rate in Cheshire East in 2016 was 10.8%, which corresponded to 17,895 households[12]. In Macclesfield Parliamentary Constituency there were 4,257 households considered fuel poor and 3,741 in Tatton Constituency which includes Knutsford.

By the end of September 2018, there were 4,413 domestic solar PV installations in Cheshire East. In the Parliamentary Constituency of Macclesfield there were 910 domestic PV installations while in Tatton there were 1,312.[13] The number of Peaks & Plains properties in Macclesfield which have solar PV is 68.

In the last few years, homeowners who have funded their own solar PV system have benefited from feed-in Tariff payments, export tariff payments and electricity savings from these systems. These benefits mean that owners have tended to pay back the system cost in 5 to 12 years.

Those living in socially rented homes with solar PV installations and those with 'rent a roof'-funded installations only benefit from electricity savings. Such households need to maximise their self-consumption to increase the benefit from the solar PV system. One way of doing this is to add a domestic battery to store electricity which would otherwise be exported to the grid.

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[10] Table 406, 2014-based Household Projects for 2015, Department for Communities and Local Government, https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections (Accessed 31 Oct 2018)
[11] LSOA Community Data, Cheshire East Council, https://opendata.cheshireeast.gov.uk/Community/LSOA-Community-Data/m4t6-cppc (Accessed 31 Oct 2018)
[12] Sub-regional fuel poverty data 2018, Department of Business, Energy and Industrial Strategy (BEIS), https://www.gov.uk/government/statistics/sub-regional-fuel-poverty-data-2018 (Accessed 8 Aug 2018)
[13] Sub-regional Feed-in Tariff Statistics, September 2018, https://www.gov.uk/government/statistical-data-sets/sub-regional-feed-in-tariffs-confirmed-on-the-cfr-statistics (Accessed 31 Oct 2018)

The market for domestic battery storage is still in the early stages of development in the UK. At the time of writing, battery storage is not covered by the Microgeneration Certification Scheme (MCS) which provides quality assurance for renewable installations. While renewable energy installers are very familiar with solar PV and the benefits can be easily estimated, experience with battery storage is more limited. The Renewable Energy Consumer Code (RECC) has written guidance on battery storage for sellers and installers following a significant number of complaints about mis-selling of the technology[14]. The BRE National Solar Centre in collaboration with RECC has also produced guidance for those considering purchasing battery storage systems[15]. Although solar PV installations can significantly increase SAP ratings, battery storage has no impact.

The feed-in tariff led to a dramatic increase in number of solar PV installations from 2010 to 2016 and played a role in the significant decrease in installation costs. There has been no such financial incentive for domestic battery storage to date. Most domestic battery installations have so far been for early adopters, specialist users or part of research trials. Organisations which have been running research trials include NEA, the Distribution Network Operators (DNOs) and electricity suppliers. Typically, these have included between 20 and 60 batteries which have been provided to households for free[16] [17] [18].

Installation numbers for domestic battery storage in the UK have so far been modest, but strong growth has been predicted by the manufacturers. Moixa, another UK battery manufacturer had installed nearly 1000 systems in the UK by July 2017 but was expecting to install 50,000 batteries in the UK by 2020[19]. Powervault also had plans to sell 50,000 units by 2020[20].

As manufacturers develop new products, there is a trend towards larger capacity batteries with greater output power. Prices per kWh of storage are predicted to fall. The economics for domestic battery storage will be further improved by batteries allowing residents to minimise their electricity costs on time of use tariffs and offering grid services income.

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[14] Battery storage for solar power: guidance for sellers/installers, (RECC,2015) https://www.recc.org.uk/pdf/guidance-on-battery-storage.pdf (Accessed 6 Dec 2018)

[15] Batteries and Solar Power: Guidance for domestic and small commercial consumers, BRE/RECC (2016) https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/NSC%20Publications/88031-BRE_Solar-Consumer-Guide-A4-12pp.pdf (6 Dec 2018)

[16] Solar energy and battery storage trial, Mayor of London, https://www.london.gov.uk/sites/default/files/renew_solar_energy_case_study2.pdf (Accessed 31 Oct 18)

[17] Batteries included: Yorkshire village seeks to solve riddle of too much sun, Adam Vaughan, The Guardian, 21 Jan 2017, https://www.theguardian.com/business/2017/jan/21/batteries-included-yorkshire-village-seeks-to-solve-riddle-of-too-much-sun (Accessed 6 Dec 2018)

[18] Domestic Energy Storage and Control (DESC), UK Power Networks, https://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-1-projects/domestic-energy-storage-and-control/ (Accessed 6 Dec 18)

[19] Moixa expansion continues with £2.5 million investment and plans for 100,000 battery Virtual Power Plant to balance grid, Moixa press release, 18 Jul 2017 http://www.moixa.com/press-release/moixa-expansion-continues-2-5-million-investment-plans-100000-battery-virtual-power-plant-balance-grid/ (Accessed 6 Dec 2018)

[20] UK solar start-up powers up to take on Tesla's home battery, Financial Times, 23 Jun 15 https://www.ft.com/content/6872b6fe-18e3-11e5-8201-cbdb03d71480 (Accessed 31 Oct 18)

1.4 Project timeline

The project commenced in December 2015. Recruitment of households started in June 2016, with installations running from early July until the end of September 2016. Households in the monitored group had initial interviews and loggers fitted in June and September 2016.

There were issues with the batch of AGM lead acid batteries which were originally fitted. On 22/23 August 2017 all the battery systems were turned off and new tubular gel lead acid batteries were fitted on 31 October/1 November 2017. During the initial high-power commissioning of the new batteries, a carbon monoxide alarm was set off at 1 site due to low emissions of hydrogen. This was due to the charging at that site having been configured with an incorrect setting. The household where this occurred had the battery permanently removed. The batteries at the other 4 households which had been installed internally were switched off until they could be relocated outside.

Final interviews with the monitored and control groups were carried out in October 2018 with the report completed in December 2018.

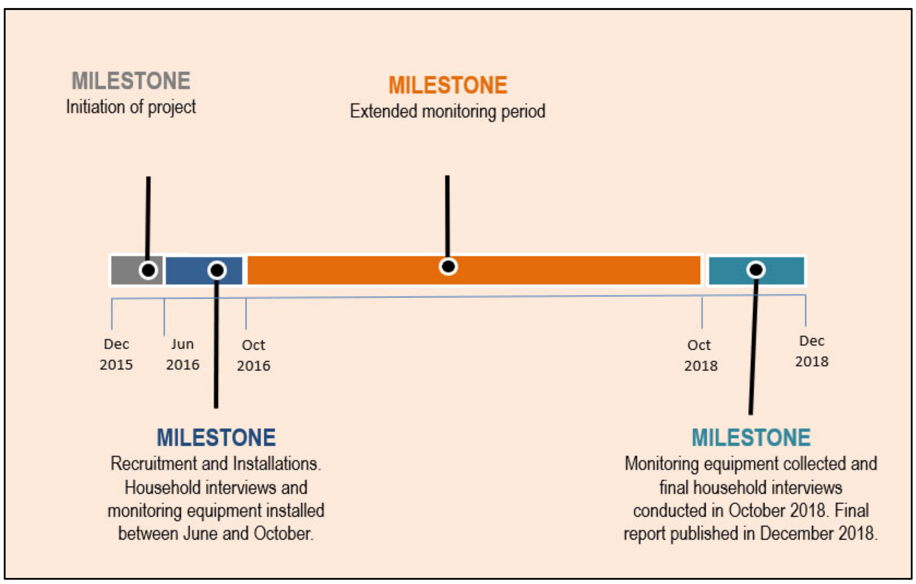

Figure 1.2 Project timeline

1.5 Attracting beneficiaries and establishing a monitored group

- Environmental social enterprises Energy Projects Plus and Go-Lo assisted by engaging with and supporting residents during the project.
- Energy Projects Plus which is based in Wallasey took the lead over households in Knutsford. They collaborated with Great Places Housing Group, the social landlord and 199 Solar, the electrical contractor.
- A list of 27 potential properties was provided by Great Places Housing Group. These had solar PV installations and the residents were likely to meet the eligibility criteria requiring low incomes and/or certain benefits.

- Each of the potential households in Knutsford were visited during the summer of 2016 and were introduced to the scheme and invited to make an expression of interest. Where no contact was made, each property was visited a minimum of 5 times, including evenings and weekends, to ensure no one missed out.
- From the initial list, a total of 5 households in Knutsford met the eligibility criteria and agreed to participate in the project and receive a Powervault battery.
- Following the installation of the Powervault batteries, Energy Projects Plus continued to be the main contact for the Knutsford households and this included arranging the visits from Powervault in August 2017. The role was then passed to Cheshire East Council as the upgrade of the batteries commenced and direct liaison then proceeded between the Council and Powervault.
- In addition to support of the battery installations, Energy Projects Plus surveyed and provided Energy Performance Certificates (EPCs) for 11 properties and also provided energy efficiency advice for the residents.
- Recruitment and household support for most of installations was carried out by Go-Lo who are based in Macclesfield. As well as resident engagement with the customers of Peaks & Plains Housing Trust in Macclesfield, Go-Lo also provided cover for Energy Projects Plus in Knutsford when their staff member was on annual leave.
- Initial recruitment of households in Macclesfield was led by the Energy Support Officer from Peaks & Plains Housing Trust. Examples of a frequently asked questions sheet and a letter for households who were out are shown in Appendix 2. The Energy Support Officer left Peaks & Plains during the early stages of the project. Further recruitment and household support was provided by Go-Lo.
- Visits were organised with the residents where the project was explained to them and they were left with information. A letter was left for residents who were not in. An engagement event was also organised in the local community centre where tea, coffee and refreshments were provided, and residents could find out more about the project and ask questions.
- Go-Lo continued to be the main contact for the 17 households in Macclesfield and also assisted by collecting meter readings and installing loggers for NEA. They provided energy saving advice and aided installation of internet connections shared between households for the battery installations where no internet was available.

1.6 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Internet Connection	The Powervault G200 battery system does not have a meter to show the amount of battery discharge and only monitors performance of the system when it is connected online. Most installations took place in homes with elderly residents, with many not having an internet connection. Some were unhappy to have the battery connected to their broadband connection. It was possible to connect 5 of the households to the internet in Nov/Dec 2016 and a further 3 in Feb 2017. Most of the remaining batteries were connected in Nov/Dec 2017 as an internet connection was a prerequisite for a Powervault extended warranty. Data quality issues occurred when an internet connection dropped out. These were typically worse at the start of the project but improved following later engineers' visits. Various methods were tried to improve the quality of the internet connection. These included 3G dongles, WiFi extenders and piggybacking other systems on a funded internet connection. By the end of the project the data quality for most systems had improved significantly.
Reversed current clamp	An initial G200 battery installation needed replacing. When the new system was installed, the current clamp for the battery was fitted on the mains meter tail the wrong way around. This led to the household incurring additional energy costs. The situation was rectified, and compensation was paid to the household.
AGM batteries	Powervault became aware of problems with other AGM batteries in the same batch used for this project, where a manufacturing defect led to swelling and cracking of some of the batteries during use. Also, it was noted that some of the AGM batteries in the system were undercharging, while others were overcharging, reducing battery performance and lifetime. All batteries were switched off on 22/23 August 2017. New tubular gel batteries were fitted at the end of October 2017 and a firmware update was made for the Powervault system to ensure the batteries were charged evenly.
Setting off carbon monoxide detector during initial commissioning charge	After the tubular gel batteries were fitted in the Powervault G200 systems, they were tested and set to undertake a commissioning charge from the grid. Due to wrong settings being used for the commissioning charge, on the evening of 2 Nov 17, the carbon monoxide alarm was set off at 1 household with an internally installed battery. The alarm was set off by hydrogen emissions from the battery as the sensor could not differentiate between carbon monoxide and hydrogen. All batteries were switched off. The household where the alarm was set off requested the battery was permanently removed. Cheshire East requested that other

	households with internal batteries had them reinstalled in outdoor enclosures which took place several months later.
Change of resident	Over the period of the project, several of the residents who received batteries either died or moved out of the property. This included 1 household in the monitored group. With these households, data was only included from a single tenant at the properties. This meant that data from the earlier or later tenant was ignored since a different tenant would have had different usage patterns and energy characteristics. The period between tenants when the property was unoccupied was also ignored.
Melted wire	When the tubular gel batteries were fitted at a household in August 2018, the wiring on the battery terminal melted due to a damaged battery connector. The batteries had previously been stored on site prior to installation, stolen and recovered by police. Powervault incorporated design changes to prevent problems with damaged battery connectors in future. A replacement Powervault G200 battery system was installed at the property.

2. Social evaluation and impacts

2.1 Details of properties

Location of the installations

Location	Total installations	Monitored group	Control properties
Macclesfield	17	9	4
Knutsford	5	1	0
Total	**22**	**10**	**4**

Table 2.1 Locations of the Powervault battery installations and controls in Cheshire East

Overall, there was a total of 22 Powervault G200 battery systems installed in Cheshire East. Out of these, 17 were fitted in bungalows in Macclesfield owned by Peaks & Plains Housing Trust and 5 in houses in Knutsford owned by Great Places Housing Group. All these properties had pre-existing solar PV. There were 4 households in Macclesfield who were recruited to be controls for the project evaluation. Here the residents lived in bungalows with solar PV and did not receive batteries.

Figure 2.2a shows that the location of the 17 installations and 4 controls in Macclesfield, which were in 2 areas of the town. Figure 2.2b shows the installations in Knutsford.

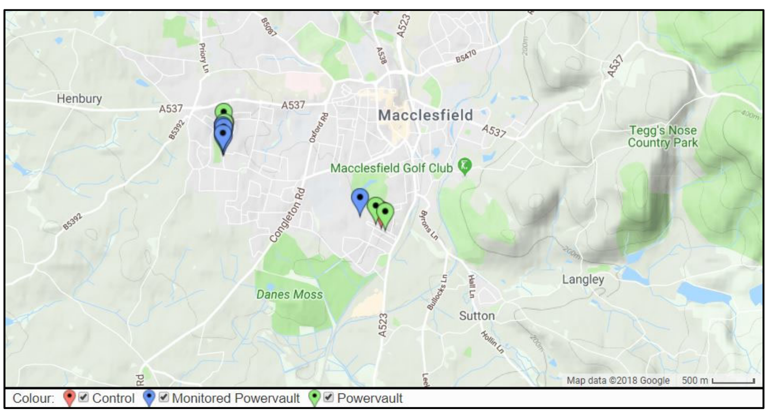

Figure 2.2a Map showing the Powervault installations and controls in Macclesfield

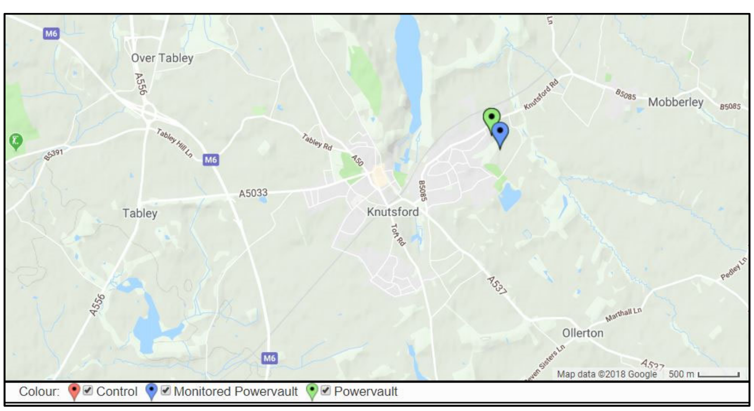

Figure 2.2b Map showing the Powervault installations in Knutsford

Characteristics of properties with battery installations

Technical Reference Number	Dwelling Type	Floor area (m^2)	Wall Type	Heating Type	SAP Rating	PV System Size (kW)	Generation in 2017 (kWh)	Date of PV Commissioning	Date of battery installation
T-01	Mid-terrace bungalow	45	Filled cavity	Mains gas	92	2.63	2442	Dec-11	06-Jul-16
T-02	End-terrace bungalow	44	Filled cavity	Mains gas		2.63	2472	Dec-11	06-Jul-16
T-03	End-terrace bungalow	45	Filled cavity	Mains gas	90	2.63	2321	Dec-11	05-Jul-16
T-04	End-terrace bungalow	54	Filled cavity	Mains gas		2.63	2606	Nov-11	22-Jul-16
T-05	Mid-terrace bungalow	30	Filled cavity	Mains gas		2.26	2287	Dec-11	29-Jul-16
T-06	Semi-detached bungalow	55	Filled cavity	Mains gas	91	2.63	2371	Nov-11	29-Jul-16
T-07	End-terrace bungalow	45	Filled cavity	Mains gas	84	2.63	1695	Nov-11	29-Jul-16
T-08	Semi-detached bungalow	54	Filled cavity	Mains gas	88	2.63	2295	Dec-11	20-Sep-16
T-09	Mid-terrace bungalow	45	Filled cavity	Mains gas	95	2.63	2494	Nov-11	05-Jul-16
T-10	End-terrace bungalow	45	Filled cavity	Mains gas	94	2.63	2582	Dec-11	11-Aug-16
T-11	Mid-terrace bungalow	44	Filled cavity	Mains gas	87	2.63	2465	Dec-11	27-Sep-16
T-12	Mid-terrace bungalow	30	Filled cavity	Mains gas	100	2.63	2761	Dec-11	11-Aug-16
T-13	Mid-terrace bungalow	44	Filled cavity	Mains gas	87	2.63	>1690	Dec-11	29-Jul-16
T-14	Semi-detached bungalow	46	Filled cavity	Mains gas		2.63	2325	Dec-11	17-Aug-16
T-15	Mid-terrace bungalow	47	Cavity	Mains gas	87	2.63	2731	Dec-11	25-Aug-16
T-16	Mid-terrace bungalow	55	Cavity	Mains gas	66	2.63	2042	Dec-11	20-Sep-16
T-17	Mid-terrace bungalow	54	Filled cavity	Mains gas	88	2.63	2767	Dec-11	19-Sep-16
Average		**46**			**88**		**2416**		

Table 2.3 Details of properties which received Powervault batteries in Macclesfield

All the households in the study have been assigned a technical reference number to maintain their anonymity. Details of the properties where Powervault batteries were installed in Macclesfield are shown in table 2.3. These were 1 or 2-bedroom terraced bungalows (figure 2.4) with gas central heating and a floor area of between 30 and 55 m^2. They were well insulated with cavity walls, although the EPC assessor was uncertain whether they were filled at 2 properties. Lofts typically had 250mm or more insulation. The SAP or Energy Efficiency Rating for these properties was high, ranging from 66 to 100. Properties in the tables which do not have a SAP rating had an EPC dating from before 2012. These were calculated using a different methodology to those from 2012 and so were therefore not comparable. Also, solar PV was fitted on the properties in Macclesfield in 2011 and so an earlier EPC would miss the impact of the solar PV and perhaps loft insulation top-ups and boiler changes.

Figure 2.4 Example of terraced bungalows in Macclesfield

The solar PV systems on the bungalows in the study in Macclesfield were all 2.63kW in size apart from a system on a smaller 30m^2 property which had a 2.26kW system. These were all fitted in November and December 2011, at the peak in the feed-in tariff rate. The Powervault batteries were all fitted between the beginning of July 2016 and end of September 2016.

The properties in Knutsford which received batteries were all 3-bedroom post-1980s terraced houses. Further details are shown in table 2.5. Those with no SAP rating again had an EPC dating from before 2012. These were larger properties and so were likely to have a higher energy consumption. Details of the 4 control properties in Macclesfield where no batteries were fitted are in table 2.6.

Technical Reference Number	Dwelling Type	Floor area (m^2)	Wall Type	Heating Type	SAP Rating	PV System Size (kW)	Generation in 2017 (kWh)	Date of PV Commissioning	Date of battery installation
T-18	Mid-terraced house	95	Filled Cavity	Mains gas	80	3.43	2400	Jul-12	15-Aug-16
T-19	Mid-terraced house	68	Filled Cavity	Mains gas		2	1407	Jul-12	02-Sep-16
T-20	Mid-terraced house	68	Filled Cavity	Mains gas		2		Jul-12	02-Sep-16
T-21	End-terrace house	77	Filled Cavity	Mains gas	75	2.9	2476	Jul-12	27-Sep-16
T-22	Mid-terraced house	83	Filled Cavity	Mains gas	79	2	>1398		29-Sep-16

Table 2.5 Details of properties which received Powervault batteries in Knutsford

Technical Reference Number	Dwelling Type	Floor area (m^2)	Wall Type	Heating Type	PV System Size (kW)	Generation in 2017 (kWh)	Date of PV Commissioning
C-01	Mid-terraced bungalow		Filled cavity	Mains gas	2.63	2229	Dec-11
C-02	End-terrace bungalow	54	Filled cavity	Mains gas	2.63	1754	Dec-11
C-03	Mid-terraced bungalow	44	Filled cavity	Mains gas	2.63	2269	Dec-11
C-04	Mid-terraced bungalow	55	Cavity	Mains gas	2.63	2718	Dec-11

Table 2.6 Details of properties in the control group

Charts illustrating the characteristics of the properties in the project are shown in figures 2.7 to 2.9. Out of the households that received battery installations, 40.9% were mid-terrace bungalows and 22.7% were end-terrace bungalows. Among the monitored properties, 40% were end-terrace bungalows.

Among the 22 properties where batteries were installed, 45.5% had a floor area of between 40 and 50m^2. With the monitored group, 50% were in this range of floor areas. There were 16 out of the 22 households which received batteries which had an EPC from or after 2012. Out of these, 50% of the properties were in SAP band B. In the monitored group, 7 households had EPCs in the post 2012 format. Here, 57.1% of the properties were in band B and 28.6% were in band A.

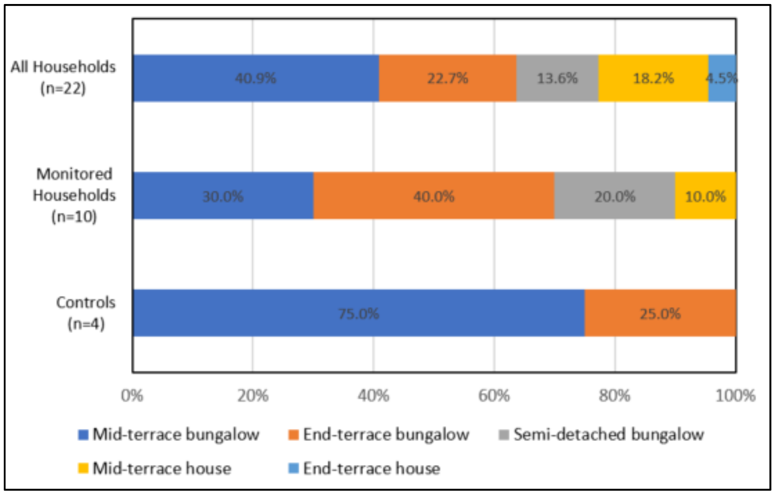

Figure 2.7 Chart illustrating the type of properties among all the households that received batteries as well as the monitored and control groups

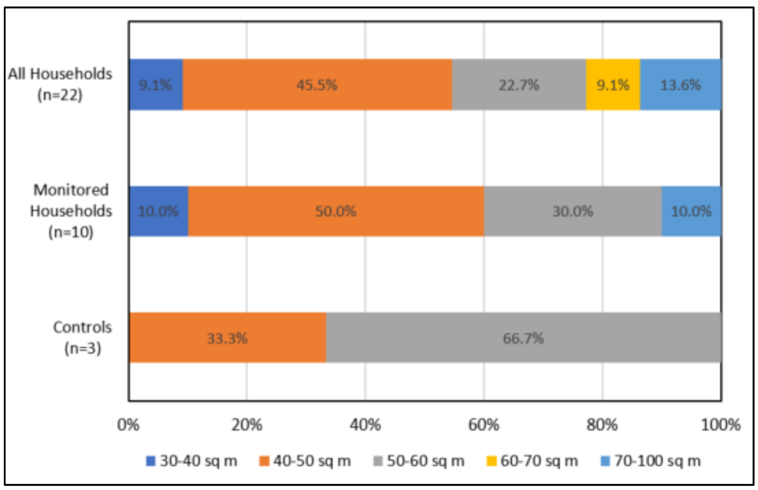

Figure 2.8 Chart illustrating the floor area of households

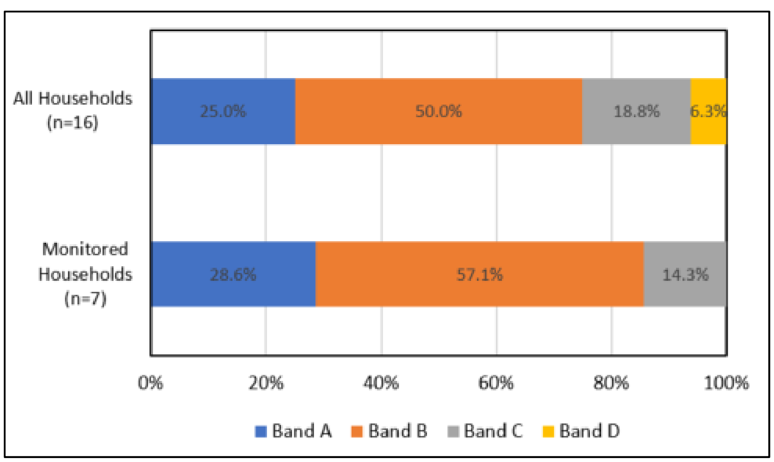

Figure 2.9 Chart illustrating the Energy Efficiency Rating Band or SAP Band of households

Details of monitored households

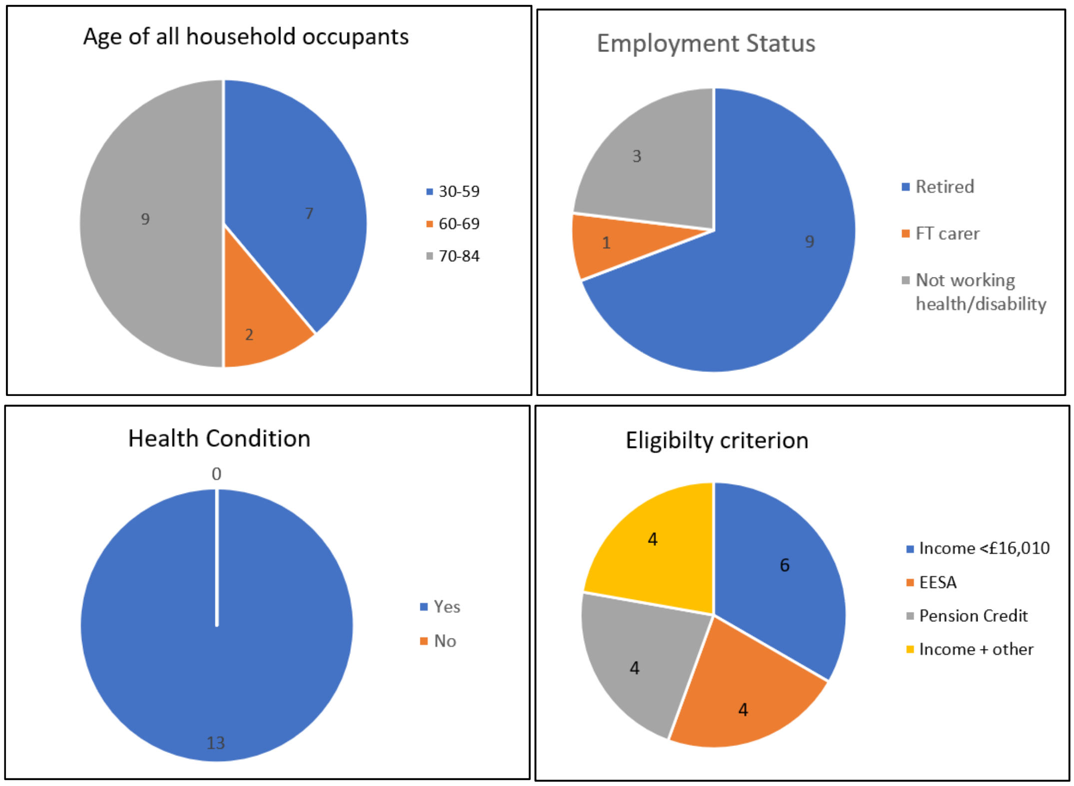

Figure 2.10 (a) Household age (n=18) (b) Employment status (n=13) (c) Health condition (n=13) (d) Eligibility criterion for installation (n=18)

It was possible to interview 13 of the monitored properties with batteries and controls. There were 18 residents and 9 of these were between 70 and 84 years, while 7 were in the age bracket 30-59. Among the 13 householders that were interviewed, 9 were retired while 3 were not working due to having a serious health condition or disability and 1 was a full-time carer for a partner who had a serious health condition. All 13 of the households had a member who had a health condition, and all noted it was made worse by the cold.

The battery installations were targeted at households on low incomes or benefits. Figure 2.10(d) shows the eligibility route for 18 of the battery installations. For 6 households this was due to their income being less than £16,010 per annum while 4 households were in receipt of Employment and Support Allowance with supplementary payments for disability etc. (EESA). There were 4 households receiving Penson Credit and 4 households who had an income less than £16,010 and were in receipt of another benefit such as employment and support allowance (ESA) and disability living allowance (DLA).

2.2 Affordability of energy bills

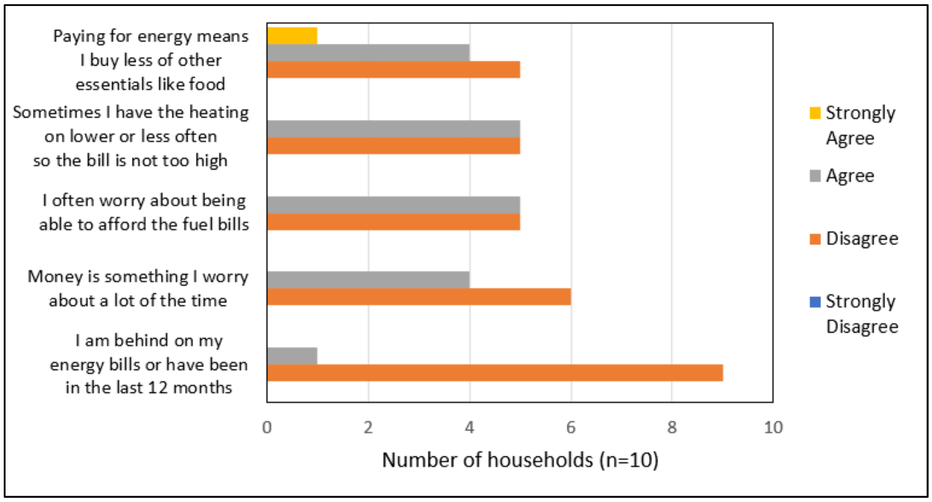

Figure 2.11 Chart illustrating the affordability of energy bills for the households interviewed

There were 10 households in the monitored group who received batteries and were asked about the affordability of the energy bills (figure 2.11). Out of these, 4 households agreed that paying for energy meant they bought less of other essentials like food while 5 disagreed. A further household strongly agreed with the statement and this resident was unable to work due to a long-term health condition or disability. Equal numbers agreed and disagreed with the statements that they sometimes had the heating on lower or less often, so the bill was not too high, and that they often worried about being able to afford the fuel bills. There were 4 out of the 10 who agreed that they worried about money a lot of the time. A single household agreed they had been behind on their energy bills during the last 12 months and this was the household which sometimes bought fewer essentials in order to afford their energy bills.

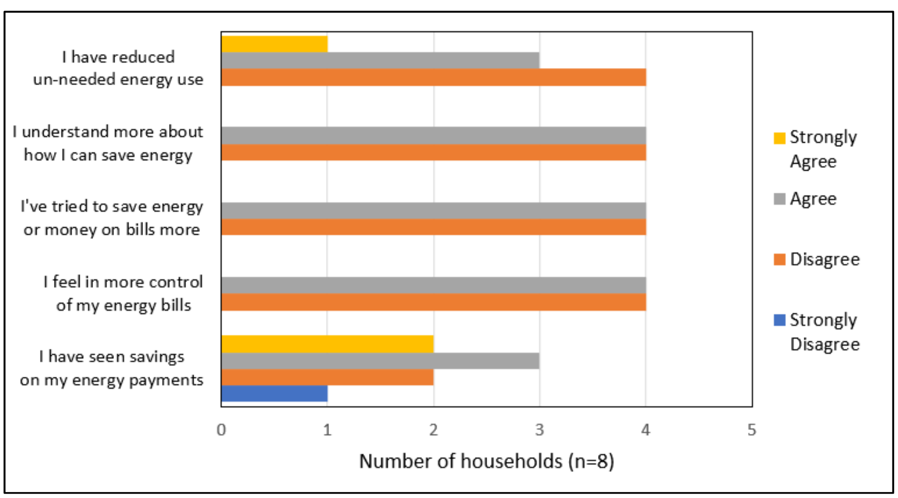

Figure 2.12 Chart illustrating changes since the start of the project

Among the 8 households in figure 2.12 who were asked about changes to their energy use, 1 strongly agreed they had reduced energy they didn't need to use while a further 3 agreed with the statement. Equal numbers agreed and disagreed with the statements that they understood more about how they could save energy, tried to save energy more and felt more in control of their energy bills after the project.

There were 2 households out of the 8 that strongly agreed and 3 that agreed that they had seen savings on their energy payments. Among these, 1 household had been recording meter readings every week since 2012 while another regularly recorded meter readings over the project. A further 2 of these households were on prepayment meters which meant they noticed any changes to their electricity costs close to the time of use. This included a household with a smart meter who noted he was aware when the battery was powering appliances as the In-Home Display (IHD) of the smart meter in some cases did not show a rise in consumption when he turned appliances on.

2.3 Resident acceptance and satisfaction

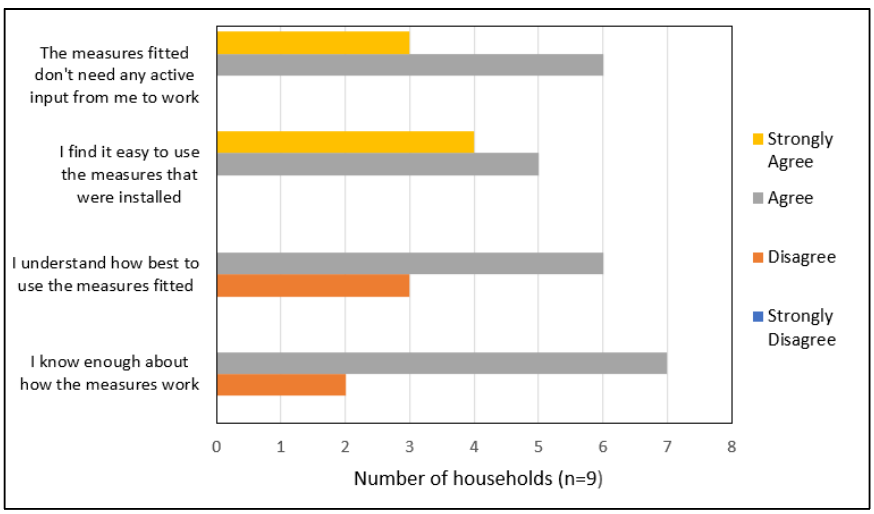

Figure 2.13 Chart illustrating ease of use of the system and knowledge of how it works

Out of 9 households in the monitored group with batteries, figure 2.13 shows that all either strongly agreed or agreed that the battery did not need any active input from them to work. They also all found the battery easy to use, with 4 strongly agreeing and 5 agreeing. This reflected that once the battery was fitted, it was not necessary to do anything or change settings on the battery while working. There were 7 out of the 9 households who felt they knew enough about how the battery worked and 6 who felt they understood how best to use the battery.

The household satisfaction with the installation process is considered in figure 2.14. There were 3 households who strongly agreed and 4 who agreed that the installations were neat and tidy and that the installations had no loose wires and connections. Out of the 9 households who were interviewed, 2 disagreed with these statements. A reason for this was untidy wiring and 1 of these households felt the installers were carrying out the installation for the first time. This was however an early project installation.

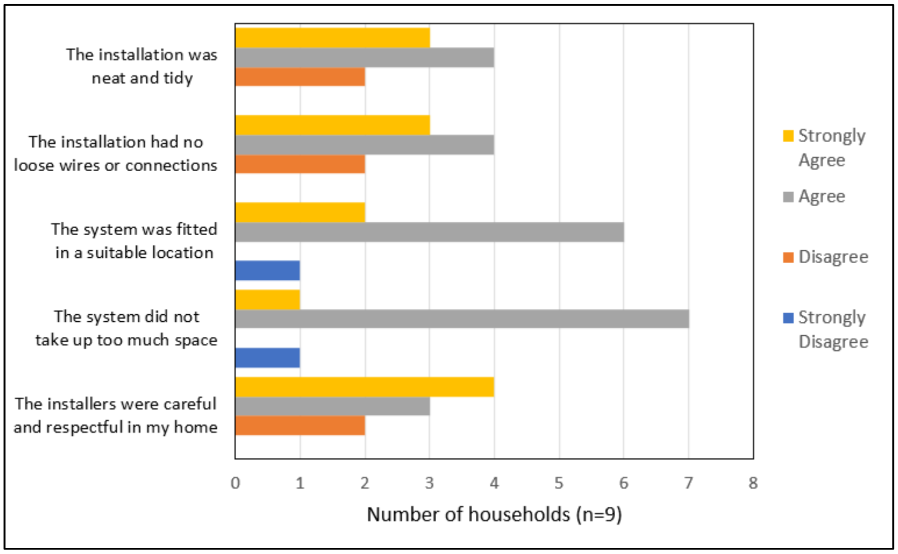

Figure 2.14 Satisfaction with the installation process

The batteries were either fitted in a utility room in the house or outdoors in a cabinet constructed out of breeze-blocks. When asked whether the Powervault G200 system, which was about the size of a fridge, was fitted in a suitable location, 2 households strongly agreed and 6 agreed while 1 strongly disagreed. The household which strongly disagreed had the battery system fitted in a utility room with the gas boiler. Later in the project, the carbon monoxide (CO) alarm for this household was set off during an initial 'commissioning charge', where the battery is set to charge at high power. The commissioning charge setting had been set incorrectly. CO alarms with electrochemical sensors have a cross sensitivity for hydrogen and can be set off by hydrogen emitted from lead acid batteries[21]. The battery was subsequently removed from this property.

When asked if the battery did not take up too much space, 7 of the 9 households agreed and a further household strongly agreed. The only household who strongly disagreed had the problem with the CO alarm. Since in many cases the battery was fitted in an outdoor cabinet, there was little concern about the size of the Powervault G200 system.

Out of the 9 households asked, 4 strongly agreed that the installers were careful and respectful in their home and a further 3 agreed. There were 2 households who disagreed with the statement and these were the same 2 that were unhappy over the tidiness of the installation and loose wiring. It was noted by 1 of these households that they were not notified in advance of the installation and the contractors had not turned up when scheduled.

[21] Battery Powered Carbon Monoxide Alarms Ei207/208 Series p.29, Ei Electronics https://www.aico.co.uk/wp-content/uploads/2016/06/Ei208-Instructions-Rev7.pdf (Accessed 12 Nov 2018)

2.4 Ease of use and reliability

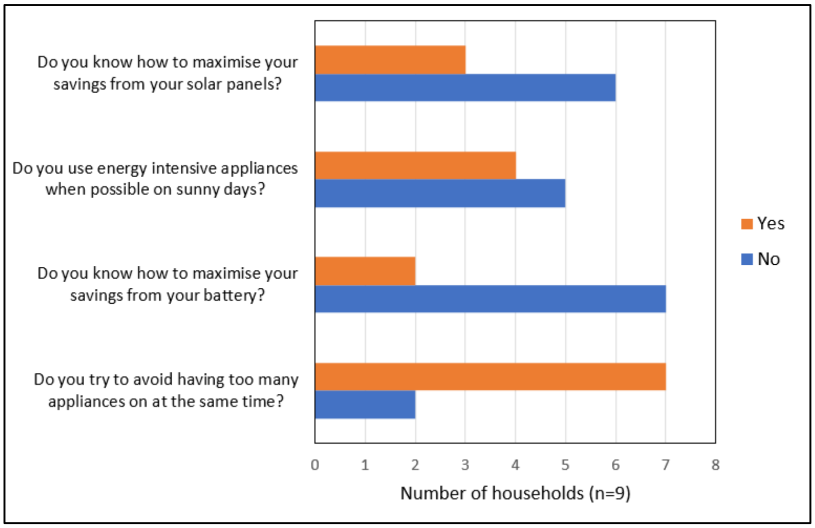

Figure 2.15 How well the households knew how to use the battery and solar systems

Questions shown in figure 2.15 investigated whether the residents in the NEA monitored group were getting the most benefit out of the battery solar system. Only 3 of the 9 households asked felt they knew how to maximise their savings from their solar panels. There were 4 of the 9 households who tried to use energy-intensive appliances on a sunny day. Only 2 of the households felt they knew how to maximise their savings from the battery. However, 7 of the 9 households tried to avoid having too many appliances on at once. The maximum continuous AC power output from the Powervault G200 is 0.8kW. Therefore, if a household had both a kettle and a toaster on at once, it could only partially power 1 of these appliances and the second would be fully powered from the electricity grid. These results and discussions during the final interviews suggest that better information should be provided explaining how the solar PV and battery systems work and how to maximise savings.

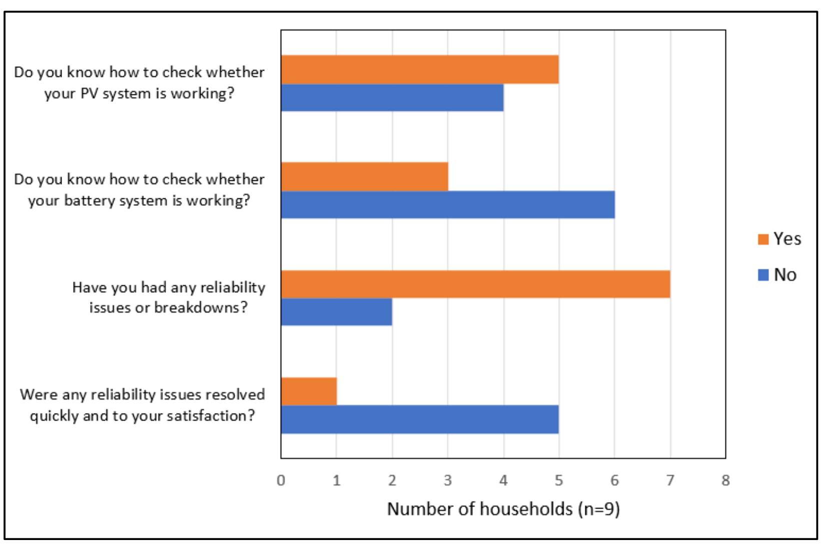

Figure 2.16 Reliability of the battery - solar systems

The same 9 households were also asked about the reliability of their battery-solar system. There were 5 of the households who knew how to check whether their solar PV system was working. This was usually by seeing the flashing red LED pulses from the generation meter or by recording the meter readings and noting whether they increased. Only 3 of the 9 households knew how to check whether the battery system was working. On the front of the Powervault G200 is a series of LEDs and these show whether the system is charging or discharging and the level of charge. Many of the residents did not regularly look at the battery in the outdoor cabinet.

There were 7 of the 9 households who said the system had reliability issues or breakdowns when asked. The issues which occurred included replacement of the original AGM Lead Acid batteries (which came from a faulty batch) with tubular gel Lead Acid batteries. There was also a problem where hydrogen emissions from a battery system set off a household CO alarm during an initial commissioning charge where the system had been set to charge at the incorrect rate. Out of the 2 households who did not note reliability issues, 1 had an externally installed battery from the start. Both households had the AGM batteries replaced by tubular gel lead acid.

There were 5 households who noted that the reliability issues were not resolved quickly and to their satisfaction. All the batteries were switched off on 22/23 Aug 2017 following instructions from Powervault after the problem with the AGM lead acid batteries was recognised. Most of the new tubular gel batteries were fitted on 31 Oct/1 Nov 2017. The problem with the CO monitor event took place on the evening of 2 Nov 2017. The internal batteries in 4 households were reinstalled in outdoor enclosures. This required new enclosures to be built and the batteries were not reinstalled until Spring 2018.

2.5 Perceived benefits

Residents in the monitored group with the battery-solar systems were asked whether they had experienced a series of benefits since the system was fitted (figure 2.17).

Out of the 9 households questioned, 6 thought they saw a reduction in their energy bills. There were 5 who felt they had more control over their electricity use, while 7 believed they were saving energy in the home. A total of 4 of the households asked thought they saw an improvement to the quality of their home, while 5 believed they were reducing their household's effect on Climate Change.

When asked about the impact of the battery on the cost of their bills, 3 of the households interviewed thought their bills were about the same and 6 thought they were cheaper.

None of the households thought their bills were more expensive. It should be noted that a household briefly experienced higher bills during the project. Here the initial battery system installed had problems and needed replacing. When the new system was fitted, the current clamp for the battery was fitted the wrong way around. This led the battery system to be confused about when the household was importing and exporting electricity and caused an increase in household consumption. Once this was realised, the current clamp was correctly fitted, and compensation was later paid.

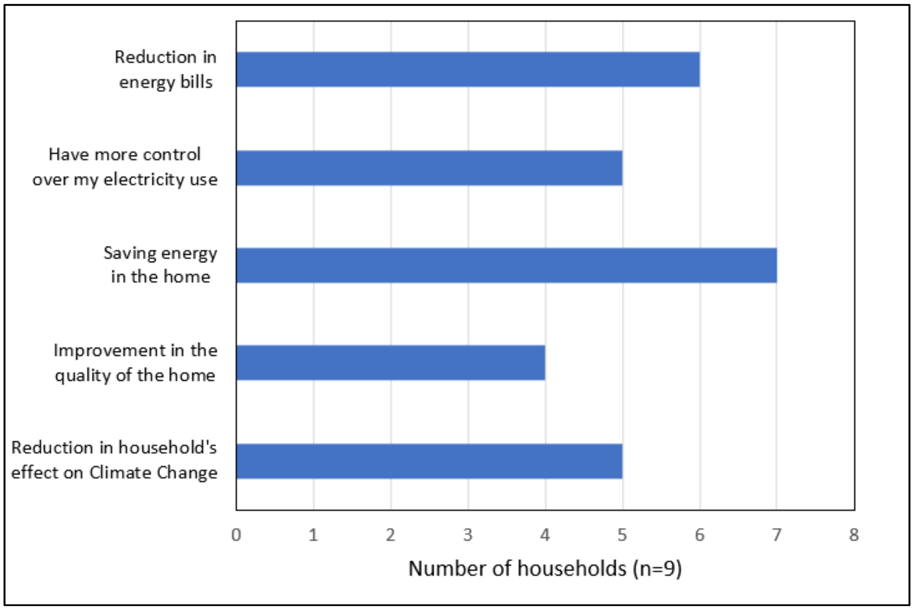

Figure 2.17 Benefits perceived by residents after installation of the solar-battery system

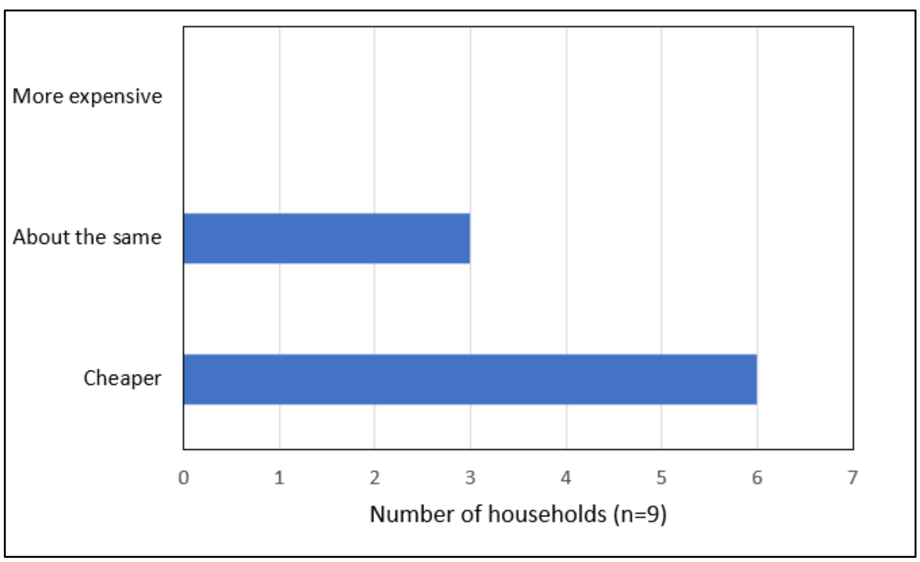

Figure 2.18 Impact of the battery on the cost of bills

3. Technical evaluation and results

3.1 Overview of technology

The first battery was invented by Alexander Volta in 1800 with pairs of dissimilar metal discs separated by an electrolyte placed in a pile. The lead acid battery was the first rechargeable battery and was invented in 1859 by Gaston Planté[22]. Maintenance free lead-acid batteries were available from the 1970s. They are also known as Sealed or Valve Regulated Lead Acid (VRLA) batteries. They have a one-way valve which will allow the release of gases (hydrogen and oxygen) if excessive internal pressure develops, such as when overcharged[23].

The 2 types of maintenance free lead acid batteries are Gel batteries and Absorbent Glass Mat (AGM). With the Gel lead-acid battery, the sulphuric acid electrolyte has been turned into a viscous gel by the addition of silica gel. The AGM lead acid battery has the acid electrolyte soaked into fine fibre glass matting which has been placed between plates of the battery.

A rechargeable battery goes through cycles of charge and discharge. A measure of the level of charge of the battery prior to recharging is the Depth of Discharge (DoD). This is the percentage of the maximum battery capacity that has been discharged. A lead-acid battery for starting cars only has a small DoD. Those used to provide power over a period of hours have a large DoD and are known as ‘Deep Cycle’ batteries. They have thicker plates (anodes and cathodes) than the batteries used in cars to extend their lifespan as high levels of discharge damages the plates.

A maintenance free deep cycle lead-acid battery such as an AGM might have a life span of about 1000 charge and discharge cycles if the Depth of Discharge (DoD) is 50%. The lifespan decreases to about 500 cycles if the DOD increases to 80% of full charge[24]. Tubular gel batteries have a longer cycle life and can operate with a great depth of discharge than AGM batteries. The tubular positive plates consist of a series of tubular spines connected by a common busbar[25]. The design is more robust than flat plate electrodes and contributes to the longer battery lifespan.

Lithium-ion batteries have been developed since the 1990s and have a better energy density (Wh per litre) and specific energy (Wh per kg) than lead-acid batteries. All Lithium-ion batteries are ‘deep cycle’, usually taken to 80% DoD and have a longer lifespan than lead acid batteries. Lithium-ion batteries are more expensive than lead-acid batteries, but their costs have been falling as the technology develops and production increases. At the time this project commenced, lead acid batteries were considered better value for money and enabled a significantly larger battery capacity to be fitted for the installation cost.

[22] BU-201: How does the Lead Acid Battery Work?, Battery University http://batteryuniversity.com/learn/article/lead_based_batteries (Accessed 31 May 2018)

[23] Blue Box Batteries Blog, Gel vs AGM batteries, https://www.blueboxbatteries.co.uk/blog/vrla-batteries-gel-vs-agm-36#.W3bvSOhKiUk (Accessed 14 Nov 2018)

[24] A Comparison of Lead Acid to Lithium-ion in Stationary Storage Applications, AllCell Technologies (2012) https://www.batterypoweronline.com/wp-content/uploads/2012/07/Lead-acid-white-paper.pdf (Accessed 16 Aug 2018)

[25] Eastman Tubular Gel Battery, https://www.youtube.com/watch?v=7s0kLnaJllw (Accessed 14 Nov 2018)

Solar panels generate and batteries store DC (direct current) electricity. This means an inverter is necessary to convert the electricity into higher voltage mains (AC) for use in the home. A battery can be connected between the solar panels and the solar inverter. This arrangement is less common and is known as a DC coupled system.

Most retrofitted battery storage systems are AC coupled and have the battery connected to the household consumer unit or a sub-board.[26] In this case, the battery requires circuitry to convert the AC electricity to DC electricity which can be stored in the battery (figure 3.1). Use of both a solar and battery inverter in an AC-coupled battery storage system can result in higher losses. However, AC-coupled batteries are easier to retrofit to existing solar systems and do not need to be fitted close to the solar inverter, which can be fitted in the loft, despite the higher temperatures. They can also take advantage of time of use electricity tariffs and can import electricity from the grid when it is cheaper. The Powervault G200 battery system trialled in this project is an AC coupled system.

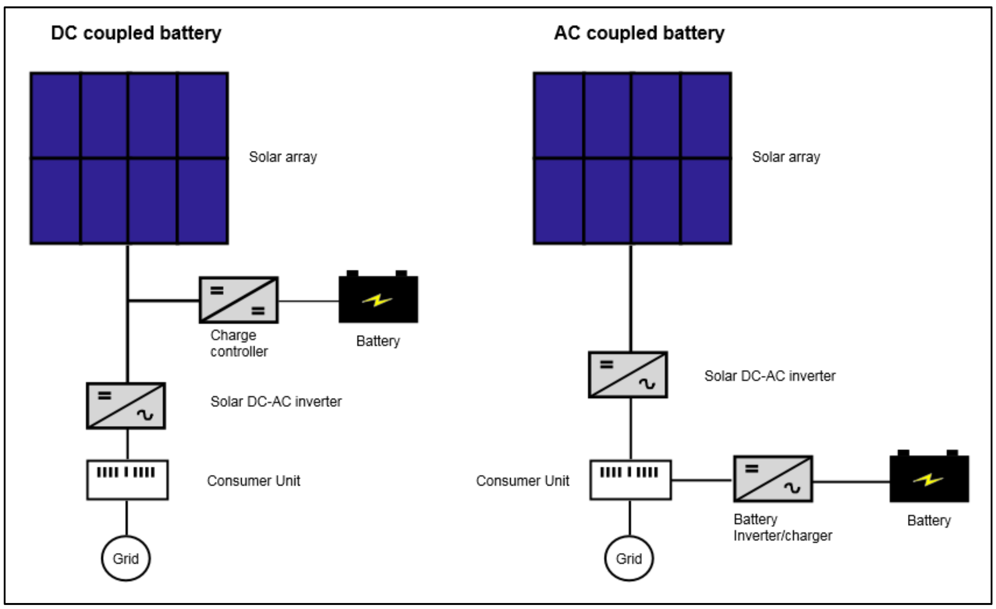

Figure 3.1 Schematic diagram showing DC and AC coupled battery systems

[26] Batteries and Solar Power: Guidance for domestic and small commercial consumers, BRE/RECC (2016) https://www.bre.co.uk/filelibrary/nsc/Documents%20Library/NSC%20Publications/88031-BRE_Solar-Consumer-Guide-A4-12pp.pdf (6 Dec 2018)

Powervault G200

Figure 3.2 Powervault installation in outdoor enclosure

Figure 3.3 Front of the Powervault G200 system

The Powervault G200 system is about the size of a fridge (500x580x820mm). The system is agnostic about the type of battery used and either AGM lead acid, tubular gel lead acid or lithium-ion batteries can be fitted with the system (table 3.4). The most expensive batteries were Lithium-ion followed by Tubular Gel. It was decided to fit AGM lead acid batteries with the larger 4kWh usable capacity, which provided the largest battery capacity at a lower cost. This meant using 6x 105Ah batteries (figure 3.5) with a nominal capacity of 8.8kWh.

Battery specifications

	Lithium-ion			Lead Acid: Tubular Gel		Lead Acid: AGM	
	2kWh	4kWh	6kWh	2.5kWh	4kWh	3kWh	4kWh
Battery chemistry	LiFePO4			Lead Acid Tubular Gel		Lead Acid AGM	
Battery configuration	1 x 75Ah	2 x 75Ah	3 x 75Ah	4 x 90Ah	6 x 90Ah	4 x 105Ah	6 x 105Ah
Usable capacity (AC)	2.0kWh	4.0kWh	6.0kWh	2.5kWh	4.0kWh	3.0kWh	4.0kWh
Nominal capacity (AC)	2.2kWh	4.4kWh	6.6kWh	3.25kWh	5.2kWh	6.6kWh	8.8kWh
Depth of discharge	90%			70%		50%	
Expected lifetime (25°C)	11 – 13 years			5 – 7 years		3 – 5 years	
Cycles (25°C)	> 4,000			> 1,800		> 800	
Cooling	Natural convection, air grille						
Maintenance	Nil						

Table 3.4 Specification for the batteries available with the Powervault G200 system[27]

[27] Powervault G200 Technical Specification (April 2016), http://www.powervault.co.uk/wp-content/uploads/2016/04/Powervault_Technical-Specification_April-2016.pdf (Accessed 15 Nov 2018)

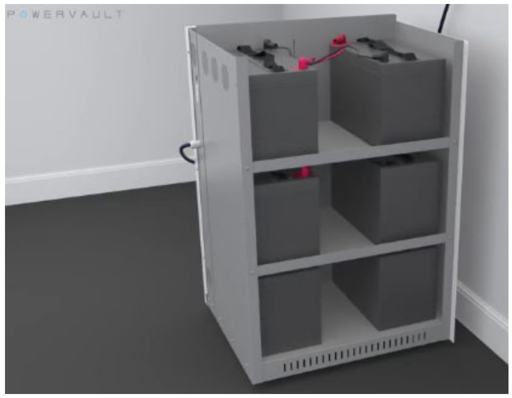

Figure 3.5 Schematic showing 6 batteries fitted in a Powervault G200 unit

A video showing the installation process for a Powervault G200 system has been produced by Powervault.[28] Installation usually takes under 2 hours. The Powervault G200 is connected to the main fuse board through its own dedicated 16A RCBO (Residual-current circuit breaker with overcurrent protection)[29]. This provides overcurrent, short-circuit and earth leakage protection. The Powervault should be hard-wired to an AC rotary isolator via a 7A or 10A fused spur. A 13A socket should be installed next to the fused spur and this can be used to power accessories such as TP Links which help provide access to the internet for the Powervault system. In figure 3.3, it can be seen that there is a 13A socket in the bottom right corner of the front of the Powervault unit. This can be used to power appliances in the event of a power outage. For some installations on the project, it was also used to power appliances for accessing the internet or monitoring.

A current clamp sensor is fitted on the main electrical incomer with the arrow pointing in the direction of current flowing into the house. There is a 25m maximum wiring distance for the current clamp between the main incomer and the Powervault unit. If the current clamp is fitted the wrong way around, the Powervault unit thinks the household is exporting electricity when it is actually importing. The installer fitted the current clamp the wrong way around for a household on this project. This resulted in increased electricity consumption by the household rather than savings until the issue was addressed. The household was financially compensated for the mistake. There are risks that the current clamp could be tampered with by residents or not correctly replaced by installers when fitting smart meters.

The maximum continuous output of the Powervault G200 is 800W and it can supply about 1150W for short periods. For comparison the Maslow battery manufactured by Moixa supplies 430W and a single PowerFlow SunDial can provide 500W. These are Lithium-ion batteries with a nominal capacity of 2kWh and a usable capacity of 1.6kWh. This compares with the 4kWh usable capacity with the Powervault system trialled here. NEA trialled the Maslow and Powerflow Sundial batteries in another study[30]. This study included the Victron Multiplus Compact 12/800/35 with a Leoch 260Ah AGM battery with a usable capacity of 1.56kWh. The inverter used in the Powervault G200 was also produced by Victron.

[28] Powervault G200 Installation, https://www.youtube.com/watch?v=VVljB-ppeuM (Accessed 14 Nov 2018)

[29] Powering the smart home – G200 Installation Manual, Powervault (January, 2017), http://www.powervault.co.uk/wp-content/uploads/2017/01/Powervault-Installation-Manual_Jan-2017.pdf (Accessed 15 Nov 2018)

[30] Paul Rogers & Michael Hamer, SunGain Battery Bank, NEA, (in press)

Other Powervault trials

Since the start of the NEA Cheshire East project, other trials have taken place with Powervault batteries. Domestic Energy Storage and Control (DESC) was a Network Innovation project with UK Power Networks (UKPN) which ran from September 2016 to June 2018[31]. The project installed 45 Powervault G200 batteries. Objectives and outputs planned included gaining empirical data to inform faster and cheaper installations, collecting characteristic load profiles and making a cost benefit analysis for aggregated control of batteries. UKPN announced a further project with Powervault in June 2018. Here 40 batteries were to be installed in the London Borough of Barnet. The plan was to aggregate the 320kWh of energy storage capacity to deliver local flexibility on the network via a virtual power platform[32]. It was noted at the time of this announcement that during the DESC trial, household evening demand was reduced on average by 60%.

In January 2017, UK energy supplier Green Energy UK launched a time of use tariff called TIDE[33]. This offered customers electricity at different prices during the day. Initial weekday prices were:

- Low Tide 23.00 – 06.00 4.99p/kWh
- Tide Weekday 06:00 – 16:00 11.99p/kWh
- High Tide 16:00 – 19:00 24.99p/kWh
- Tide Weeknight 19: 00 – 23:00 11.99p/kWh

Prices have subsequently risen, but the same principle remains. Powervault agreed a partnership with Green Energy UK where TIDE tariff customers with solar PV were offered up to 20% off a Powervault G200 battery system. The Powervault G200 has the ability to charge off the grid and TIDE customers could charge the battery at ‘Low Tide’ and consume this during the ‘High Tide’ period with higher electricity costs. It should be noted that the G200 could only supply 800W continuously, although about 1,150W for short periods, and so could only provide a proportion of the power for an electric cooker for example when cooking dinner.

[31] Domestic Energy Storage and Control (DESC) https://innovation.ukpowernetworks.co.uk/innovation/en/Projects/tier-1-projects/domestic-energy-storage-and-control/ (Accessed 15 Nov 18)
[32] Domestic batteries to power new virtual power plant in first for UKPN and Powervault (22 Jun 2018) https://www.current-news.co.uk/news/domestic-batteries-to-power-new-virtual-power-plant-in-first-for-ukpn-and-powervault (Acccessed 15 Nov 18)
[33] Green Energy launches ‘time-of-day’ tariff – electricity savings available but gas remains pricey, https://www.moneysavingexpert.com/news/2017/01/green-energy-launches-time-of-day-tariff---electricity-savings-available-but-gas-remains-pricey/ (Accessed 16 Nov 18)

Powervault 3

In 2018, Powervault released their Powervault 3 battery system (figure 3.6), which was a significant upgrade compared to the Powervault G200. The battery typically uses Lithium-polymer cells (Li-MNC) and is available in 4.1kWh and 8.2kWh capacities. The case for the 4.1kWh version is 900x980x250mm, with the 8.1kWh version taller at 1200mm.

Whereas the Powervault G200 had a maximum continuous output of 800W, the Powervault 3 can supply a continuous 4.6kW. The maximum continuous power input from solar PV or the grid was now 3.3kW, allowing faster charging and less export to the grid. The batteries have an estimated life in excess of 6000 cycles. The battery system can operate with advanced time of use tariffs like TIDE and provide grid services. It also has memory which means it can record system performance when off line with data collected every second.

Figure 3.6 Powervault 3 battery

Powervault has taken all the experience gained over 5 years of development, including all learnings from this trial, into consideration when designing the Powervault 3.

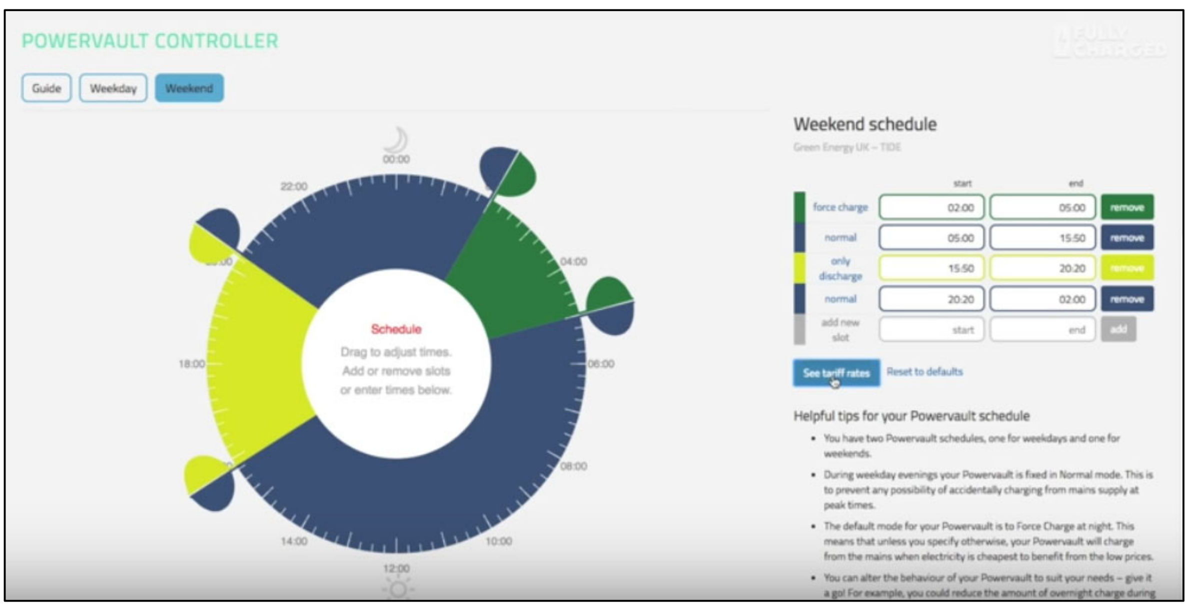

Figure 3.7 Scheduling of the charge and discharge times on the Powervault 3 system[34]

A screenshot from the new Powervault controller is shown in figure 3.7. This allows the owner detailed control for use with advanced time of use tariffs. The charge and discharge times can be set to the minute for weekdays and weekends.

[34] Fully Charged, Powervault (9 Oct 2018), https://www.youtube.com/watch?v=8ZDllPFmXNg (Accessed 16 Nov 2018)

3.2 Technological monitoring

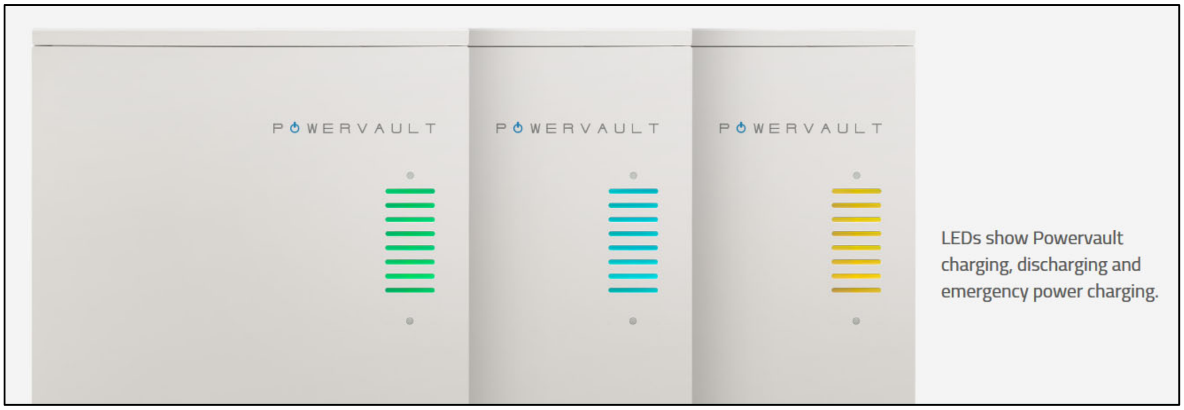

Figure 3.8 LED Display on the Powervault G200 battery system

Residents can check whether the battery is charging, discharging or supplying emergency power by the colour of the LEDs on the front panel of the G200 unit. There is no meter or memory on the Powervault G200 to show residents long term performance of the battery. A 'kettle test' could be used as a diagnostic to indicate active operation of the battery. Turning on a high demand appliance such as a kettle during the day should cause the system to switch from charge to discharge mode, with the appropriate change in LED colour. However, the light "ladder" that was designed to illustrate the level of charge available was unreliable and in many cases defaulted to a low reading, despite the battery being fully charged. This was confusing for some users. The fault was substantially corrected via changes in the firmware later in the study.

Performance of the G200 was only recorded on the Powervault servers when the system was connected to the internet. This was a problem on the project as many of the elderly residents did not have an internet connection. In some cases, it was possible for neighbours to piggy-back the connection for their battery systems onto a WiFi connection of another household in the trial. In some cases where no internet connection was available, an internet connection was set up for several neighbouring batteries. However, when the connection was only used by the batteries, no one noticed if the connection was lost and there might be an extended period until the connection was reset. Another issue with sharing connections between households was that the WiFi signal may not have been strong enough and there were periods where data was lost due to a poor connection. Data quality typically improved over the course of the project with engineers' visits.

The Powervault portal for the G200 can show graphs such as figure 3.9 with the following data:

- Grid Power In — kW power imported from the grid
- Grid Power Out — kW power exported to the grid (solar export)
- Device Power In — kW power charged in Powervault
- Device Power Out — kW power discharged by Powervault

The portal dashboard will also show charts of historic data which can be shown by either day, week, month or year (figure 3.10).

The Live Data section shows current data for the Powervault Power, Grid Power, Grid Energy Import and Export, State of Charge, AC voltage and current as well as DC voltage and current.

The electricity tariff section allows households to set the Powervault to charge when electricity is cheapest or avoid charging from mains during peak times. It is possible to set tariffs for: Standard rate, Economy 7 and Green Energy UK's TIDE tariff.

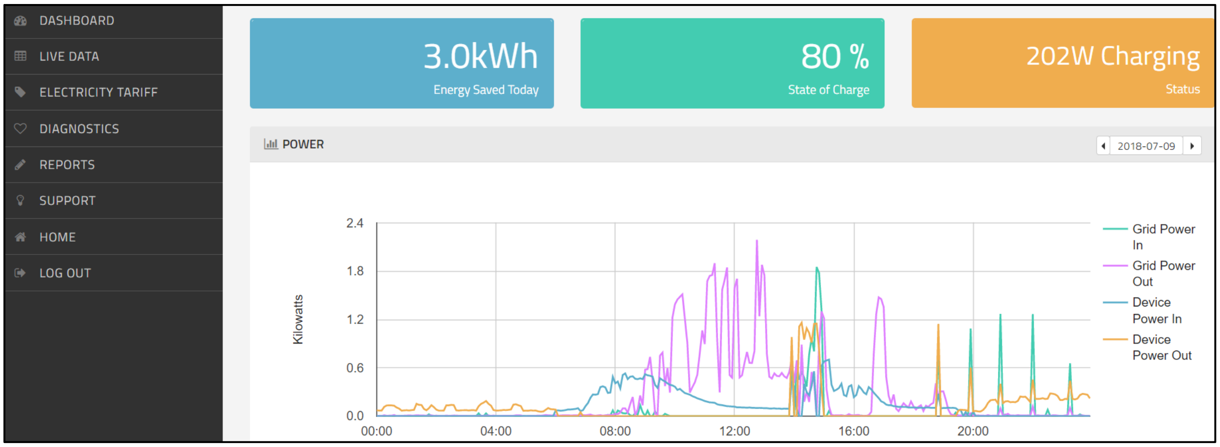

Figure 3.9 Plot of power flows over a day for a Powervault G200 installation

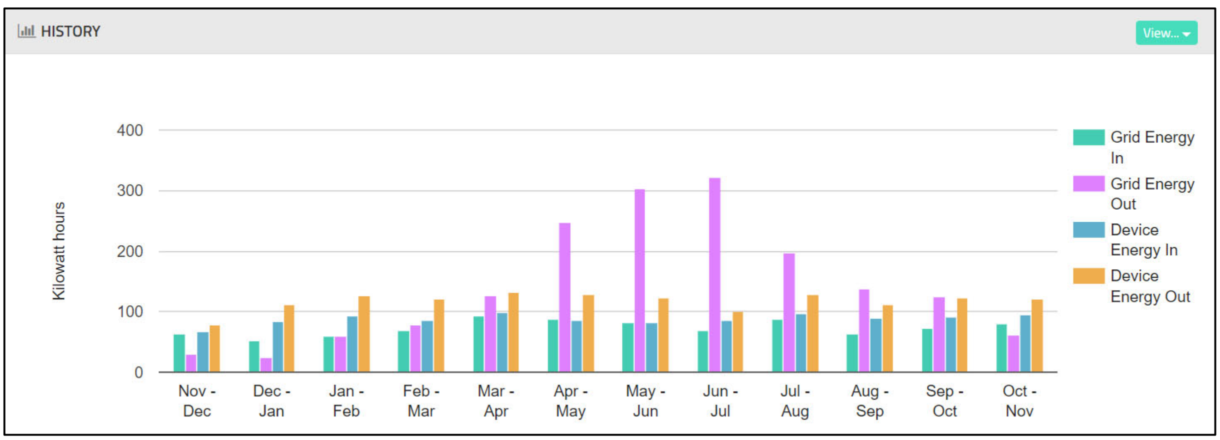

Figure 3.10 Chart showing historic performance of a Powervault installation

There is also a Diagnostics tab on the portal. This aimed to show diagnostics information for selected time periods. This would have included Grid power, Device (AC) power, DC voltage and the Powervault status. It is not currently available and may not be developed following the release of the Powervault 3 battery system. Likewise, there is a Reports tab on the portal. This was to allow households and owners to download reports in the form of CSV files which would provide details of all the metrics recorded by the Powervault system. This data is unlikely to be released.

Data from the battery systems was provided by Powervault for analysis for the project. This was 5-minute aggregated data, although the system was actually recording data every 30 seconds. In addition to data from the batteries, residents were asked to record electricity meter readings in a logbook. Also, meter readings were obtained from their electricity suppliers to expand the data set.

Omega OM-CP-PULSE101A loggers were used to measure the PV generation or electrical supply on meters which had a LED pulse output (figure 3.11). The generation meters for the solar PV systems recorded meter readings online on a daily basis. These were provided by the social landlords for a period of over 2 years.

Figure 3.11 Omega OM-CP-PULSE101A logger and fitted to a Landis & Gyr E110 electricity meter

On the Domestic Energy Storage and Control (DESC) trial with UKPN, Powervault used Verv data loggers produced by Green Running Ltd[35]. The Verv logger was able to record Power, current and voltage every second and had memory which was beneficial for periods where the internet connection was lost.

Figure 3.12 shows a Verv logger which is mains powered and collects the data using a current clamp. The clamp was fitted on the cable between the battery and consumer unit in order to measure the battery charge and discharge. The live and neutral for this cable needed separating out and the clamp fitted over just the live cable. These loggers were therefore fitted by an installer. The Verv logger was connected to the internet via an ethernet cable to a TP Link connected to the household WiFi. This should have made it possible to download daily files from the internet. This was less successful than anticipated and so the data could only be recovered at the end of the project by Green Running Ltd. The Verv loggers were in place at 5 installations between Spring 2018 and October 2018. It was possible to obtain data from 3 of these installations for the report.

Figure 3.12 Mains powered Verv data logger and current clamp

[35] https://www.greenrunning.com/ (Accessed 10/12/2018)

3.3 Control solar PV systems

There were 4 control households recruited for the study which had a solar PV system and no battery was fitted. The properties were bungalows of the same type which had solar PV systems of the same size and orientation as properties in Macclesfield which received the Powervault G200 battery systems.

Table 3.13 shows the grid consumption and PV generation for control household C-01. The household consisted of a single elderly resident for most of the study. She used an oxygen concentrator which had a power consumption of 350W. The device had a meter showing hours of operation and users can claim back electricity costs for the device. Based on the operation time for the device, the average power consumption for the device was 4.87 kWh/day. The property also had an electric shower. It should be noted that the inverter for the solar PV system broke down on 15 Oct 17 and the system was not fully operational again until 25 Aug 18. This led to a significant increase in the grid consumption for the household over this period.

Start Date	End Date	Consumption (kWh)	Consumption (kWh/day)	Generation (kWh)	Generation (kWh/day)	Start Date	End Date	Consumption (kWh)	Consumption (kWh/day)	Generation (kWh)	Generation (kWh/day)
30-Dec-16	28-Jan-17	186	6.41	55.9	1.93	05-Jan-18	02-Feb-18	190	6.79	0	0
28-Jan-17	25-Feb-17	151	5.39	90.1	3.22	02-Feb-18	02-Mar-18	169	6.04	0	0
25-Feb-17	25-Mar-17	96	3.43	158.3	5.65	02-Mar-18	30-Mar-18	171	6.11	0	0
25-Mar-17	24-Apr-17	89	2.97	284.3	9.48	30-Mar-18	29-Jun-18	543	5.97	56.8	0.62
24-Apr-17	03-Jun-17	114	2.85	455.3	11.38	29-Jun-18	23-Jul-18	117	4.88	6.8	0.28
03-Jun-17	03-Jul-17	73	2.43	307.5	10.25	23-Jul-18	24-Aug-18	155	4.84	6.8	0.21
03-Jul-17	24-Jul-17	39	1.86	242.3	11.54	24-Aug-18	15-Oct-18	192	3.69	382.8	7.36
24-Jul-17	01-Sep-17	85	2.18	368.1	9.44						
01-Sep-17	29-Sep-17	77	2.75	201.9	7.21						
29-Sep-17	27-Oct-17	97	3.46	68.2	2.44						
27-Oct-17	24-Nov-17	128	4.57	0	0						
24-Nov-17	22-Dec-17	166	5.93	0	0						

Table 3.13 Consumption and PV generation for control household C-01. The period where the PV inverter was not working has the darker shading.

Start Date	End Date	Consumption (kWh)	Consumption (kWh/day)	Generation (kWh)	Generation (kWh/day)	Start Date	End Date	Consumption (kWh)	Consumption (kWh/day)	Generation (kWh)	Generation (kWh/day)
01-Jan-17	01-Feb-17	104.6	3.37	42.8	1.38	01-Jan-18	01-Feb-18	116.7	3.76	46.6	1.50
01-Feb-17	01-Mar-17	84.4	3.01	67.1	2.40	01-Feb-18	01-Mar-18	96.9	3.46	95.5	3.41
01-Mar-17	01-Apr-17	74.0	2.39	175.6	5.67	01-Mar-18	01-Apr-18	89.9	2.90	154.4	4.98
01-Apr-17	01-May-17	64.9	2.16	221.6	7.39	01-Apr-18	01-May-18	78.1	2.60	198.7	6.62
01-May-17	01-Jun-17	54.7	1.77	254.4	8.21	01-May-18	01-Jun-18	63.1	2.03	290.6	9.37
01-Jun-17	01-Jul-17	45.1	1.50	211.5	7.05	01-Jun-18	01-Jul-18	51.1	1.70	287.2	9.57
01-Jul-17	01-Aug-17	61.5	1.99	239.9	7.74	01-Jul-18	01-Aug-18	48.3	1.56	253.7	8.18
01-Aug-17	01-Sep-17	64.2	2.07	216.3	6.98	01-Aug-18	01-Sep-18	51.7	1.67	188.5	6.08
01-Sep-17	01-Oct-17	66.5	2.22	140.9	4.70	01-Sep-18	01-Oct-18	41.9	1.40	160.2	5.34
01-Oct-17	01-Nov-17	94.9	3.06	90.7							
01-Nov-17	01-Dec-17	111.7	3.72	63.6							
01-Dec-17	01-Jan-18	128.5	4.14	29.7							

Table 3.14 Consumption and PV generation for control household C-02.

The consumption and PV generation for household C-02 is shown in table 3.14 The household again consisted of a single elderly resident and the property also had an electric shower. The grid consumption for C-02 was noticeably lower than C-01 and the use of the oxygen concentrator at household C-01 was likely to be the main cause of the higher consumption. The bungalow for C-02 was in the same row as C-01. Typically, the PV generation was lower for C-02 than for C-01 due to shading from a tree. On 1 Jan 18, the total PV generation for the system at C-01 was 13,435kWh compared to 11,078kWh for C-02 despite being comparable systems installed at a similar time.

The total PV generation by 1 Jan 18 for the systems with batteries ranged from 7,877kWh to 16,428kWh despite them typically being PV systems of the same size and orientation, which were fitted at similar times. During the 2 years of monitoring for the project, 3 of the 17 households in Macclesfield with batteries had a breakdown of their PV system. As discussed earlier 1 of the 4 control properties also had a PV system breakdown. Solar PV inverter failures (unrelated to the Powervault system) leading to periods where the PV system was not working, along with shading from bushes and trees led to a wide variation in the long-term performance of the PV systems for the households that took part in this study.

3.4 Powervault G200

Overview of installations

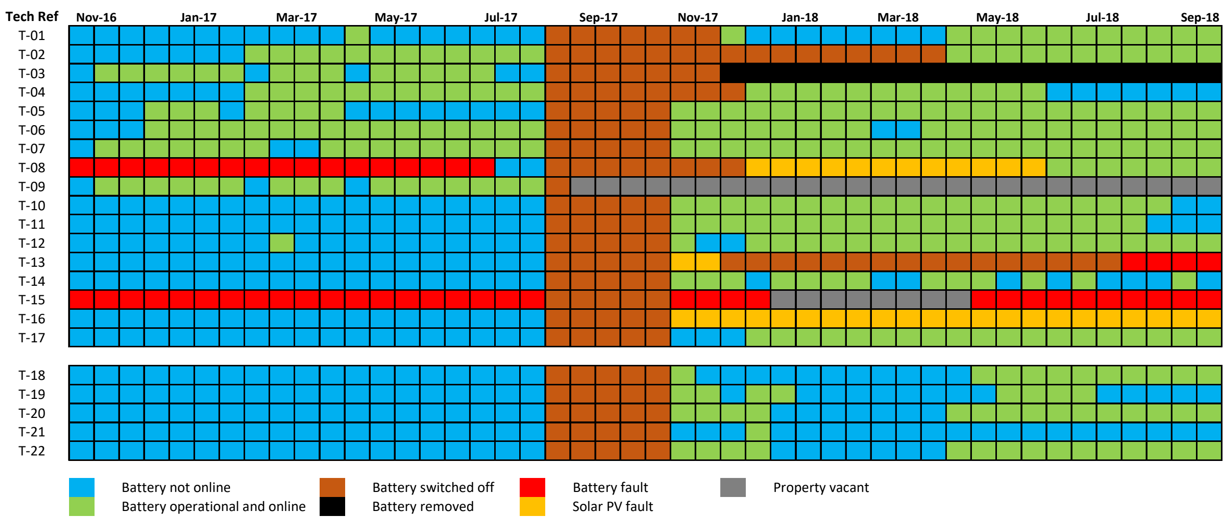

Figure 3.15 Gant chart showing operational status for the Powervault G200 batteries in Macclesfield (T-01 to T-17) and in Knutsford (T-18 to T-22). The periods in blue show when the battery was not connected to the internet, however in the majority of cases the battery was operational during these dates.

There were 17 Powervault G200 battery systems installed in properties in Macclesfield (households T-01 to T-17) and a further 5 in Knutsford (households T-18 to T-22). The Gant Chart in figure 3.15 shows the operational status of the batteries over the course of the project.

At the time of installation between July and September 2016, none of the batteries had an online connection. As a result, no performance data was recorded at this stage. Most of the batteries were working correctly at this time, but no monitoring data was verifying this. A couple of the batteries had issues from around the time of installation. Where the battery was offline, it is shown in light blue and where there was a battery fault it is shown in red on the Gant Chart.

Between November 2016 and February 2017, batteries at 8 households were connected to the internet to provide data on the performance of the monitored systems. Some households shared a WiFi connection for the batteries and the quality of the connection was variable, resulting in gaps in the data. Periods where the batteries were online and working correctly are shown in green on the Gant Chart.

Powervault discovered that the AGM batteries originally fitted in the units deployed through this project were part of a batch where the manufacturing had been identified as sub-standard. They advised that all the G200 units on the project should be switched off and this was carried out on 22/23 August 2017. The period the batteries were switched off is shown in brown on the Gant chart.
On examination of the batteries, it became apparent that some had swelled and also cracked in places (figure 3.16). Out of the 6 batteries installed in the G200, some had been overcharged, which led to the swelling and others were undercharged. This was due to the batteries being from a bad batch. A firmware update for the systems was also carried out to detect and mitigate further risks from over/under-charging batteries.

The AGM batteries were replaced by Powervault with tubular gel lead acid batteries which again had a usable capacity of 4kWh. These were superior to the AGM batteries and had an expected life in excess of 1800 cycles instead of more than 800 cycles for the AGM. The tubular gel batteries were also able to be taken to 70% depth of discharge (DoD) instead of only 50% DoD for the AGM. This meant smaller capacity 90Ah tubular gel batteries could be used.

Most of the tubular gel lead acid batteries were fitted at the end of October 2017 and were set for a full charge from the grid. A carbon monoxide (CO) detector was set off in household T-03 which had the Powervault system fitted in a utility room with the gas boiler. This was caused by incorrect over-charging of the battery during a higher power commissioning charge with the wrong settings which led to release of hydrogen and oxygen through the one-way valve on the batteries. The sensor in CO alarms is unable to differentiate between hydrogen and carbon monoxide[36]. The household where the alarm was set off requested the battery was permanently removed (shown in black on the Gant chart). The battery systems at households T-01, T-02, T-09 and T-13 where the Powervault units were also fitted internally were switched off and reinstalled in outdoor cabinets a few months later.

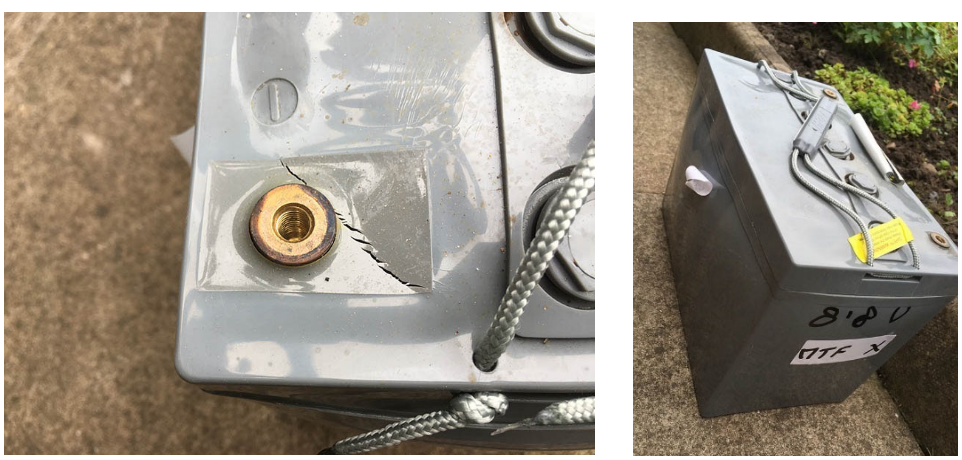

Figure 3.16 Swelling and cracking on an AGM lead acid battery from a Powervault G200 unit

[36] Battery Powered Carbon Monoxide Alarms Ei207/208 Series p.29, Ei Electronics https://www.aico.co.uk/wp-content/uploads/2016/06/Ei208-Instructions-Rev7.pdf (Accessed 12 Nov 2018)

Since 2014, Powervault's standard customer warranty has required systems to be connected online to ensure correct performance. Not all customers in the Cheshire East trial had internet access and during the trial Powervault recommended that internet access be provided.

As a result, engineers aimed to connect the remaining battery systems online from November 2017. Further visits were carried out in December 2017 and April 2018. The number and quality of the online connections improved following these visits, although the period online at some sites was still below 90%.

The solar PV systems in Maccclesfield were fitted in the autumn of 2011. As discussed in the previous section, several of the solar PV systems broke down during the project due to inverter failures. When the solar PV system was not operating, there was no charging of the Powervault G200 battery system and so it was not providing any benefit to the household. The G200 has a self-consumption of 35W and so without the solar PV, it was costing the household money. Leaving the battery running without the solar PV for a year could cost the household nearly £50.

The PV system for household T-16 broke down on 28 Aug 2017 shortly after the G200 system had been turned off prior to replacing the batteries. It was still malfunctioning when the batteries were replaced in November 2017 and at the time of writing in November 2018. Staff at the housing association had notified their maintenance team, but the issue had not been addressed. Although the battery system was online from December 2017, no battery discharge was recorded as a result of the PV fault (shown in yellow on the Gant Chart).

Household T-08 also had a PV fault and this occurred between 2 Oct 17 and 14 Jun 18. The initial Powervault G200 battery system that was installed developed a fault and a new unit was fitted. When this took place, the current clamp on the mains supply which provided a signal as to when the electricity supply was importing or exporting electricity was fitted the wrong way around. This meant that when the home was importing electricity, the battery thought it was exporting and so would charge the battery from the grid rather than from the solar panels. This fault was rectified in the summer of 2017 and compensation was paid for the losses. New tubular gel batteries were fitted at the site in December 2017, but there was no benefit from them until 14 Jun 18 when the solar PV system was repaired. Periods where the Powervault G200 system had a fault have been shown in red on the Gant chart.

Although the battery at household T-15 was initially connected to the internet in December 2016, there was a poor online connection. From installation, there was little or no electricity import or battery discharge recorded. This might have been due to a faulty current clamp. The property was vacant in the first half of 2018 until a new tenant moved in. The internet connection improved following an engineer's visit in April 2018 and the system recorded solar export, but still limited import or battery discharge. The Powervault system stopped recording sensible data around the time the tubular gel batteries were fitted in August. The battery was shown to not be working in October 2018 and during a maintenance visit in November, the battery was able to discharge about 1kW, but subsequently went offline. The engineer thought that the CT clamp had been refitted the wrong way around when a smart meter was installed and that the CT cable had been snagged in the loft when a new boiler was installed 3 months before.

The solar PV system for household T-13 also broke down during the study and was malfunctioning between 4 Sep 17 and 23 Nov 17. There was a period when the property was unoccupied between tenants. The batteries from this unit were stored on site and were stolen. After they had been returned by the police, the batteries were fitted. When this took place in August 2018, wiring in the Powervault G200 case melted due to a damaged battery connector. Powervault has incorporated changes to prevent problems with damaged battery connectors in future. A replacement Powervault G200 unit was subsequently provided and installed in October 2018.

The property at household T-09 was unoccupied from September 2017. Data was only recorded at this site during the period with AGM lead acid batteries in the Powervault G200 system.

Overview of the performance of the Powervault G200 systems

Technical Reference Number	Start Date	End Date	Number of days	Import Power (kWh)	Export Power (kWh)	Battery Charge (kWh)	Battery Discharge (kWh)	Battery Discharge (kWh/day)	Round Trip Efficiency (%)	Period online (%)	PV generation over period (kWh)
T-01	18-Apr-18	30-Sep-18	165	126.4	1430.9	461.5	207.5	1.26	45.0%	99.4%	2025
T-02	19-Apr-18	30-Sep-18	164	169.4	1159.5	525.3	260.5	1.59	49.6%	69.4%	1927
T-03	23-Nov-16	22-Jul-17	241	559.8	624.5	442.5	242.4	1.01	54.8%	74.4%	1451
T-04	13-Dec-17	16-Jun-18	185	439.2	266.1	299.9	190.4	1.03	63.5%	60.4%	1430
T-05	01-Nov-17	30-Sep-18	333	199.3	1577.4	825.3	480.1	1.44	58.2%	98.1%	2458
T-06	01-Nov-17	30-Sep-18	333	988.8	801.3	915.0	559.3	1.68	61.1%	77.9%	2512
T-07	01-Nov-17	30-Sep-18	333	903.9	612.6	1004.9	618.6	1.86	61.6%	98.4%	1898
T-09	23-Nov-16	23-Aug-17	273	270.7	1011.5	635.8	336.8	1.23	53.0%	77.7%	2016
T-10	01-Nov-17	23-Aug-18	295	826.0	1418.9	797.9	388.0	1.32	48.6%	97.6%	2399
T-11	02-Nov-17	23-Aug-18	294	1311.4	1047.5	963.7	572.5	1.95	59.4%	94.6%	2379
T-12	13-Dec-17	30-Sep-18	291	487.8	1685.7	931.8	521.6	1.79	56.0%	99.6%	2836

Tubular Gel lead acid batteries
AGM lead acid batteries

Table 3.17 Summary of better performing battery systems in Macclesfield using the Powervault system data

The only battery systems that will be discussed in greater depth in the following sections are those that were online for a significant period or had logging equipment which recorded battery performance data.

Out of the 22 Powervault G200 battery systems, there were 11 which were online and operational for a significant period of time. A summary of the performance of these systems is shown in table 3.17. The Powervault G200 battery systems produced data every 30 seconds, although there may be gaps in the data recorded during for periods when the WiFi connection for the battery system dropped out. Powervault provided NEA with 5 minute aggregate data for the analysis shown.
The Import Power is the electricity import for the household as measured by the Powervault current clamp on the mains meter tail. The Export Power is the electricity export due to excess solar PV generation measured by the current clamp. The Battery Charge is the total amount the battery has charged in kWh during the analysis period while the Battery Discharge is the total amount in kWh that has been supplied to the home by the battery. There are losses during the charge-discharge cycle for the system. A measure of this is the battery round trip efficiency, which is the ratio of battery discharge to battery charge. The percentage online was calculated from the number of 5 minute periods where data was available divided by the total number of 5 minute intervals in the analysis period. Systems with a lower percentage online recorded less of the battery discharge from the installation. The value of battery discharge in kWh/day in table 3.17 only takes into

account the number of days in the measuring period and not the percentage of that time the system was online. The PV generation shown was based on daily readings from a smart generation meter. This reading did not come from the Powervault system and was not affected by the period online.

The data shown in table 3.17 for households T-03 and T-09 only covers the period where AGM lead acid batteries were used in the Powervault G200 system. For all the other households, the data shown only covers the period with the replacement tubular gel lead acid batteries.

The average battery discharge ranged from 1.01 kWh/day to 1.95 kWh/day. Households T-03 and T-04, the 2 systems with the lowest discharge, had shorter periods online and so recorded a lower percentage of the actual battery discharge. Household T-01 was online for 99.4% of the period measured and had a battery discharge of 1.26 kWh/day. The households with higher levels of battery discharge were those where the Powervault system recorded higher levels of electricity import. Examples are households T-07 and T-11 with a battery discharge of 1.86 and 1.95 kWh/day respectively and an import of 903.9 and 1311.4 kWh.

Assessment of the performance of individual battery systems

Household T-01

Start Date	End date	Import Power (kWh)	Export Power (kWh)	Charge (kWh)	Discharge (kWh)	% Online	Round Trip Efficiency	Import Power (kWh/day)	Export Power (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
19-Apr-18	01-May-18	13.92	-69.76	44.51	-24.70	99.83%	55.50%	1.16	-5.82	3.72	-2.06
01-May-18	01-Jun-18	26.77	-341.28	93.67	-45.60	99.97%	48.68%	0.86	-11.01	3.02	-1.47
01-Jun-18	01-Jul-18	22.71	-315.42	77.57	-34.89	99.81%	44.99%	0.76	-10.53	2.59	-1.17
01-Jul-18	31-Jul-18	18.38	-314.39	83.23	-34.15	99.92%	41.04%	0.61	-10.49	2.78	-1.14
01-Aug-18	31-Aug-18	22.94	-213.47	84.30	-34.26	99.64%	40.64%	0.77	-7.14	2.82	-1.15
01-Sep-18	30-Sep-18	20.37	-172.71	76.58	-33.06	99.38%	43.18%	0.71	-5.99	2.66	-1.15

Table 3.18 Performance of the Powervault G200 battery system at household T-01 with tubular gel lead acid batteries showing values derived from Powervault 5-minute aggregate data

Start Date	End date	Charge (kWh)	Discharge (kWh)	% Online	Round Trip Efficiency	Charge (kWh/day)	Discharge (kWh/day)
19-Apr-18	01-May-18	40.96	-20.40	100.00%	49.80%	3.41	-1.70
01-May-18	01-Jun-18	78.42	-36.34	100.00%	46.34%	2.53	-1.17
01-Jun-18	01-Jul-18	61.84	-27.45	99.81%	44.39%	2.07	-0.92
01-Jul-18	01-Aug-18	65.72	-26.95	100.00%	41.01%	2.12	-0.87
01-Aug-18	31-Aug-18	59.76	-26.44	91.92%	44.25%	2.17	-0.96

Table 3.19 Performance of the Powervault G200 battery system at household T-01 with tubular gel lead acid batteries showing values derived from a Verv logger with 1 second interval data

There was a single retired resident in household T-01 who was regularly in the property during the day using appliances like a computer and television. The battery system was initially connected online in April 2017, but a poor WiFi connection meant there was little useful data recorded. The internally installed battery system was reinstalled in an outdoor enclosure and the battery system was online for over 99% of the time following a service visit on 18 Apr 18.

Table 3.18 shows values derived from the Powervault battery system data for household T-01 while table 3.19 shows the battery charge and discharge measured by a Verv data logger. The accuracy of the readings from the Verv logger was higher than for the Powervault data. While the Verv logger measured the power flow every second with a current clamp, the Powervault data that was analysed was 5-minute averages of data produced every 30 seconds. The values of battery charge and discharge measured by the Verv logger were about 20% lower than from the aggregate Powervault data. Other trials where Powervault and Verv equipment have been used have not identified a similar difference when using raw 30 second Powervault data.

The round trip efficiency for the battery was typically between 40 and 50% for the months studied. The value was lower than for the other batteries compared in table 3.17 in the performance overview. The discharge of between 0.87 and 1.7 kWh/day in summer was quite low for a battery with a usable capacity of 4 kWh. This might be explained by the household import measured by the Powervault battery system being low (18 – 27 kWh/month) and the household demand not requiring a greater battery discharge.

Approximately monthly values of electricity grid consumption are shown in table 3.20 along with values for solar PV generation. These were derived from smart electricity meter readings and daily values from a smart PV generation meter. It is apparent that the values of grid import of 81 to 117 kWh are several times greater than the values of grid import recorded by the Powervault system from the current clamp. It is likely that the current clamp was not operating correctly and this led to the lower values measured for the grid import which resulted in the lower values for battery discharge. It is possible that the long cable run from the battery to the meter tails was a factor in this poor performance. Had the system registered greater household demand, it is likely that greater battery discharge would have been supplied. When interviewed, the resident thought the electricity bills were about the same following the battery installation and strongly disagreed there had been savings on energy payments.

		2017				2018			
Start date	End date	Grid Import (kWh)	Grid Import (kWh/day)	PV Generation (kWh)	PV Generation (kWh/day)	Grid Import (kWh)	Grid Import (kWh/day)	PV Generation (kWh)	PV Generation (kWh/day)
06-Jan	06-Feb					196	6.32	58.5	1.89
06-Feb	06-Mar	167	5.96	80.66	2.88	160	5.71	107.8	3.85
06-Mar	06-Apr	139	4.48	263.32	8.49	144	4.65	215.6	6.95
06-Apr	07-May	104	3.35	332.59	10.73	107	3.57	294	9.80
07-May	06-Jun	96	3.20	357.26	11.91	92	2.97	481	15.52
06-Jun	06-Jul	98	3.27	319.9	10.66	81	2.70	478.6	15.95
06-Jul	06-Aug	114	3.68	335.8	10.83	87	2.81	398.6	12.86
06-Aug	06-Sep	120	3.87	303.3	9.78	110	3.55	272	8.77
06-Sep	07-Oct	143	4.61	205.9	6.64	117	3.77	203.1	6.55
07-Oct	06-Nov	165	5.50	100.8	3.36	137	4.57		
06-Nov	07-Dec	188	6.06	58.4	1.88				
06-Dec	06-Jan	176	5.87	30.9	1.03				

Table 3.20 Grid import and PV generation in 2017 and 2018 based on smart meter readings for household T-01

Household T-02

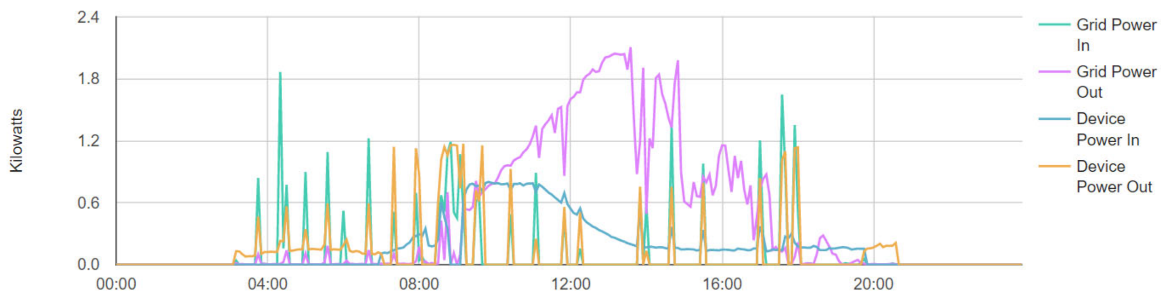

Figure 3.21 Plot from the Powervault portal showing the performance of the battery system at household T-02 on 27 Jul 18 with tubular gel lead acid batteries

There was again a single retired resident at household T-02. The property had a cooker with an electric hob and oven. A microwave was used to reheat food most days. An electric shower was used in the early evening 3 to 4 days a week, while the washing machine was used once a week in the morning. The television was typically used 6 to 7 hours a day. The bungalow had gas central heating with a combi boiler. In the summer the resident did not use gas for water heating and instead used an electric kettle.

Figure 3.21 shows a plot from the Powervault monitoring portal for household T-02 on 27 Jul 2018. Grid Power In (electricity import) is shown in green and Grid Power Out (export due to excess solar generation) is shown in purple. Device Power In (battery charge) is shown in blue and Device Power Out (battery discharge) is in orange. 27 Jul 2018 was a sunny day and there was excess solar generation from about 09:00 to 17:00 with electricity export of up to 2.1kW occuring. During the morning, the battery was charging at nearly 800W, with the charge level dropping in the afternoon. In summer and winter, the household recorded regular peaks in consumption (and battery discharge) throughout the day. It is possible that this might be due to activities such as boiling a kettle, but such frequent use from before 04:00 is surprising. Alternatively it is possible there may be a fault with data recorded by the system.

Tables 3.22 and 3.23 show values of import, export, charge and discharge calculated from the 5-minute aggregate data provided by Powervault for the monitoring periods with the AGM and tubular gel lead acid batteries respectively. The percentage of the time online during these periods was typically between 60 and 80%. It was lower in August 2017 since the batteries were turned off on August 23rd. During the period with the tubular gel batteries, there were regular gaps in the Powervault data, with missing periods on a daily basis typically between about 20:00 and 02:00. This can also be seen in figure 3.21 where no data is recorded from 20:45 until 03:00. It is possible that the resident regularly turned off the WiFi during these periods, however when interviewed he said he never turned off the WiFi router. This anomoly may have led the values of Charge in kWh/day to be too high. These were calculated taking into account the missing periods online as well as the number of days. A greater proportion of time with the battery charging was included in the period the system was online.

A Verv logger was also fitted at this site and values of charge and discharge for the battery are shown in table 3.24. Any gaps in the data were for a continuous period avoiding the issues over the regular daily gaps with the Powervault data.

Months where there was greater electricity import tended to have a higher battery discharge for both the AGM and tubular gel batteries. Values of discharge measured by the Powervault system ranged from 35.84 kWh to 70.94 kWh per month for the AGM batteries and from 44.9 kWh to 51.9kWh for the tubular gel. The battery round trip efficiency for the tubular gel batteries was typically about 50%, however it was over 60% for the AGM batteries between May and August.

The Powervault system recorded a grid import of 158.8 kWh while online between 1 Mar 2017 and 23 Aug 2017. This compared to 473 kWh recorded by the household electricity meter between 15 Mar and 22 Aug 2017. Even taking into account the period offline, these values suggest that the grid import measured by the Powervault current clamp was too low just as for household T-01. The system might have been able to provide greater battery discharge had the electricity import been more accurately measured.

Comparing the Powervault data and Verv logger data during the summer of 2018 shows that values of battery charge and discharge measured by the Verv logger were about 25% lower than for the values derived from the 5-minute aggregate data from Powervault.

Start date	End date	Import Power (kWh)	Export Power (kWh)	Charge (kWh)	Discharge (kWh)	% Online	Round Trip Efficiency	Import Power (kWh/day)	Export Power (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
01-Mar-17	31-Mar-17	15.19	-117.69	98.19	-47.74	80.41%	48.62%	0.63	-4.88	4.07	-1.98
01-Apr-17	30-Apr-17	13.37	-108.87	78.23	-35.84	73.92%	45.81%	0.62	-5.08	3.65	-1.67
01-May-17	31-May-17	36.44	-172.39	96.85	-61.84	81.27%	63.86%	1.49	-7.07	3.97	-2.54
01-Jun-17	30-Jun-17	26.15	-108.24	68.50	-46.04	64.34%	67.21%	1.40	-5.80	3.67	-2.47
01-Jul-17	31-Jul-17	44.61	-146.43	107.14	-70.94	81.65%	66.22%	1.82	-5.98	4.37	-2.90
01-Aug-17	31-Aug-17	22.99	-90.29	57.80	-35.75	53.35%	61.85%	1.44	-5.64	3.61	-2.23

Table 3.22 Performance of the Powervault G200 battery system at household T-02 with AGM lead acid batteries showing values derived from Powervault 5-minute aggregate data

Start date	End date	Import Power (kWh)	Export Power (kWh)	Charge (kWh)	Discharge (kWh)	% Online	Round Trip Efficiency	Import Power (kWh/day)	Export Power (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
20-Apr-18	01-May-18	13.93	-63.17	40.91	-22.32	73.96%	54.56%	1.71	-7.76	5.03	-2.74
01-May-18	01-Jun-18	30.72	-309.09	104.39	-51.89	73.68%	49.71%	1.34	-13.53	4.57	-2.27
01-Jun-18	01-Jul-18	29.63	-245.21	99.56	-46.98	72.41%	47.18%	1.36	-11.29	4.58	-2.16
01-Jul-18	31-Jul-18	27.35	-223.72	103.57	-48.68	69.47%	47.01%	1.31	-10.74	4.97	-2.34
01-Aug-18	31-Aug-18	33.29	-169.43	95.38	-44.94	69.49%	47.11%	1.60	-8.13	4.58	-2.16
01-Sep-18	30-Sep-18	34.30	-146.98	80.49	-45.26	61.74%	56.23%	1.92	-8.21	4.50	-2.53

Table 3.23 Performance of the Powervault G200 battery system at household T-02 with tubular gel lead acid batteries showing values derived from Powervault 5-minute aggregate data

Start Date	End date	Charge (kWh)	Discharge (kWh)	% Online	Round Trip Efficiency	Charge (kWh/day)	Discharge (kWh/day)	PV Generation (kWh)	PV Generation (kWh/day)
20-Apr-18	01-May-18	34.51	-17.35	90.91%	50.29%	3.45	-1.74	109.1	9.92
01-May-18	01-Jun-18	72.85	-39.27	87.10%	53.90%	2.70	-1.45	465.9	15.03
01-Jun-18	20-Jun-18	42.26	-22.12	88.18%	52.35%	2.52	-1.32	216.1	11.37

Table 3.24 Performance of the Powervault G200 battery system at household T-02 with tubular gel lead acid batteries showing values derived from a Verv logger with 1-second interval data

Household T-05

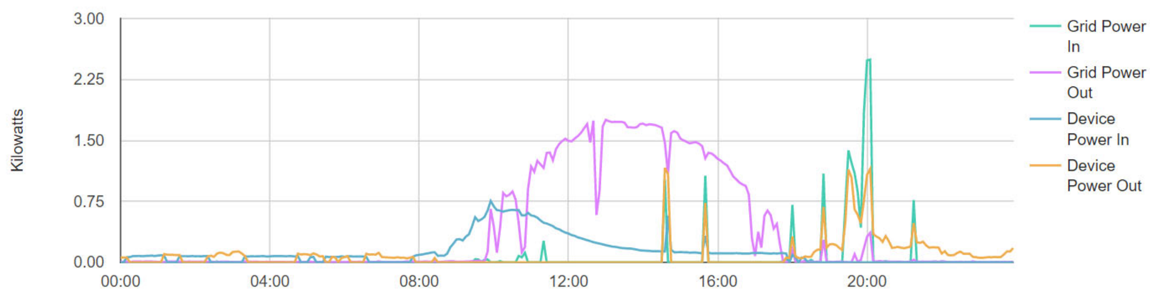

Figure 3.25 Plot from the Powervault portal showing the performance of the battery system at household T-05 on 27 Sep 18 with tubular gel lead acid batteries

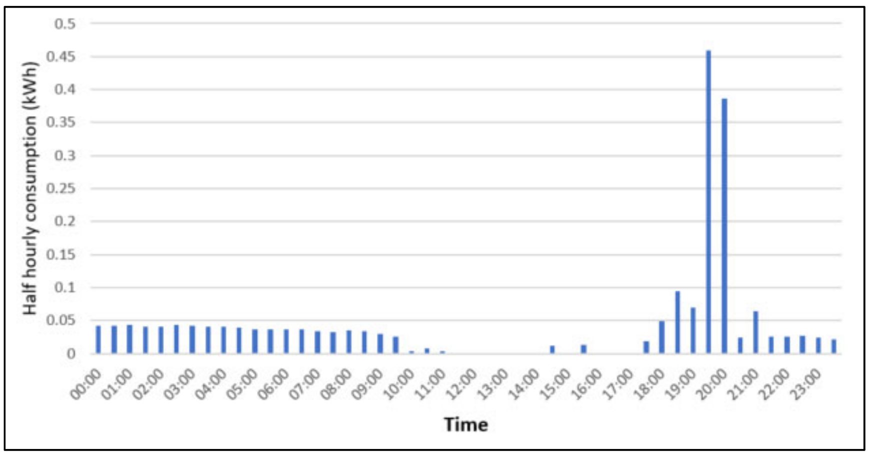

Figure 3.26 Plot of the half hourly electricity consumption at household T-05 on 27 Sep 18

For household T-05 there was a single resident not working due to a health condition. It was a mid-terraced bungalow with a floor area of 30m^2, which was smaller than many others in the study which were 45m^2. The cooker had an electric hob and oven and was used in the afternoon or evening. The electric shower was used a couple times a week and the washing machine was not used every week. There was an older cathode ray tube television which was likely to consume more electricity than an LCD model and a HiFi system was used in the afternoons.

Figure 3.25 shows a plot of the performance of the battery system on a sunny day on 27 Sep 2018. From about 08:00, there was excess solar generation and the battery system started to charge with the ‘Device Power In’, shown in blue increasing until about 10:00. The PV generation was greater than the household consumption and battery charging and so there were high levels of export (Grid Power Out, shown in purple) between 10:00 and 17:30. Periods where the household consumption was not met by the solar generation can be seen as peaks in ‘Grid Power In’ shown in green. There were peaks in ‘Grid Power In’ at 14:30 and 15:45 of about 1 kW. At these times, the battery also supplied power (Device Power Out, in orange). In the early evening when the solar generation decreased there was greater household consumption. Between 19:30 and 20:00, the resident may have been cooking and there was up to 2.5 kW drawn from the grid. The Powervault battery system supplied up to 1.15 kW during this period. Later in the evening the battery continued to supply most of the power requirements of the household. Figure 3.26 shows the half-hourly electricity consumption from a smart meter for the same day as the plot from the Powervault portal. There was little or no consumption in the middle of the day when there was significant solar generation. Increases occurred at 14:30 and 15:30 when peaks occurred on the Powervault portal plot. Higher consumption was recorded in the early evening, particularly between 19:30 and 20:00.

The property had a smart electricity meter fitted on 18 Jul 18. The resident noted during the household interview that the power consumption on the smart meter In-Home Display (IHD) frequently did not increase when he turned on appliances. This made him confident that the battery system was saving him money.

The battery system was connected online in December 2016 but went offline in April 2017. The system was turned off in August and turned back on with new tubular gel batteries on 31 Oct 2017. From January 2018, the system was online for more than 99% of the time. This meant that little data missed being collected due to the battery system internet connection being offline.

Table 3.27 shows Powervault battery data for the period between 1 Nov 2017 and 1 Nov 2018. Values in kWh/day take into account the number of days and the percentage of time online. The battery discharge measured ranged from 0.64 kWh/day in November 2017 to 1.98 kWh/day in March 2018. The values in kWh/day for November 2017 may be somewhat anomalous due to the effect of the system being online for only 82% of the time. The higher values of discharge in March and October 2018 may result from there being sufficient PV generation to charge the battery as well as higher household consumption than in the middle of summer.

Over the year, from 1 Nov 17 to 31 Oct 18, the battery discharge was measured to be 533 kWh, which averaged out at about 1.49 kWh/day when taking into account periods offline. The round-trip efficiency for the battery system over the year was 59.0%.

Start Date	End date	Import Power (kWh)	Export Power (kWh)	Charge (kWh)	Discharge (kWh)	% Online	Round Trip Efficiency	Import Power (kWh/day)	Export Power (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
01-Nov-17	01-Dec-17	39.48	-50.13	42.17	-15.84	82.14%	37.57%	1.60	-2.03	1.71	-0.64
01-Dec-17	01-Jan-18	19.15	-15.44	66.44	-39.15	98.59%	58.93%	0.63	-0.51	2.17	-1.28
01-Jan-18	01-Feb-18	20.64	-30.88	74.60	-42.54	99.90%	57.02%	0.67	-1.00	2.41	-1.37
01-Feb-18	01-Mar-18	13.19	-82.93	67.28	-44.00	99.96%	65.40%	0.47	-2.96	2.40	-1.57
01-Mar-18	01-Apr-18	20.99	-87.55	91.31	-60.88	99.32%	66.67%	0.68	-2.84	2.97	-1.98
01-Apr-18	01-May-18	19.13	-143.47	78.88	-47.91	99.46%	60.73%	0.64	-4.81	2.64	-1.61
01-May-18	01-Jun-18	14.01	-315.26	78.93	-44.44	99.97%	56.30%	0.45	-10.17	2.55	-1.43
01-Jun-18	01-Jul-18	7.91	-290.57	72.24	-37.49	100.00%	51.89%	0.26	-9.69	2.41	-1.25
01-Jul-18	01-Aug-18	12.67	-265.03	86.22	-47.29	99.83%	54.85%	0.41	-8.56	2.79	-1.53
01-Aug-18	01-Sep-18	14.60	-151.52	84.59	-49.42	99.80%	58.43%	0.47	-4.90	2.73	-1.60
01-Sep-18	01-Oct-18	17.54	-144.60	82.70	-51.22	99.47%	61.94%	0.59	-4.85	2.77	-1.72
01-Oct-18	01-Nov-18	24.26	-75.34	78.85	-52.98	96.68%	67.19%	0.81	-2.51	2.63	-1.77
01-Nov-17	**01-Nov-18**	**223.6**	**-1652.7**	**904.2**	**-533.2**	**97.94%**	**59.0%**	**0.63**	**-4.62**	**2.53**	**-1.49**

Table 3.27 Performance of the Powervault G200 battery system at household T-05 with tubular gel lead acid batteries showing values derived from Powervault 5-minute aggregate data

The grid import for the household measured by the Powervault system was in the range 0.26 to 0.68 kWh/day in 2018. Values of PV generation from a smart generation meter and grid import from the electricity smart meter are shown in table 3.28. The Powervault system measured the grid import to be 0.41, 0.47, 0.59 and 0.81 kWh/day for the months from July to October. The electricity smart meter measured 1.13, 1.32, 1.72 and 2.18 kWh/day for these months. Again there may be an issue with the values recorded by the Powervault current clamp. Had the system recorded the grid import more accurately, it is possible the system may have been able to supply greater battery discharge. This might have resulted in lower overnight consumption in figure 3.26 for example.

Comparing the average charge in table 3.27 with the PV generation in table 3.28, it is apparent that the charge exceeds the PV generation in December 2017 and January 2018. This is likely to be due to the charge including grid charging of the battery. Low power charging was also apparent overnight when there was no excess solar generation.

Start Date	End date	PV Generation (kWh)	PV Generation (kWh/day)	Grid Import (kWh)	Grid Import (kWh/day)
01-Nov-17	01-Dec-17	88.8	2.96		
01-Dec-17	01-Jan-18	39.9	1.29		
01-Jan-18	01-Feb-18	60.1	1.94		
01-Feb-18	01-Mar-18	135.4	4.84		
01-Mar-18	01-Apr-18	188.6	6.08		
01-Apr-18	01-May-18	237.3	7.91		
01-May-18	01-Jun-18	434.4	14.01		
01-Jun-18	01-Jul-18	399.5	13.32		
19-Jul-18	01-Aug-18	137.3	10.56	14.74	1.13
01-Aug-18	01-Sep-18	253.4	8.17	40.9	1.32
01-Sep-18	01-Oct-18	233.6	7.79	51.5	1.72
01-Oct-18	01-Nov-18	151.9	4.9	67.7	2.18

Table 3.28 Values of PV generation and grid import derived from smart meters at Household T-05

Household T-06

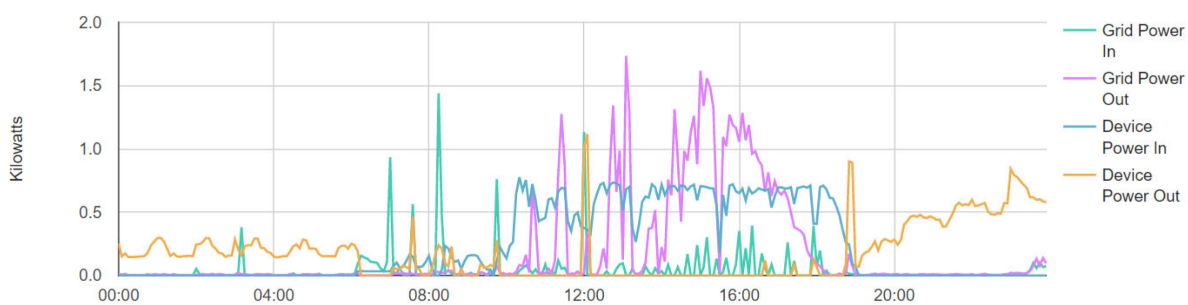

Figure 3.29 Plot from the Powervault portal showing the performance of the battery system at household T-06 on 2 Aug 18 with tubular gel lead acid batteries

Household T-06 was made up of a retired couple, although one of them passed away during the summer of 2018. There was gas central heating from a combi-boiler and an electric shower. There was a tall freezer and a standard fridge. The washing machine was used once a week. The fish pond in the garden had a 95W pump which ran 24 hours a day from March to October. An electric blanket was used 1 hour per day and a 2kW supplementary heater was used in the bathroom in the winter.

Figure 3.29 shows a plot of the battery system performance on 2 Aug 2018. The battery provided the baseload power consumption of 0.15 to 0.3 kW between 00:00 and 06:00. This was likely to be primarily powering the fish pond pump, fridge and freezer. Between 06:30 and 08:30 the resident was getting up and having breakfast and there were 3 peaks in grid import, with the battery also supplying power. There was an increase in the battery charging from 10:00, with the battery charging at about 0.7 kW for much of the time until about 18:00. During this period there was also grid export of up to 1.7kW due to excess solar generation. By about 19:00 there was no further grid export or charging of the battery. The battery supplied a peak of about 0.9 kW to the household at 19:00. Nearly all the household power requirements were supplied by the battery for the rest of the evening, averaging at about 0.5 kW and with a peak of 0.84 kW at 23:00.

The battery system for household T-06 was connected to the internet in December 2016. Data was collected each month in 2017 apart from September and October when the Powervault G200 system was turned off while awaiting new tubular gel batteries and a firmware update. During most months, the WiFi connection was lost for a few days, which accounted for the lower percentage of time online. Table 3.30 shows the battery system performance during 2017, with the period using tubular gel batteries shaded lighter. It is apparent that the battery discharge for the earlier period with AGM lead acid batteries ranged from 0.42 to 2.38 kWh/day once the period online was also taken into account. The round trip efficiency ranged from 31.5% to 66%.

Table 3.31 shows the performance in 2018 with the tubular gel lead acid batteries. The battery discharge ranged from 0.49 kWh/day in January to 3.63 kWh/day in May 2018 with higher values than for the AGM batteries. The battery charge per day exceeded 4 kWh (the battery capacity) between April and September 2018. These high values may be due to a range of factors. The battery may have been charging again after partially discharging during the day due to high PV generation and household consumption. Also the values of charge and discharge derived from the 5 minute aggregate Powervault data is generally higher than values calculated from more accurate 1 second Verv logger data. In January 2018 the battery round trip efficiency was 32.2% (and only 24.1% in December 2017), rising to 68.9% in June 2018. This ignores the anomalously high value in March where the battery was only online for 10.9% of the time.

Month	Import (kWh)	Export (kWh)	Charge (kWh)	Discharge (kWh)	%Online	Round trip efficiency (%)	Import (kWh/day)	Export (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
Jan-17	118.9	-6.1	28.0	-8.8	67.3%	31.5%	5.70	-0.29	1.34	-0.42
Feb-17	89.8	-14.3	46.7	-19.9	68.6%	42.6%	4.67	-0.75	2.43	-1.03
Mar-17	88.6	-75.7	75.8	-42.8	81.2%	56.5%	3.52	-3.01	3.01	-1.70
Apr-17	70.0	-86.7	70.8	-41.9	66.7%	59.2%	3.50	-4.33	3.54	-2.09
May-17	78.7	-137.9	92.1	-57.3	87.4%	62.3%	2.91	-5.09	3.40	-2.12
Jun-17	56.1	-112.3	97.7	-64.5	90.2%	66.0%	2.08	-4.15	3.61	-2.38
Jul-17	84.9	-133.6	108.6	-66.7	91.5%	61.4%	2.99	-4.71	3.83	-2.35
Aug-17	72.0	-85.8	77.6	-44.7	70.2%	57.6%	3.31	-3.95	3.57	-2.05
Sep-17	0.0	0.0	0.0	0.0	0.0%					
Oct-17	0.0	0.0	0.0	0.0	0.0%					
Nov-17	169.6	-21.3	36.1	-11.6	82.4%	32.1%	6.86	-0.86	1.46	-0.47
Dec-17	159.5	-2.7	27.6	-6.7	68.7%	24.2%	7.49	-0.13	1.30	-0.31

Table 3.30 Performance of the Powervault G200 battery system at household T-06 in 2017, with AGM lead acid batteries (shaded darker) and tubular gel batteries (shaded lighter) based on Powervault data

Month	Import (kWh)	Export (kWh)	Charge (kWh)	Discharge (kWh)	%Online	Round trip efficiency (%)	Import (kWh/day)	Export (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
Jan-18	214.9	-8.2	46.5	-15.0	99.4%	32.2%	6.97	-0.27	1.51	-0.49
Feb-18	141.8	-28.3	71.6	-36.9	91.2%	51.6%	5.56	-1.11	2.80	-1.45
Mar-18	10.5	-4.7	11.8	-9.7	10.9%	81.8%	3.10	-1.39	3.51	-2.87
Apr-18	89.7	-90.2	120.6	-75.4	99.8%	62.5%	3.00	-3.01	4.03	-2.52
May-18	46.3	-193.2	165.5	-112.6	99.9%	68.0%	1.49	-6.24	5.34	-3.63
Jun-18	27.9	-196.5	150.7	-103.8	99.7%	68.9%	0.93	-6.57	5.04	-3.47
Jul-18	21.8	-157.6	123.2	-89.1	83.4%	72.4%	0.84	-6.09	4.76	-3.45
Aug-18	57.3	-60.1	97.4	-60.2	70.9%	61.8%	2.61	-2.74	4.43	-2.74
Sep-18	49.5	-38.4	64.0	-38.4	52.5%	60.0%	3.14	-2.44	4.06	-2.44

Table 3.31 Performance of the Powervault G200 battery system at household T-06 in 2018 with tubular gel lead acid batteries showing values derived from Powervault 5-minute aggregate data

Start date	End date	Consumption (kWh)	Generation (kWh)	Consumption (KWh/day)	Generation (kWh/day)
30-Dec-16	27-Jan-17	171	38.5	6.11	1.38
27-Jan-17	03-Mar-17	179	102.8	5.11	2.94
03-Mar-17	31-Mar-17	108	203.3	3.86	7.26
31-Mar-17	28-Apr-17	119	270.6	4.25	9.66
28-Apr-17	02-Jun-17	114	413.4	3.26	11.81
02-Jun-17	30-Jun-17	69	278.7	2.46	9.95
30-Jun-17	28-Jul-17	91	316.4	3.25	11.30
28-Jul-17	01-Sep-17	143	339.3	4.09	9.69
01-Sep-17	29-Sep-17	169	191.3	6.04	6.83
29-Sep-17	27-Oct-17	193	95.6	6.89	3.41
27-Oct-17	01-Dec-17	250	89.2	7.14	2.55
01-Dec-17	29-Dec-17	232	29.6	8.29	1.06

Table 3.32 Electricity consumption and PV generation based on household meter readings for T-06 in 2017. The period with AGM lead acid batteries in the Powervault G200 system is shaded darker

Start date	End date	Consumption (kWh)	Generation (kWh)	Consumption (kWh/day)	Generation (kWh/day)
29-Dec-17	28-Jan-18	241	46.9	8.03	1.56
28-Jan-18	02-Mar-18	205	126	6.21	3.82
02-Mar-18	30-Mar-18	113	184.5	4.04	6.59
30-Mar-18	27-Apr-18	92	235.9	3.29	8.42
27-Apr-18	01-Jun-18	75	495.8	2.14	14.17
01-Jun-18	29-Jun-18	34	398.8	1.21	14.24
29-Jun-18	03-Aug-18	42	462.6	1.20	13.22
03-Aug-18	31-Aug-18	98	236.6	3.50	8.45
31-Aug-18	28-Sep-18	117	209.6	4.18	7.49

Table 3.33 Electricity consumption and PV generation based on household meter readings for T-06 during 2018, with tubular gel lead acid batteries in the Powervault G200 system

The resident at household T-06 had been recording the electricity and PV generation meter readings every week since 2012. Tables 3.32 and 3.33 show the consumption and PV generation for 2017 and 2018 respectively. The import measured by the Powervault system for households T-01, T-02 and T-05 was significantly lower than for the household electricity meter. Tables 3.31 to 3.33 show that for household T-06, the import measured by the battery was closer to the values from the electricity meter after compensation for periods offline. This suggests the Powervault current clamp on the mains meter tail for this installation was measuring the current more accurately.

Based on utility meter readings, the grid import for household T-06 was significantly higher than for household T-05. In August and September 2018 the grid import for household T-06 was 3.5 and 4.18 kWh/day respectively. This compared to 1.32 and 1.72 kWh/day for household T-05. The import derived from the Powervault data for T-05 was even lower at 0.47 and 0.59kWh/day. The greater household demand led to greater battery discharge. For household T-06 it was 2.7 kWh/day in August and 2.44 kWh/day in September 2018 compared to 1.6 and 1.72 kWh/day for T-05. Where there was sufficient PV generation to charge the battery, a higher household demand led to a higher battery discharge. Where the Powervault system recorded lower values of grid import than actually occurred, the discharge of the battery was lower still.

Table 3.34 shows the approximately yearly electricity consumption and solar PV generation for household T-06 based on weekly meter readings. Between 5 Feb 2016 and 27 May 2016, the solar PV system had broken down. This explains the lower PV generation and higher household consumption between 31 Jul 2015 and 29 Jul 2015.

The average annual household consumption with just the solar PV was 1974 kWh/year based on the first 2 years of data and compensating for the full year. The average annual consumption was 1636 kWh/year based on the 2 years with the batteries. This indicates a reduction of 338 kWh/year after having the battery system. However it should be noted that the battery system was turned off between 23 Aug 2017 and 31 Oct 2017. Also the PV generation was higher for July 2016-2018 than for August 2013-July 2015. It is not possible to obtain an accurate indication of the contribution from the battery by this method due to variations in PV generation, battery use and household behaviour. However, the data shows the battery system had clearly produced savings for the household.

Start date	End date	No of days	Consumption (kWh)	PV Generation (kWh)
02-Aug-13	01-Aug-14	364	1,879	2,163.6
01-Aug-14	31-Jul-15	364	2,059	2,253.4
31-Jul-15	29-Jul-16	364	2,287	1,372.3
29-Jul-16	28-Jul-17	364	1486	2,454.9
28-Jul-17	27-Jul-18	364	1778	2,635.2

Table 3.34 A comparison of electricity consumption and PV generation for household T-06 in years with only solar PV and with the solar PV along with the Powervault G200

Household T-07

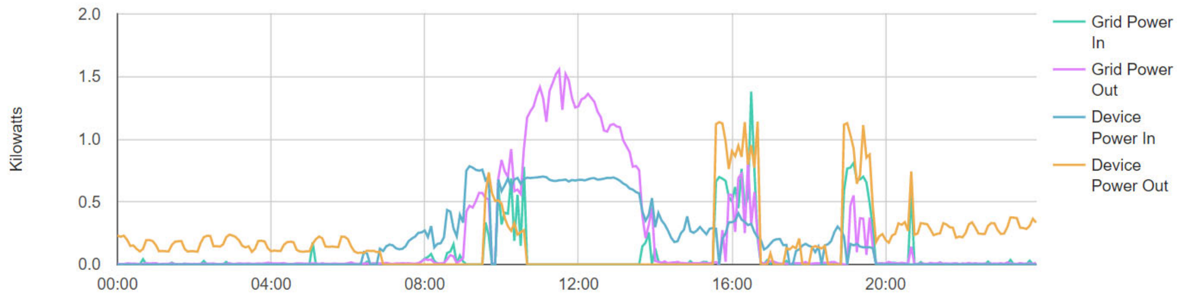

Figure 3.35 Plot from the Powervault portal showing the performance of the battery system at household T-07 on 27 Jul 2018 with tubular gel lead acid batteries

There was a single retired resident in household T-07. She was a higher electricity user and liked to cook with the oven. A plot of the battery system performance on 27 Jul 2018 is shown in figure 3.35. From midnight until 06:00, the household baseload power of 0.1 to 0.24 kW was provided by the Powervault battery system. It was a sunny day and from 07:00, the battery started to charge and from 09:00 to 14:00 there was sufficient excess solar generation to export to the grid, reaching a peak of 1.56 kW at 11:30. There were periods of higher household consumption at 15:30-16:30 and 19:00-19:45 where the battery system supplied over 1 kW for a period. However, the consumption varied during these periods and at times there was electricity export and battery charging. From about 20:00 until 00:00, the Powervault system provided the household consumption of 0.2 – 0.35 kW, with a higher consumption peak of 0.74 kW at 20:40.

The Powervault G200 battery system at household T-07 was connected online in November 2016. While the system was online for 89% of the time in January 2017, it was only 17.7% in March. The AGM batteries were turned off in August 2017 and replaced by tubular gel batteries at the beginning of November. The WiFi connection was also improved and after December 2017 the system was online for more than 99% of the time.

Table 3.36 shows the performance in 2017 recorded by the Powervault system for household T-07. The values in kWh/day are likely to be less accurate for March 2017 and August 2017 as the system was online for only 17.7 and 12.1% of the time respectively. The discharge from the AGM batteries ranged from 1.05 to 2.53kWh per day but went as low as 0.35 kWh/day in December with the tubular gel batteries.

The performance of the system in 2018 with tubular gel batteries is shown in table 3.37. In January 2018, the battery discharge was 0.59 kWh/day and the round-trip efficiency was 36.6%. May 2018 saw the greatest battery discharge of 3.03 kWh/day. The round-trip efficiency was 70.5%, although an even higher value of 71.2% was seen in July 2018. The monthly electricity import measured varied from 4.92 kWh/day in January to 0.64 kWh/day in May 2018.

Start Date	End date	Import (kWh)	Export (kWh)	Charge (kWh)	Discharge (kWh)	%Online	Round trip efficiency (%)	Import (kWh/day)	Export (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
01-Jan-17	01-Feb-17	33.3	-62.7	83.2	-43.0	89.0%	51.7%	1.21	-2.27	3.02	-1.56
01-Feb-17	01-Mar-17	15.1	-124.5	62.1	-22.3	75.7%	36.0%	0.71	-5.87	2.93	-1.05
01-Mar-17	01-Apr-17	5.1	-42.0	16.3	-7.5	17.7%	46.1%	0.92	-7.64	2.97	-1.37
01-Apr-17	01-May-17	8.6	-13.1	29.9	-19.8	40.8%	66.1%	0.70	-1.07	2.44	-1.61
01-May-17	01-Jun-17	37.8	-74.6	95.2	-60.8	77.5%	63.8%	1.57	-3.11	3.97	-2.53
01-Jun-17	01-Jul-17	43.9	-38.0	63.2	-39.1	65.0%	61.9%	2.25	-1.95	3.24	-2.01
01-Jul-17	01-Aug-17	41.5	-46.0	70.2	-41.5	65.9%	59.1%	2.03	-2.25	3.44	-2.03
01-Aug-17	01-Sep-17	8.3	-5.6	10.7	-7.4	12.1%	69.0%	2.22	-1.49	2.84	-1.96
01-Sep-17	01-Oct-17	0.1	-0.4	0.2	0.0	0.1%	12.8%				
01-Oct-17	01-Nov-17	0.0	0.0	0.0	0.0	0.0%					
01-Nov-17	01-Dec-17	136.8	-25.5	37.3	-14.6	85.3%	39.0%	5.34	-1.00	1.46	-0.57
01-Dec-17	01-Jan-18	163.5	-5.7	40.9	-10.9	99.3%	26.7%	5.31	-0.19	1.33	-0.35

Table 3.36 Performance of the Powervault G200 battery system at household T-07 in 2017, with AGM lead acid batteries (shaded darker) and tubular gel batteries (shaded lighter) based on Powervault data

Start Date	End date	Import (kWh)	Export (kWh)	Charge (kWh)	Discharge (kWh)	%Online	Round trip efficiency (%)	Import (kWh/day)	Export (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
01-Jan-18	01-Feb-18	152.5	-10.8	49.9	-18.3	99.96%	36.6%	4.92	-0.35	1.61	-0.59
01-Feb-18	01-Mar-18	109.9	-29.7	71.3	-37.7	99.96%	52.9%	3.93	-1.06	2.55	-1.35
01-Mar-18	01-Apr-18	75.0	-34.1	104.6	-66.4	100.00%	63.5%	2.42	-1.10	3.37	-2.14
01-Apr-18	01-May-18	48.1	-65.7	113.1	-72.0	99.76%	63.7%	1.61	-2.19	3.78	-2.41
01-May-18	01-Jun-18	19.8	-147.4	133.1	-93.9	99.85%	70.5%	0.64	-4.76	4.30	-3.03
01-Jun-18	01-Jul-18	27.3	-97.2	130.1	-89.3	99.32%	68.6%	0.92	-3.26	4.37	-3.00
01-Jul-18	01-Aug-18	23.5	-109.6	125.8	-89.5	98.92%	71.2%	0.77	-3.57	4.10	-2.92
01-Aug-18	01-Sep-18	65.6	-39.3	106.2	-69.0	99.99%	64.9%	2.12	-1.27	3.43	-2.23
01-Sep-18	01-Oct-18	81.8	-47.5	92.6	-57.1	99.95%	61.6%	2.73	-1.58	3.09	-1.90
01-Oct-18	01-Nov-18	111.2	-26.7	70.1	-37.6	97.23%	53.7%	3.69	-0.89	2.33	-1.25
01-Nov-17	**01-Nov-18**	**1015.1**	**-639.3**	**1075.0**	**-656.2**	**98.31%**	**61.0%**	**2.83**	**-1.78**	**3.00**	**-1.83**

Table 3.37 Performance of the Powervault G200 battery system at household T-07 in 2018 with tubular gel lead acid batteries showing values derived from Powervault 5-minute aggregate data

A full year of data with the tubular gel batteries was available for this site. Between 1 Nov 2017 and 31 Oct 2018, the battery discharge measured was 656.2 kWh. This averaged out at 1.83 kWh/day once account was taken for the period online. The round-trip efficiency for the battery system over the year was 61.0%.

The values of battery discharge were greater for the tubular gel batteries for the months February to August 2018 than for the corresponding months with AGM batteries in 2017. The discharge for the tubular gel batteries was 49% higher than for the AGM batteries in June and 44% higher in July. This corresponded to a period of significantly higher solar generation in 2018 as shown by table 3.38. However, there was 56% greater discharge in March 2018 compared to the year before and this corresponded to a period with lower solar generation.

The PV generation for household T-07 was lower than at many sites due to shading of the PV array by bushes. Factors such as household consumption and the periods when consumption and generation occur are also likely to be important factors in the performance of the system along with the type of battery.

Month	2017 PV Generation (kWh)	PV Generation (kWh/day)	2018 PV Generation (kWh)	PV Generation (kWh/day)
Jan	54.2	1.75	59.3	1.91
Feb	85.1	3.04	115.5	4.13
Mar	191.6	6.18	166.5	5.37
Apr	237.9	7.93	213.9	7.13
May	262.7	8.47	332.2	10.72
Jun	196.9	6.56	274.6	9.15
Jul	207.7	6.70	289.3	9.33
Aug	170.9	5.51	176.1	5.68
Sep	115.2	3.84	158.9	5.30
Oct	61.6	1.99	109.2	3.52
Nov	71.2	2.37		
Dec	40.0	1.29		

Table 3.38 A comparison of PV generation for household T-07 during periods with AGM lead acid batteries in the Powervault G200 system (shaded darker) and with tubular gel batteries (shaded lighter)

There were not such detailed records of household consumption available as for household T-06. It was still possible to compare the consumption recorded by the electricity meter with that recorded by the Powervault system. Between 23 Dec 2017 and 30 Aug 2018, the electricity meter showed a consumption of 712 kWh or 2.85 kWh/day. This compared to 521.7 kWh between 1 Jan 2018 and 1 Sep 2018 or 2.15 kWh/day as determined from the Powervault data. The grid import from the Powervault data was closer to the actual meter readings for household T-07 than for households T-01, T-02 and T-05 and may be a factor in the greater battery discharge for T-07.

Household T-18

Household T-18 was the only Knutsford household to be part of the monitored group. The Powervault battery system was connected online and first recorded data at the beginning of November 2017, but the connection was lost after a few days. There was a further engineer's visit on 19 April 2018. The internet connection was re-set and good data was obtained from 20 Apr 2018. A Verv data logger was also fitted in April and this recorded data until 15 Oct 2018 when the logger was collected during the final household interview.

Table 3.39 shows values derived from the 5-minute aggregate data from the Powervault system for the period in the summer of 2018 that the battery system was online. It can be seen that the battery discharge measured was between 2.57 and 3.02 kWh/day and the battery round trip efficiency was between 63.8 and 80.2%.

Start Date	End date	Import (kWh)	Export (kWh)	Charge (kWh)	Discharge (kWh)	%Online	Round trip efficiency (%)	Import (kWh/day)	Export (kWh/day)	Charge (kWh/day)	Discharge (kWh/day)
20-Apr-18	01-May-18	11.0	-45.6	44.2	-31.3	100.00%	70.7%	1.00	-4.14	4.02	-2.84
01-May-18	01-Jun-18	18.4	-265.9	122.3	-80.4	100.00%	65.8%	0.59	-8.58	3.94	-2.59
01-Jun-18	01-Jul-18	18.5	-266.3	120.7	-77.0	99.95%	63.8%	0.62	-8.88	4.03	-2.57
01-Jul-18	01-Aug-18	22.2	-231.7	131.7	-87.5	99.97%	66.5%	0.72	-7.48	4.25	-2.82
01-Aug-18	01-Sep-18	22.4	-108.5	126.8	-93.6	100.0%	73.9%	0.72	-3.50	4.09	-3.02
01-Sep-18	01-Oct-18	19.8	-82.0	112.2	-90.0	100.0%	80.2%	0.66	-2.73	3.74	-3.00

Table 3.39 Performance of the Powervault G200 battery system at household T-18 with tubular gel lead acid batteries showing values derived from Powervault 5-minute aggregate data

Start date	End date	Charge (kWh)	Discharge (kWh)	% Online	Round trip Efficiency	Charge (kWh/day)	Discharge (kWh/day)
20-Apr-18	01-May-18	40.31	-24.22	100.00%	60.09%	3.66	-2.20
01-May-18	01-Jun-18	99.36	-57.84	96.77%	58.21%	3.31	-1.93
01-Jun-18	01-Jul-18	92.65	-53.03	91.77%	57.24%	3.37	-1.93
01-Jul-18	31-Jul-18	108.67	-65.07	96.77%	59.88%	3.74	-2.24
01-Aug-18	31-Aug-18	115.01	-72.05	100.00%	62.64%	3.83	-2.40
01-Sep-18	30-Sep-18	103.86	-65.70	100.00%	63.26%	3.58	-2.27
01-Oct-18	15-Oct-18	35.29	-24.97	93.33%	70.76%	2.70	-1.91

Table 3.40 Performance of the Powervault G200 battery system at household T-18 with tubular gel lead acid batteries showing values derived from a Verv logger with 1 second interval data

Values of charge and discharge for the battery which were derived from 1 second Verv logger data are shown in table 3.40. It can be seen that in May, June, July and October the logger did not record data 100% of the time. Here the logger missed around a day or more of data. This was for a continuous period and so covered either 1 or 2 full charge and discharge cycles.

As for the other Verv loggers, the values of charge and discharge were lower than the values from the Powervault data. Values of discharge from the Verv logger were 20 to 25% lower that the values from the 5-minute aggregate Powervault data. Data was available from 3 of the Verv loggers for the evaluation. Out of these, household T-18 showed the greatest discharge, with a value of 2.59 kWh/day in May 2018 compared to 1.17 kWh/day for household T-01 and 1.45 kWh/day for household T-02.

Start date	End date	Grid Import (kWh)	Grid Import (kWh/day)	Solar PV Generation (kWh)	Solar PV Generation (kWh/day)
20-Apr-18	01-May-18	22.0	2.00	118.0	10.73
01-May-18	30-May-18	41.0	1.41	466.0	16.07
30-May-18	27-Jun-18	42.0	1.50	416.0	14.86
27-Jun-18	01-Aug-18	56.0	1.60	525.0	15.00
01-Aug-18	30-Aug-18	51.0	1.76	268.0	9.24
30-Aug-18	02-Oct-18	57.0	1.73	282.0	8.55
02-Oct-18	17-Oct-18	46.0	3.07	62.0	4.13

Table 3.41 Electricity import and solar PV generation for household T-18 covering similar time periods to the Powervault and Verv data

Regular electricity meter readings were also obtained for the household and values of grid import and PV generation are shown in table 3.41. Between May and August, the meter readings were between 2.23 and 2.43 times higher than the values of import derived from the 5 minute aggregate Powervault data. Although the battery system for household T-18 performed well, the difference between the import measured by the G200 system and the utility meter was significant. For household T-01 where performance was significantly poorer, the grid import from the utility meter was between 3 and 5.3 times larger than the value from the G200 data. Such a large difference is likely to have had a greater impact on the system performance.

Financial benefit from Powervault G200 battery systems

Project	Battery system	Usable capacity (kWh)	Technical Reference Number	Start date	End date	Battery discharge (kWh)	Battery dischage (kWh/year)	Saving (£)	Saving (£/year)
Cheshire East , CP776	Powervault G200	4	T-05	01-Nov-17	01-Nov-18	533.2	533.2	£ 85.31	£ 85.31
Cheshire East, CP776	Powervault G200	4	T-07	01-Nov-17	01-Nov-18	656.2	656.2	£ 104.99	£ 104.99
Thurrock, CP775	Moixa Maslow	1.6	T-09	01-Jul-17	01-Jul-18	340.8	340.8	£ 54.53	£ 54.53
Thurrock, CP775	PowerFlow Sundial	1.6	T-19	19-Jul-16	13-Jul-18	836.4	421.7	£ 133.82	£ 67.47
Thurrock, CP775	Victron/Leoch AGM	1.56	T-34	01-Aug-16	01-Aug-18	574.9	287.5	£ 91.99	£ 45.99

Table 3.42 Assessment of the financial benefit of Powervault G200 battery installations compared to other battery systems on another NEA trial. A standard electricity price of 16p/kWh was used.

A full year of data was available for households T-05 and T-07. Here the battery discharge derived from the 5-minute aggregate Powervault data was 533.2 and 656.2 kWh respectively. Using a standard price for electricity of 16p/kWh, the annual savings were £85.31 and £104.99.

Verv data loggers were used on some installations and these recorded data at 1-second intervals. It was found that the values derived from the Verv data loggers were about 20% lower than those calculated from the 5-minute aggregates of 30-second data from the Powervault system. Although both logging methods used current clamps, the higher sample rate of the Verv logger meant that it was likely to have greater accuracy. Assuming the battery discharge at the Cheshire East sites was 20% lower than the values shown in table 3.42, the annual savings would be reduced to £68.24 and £83.99.

In another NEA Technical Innovation Fund trial in the Thurrock area, Maslow, PowerFlow Sundial and Victron charger/inverters with Leoch AGM lead acid batteries were installed[37]. Table 3.42 shows details of the battery systems along with their usable capacity. The Maslow and Powerflow Sundial batteries were both Lithium-ion. A single Leoch 260Ah AGM lead acid battery was fitted with a Victron MultiPlus Compact charger/inverter. The maximum battery discharge recorded after a year among the Maslow batteries was 340.8 kWh while there was a discharge of 836.4 kWh after nearly 2 years for the best performing PowerFlow Sundial battery. The net battery discharge for the Victron/Leoch system was 574.9 kWh after 2 years. This took into account 28.5 kWh of grid charging, something that has not been considered with the Powervault data.

The best performing batteries were the 2 Powervault installations which had the larger 4 kWh batteries. The savings from the Sundial and Maslow batteries were lower, but these only had batteries with a 1.6 kWh usable capacity. It should be noted the Sundial and Maslow systems were more compact than the Powervault G200 and their Lithium-ion batteries had a longer lifespan. The combination of the Victron charger/inverter with the Leoch battery performed least well. This was due to the poorer performance of the Leoch AGM lead acid battery which had a smaller usable capacity and shorter life span.

[37] Paul Rogers and Michael Hamer, SunGain Battery Bank, Thurrock, Nottingham Energy Partnership, NEA (in press)

4. Conclusions and recommendations

4.1 Conclusions

Household electricity costs can be reduced by installing battery storage alongside solar PV systems. This can store excess solar generation during the day for use at times of higher demand and lower solar generation, such as in the evening.

This project installed Powervault G200 battery systems in social housing in Cheshire East which had pre-existing solar PV systems and aimed to:

- Assess the performance of the Powervault G200 system with 4kWh lead acid batteries
- Assess levels of resident satisfaction with the technology
- Determine the battery performance over about 2 years and the savings for the residents from the batteries and the solar PV systems
- Consider any challenges associated with deployment and operation of the technology

A total of 22 Powervault G200 battery systems were installed with 17 in bungalows in Macclesfield and 5 in houses in Knutsford. Out of these,10 households receiving batteries were recruited to be part of a monitored group for the evaluation and a further 4 households which only had solar PV were control properties.

Resident satisfaction

- All the residents in the monitored group agreed or strongly agreed that the batteries didn't need any active input to work and found the systems easy to use.
- Out of the 9 households interviewed, 7 felt they knew enough about how the battery worked, while 6 agreed that they understood how best to use the battery.
- There were 6 out of 9 households who felt they had seen a reduction in their energy bills, with the other 3 saying their bills were about the same.

Installation and reliability issues

- When the monitored group was interviewed, 7 households thought the installation was neat and tidy with no loose wires or connections, but 2 disagreed.
- A Powervault G200 system at household T-08 failed and when a replacement system was installed, the current clamp was fitted the wrong way around. This resulted in higher bills for the household rather than savings and compensation was paid to the residents as a result.
- There were issues with the batch of AGM lead acid batteries used for these installations. As a result, Powervault advised switching off the battery systems on 23 Aug 2017.
- After the batteries were switched off, it was discovered that some of the batteries had swelled and in places cracked due to a manufacturing defect. The batteries were replaced to overcome this issue and the component supplier was changed. A firmware update for the systems was also carried out to detect and mitigate further risks from over/under-charging batteries. The importance of an online connection was also highlighted to allow remote monitoring of battery health as well as system performance.
- New tubular gel lead acid batteries were fitted at the end of October 2017 and the battery systems were turned on again and provided with a charge from the grid.

- On the evening of 2 Nov 2017, the carbon monoxide alarm was set off at household T-03 when the faulty batteries were replaced. This was caused by an incorrect setting of an initial commissioning charge causing over-charging of the batteries, leading to release of hydrogen and oxygen through the 1-way valve on the batteries. The sensor on the carbon monoxide alarm was unable to differentiate between hydrogen and carbon monoxide.
- The household where the alarm was set off requested that the battery was permanently removed from the property. The other 4 internally installed batteries on the project at households T-01, T-02, T-09 and T-13 were switched off and later reinstalled in outdoor cabinets.
- The battery system at household T-15 recorded little or no electricity import or battery discharge and this was likely to be due to issues with the current clamp. The battery was serviced in October 2018 and was seen to discharge although it went offline shortly after.
- The batteries for the system at household T-13 were replaced with tubular gel lead acid batteries in August 2018. The batteries had been stored onsite, stolen and recovered by the police. When these batteries were installed the insulation on some wiring in the G200 unit melted due to a damaged battery connector. Powervault has incorporated design changes to prevent problems with damaged battery connectors in future.
- The solar PV systems for the properties in Macclesfield were installed in 2011. There have been a number of PV inverter failures among the systems in recent years. During the study, PV faults occurred at 3 households with batteries (T-08, T-13 and T-16) and control household C-01. The PV system was off for over a year at household T-16. The battery system was switched on for much of this time and with no solar generation, it provided no benefit and was consuming about 35W of power.
- Most of the households that received installations had elderly residents and few had internet connections. Initially it was mainly the households in the monitored group where the battery systems were connected online. From November 2017, there was an aim to connect all the systems online to allow monitoring of system performance and battery health and comply with the warranty requirements. However, there were in some cases challenges in maintaining a good internet connection.

Methods for analysing battery performance

- The Powervault G200 battery system could output up to about 1.15 kW for short periods of time and was able to charge at up to about 0.8 kW.
- The performance of the battery system could only be monitored when it was online as there was no meter on the battery system or memory to record data when the system was offline.
- The Powervault G200 system recorded data every 30 seconds and data that was averaged every 5 minutes was provided to NEA for analysis. No data was recorded if the G200 system lost its WiFi connection.
- Verv data loggers were used to measure the charge and discharge of batteries at 3 households. These used a current clamp to measure the power every second. The higher sample rate improved the accuracy over the 5-minute aggregate data from the G200 system and values of charge and discharge calculated were about 20 to 25% lower. Other trials where Powervault and Verv equipment have been used have not identified a similar difference. In this case raw 30-second Powervault data was used for analysis.
- Grid import for the households were obtained from manual meter readings, utility bill meter readings and smart meter data.

Overview of the performance of the Powervault G200 battery systems

- There were 11 of the batteries which recorded performance for between 164 and 333 days, with periods online varying from 60.4 to 99.6%.
- The battery discharge derived from the 5-minute aggregate Powervault data ranged from 190.4 to 618.6 kWh.

Low values of battery discharge at some sites may have been influenced by low readings for household electricity import

- The battery discharge for household T-01 ranged from 1.14 to 1.17 kWh/day between June and September based on data from the G200 system. Analysis of data from a Verv logger showed discharges of 0.87 to 0.92 kWh/day for these months.
- Over the 12 days recorded in April data from the G200 system showed a discharge of 2.06 kWh/day and 1.70 kWh/day from the Verv data logger.
- These values of discharge were low for a battery system with a 4 kWh usable capacity in summer where there was good PV generation. The resident had noted he had seen no reduction in electricity bills after the battery installation.
- The battery system recorded a low grid import of 1.16 kWh/day in April and 0.71 kWh/day in September. Readings from a MID approved smart electricity meter showed average values of grid import in April of 3.57 kWh/day and September of 3.77 kWh/day.
- It is possible that the low readings of electricity import were due to a problem with readings from the current clamp for the G200 system. A longer cable run from the battery to the meter tails may have been a factor in this. Had the G200 system more accurately measured the household demand, it is likely that the system would have supplied greater power to the household.
- Similar issues seemed to occur with household T-02 and T-05 where there were lower values of battery discharge and the import power recorded by the G200 system was significantly lower than the electricity consumption measured by the utility meter.

Better performing Powervault G200 systems

- There was a battery discharge of 559 kWh measured by the G200 battery system for household T-06 between 1 Nov 2017 and 30 Sep 2018.
- The discharge with the AGM batteries ranged from 0.42 kWh/day in January 2017 to 2.38 kWh/day in June 2017 and round-trip efficiencies of 31.5% in January and 66% in June.
- The battery discharge after the tubular gel batteries were fitted ranged from 0.31 kWh/day in December 2017 to 3.63 kWh/day in May 2018. The round-trip efficiency ranged from 24.2% in December 2017 to 72.4% in July 2018.
- The battery system was able to provide nearly all the electricity consumption for household T-06 after 7pm on a sunny summer's day. The baseload power of 0.15 to 0.3 kW could be supplied by the battery overnight.
- The grid consumption in April and September 2018 based on utility meter readings was 3.29 and 4.18 kWh/day respectively compared to 3.0 kWh/day and 3.14 kWh/day calculated from the G200 data.

- Household T-06 consumed more electricity than many in the study and the values of import recorded by the battery system were closer to the actual values of import. As a result, there was higher battery discharge.
- The average annual consumption for household T-06 was 1974 kWh/year when there was only solar PV. During the 2 years of the solar PV with the Powervault G200 system, the average household consumption had reduced to 1636 kWh/year. It should be noted this calculation included a period of over 2 months with the battery system turned off.
- Household T-07 also had a battery system with higher levels of discharge. The PV generation in 2017 was however almost the lowest in the study due to shading of the PV system by trees and bushes.
- Between 1 Nov 2017 and 1 Nov 2018 there was a discharge of 656 kWh from the tubular gel batteries, which averaged out at 1.83 kWh/day once the period online was taken into account. The average round-trip efficiency was 61% and the annual grid import measured by the system was 1015 kWh.
- Higher values of discharge were typically recorded by the tubular gel batteries than the AGM batteries. While this may illustrate battery behaviour, other factors such as PV generation, household consumption and the period online may also have had an impact.
- The discharge from the tubular gel batteries ranged from 0.35 kWh/day in December 2017 to 3.03 kWh/day in May 2018.
- Between 23 Dec 2017 and 30 Aug 2018, the electricity meter showed a consumption of 712 or 2.85 kWh/day. This compared to 521.7 or 2.15 kWh/day between 1 Jan 2018 and 1 Sep 2018 as determined from the Powervault G200 data.
- It is likely that the battery discharge for household T-07 was higher than for households T-01, T-02 and T-05 at least in part because the values of grid import for the Powervault data were closer to the utility meter readings than for the other households.
- There was a Verv data logger fitted on the battery at household T-18. This showed the greatest levels of discharge out of the 3 Verv loggers installed with values of discharge between 1.91 and 2.4 kWh/day.
- The household consumption was between 2 and 2.6 times the values derived from the Powervault G200 5-minute aggregate data. This compared to between 3 and 5.3 times greater for household T-01. The smaller difference between the actual household electricity import and the value derived from the Powervault data may be a factor in the better performance of household T-18.

Factors affecting battery performance

- There must be sufficient excess solar generation in the day to charge the battery.
- For households with relatively low electricity consumption and a larger PV system, it is possible to charge the battery on most days in months outside winter. In order to maximise benefit from the system there needs to be sufficient electricity consumption over the evening and night to discharge the battery.
- If the household electricity consumption exceeds about 1.1 kW, any extra consumption will be imported from the grid. As a result, it is best not to have more than one high consuming appliance on at once.
- If the grid import measured by the battery system is significantly lower than the actual household import, the system may not supply the appropriate amount of electricity from the batteries.

Comparison with other battery systems

There were 2 of the Powervault G200 battery systems on this project which recorded good quality data over a period of a year. They had tubular gel batteries with a 4 kWh usable capacity and discharged 553 kWh and 656 kWh. This equates to savings of £85 and £105 per year using an electricity price of 16p/kWh. More accurate monitoring equipment suggested the discharge may however be about 20% lower than these values.

There were 3 other battery systems tested on another NEA trial in Thurrock[38]. The best performing Maslow battery with a 2kWh nominal capacity (1.6kWh usable) discharged 341 kWh in a year and the best performing PowerFlow Sundial battery of the same size discharged 422 kWh. A Victron charger/inverter with a Leoch AGM lead acid battery with a 1.56 kWh usable capacity had a net battery discharge of 288 kWh in the year.

4.2 Recommendations for potential future installations

The current challenge for battery storage is to reduce the cost of systems while improving the technology and quality of installations. There has been considerable learning over this project which has led to developments of the battery system technology and lessons on issues to avoid with installations.

Social landlords planning a battery storage project should allow sufficient time and resource for customer recruitment. This might take over 3 months, with communications provided by letter and email as well as community engagement events.

It is important to collect accurate details about a household to determine suitability. Full surveys are needed of properties to check there is a suitable location for the battery with adequate ventilation and separation distances from the walls. The system should be installed in a location where residents are able to check the system is working and there should be a sensible cable run from the battery to the consumer unit. An assessment should be made of the household energy consumption and patterns of use. This should assist in checking the suitability of the household and allow a suitably sized battery to be selected. If a new PV system is to be installed, it should be sized to be able to charge the battery. If the solar PV system is too small and there is little excess generation, there would be little benefit from installing a battery.

In order to know that the battery system is operating correctly and to follow warranty requirements, the battery system must have a good online connection. While selecting households, it must be checked that there is currently an internet connection and the residents would be willing to allow the battery system to be connected to this. Concerns may need to be overcome include the bandwidth requirements of the system or issues over privacy with household consumption.

Households with elderly residents are less likely to have an internet connection and some younger residents may rely on a mobile phone. Dedicated broadband connections can be set up for the battery for additional cost. However, only a single broadband account is possible on a single phone line. If only the battery system is connected to a broadband connection, it may be several weeks before someone notices that the battery system has gone offline. On this project the batteries from

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[38] Paul Rogers and Michael Hamer, SunGain Battery Bank, Thurrock, Nottingham Energy Partnership, (NEA, in press)

several households were piggybacked on a single broadband connection. The signal strength was not high and as a result there were periods where these batteries went offline. In social housing there can be regular changes in tenancy. While the current resident may be happy to have a broadband connection with other battery systems connected, a new tenant may be less happy with this arrangement. A 3G connection on the battery alone is rarely good enough to provide the required communications. TP Links can connect the battery system to a WiFi router, but a hard-wired connection is more reliable.

Although the majority of domestic battery systems now use Lithium-ion batteries, those using maintenance-free lead acid should be fitted in accordance with the manufacturer's recommendations. This is due to the small risk of hydrogen production if the batteries are overcharged. Installation recommendations vary from manufacturer to manufacturer dependent on charging rates, control system voltages and the type of lead acid battery which influence the amount of ventilation required.

There have been issues with CT clamps used to measure the electricity import from the grid and the solar export. Examples include them being fitted the wrong way around at installation, causing higher bills or measuring the household electricity import incorrectly. There is also the risk of them being tampered with by residents or refitted incorrectly after a smart meter is installed. Some companies like Moixa have moved away from use of CT clamps to small MID approved meters fitted in a consumer unit. This improved the accuracy and reliability. Powervault has incorporated class 1 metering of its own input/output; self-calibrating high accuracy CT measurement with screened cables and the ability to interface with external MID approved meters in its new Powervault 3 product.

During several of the NEA battery trials there have been installations where either the battery or the solar PV system has developed a fault and gone offline for a number of months. This represents lost income to the social landlord from lower feed-in tariff payments and increased electricity costs for the residents. Better systems should be developed by social landlords and manufacturers to avoid this in future. This should include regular analysis of performance data and the ability to rapidly respond over repairs. Another issue is shading of PV arrays by trees and bushes. These need regular pruning if they are not to be cut down entirely.

There is a greater risk that battery systems may be left not working or may underperform when installed in social housing. The residents are less likely to closely monitor the system and follow up with the installer if there are potential problems. The installer or manufacturer needs to check the battery system is performing as expected at least a month after installation. This should include checking the battery discharge, household import and PV generation and comparing values with those derived from electricity and generation meters. Manufacturers should also consider offering similar performance checks on at least a yearly basis.

Residents need to receive advice at the time of installation and be provided with documentation which advises on how the system works, how to maximise savings and the impact of different patterns of energy use. The battery system should provide a means for the customer to see the unit is working correctly and a monitoring system, with either a display on the battery, an App or an online portal. These should have an easy way to see what savings the battery has produced and more detailed information which would allow the customer to work out how to improve savings. A staff member at a social landlord should be able to advise on how to get the best use out of the battery and solar system. Alternatively, the social landlord should have a partnership with a local energy advice organisation.

Battery systems have developed since the Powervault G200 installations at Cheshire East. New models such as the Powervault 3 now normally use lithium-ion batteries. The inverters used in the latest generation of batteries allow charging and discharging at higher rates. Some systems like the Powervault 3 and Tesla Powerwall 2 can provide at least 3.6kW of power output, which can cover more of the requirements for high power appliances like kettles and cookers. Although 2 kWh was a popular size for battery systems at the start of the NEA battery trials, now battery sizes between 4 and 13.5 kWh are common on domestic installations. Most systems will now allow both solar and grid-charging of the battery. Monitoring for battery systems has improved. The Powervault 3 records data every second and has built-in memory which ensures performance data is not lost if the WiFi connection drops out for a few days.

4.3 Impact on fuel poverty

Installation of solar PV is an established way to reduce electricity bills. However, where residents are out during the day or are low electricity consumers, a significant amount of the solar generated electricity is exported to the grid. A battery system can store some of this excess generation for use later in the day by the residents.

Based on the figures from the Powervault system data, the battery at household T-07 discharged 656 kWh between 1 Nov 17 and 1 Nov 18, saving £105 in the year. The discharge of the battery at household T-05 was 553 kWh between these dates, saving about £85. There were households like T-01 where the battery had lower rates of discharge. If technical issues with these systems are resolved, it is likely higher savings could be achieved at these sites.

4.4 Economic business case for installation of measures

Measure	Capital Cost	Annual energy saving (from this study)	Indicative annual payback (years)	Assumptions
Powervault G200 with 4 kWh batteries	£ 2,894.00	£ 105.00	27.56	• Cost of £2894 + VAT includes installation • Using annual savings for household T-07 • Using discharge of 656 kWh measured by G200 system • Electricity price of 16p/kWh which remains static

Table 4.1 A simple assessment of the business case for the Powervault G200 battery system

A simple assessment of the business case for the installation of the Powervault G200 battery system is shown in table 4.1. The Powervault G200 system with AGM batteries cost £2,894 +VAT and included installation. The VAT rate was 20% for retrofitting the battery system onto a solar installation. The VAT rate is 5% when installing a battery system at the time of the solar installation[39]. A social landlord owning properties would be able to claim the VAT back on similar installations. Cheshire East Council budgeted about £1,360 per household for marketing, resident

[39] STA secures tax win for solar and batteries for householders https://www.solar-trade.org.uk/sta-secures-tax-win-for-solar-and-batteries-for-householders/ (Accessed 5 Dec 2018)

engagement and support.

Based on the battery discharge from household T-07, the annual saving determined from the G200 performance data was £105. Assuming a static electricity price of 16p/kWh, this would indicate that the household savings would have covered the capital cost of the battery system in 27.6 years. Powervault expect tubular gel batteries to have a cycle life > 1800 cycles at 70% depth of discharge (DoD) and have a lifespan of 5–7 years. It is apparent that the system will not repay the capital cost of the system within the lifespan of the batteries. There is currently no payback for battery storage systems through solar timeshifting alone. Other forms of savings or benefits are needed if battery storage is to have a robust business case in the future.

The Powervault G200 battery system is capable of grid-charging as well as from the solar PV system. If a household is on a time-of-use tariff such as Economy 7 or Green Energy UK's TIDE tariff, the battery could charge off the grid overnight to ensure the household minimises electricity consumption during peak daytime electricity charges. A combination of solar and grid-charging could improve the savings for the household and reduce the payback time.

New battery storage systems such as the Powervault 3 are incorporating grid services into the system to provide additional income for the owner and/or reduce the cost of the system. A large number of battery systems can be aggregated together to behave as a virtual power plant. Sources of income may come from:

- The local Distribution Network Operator (DNO) – supplying power to the local network at times of the highest demand in areas where the network is constrained.
- National Grid – Firm Frequency Response (FFR) – providing power to the network when the grid frequency deviates too far away from 50 Hz.

Other benefits which can be provided by battery storage include:

- Allowing more extensive installation of solar PV in an area. Where a social landlord or developer plans for multiple domestic solar PV systems to be installed in a small area, the DNO may limit the number of installations allowed to ensure there is not too much PV export onto the grid. The DNO is likely to allow a greater number of PV installations if installed with battery storage as charging of the batteries would reduce the PV export.
- Maintaining power during a grid outage. The Powervault G200 unit has a socket which can provide power during a power cut. More systems are becoming available which can power either a separate household circuit or even the whole house. This is particularly beneficial for rural households which frequently experience power cuts or rely on critical appliances.
- Monitoring the performance of the solar PV system and detecting when a fault develops to avoid potential lost income from the PV system.

Appendix 1: Glossary of Terms

AC	*Alternating Current*
AGM	*Absorbent Glass Mat*
CO	*Carbon Monoxide*
DC	*Direct Current*
DNO	*Distribution Network Operator*
DOD	*Depth of Discharge*
EPC	*Energy Performance Certificate*
HIP	*Health and Innovation Programme*
IHD	*In Home Display for smart meter*
LED	*Light Emitting Diode*
MCB	*Miniature Circuit Breaker*
MCS	*Microgeneration Certification Scheme*
MID	*Measuring Instruments Directive*
NEA	*National Energy Action – the National Fuel Poverty Charity*
PV	*Photovoltaic*
RCD	*Residual Current Device*
RECC	*Renewable Energy Consumer Code*
SAP	*Standard Assessment Procedure (for assessing home energy efficiency)*
SOC	*State of Charge*
TIF	*Technological Innovation Fund*
TP Link	*A brand of powerline network device which uses household electrical wiring to act as a wired data network*
UKPN	*UK Power Networks*
VRLA	*Valve Regulated Lead Acid Battery*

Appendix 2: Example recruitment materials

Dear Sir/Madam

Re Energy Saving Project "Powervault"

I called round today to talk to you about an energy project Peaks & Plains, Cheshire East Council and Go-lo and Energy Projects Plus are delivering which aims to save people money on their energy bills.

You may be aware that we have recently been involved with bringing a unique energy saving project to our residents. Peaks and Plains are working with partners to deliver a new innovative technology; "Powervault", which aims to save people money on their energy bills. We are excited to be able to offer you the opportunity to be involved under our commitment to providing our tenants with good quality, affordable housing.

We will be looking to install Powervault Batteries into properties with solar panels free of charge. The Powervault Battery stores unused energy from the solar panel. This means people can use the energy stored in the battery in the evening or at night for lighting and other electricity usage.

If you would like to know more about this project, please call [redacted] from the Smart Energy Team on [redacted].

We look forward to hearing from you,

Yours Sincerely

[redacted]
Smart Energy Advisor

Figure 5.1 Recruitment letter from Peaks & Plains Smart Energy Advisor for households who were not in

NEA
Action for Warm Homes
TECHNICAL INNOVATION FUND

Frequently asked questions

What is a Powervault Battery?

The Powervault Battery is a battery that stores electricity that is generated from your solar panels that isn't used in the day time. Normally the electricity that you don't use from your solar panels goes back into the National Grid; so with the Powervault Battery, you get to use all your generated electricity – even at night time – and it's free!

What happens if my Powervault Battery doesn't have enough stored electricity in the evening or at night time?

At the moment you use electricity made from your solar panels, and when nothing more can be made from them, you get your electricity from the National Grid. The same applies to a Powervault Battery, when you've used all the stored energy that has been converted in electricity, your supply then switches to the National Grid - which is charged at a unit cost rate.

What are the benefits?

Having a Powervault Battery installed into your property could potentially save you up to 20% on the electricity bill (depending on your personal usage).

How big is the Powervault Battery?

It's about the size of a small fridge.

I have storage heaters and am on Economy 7 – could I still have one?

Definitely – having a Powervault Battery can still benefit you.

Where does it go?

Ideally in your home, some people are having them put in their pantry or if that's not possible, we can look at building a small secure area for it outside.

What work is involved to get it fitted and how long will it take?

We'd be looking at a couple of hours, depending on where the unit could go. If an area outside needs to be built, then this may take longer. We would run a wire from your meter to the unit using your loft space. We would endeavour to make the installation as simple as possible.

How much will this cost me?

Absolutely nothing – you just get any benefits.

What happens if it breaks?

Powervault will maintain the units for the length of the project – 5 years.

How do I find out more?

If you are interested please call [redacted], Energy Support Officer, at Peaks and Plains on [redacted]

Figure 5.2 Frequently asked questions leaflet provided for households by Peaks & Plains Housing Trust.

Appendix 3: Health and Innovation Programme 2015 – 2018

The Health and Innovation Programme (HIP) was a £26.2 million programme to bring affordable warmth to fuel poor and vulnerable households in England, Scotland and Wales.
The programme launched in April 2015 and was designed and administered by fuel poverty charity National Energy Action as part of an agreement with Ofgem and energy companies to make redress for non-compliance of licence conditions/obligations. To date, it remains the biggest GB-wide programme implemented by a charity which puts fuel poverty alleviation at its heart.

The programme comprised 3 funds:

- **Warm and Healthy Homes Fund (WHHF):** to provide heating, insulation and energy efficiency measures for households most at risk of fuel poverty or cold-related illness through health and housing partnerships and home improvement agencies

- **Technical Innovation Fund (TIF)**: to fund and investigate the impact on fuel poverty of a range of new technologies

- **Warm Zones Fund (WZF):** to install heating and insulation and provide an income maximisation service to households in or at risk of fuel poverty, delivered cost-effectively through partnership arrangements managed by NEA's not-for-profit subsidiary Warm Zones Community Interest Company

What it involved

- **Grant programmes** to facilitate the delivery of a range of heating and insulation measures and associated support. Grant recipients were encouraged to source match and/or gap funding to increase the number of households assisted and to enhance the support provided to them
- **Free training** to equip frontline workers with the skills needed to support clients in fuel poverty
- **Outreach work and community engagement** to provide direct advice to householders on how to manage their energy use and keep warm in their homes

In addition, we undertook substantial **monitoring and evaluation** work, to assess the effectiveness and measure the performance of the technologies, and to understand the social impacts of the programme. Our **communications programme** helped partners to promote their schemes locally as well as share best practice with others. The programme generated a considerable amount of **knowledge and insight** which will be made freely available to help support future policy and delivery.

Proper investment of advanced payments allowed us to generate interest which, along with efficiency savings, was reinvested back into the programme in the form of additional grants and support which helped us further exceed our targets.

For more information see www.nea.org.uk/hip

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Action for Warm Homes