CP775
Sungain Battery Bank, Thurrock
Nottingham Energy Partnership

Technical Evaluation Report

Paul Rogers and Michael Hamer
November 2018

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, it 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 include in 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 the installation and evaluation of technologies costing up to a maximum £7,400 per household, and a smaller measures programme with up to the value of £1,000 per household. It 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 some form of intervention under this programme that has resulted in a positive impact on either their warmth and wellbeing, or on energy bill savings. 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.

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 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.

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.

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Legal limitations and disclaimer

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Executive summary

Project overview

The project was led by Nottingham Energy Partnership (NEP) and had the following aims:

- Install domestic battery storage in 35 privately owned homes with solar PV in the Unitary Authority of Thurrock.
- Assess the performance of 3 different battery technologies:
  - Maslow V3 battery manufactured with a capacity of 2kWh
  - PowerFlow Sundial SDM-2.0-500 with a capacity of 2kWh
  - Victron MultiPlus Compact C-12/800/35 with 260Ah AGM lead acid battery
- 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

Context

There are estimated to be 67,932 households in the Unitary Authority of Thurrock in 2018[1], and among these, about 5,600 were estimated to be fuel poor[2]. By the end of June 2018, there were 1,386 domestic solar PV installations in the area of the Unitary Authority.[3]

While many of these solar PV installations will have been funded by the home owners, a significant proportion are likely to have been funded by 'rent a roof' schemes. With such a scheme, the householder is able to use any electricity generated by the solar panels for free, but the company who paid for the installation claims the feed-in tariff (FiT) and export tariff. Households need to maximise their self-consumption to increase the benefit from the system. One way of doing this is to add a domestic battery to store electricity which would otherwise be exported to the grid.

The market for domestic battery storage is still in the early stages of development in the UK. Battery storage is not currently covered by the Microgeneration Certification Scheme (MCS). Although installers can easily estimate the generation and financial benefit for a solar PV system, it is difficult to estimate the benefits for battery storage. The Renewable Energy Consumer Code (RECC) has written guidance on battery storage for sellers and installers following a significant number of complaints about miss-selling of the technology[4]. The BRE National Solar Centre in collaboration with RECC has also produced guidance for those considering purchasing battery

[1] Table 406, 2014-based Household Projects for 2018, Department for Communities and Local Government, https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections (Accessed 8 August 2018)

[2] 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 August 2018)

[3] Sub-regional Feed-in Tariff Statistics, June 2018, https://www.gov.uk/government/statistical-data-sets/sub-regional-feed-in-tariffs-confirmed-on-the-cfr-statistics (Accessed 8 August 2018)

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

storage systems[5]. 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 and played a role in the significant decrease in installation costs. There has been no such financial incentive for domestic battery storage to date. Installation numbers for domestic battery storage in the UK have so far been modest, but strong growth is predicted. Apart from first adopters, the main activity to date has been focused on research trials where batteries have typically been installed in between 20 and 60 homes for free.

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 offering grid services and allowing residents to minimise their electricity costs on time of use tariffs.

The technology

Maslow V3 battery

The Maslow V3 battery, manufactured by Moixa is an AC (alternating current) coupled battery system which uses a lithium iron phosphate battery and 2 microinverters. The version used in this study had a 2kWh total capacity, which could be taken to a depth of discharge (DoD) of 80%. This meant the 2kWh battery had a usable capacity of 1.6kWh. The power output from the battery was up to 430W, but the battery would normally start to discharge when the household demand reached 250W. The battery had an expected lifespan of 10,000 charge and discharge cycles and a warranty of 10 years. The system needs to be connected to the internet for monitoring to assist with battery control. The battery has an external WI-FI antenna and a 3G transmitter, but most batteries were connected to the WI-FI routers using power-line adapters or TP Links.

PowerFlow Sundial SDM 2.0 500 battery

The PowerFlow Sundial SDM 2.0 is again an AC coupled battery system that uses lithium iron phosphate battery technology. Like the Maslow battery on the trial, the battery had a total capacity of 2.0kWh and a usable capacity of 1.6kWh. The system is modular and additional Sundial S units can be added to the system at a later date. The input power can reach a maximum of 300W in steps of 50W depending on the excess solar generation. The output power can increase in 4 steps of 125W up to a maximum of 500W. The battery has a standard 2-year product replacement warranty. The warranty can be extended to 5 years on the electronic components and 10 years on the battery performance or 4000 cycles if the owner registers the product. At the time the project started there was no monitoring system for the PowerFlow Sundial battery. However, during 2018, PowerFlow released their Energy Gateway device which can provide monitoring and control for grid charging.

[5] 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 Mar 2018)

Victron MultiPlus Compact 12/800/35 with AGM Lead Acid battery

Unlike Maslow and PowerFlow, Victron typically supplies the charger/inverter, battery and battery monitor in separate units. This offers greater flexibility for system design but means everything is not combined in a single attractive unit. A Victron MultiPlus Compact 12/800/35 charger/inverter was used along with a Victron Colour Control GX. The system can work with lead acid and lithium ion batteries. A Leoch 260Ah AGM lead acid was selected by the installer. This had a usable capacity of 1.56kWh with a depth of discharge of 50% and a typical maximum life span of 600 cycles at 50% DoD. The Victron MultiPlus Compact was able to provide a continuous output of 800W, with short periods at higher outputs of up to 1600W. Detailed monitoring was available for the systems using the VRM (Victron Remote Management) website.

The project

Nottingham Energy Partnership (NEP) targeted recruitment in the Thurrock area, but the scheme was expanded to neighbouring wards to achieve the required number of installations. Aerial maps were used to identify properties with solar PV. About 300 addresses in Thurrock and Basildon were identified as suitable. These properties were further shortlisted, focusing on lower super output areas, lower SAP ratings and off gas grid properties. Letters were sent to residents and articles were printed in local newspapers promoting a community engagement event on 26 May 2016. The aim was to recruit 35 households with solar PV for free battery installations. Households that signed up received a technical survey from a NEP staff member. Installations took place between 15 Jun 16 and 1 Aug 16.

A total of 17 Maslow V3 batteries, 14 PowerFlow Sundial SDM 2.0 and 4 Victron energy storage systems were installed. A household later requested that their Maslow battery was removed because it had not been correctly installed and never operated.

A group of monitored properties were recruited for the project evaluation carried out by NEA. This included 4 households with Maslow batteries, 5 households with PowerFlow Sundials and all 4 of the households with Victron energy storage systems. The evaluation included interviews with residents in the monitored group and technical analysis of the performance of the battery. A basic assessment was also possible of the performance of all Maslow battery systems using Moixa portal data. 6 control properties for the study with just solar PV were recruited with the assistance of Colchester Borough Homes.

Initial questionnaires were completed by the households between June and December 2016. Intermediate visits were carried out in March and April 2017 to maintain contact with the households, replace logging equipment and check for any household changes during the project. Final visits were carried out in July 2018 and logging equipment was collected. The final questionnaire assessed the benefit of the battery, any reliability issues and 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 thought that the batteries didn't need any active input to work and found the systems easy to use.
- A majority of households felt they knew how best to use the battery with 8 out of 13 agreeing or strongly agreeing. However, a minority of households felt they knew enough about how the battery worked.
- Only 5 out of 13 households in the monitored group thought there was a reduction in their energy bills after the battery was installed, while 11 thought they were saving energy in the home. Rising prices and direct debit payments are likely to have made it harder to perceive any savings.

Installation and reliability issues

- Apart from a Maslow battery that was incorrectly installed and later removed, other issues were also noted during the installation phase of the project.
- A loose connection on the MCB from installation and spikes in the supply caused a PowerFlow battery to need replacing twice.
- Installers temporarily used the way in the consumer unit for the immersion heater and left the household without water heating for a month.
- Batteries were not always fitted with the correct separation distances and this may have led to overheating and poorer performance in some cases.
- Wires to and from the battery were not routinely fitted in plastic trunking and were sometimes left loose.
- Maslow and Victron battery systems connected to portals had problems with the systems going offline. Reasons included PV systems tripping out and sending the Maslow battery into bypass mode, issues with TP Links connecting the battery to the household WI-FI and residents switching internet service provider.

Maslow V3 batteries

- Among the 16 Maslow battery installations, only 9 were online for more than 75% of the time during 2017.
- For these 9 Maslow batteries, between 1 Jul 17 and 30 Jun 18, the battery discharge was in the range 152kWh to 341kWh or 0.42kWh/day to 0.93kWh/day.
- The household with the lowest battery discharge also had the highest self-consumption of the solar PV (88%). There was limited excess PV generation available to charge the battery which led to the low battery discharge.
- The level of PV self-consumption was only 40% for the household with the highest battery discharge. Here the excess generation was able to regularly charge the battery.
- Among the monitored properties, the battery at household T-03 discharged 294kWh between 1 Jul 17 and 30 Jun 18. This was the highest for the monitored Maslow batteries. There was sufficient excess PV generation to charge the battery and consumption early in the evening to regularly fully discharge the battery.
- There was a significant decrease in the battery discharge between 2017 and 2018 for household T-02. This was most likely to be due to a hardware fault.

- Electricity savings from the batteries with better online connections ranged from £24 to £55 per year. The household which saved the least from the battery, had high savings of £375 from consuming electricity from their solar PV system. The household with greatest battery discharge consumed less of the solar generation, saving £159.

PowerFlow Sundial SDM 2.0 500 battery

- Online monitoring of the PowerFlow battery was not possible during the project as the PowerFlow Energy Gateway device was only released in Spring 2018. However, it was possible to get battery cell discharge readings from 6 of the PowerFlow systems after about 2 years of operation.
- The battery discharge over about 2 years ranged from 282kWh to 836kWh or 0.39kWh/day to 1.16kWh/day. This equated to savings of between £22.57/year and £67.47/year based on a single rate tariff of 16p/kWh.
- The worst performing of the monitored batteries had a discharge of 260kWh and 22kWh from the 2 cells in the battery system. The poor performance of the second cell might have been due to a cell coming from a substandard batch of battery cells. Other factors influencing performance may have been high daytime household consumption and limited ventilation around the battery.
- There were 4 batteries which had a discharge of between 0.70 and 0.78kWh/day which corresponded to a saving of about £40 to £46/year.
- The best performing PowerFlow battery had a discharge of 1.16kWh/day and was fitted on a 4kW solar PV system split across an east-west roof. Household consumption was low in the day, which allowed the battery to charge. There was electric water and space heating overnight, which ensured the battery regularly fully discharged.

Victron Multicompact C-12/800/35 and Leoch LAGM-260 battery

- All 4 of the Victron systems that were installed were part of the monitored group. However, a detailed assessment was only possible for a single system where good quality monitoring data was available.
- Between July 2017 and June 2018, the battery discharged 287kWh. The solar PV system provided 482kWh to charge the battery while 17kWh came from the mains supply.
- The battery round trip efficiency ranged from 45.5% in December 2017 to 61.9% in July 2017.
- The net battery discharge over 2 years was 575kWh, which equated to £46/year based on a single rate tariff at 16p/kWh.
- While the 2 best performing Victron systems regularly saw the battery discharge to nearly 50%, the state of charge for another system was only reaching a minimum of about 82% on discharge during June 2018. This was likely to be due to this AGM battery reaching the end of its life span.

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.
- Households where the residents are out during the day and have higher evening consumption are particularly suitable for the batteries trialled in this project.
- Domestic battery storage is a technology still under development and is currently at the stage of undergoing large-scale trials and purchasers include early adopters and specialist users.
- Problems can occur with installations due to the contractors having limited experience with the technology and not following installation guidance. Customers should choose an installer who has been on a manufacturer's training course and has previous installation experience. A locally based renewable energy installer is often a better option.
- Social landlords planning larger numbers of battery installations, should allow sufficient time and resources for customer recruitment. Good communications by letter, email and community engagement events over a period of months are key to build customer trust.
- A full site surveys are necessary to determine the suitability for a battery installation along with an energy audit of the household. This would examine household consumption and patterns of energy use and assess whether there would be sufficient excess solar PV generation to charge the battery.
- A battery system requires good internet connectivity and 3G cannot be relied on to provide a consistent service. Project planners need high levels of customer engagement to confirm that households have WI-FI installed, will allow the battery access to the WI-FI and they will not turn off the router.
- A hard-wired connection is best between the router and the battery as TP Links and WI-FI connections are not robust enough to maintain long term connections. Households should be provided with advice on what to do if they switch internet service provider.
- A larger project requires a project management team with clearly defined roles and responsibilities. Regular meetings are necessary, which are more frequent during critical phases. Good communication is required with project partners like installers and manufacturers. Customer recruitment and post-installation liaison can be carried out by energy champions or tenant liaison officers or by external partners such as energy advice organisations or community energy groups.
- Customers need good advice at the time of installation and documentation which explains the relationship between patterns of use, battery performance and expected savings.
- The battery system should provide a clear 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.
- Payback times for batteries can currently exceed their lifespan. However, battery technology is rapidly advancing, and new developments are likely to improve the economic case for installations. These include reduced product cost, higher battery charge rates, higher battery power outputs, greater battery capacities, grid charging and operation with time of use tariffs and offering grid balancing services.

1. Project overview

1.1 Introduction

The project was led by Nottingham Energy Partnership (NEP)[6], a charity which delivers projects that tackle fuel poverty and increase household energy efficiency. NEP was provided with a grant and recruited households and project managed the installations.

The project was called SunGain Battery Bank and the purpose was to encourage residents to become less reliant on the electricity grid by maximising the internal consumption of solar generated electricity through installation of a battery storage system. Although significant amounts of electricity can be generated by a domestic solar PV system during the day, a proportion is likely to be exported to the grid and not used in the home. Adding battery storage enables some of the electricity that would be otherwise exported to be stored for later use in the evening (figure 1.1). Installation of battery storage 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.

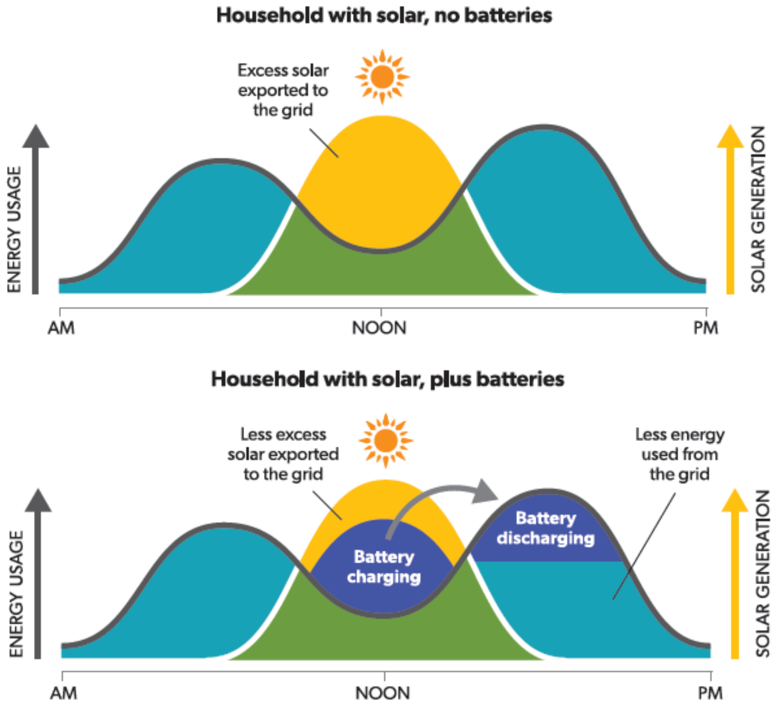

Figure 1.1 Illustration of the benefits of energy storage on a solar PV system[7]

A total of 35 batteries were installed with financing from the NEA Technical Innovation Fund. Most of the batteries were installed in the area of Thurrock Borough Council, a target area for the Technical Innovation Fund. The installer selected by NEP was T4 Sustainability Ltd of Ilkeston in Derbyshire. There was a total of 17 Maslow, 14 PowerFlow Sundial and 4 Victron batteries fitted on the project.

[6] Nottingham Energy Partnership (NEP), https://nottenergy.com/ (Accessed 8 August 2018)
[7] NSW Home Solar Battery Guide (2017), http://www.resourcesandenergy.nsw.gov.au/__data/assets/pdf_file/0005/728816/NSW-Home-Solar-Battery-Guide_WEB.pdf (Accessed 15 Mar 2018)

1.2 Aims

The project had the following aims;

- Install domestic battery storage in 35 privately owned homes with solar PV in the Unitary Authority of Thurrock.
- Assess the performance of 3 different battery technologies:
  - Maslow V3 battery with a capacity of 2kWh
  - PowerFlow Sundial SDM-2.0-500 with a capacity of 2kWh
  - Victron
- 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 are estimated to be 67,932 households in the Unitary Authority of Thurrock in 2018[8]. By the end of June 2018, there were 1,386 domestic solar PV installations in the area of the Unitary Authority. In the Parliamentary Constituency of Thurrock, the number of domestic solar PV installations was 948 compared to the neighbouring constituency of Basildon South and East Thurrock which had 780.[9]

While many of these solar PV installations will have been funded by the home owners, a significant proportion are likely to have been funded by 'rent a roof' schemes. With such a scheme, the householder is able to use any electricity generated by the solar panels for free, but the company who paid for the installation claims the feed-in tariff (FiT) and export tariff. Such schemes were only viable when the feed-in tariff rate was high and were attractive to households who could not fund a solar PV installation themselves. 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.

Fuel poverty statistics published in June 2018 using data from 2016 show that the fuel poverty rate in the Unitary Authority of Thurrock was 8.6%. For the Parliamentary constituency of Thurrock, the rate is slightly higher at 8.8%, while for Basildon and Billericay the proportion of households that were fuel poor was noticeably lower at 7.8%[10].

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

[8] Table 406, 2014-based Household Projects for 2018, Department for Communities and Local Government, https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections (Accessed 8 August 2018)

[9] Sub-regional Feed-in Tariff Statistics, June 2018, https://www.gov.uk/government/statistical-data-sets/sub-regional-feed-in-tariffs-confirmed-on-the-cfr-statistics (Accessed 8 August 2018)

[10] 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 August 2018)

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 miss-selling of the technology[11]. The BRE National Solar Centre in collaboration with RECC has also produced guidance for those considering purchasing battery storage systems[12]. 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 and played a role in the significant decrease in installation costs. There has been no such financial incentive for domestic battery storage to date. However, a number of research trials run by organisations like NEA, the Distribution Network Operators and electricity suppliers have funded projects where typically 20 to 60 batteries have been installed in homes for free[13].

Installation numbers for domestic battery storage in the UK have so far been modest, but strong growth is predicted. For example, Moixa, one of the UK's leading battery manufacturers had installed nearly 1000 systems in the UK by July 2017 but was expecting to install 50,000 batteries in the UK by 2020[14].

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 offering grid services and allowing residents to minimise their electricity costs on time of use tariffs. Moixa are already offering GridShare as a feature with their batteries, which involves trading excess power stored in the battery. Those taking part can initially earn a fixed income of £50 per year from the scheme[15].

1.4 Project timeline

The project was approved in the Autumn of 2015 and officially commenced on 1 Mar 2016. A community engagement event was held in Grays on 26 May 2016 and the 35 installations were carried out between 15 Jun 2016 and 1 Aug 2016. A monitored group of 13 households with installations was recruited and initial questionnaires were completed with these households between June and November 2016. Control households with solar PV were recruited via Colchester Borough Homes (CBH) and initial interviews with these residents were carried out in May 2017. Households were monitored up until the end of July 2018, providing up to 2 years of data. Final household visits and interviews took place in July 2018 and the report was written up in following weeks.

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

[12] 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 Mar 2018)

[13] 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 7 Mar 2018)

[14] 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 7 Mar 2018)

[15] Moixa Gridshare http://www.moixa.com/products/gridshare/ (Accessed 7 Mar 2018)

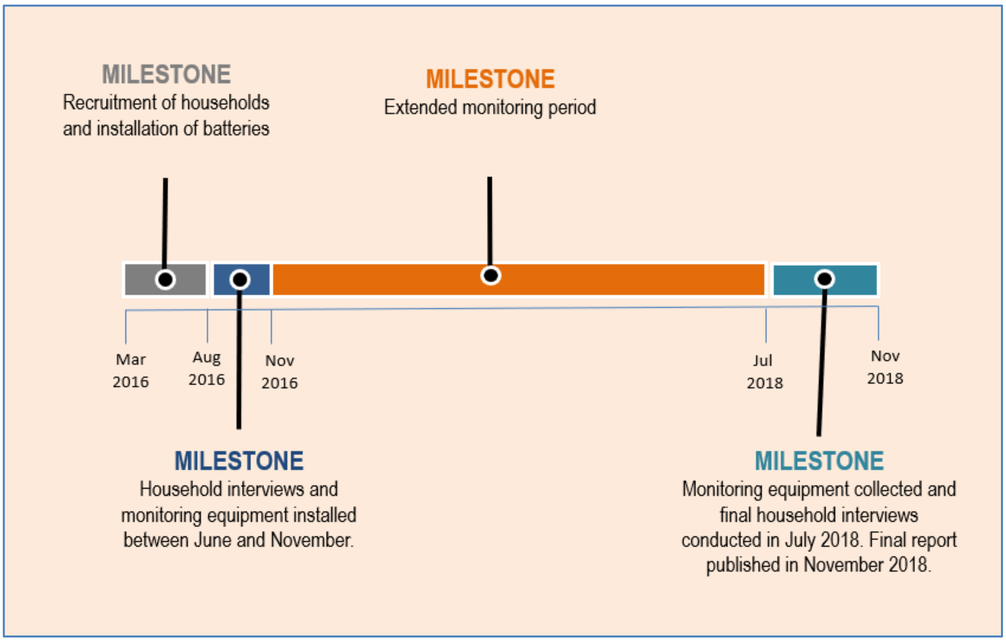

Figure 1.2 Project timeline

The project was approved in August 2015. In the first half of 2016 the partners focused on household recruitment and sourcing the PV and battery systems. Installations took place between August and November 2016 along with initial interviews for monitored households. The project was extended due to the installations taking place later in the year past the peak of solar generation. This provided potentially a year or more of data from households where there were no technical issues. Final interviews were carried out with residents in February 2018 and the project was written up over the following weeks.

1.5 Attracting beneficiaries and establishing a monitored group

Figure 1.3a/b Promotional event in Grays on 26 May 16 and pop-up banner promoting the project

- The original plan was to target households which were going to have solar PV installed through a 'rent a roof scheme' in the private sector. This scheme however, collapsed after the cuts to the feed-in tariff were announced in 2015.
- An aim had been to target at least 50% of households in socially rented properties, however research by NEP revealed that most social housing already had achieved EPC band C and a focus was on properties with an energy efficiency rating of D-G.
- Thurrock was a target area for the project, but following difficulties in recruiting households, the scheme was also promoted to neighbouring wards.
- Based on previous experience, it was thought that at least 350 letters would need to be sent out to achieve a target of recruiting 35 suitable households for installations.
- Aerial maps were used to identify households with solar PV and NEP also contacted local councillors and local authority officers to promote the scheme.
- A total of 296 addresses in Thurrock and Basildon were identified as suitable. These properties were further shortlisted to ensure they met certain criteria such as streets and properties that were within lower super output areas and had lower energy efficiency ratings. Properties that were off the gas grid were also identified.
- Letters were sent to the identified households on 3 occasions. The first letter invited householders to a community engagement event and described the scheme (see Appendix 2). Later letters reminded households of the final date and last chance to sign up to receive a free battery.
- A press release was sent out to local newspapers promoting the project (see Appendix 2). Articles were printed in Your Thurrock, the Thurrock Gazette, The Enquirer and the Clacton Gazette[16].
- The community engagement event was held at Thurrock CVS in the Beehive Resource Centre in Grays on the evening of Thursday 26th May 2016. Those taking part included the project managers, Nottingham Energy Partnership (NEP), the installer, T4 Sustainability and Moixa, the manufacturer of the Maslow battery.

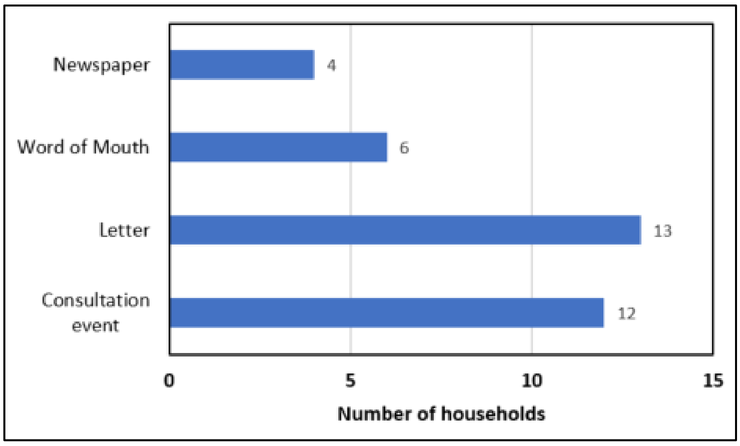

Figure 1.4 Recruitment method for households that received batteries

[16] Solar energy charity looking for Thurrock houses to pioneer 'groundbreaking' technology, Clacton Gazette, 19 May 2016, http://www.clactonandfrintongazette.co.uk/news/south_essex_news/14504726.Solar_energy_charity_looking_for_Thurrock_houses_to_pioneer__groundbreaking__technology/ (Accessed 10 August 2018)

- NEP devised a 'Refer a Friend' incentive scheme where a customer would receive a gift voucher of £25 if they recommended a friend who was also eligible for the scheme and it went through to an installation.
- Out of the total of 35 installations, 6 were the result of word of mouth, 13 due to the letters and 12 from the consultation event. The remaining 4 were recruited due to the newspaper articles.
- At the community engagement event, a register was taken, initial assessment forms were completed, and technical surveys were booked with interested households.
- A NEP staff member completed a 2-day training course with the installer to be able to competently complete the technical surveys and gather all the necessary technical data as well as photographic evidence.
- Mock ups of the battery sizes were made to help the householders to visualize the battery in the agreed location. This was also photographed for the benefit of the installer. It was important that all the required information was collected during this single visit to minimize disruption to the households and because the properties were a significant distance from NEP and the installer.
- After the survey, households were sent a summary of technical details of the battery system and an estimate of the savings. Households signed this to provide consent of the installation.
- A proportion of the households who received battery installations were recruited to be part of a monitored group for the NEA evaluation. This involved an initial and final interview, fitting of monitoring equipment, analysis of data from online battery portals and analysis of household electricity bills. Households in the monitored group were rewarded for taking part with shopping vouchers.
- A control group for the evaluation was recruited from customers of Colchester Borough Homes. These households had a solar PV installation but no battery.

1.6 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Project Change	Originally, the aim was to recruit fuel poor households for battery installations out of those who received solar PV in the 'rent a roof' scheme. This aspect of the project fell through after large cuts were announced for the feed-in tariff. An alternative approach was subsequently taken, recruiting households to receive batteries from those with pre-existing solar PV systems. The Unitary Authority of Thurrock was chosen as the area for the project as this was a target area for Technical Innovation Fund projects. Recruitment was extended to surrounding areas like Basildon in order to achieve the required number of installations
Installation errors	A household who received a Maslow battery contacted Moixa requesting for it to be removed as it had never worked. On further investigation it turned out that the installer had not correctly installed the battery and the commissioning process had been completed out of office hours when Moixa could not confirm it was working. The battery had been left not operating for a period of over a year. The residents subsequently requested British Gas to disconnect it when fitting a smart meter. The battery was later collected by another installer commissioned by NEA.
Online monitoring of PowerFlow batteries	At the time of the installations, there was no monitoring system available for the PowerFlow battery. PowerFlow were developing an Energy Gateway device which provided online monitoring and control. It was hoped that this could be provided to some of the monitored group at a later date. However, the device was not released until Spring 2018. Also, a software update was necessary for the operating system of these batteries for the Gateway to work. This required either the battery to be sent back to PowerFlow or for one of their staff or suppliers to update the software onsite. As the project was ending in a few months, it was decided not to install an Energy Gateway as part of the project.
Online monitoring of Victron battery system	The Victron battery system includes online monitoring, but this was not set up by the original installer. One of the households paid an electrician to set it up for him. NEA commissioned another installer to set up the monitoring for the remaining 3 Victron battery systems. These however did not collect data on the solar generation. The internet connection for these 3 other Victron systems was poor and led to significant gaps in the data recorded.
Online monitoring of the Maslow battery system	The Maslow battery system used the Moixa online monitoring portal. However only 9 of the 16 batteries were online for greater than 75% of 2017. Issues causing problems included PV system trips and residents switching internet service provider.

2. Social evaluation and impacts

2.1 Details of properties

Batteries installed

Type of battery	All installations	Monitored group
Maslow	16	4
PowerFlow	14	5
Victron	4	4
Total	**34**	**13**

Table 2.1 Summary of types of battery installed in the SunGain battery bank project

Overall, there were a total of 34 operating battery systems installed as part of the SunGain Battery Bank project. These comprised 16 Maslow, 14 PowerFlow and 4 Victron battery systems. A further Maslow battery was fitted; however, this unit was not correctly installed and the household requested that it was removed. Where all the battery installations are subsequently discussed, this will only include the 34 operating batteries. The monitored group of batteries comprised 4 Maslow, 5 PowerFlow and all 4 Victron battery systems.

Location of installations

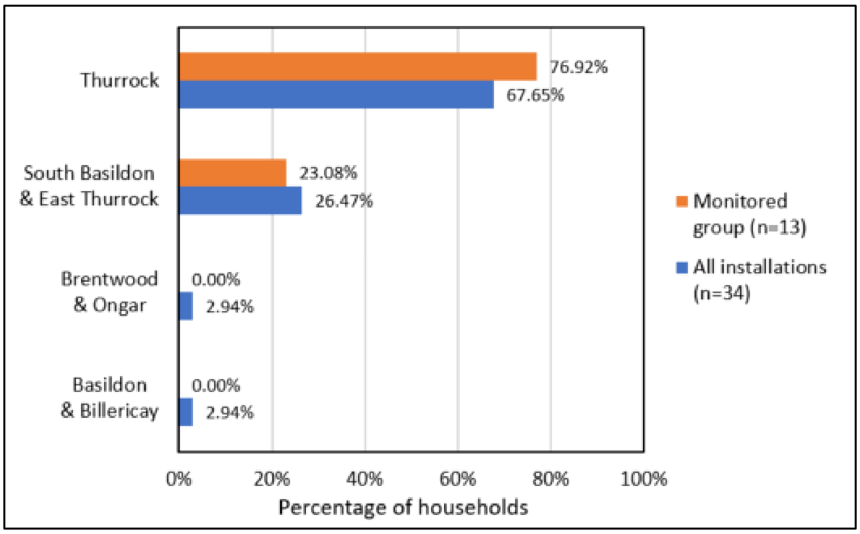

Figure 2.2 Percentage of households with a battery installation in different Parliamentary Constituencies

Figure 2.2 shows that the majority of batteries for the SunGain Battery Bank project were installed in homes in the Parliamentary Constituency of Thurrock with 23 out of the total of 34 or 67.65%. There were also 9 batteries installed in South Basildon and East Thurrock (26.47%) and 1 each in Brentwood & Ongar and Basildon & Billericay. For the monitored group there were 10 households in the Parliamentary Constituencies of Thurrock (76.92%) and 3 in Basildon & East Thurrock (23.08%). More specifically, 7 monitored households were in South Ockendon and 2 in Basildon, with the others in Chadwell St Mary, Grays, Linford and Purfleet (figure 2.3).

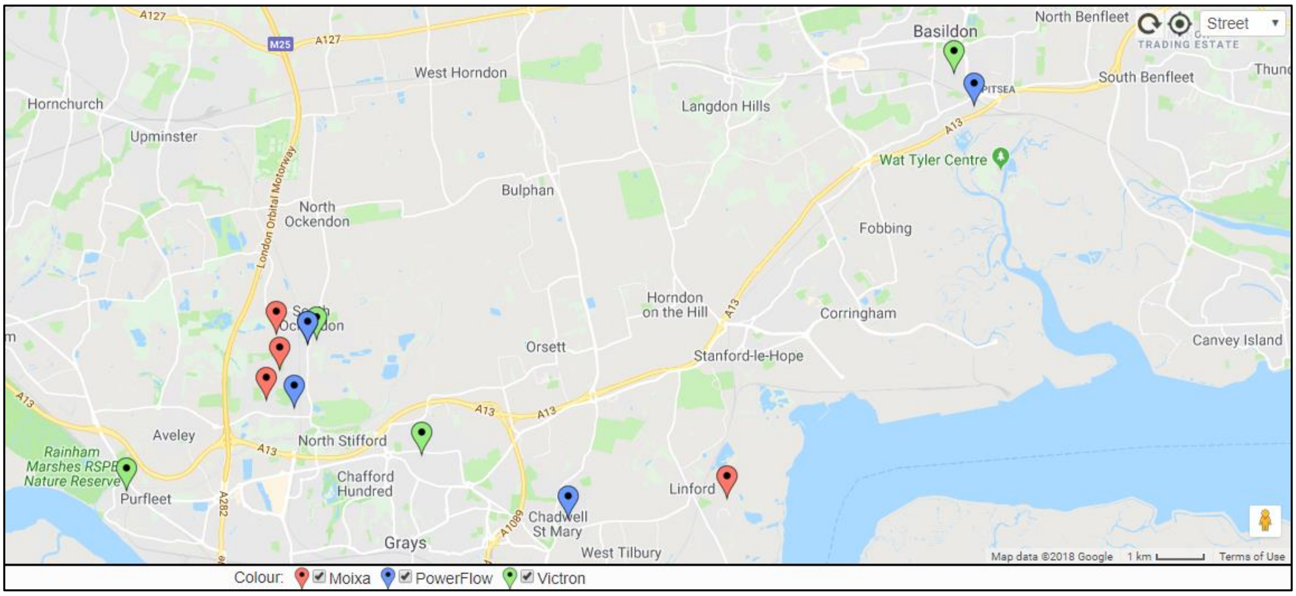

Figure 2.3 Map showing the monitored properties with battery storage installations

Figure 2.4 Map showing the control properties with just solar PV

A further 6 households were monitored as control properties (figure 2.4). These were located in and around Colchester. They were selected to be in broadly the same region as the households with battery installations and so likely to experience similar patterns of weather.

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)	PV system ownership
T-01	Mid-terrace	100	Cavity	Mains gas	59	4	Owner
T-02	Mid-terrace	95	Cavity	Mains gas	63	4	Owner
T-03	End-terrace	76	Cavity	Mains gas	75	2.4	Rent a Roof
T-04	Mid-terrace	88	Cavity	Mains gas	69	3	Rent a Roof
T-05	Mid-terrace	120	Solid	Mains gas	60	3.75	Owner
T-06	End-terrace	95	Cavity	Mains gas	59	4	Owner
T-07	End-terrace	87	Cavity	Mains gas	65	3	Rent a Roof
T-08	Bungalow	118	Solid	Mains gas	66	3.25	Owner
T-09	End-terrace	87	Cavity	Mains gas	72	2.4	Rent a Roof
T-10	Detached	164	Cavity	Mains gas	60	?	?
T-11	Mid-terrace	67	Cavity	Mains gas	61	3	Rent a Roof
T-12	Semi-detached	88	Solid	Mains gas	68	1.88	Owner
T-13	Semi-detached	116	Solid	Mains gas	62	2.4	Owner
T-14	Mid-terrace	85	Cavity	Mains gas	65	1.5 - 2.5	Owner
T-15	Mid-terrace	75	Cavity	Mains gas	62	2.5	Owner
T-16	End-terrace	55	Cavity	Mains gas	62	2	Owner
Average		94.8			64.3		

Table 2.5 Details of properties which received Maslow batteries

Technical Reference Number	Dwelling type	Floor area (m^2)	Wall type	Heating type	SAP rating	PV system size (kW)	PV system ownership
T-17	End-terrace	85	Cavity	Mains gas	62	2.82	Rent a Roof
T-18	Semi-detached	87	Cavity	Mains gas	76	3	Owner
T-19	End-terrace	74	Cavity	Electric	58	3.6	Owner
T-20	Mid-terrace	76	Cavity	Mains gas	68	1.96	Owner
T-21	Mid-terrace	95	Cavity	Mains gas	79	3	Rent a Roof
T-22	Semi-detached	171	Cavity	Mains gas	65	2.76	Owner
T-23	Detached	84	Solid	Mains gas	52	3	Owner
T-24	Semi-detached	134	Solid	Mains gas	54	2.16	Owner
T-25	End-terrace	131	Cavity	Mains gas	68	?	Rent a Roof
T-26	Mid-terrace	105	Cavity	Mains gas	63	4	Rent a Roof
T-27	Bungalow	160	Cavity	Mains gas	64	3.8	Owner
T-28	Detached	165	Solid	Mains gas	64	3.68	Owner
T-29	Mid-terrace	96	Solid	Mains gas	74	3.5	Owner
T-30	Semi-detached	148	Solid	Mains gas	68	4	Owner
Average		115.1			65.4		

Table 2.6 Details of properties which received PowerFlow batteries

Details of the properties which received Maslow and PowerFlow batteries are shown in tables 2.5 and 2.6. General characteristics about the building were taken from the most recent Energy Performance Certificate (EPC). These were lodged between October 2009 and July 2016. For some of the monitored properties, household visits showed data from the EPC to be either out of date or incorrect. In such cases, the most up to date information was used. Details of the size of the solar PV system and whether it was privately owned or financed through a ‘rent a roof’ scheme were collected during the initial assessments for the batteries. The monitored group with Maslow batteries were households T-01 to T-04, although access was available via the Moixa portal for all the Maslow batteries that were online. Households T-17 to T-21 were the monitored PowerFlow households.

Technical Reference Number	Dwelling type	Floor area (m²)	Wall type	Heating type	SAP rating	PV system size (kW)	PV system ownership
T-31	Semi-detached	118	Solid	Mains gas	64	3.2	Owner
T-32	Semi-detached	96	Cavity	Electric	59	3.78	Owner
T-33	Semi-detached	81	Cavity	Mains gas	71	3	Rent a Roof
T-34	End-terrace	98	Cavity	Mains gas	60	3.5	Owner
Average		98.3			63.5		

Table 2.7 Details of properties which received Victron energy storage systems

Information about the properties which received Victron system is shown in table 2.7. All these households were in the monitored group. Table 2.8 provides details of the properties owned by Colchester Borough Homes that only had solar PV installations and acted as controls for the study. The value for the floor area for household C-02 was not included as it was recorded as 646m^2 on the EPC for an End-terrace socially rented bungalow. It is likely that the EPC assessor made an error while lodging this EPC. Likewise, the SAP rating of 83 may not be accurate.

Figure 2.9 shows the dwelling types of the properties in the study. Among all the households receiving batteries, there were 11 (32.4%) installed in mid-terraced houses and 9 (26.5%) in end-terraced and semi-detached houses. There were also 3 in detached homes and 2 in bungalows.

Technical Reference Number	Dwelling type	Floor area (m²)	Wall type	Heating type	SAP rating	PV system size (kW)	PV system ownership
C-01	Semi-detached	74	Solid & EWI	ASHP	74	3	Rent a Roof
C-02	End-terrace		Cavity	Mains gas		3.75	Rent a Roof
C-03	Mid-terrace	82	Cavity	Mains gas	77	3	Rent a Roof
C-04	End-terrace	70	Cavity	Mains gas	70	3.5	Rent a Roof
C-05	End-terrace	86	Cavity	Mains gas	78	2.9	Rent a Roof
C-06	Mid-terrace	65	Cavity	Electric	64	2.25	Rent a Roof
Average		75.4			72.6		

Table 2.8 Details of control properties with solar PV and no battery

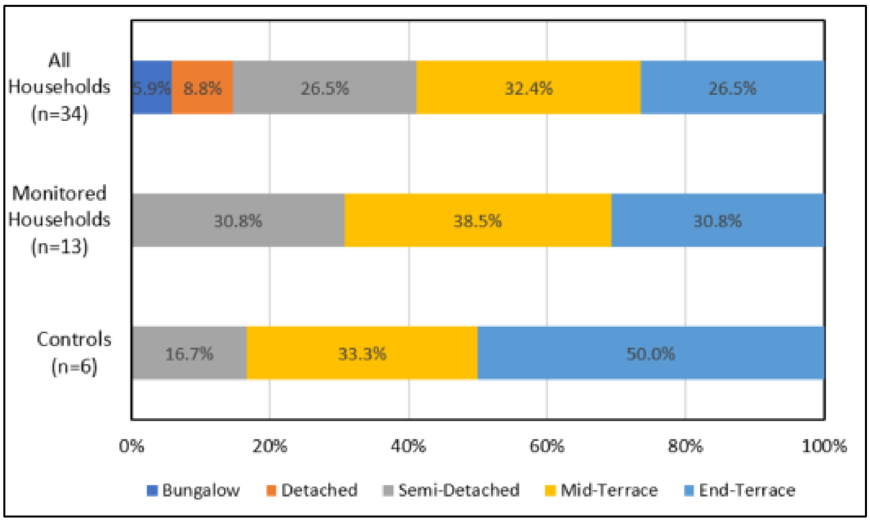

Figure 2.9 Chart illustrating the type of properties among all the households that received batteries as well as the monitored and control groups

For the monitored households, again the highest proportion were installed in mid-terraced houses (5 houses or 38.5% of the total). The other households were split between end-terraced properties and semi-detached, with 4 households each. Among the 6 control properties, 3 were end-terraced, 2 mid-terraced and 1 semi-detached.

The floor area of the properties is compared in figure 2.10. Among all the households which received installations, a total of 21 homes or 61.8% had floor areas between 50 and 99m^2. A further 9 homes (26.5%) were between 100 and 150m^2, while 4 of the installations were in properties larger than 150m^2. Among the 13 monitored properties, the majority (11 homes or 84.6%) were between 50 and 99m^2. The remaining 2 properties had a floor area between 100 and 150m^2. All the control properties were under 100m^2.

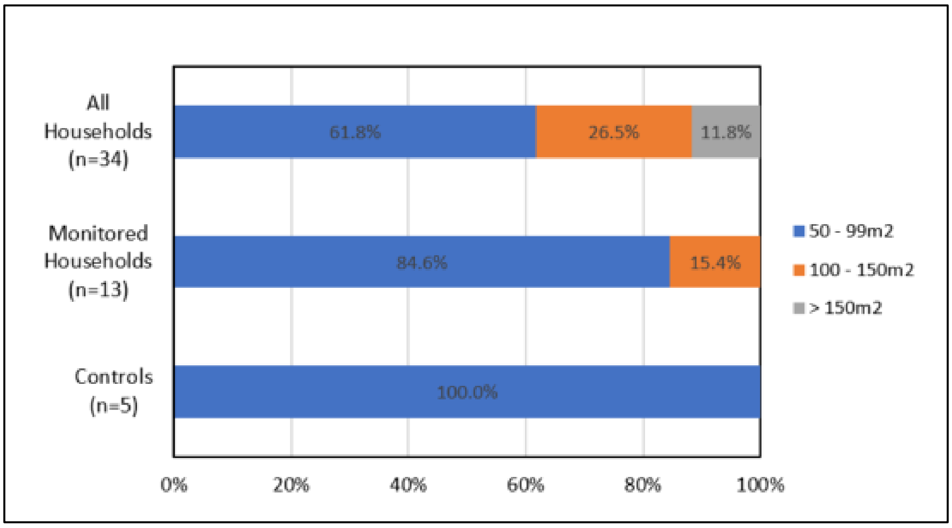

Figure 2.10 Chart illustrating the foor area of households

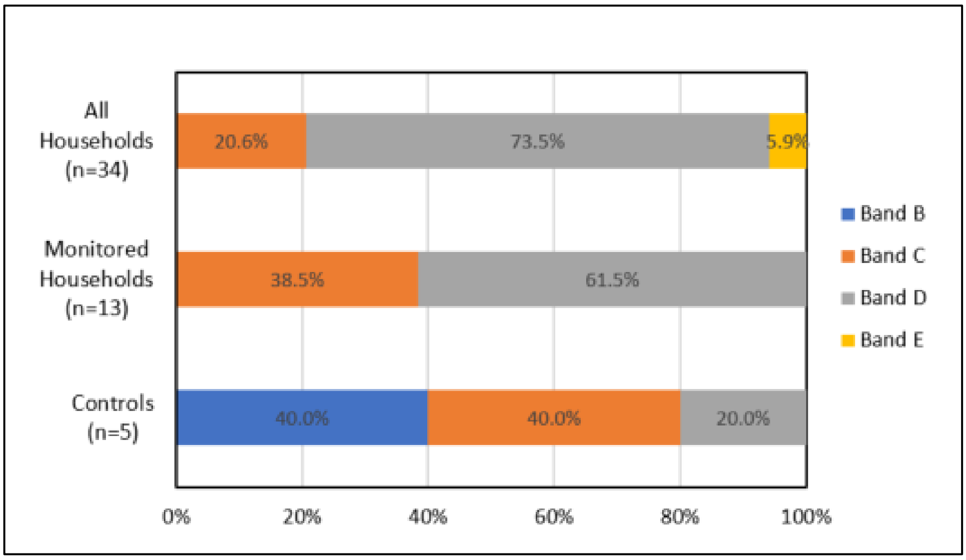

Figure 2.11 Chart illustrating the Energy Efficiency Rating Band or SAP Band of households

Figure 2.11 shows the Energy Efficiency Rating band for the properties in the study. These were obtained from the latest EPCs for each property. The majority of properties which had batteries installed were in Band D - 25 households or 73.5% of the total. Among the other properties, 7 (20.6%) were in Band C and 2 homes were in Band E. For the monitored properties, 8 were in Band D and the remaining 5 properties (38.5%) were Band C properties. The control properties included 2 in Band B, 2 in Band C and 1 in Band D.

Some of the household solar PV installations were funded by 'rent a roof' schemes. Out of the 34 households that received battery installations, 10 (29.4%) had 'rent a roof' solar arrays (Figure 2.12). Among the monitored group of 13 households, 5 of these (38.5%) had 'rent a roof' PV systems. Among the control properties that were owned by Colchester Borough Homes (CBH), all the PV arrays were funded by 'rent a roof' schemes.

Figures 2.13 a shows household where a PowerFlow battery was installed. The solar array had 8 solar panels fitted on each roof face. For the other example in figure 2.13 b where a Maslow battery was fitted, the solar PV array had 10 panels which faced south.

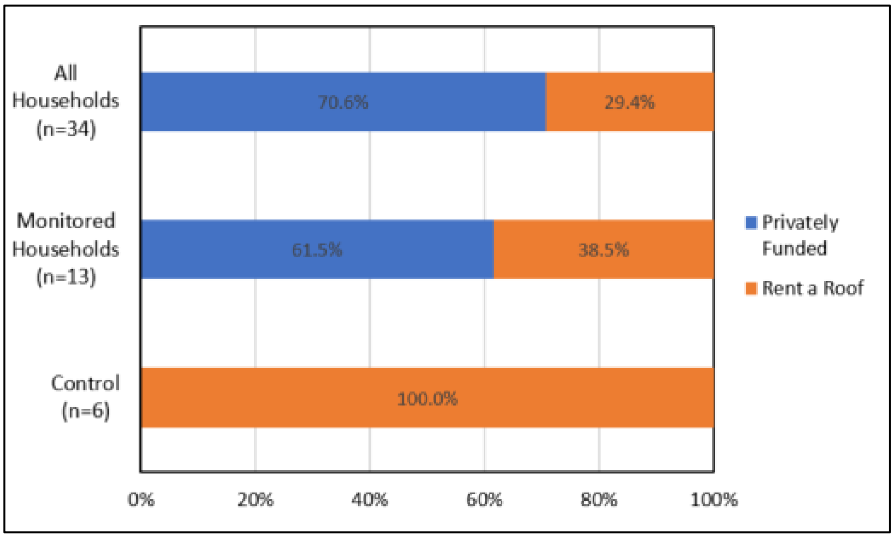

Figure 2.12 Chart illustrating the ownership of solar PV systems in the project

Figure 2.13 a/b Examples of households which received battery installations

Details of solar PV and battery installations

Technical Reference Number	Install Date	Battery system	Storage capacity (kWh)	PV System size (kW)	Inverter	Roof type	Predicted generation on MCS Certificate	Other installations
T-01	19-Jul-16	Maslow	2	4	PowerOne PVI-3.6-TL-OUTD	East / West		
T-02	14-Jul-16	Maslow	2	4	ABB PVI-3.6-TL-OUTD	East / West	3300 kWh	Solar iBoost
T-03	11-Jul-16	Maslow	2	2.45	Samil Power Solar River 2300TL	165° South	2176 kWh	
T-04	28-Jun-16	Maslow	2	3	-	South		
T-17	26-Jul-16	PowerFlow	2	2.82	SMA Sunny Boy 2500HF-30	170° South	2396 kWh	
T-18	12-Jul-16	PowerFlow	2	2.88	SMA Sunny Boy 2500	100° East	2401 kWh	Solar Thermodynamics
T-19	19-Jul-16	PowerFlow	2	4	ABB PVI-3.6-TL-OUTD	SE / NW	2787 kWh	
T-20	29-Jun-16	PowerFlow	2	1.96	SMA Sunny Boy 1700	155° South East	2068 kWh	Energy Recovery System
T-21	20-Jul-16	PowerFlow	2	3	PowerOne PVI-3.0-TL-OUTD	160° South	2682 kWh	
T-31	01-Aug-16	Victron	3.12	3.2	SMA Sunny Boy	West	2733 kWh	
T-32	05-Jul-16	Victron	3.12	3.78	2 x Diehl AKO 2100S	North / South		Immersun
T-33	28-Jun-16	Victron	3.12	3		170° South		
T-34	12-Jul-16	Victron	3.12	3.5	14 x Enecsys 240-60MP micro	South	3307 kWh	

Table 2.14 Details of the 13 battery-solar systems which made up the monitored group

Details of the monitored group of 13 battery-solar systems are shown in table 2.14. All the properties had pre-existing solar installations and these batteries were fitted between 28 June 16 and 1 Aug 16. There were 4 Maslow V3 batteries, 5 PowerFlow Sundial SDM 2.0-500 and 4 Victron battery systems. The Maslow and PowerFlow batteries used 2kWh Lithium Iron Phosphate batteries with a usable capacity of 1.6kWh. The Victron battery system comprised several components including a separate Deep Cycle AGM Lead-acid battery. The battery used was a Leoch LAGM 12V 260Ah battery, which had a total capacity of 3.12kWh. Although lithium-ion batteries like those used for the Maslow and PowerFlow battery units can regularly be taken to 80% depth of discharge, lead-acid batteries should only be taken to 50% depth of discharge. Therefore, the usable capacity of the battery for the Victron system was 1.56kWh, which was comparable to that for the Maslow and PowerFlow systems.

The PV system sizes ranged from 2 to 4 kW in size. Some of the larger systems such as T-01 and T-02 had roof aspects which were facing east and west and 8 x 250W panels were fitted on each roof. While such an installation does not generate as much over the year as a 4kW system facing south, there is greater generation from the system in the morning and the evening, which can improve self-consumption. Household T-32 also had a split array, but in this case 8 of the panels faced south and 8 faced north. It is possible to estimate the annual generation from each roof using the MCS irradiance dataset for London (Zone 1 for the UK)[17]. Assuming no shading and a 25° inclined roof, the MCS method suggests an annual generation of 1928kWh from the south facing roof and 1240kWh from the north facing roof. The installers fitted separate inverters for each of the arrays. Household T-34 had 240W Enecsys microinverters on each solar panel, which enabled each panel to operate separately. All the other systems had string inverters. For these, when a panel was affected by shading, all the other panels in the same string would also see a decrease in generation.

Several of the households had additional equipment installed which could use solar power to generate hot water. The Magic Thermodynamic Box at household T-18 was a separate solar

[17] Guide to the Installation of Photovoltaic Systems and Irradiance Datasets, https://www.microgenerationcertification.org/mcs-standards/installer-standards/solar-pv/ (Accessed 13 August 2018)

thermodynamics hot water heating system.[18] The Energy Recovery System at household T-20 was an advanced solar immersion heating device developed by PowerFlow[19]. The system uses any excess solar generation after electricity has been diverted to the PowerFlow battery. The Immersun and Solar iBoost are other solar immersion devices which use excess generation which would otherwise be diverted to grid[20] [21].

Details of monitored households

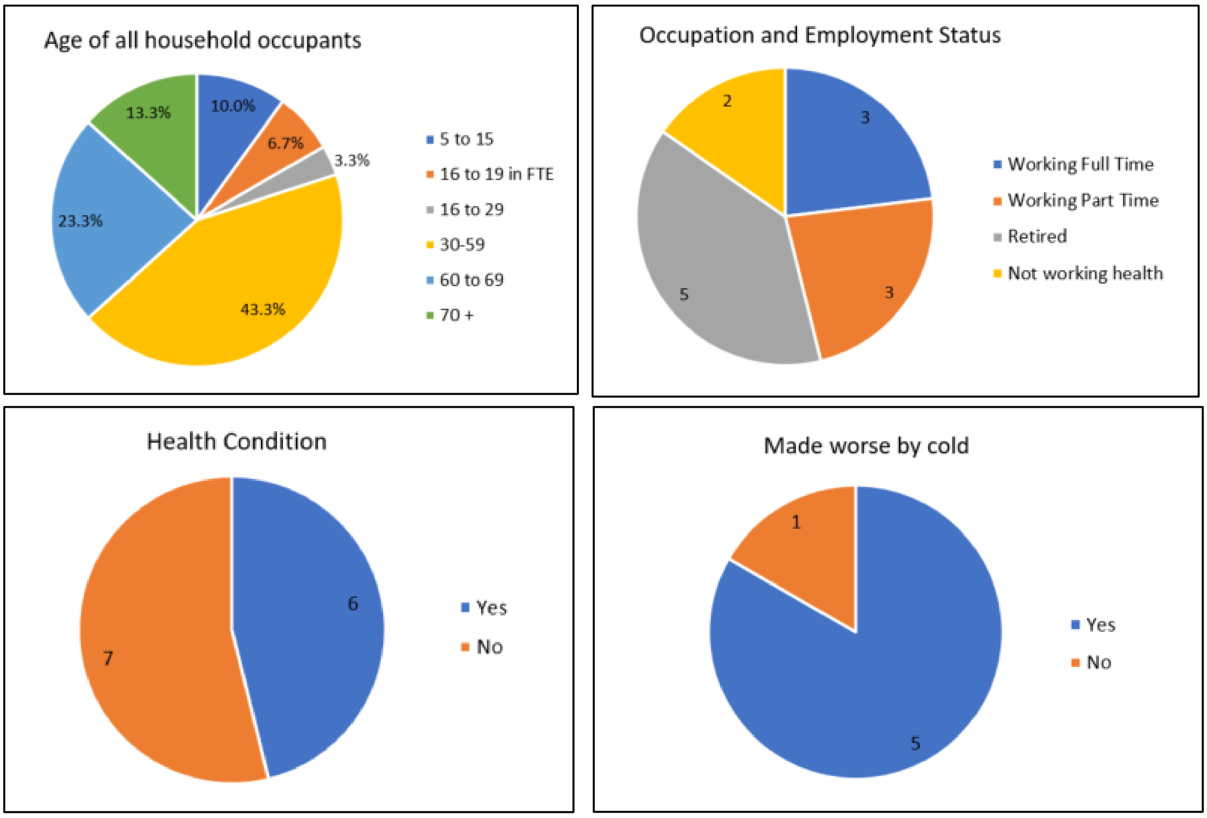

Figure 2.15 (a) Household age (b) Occupation (c) Health conditions (d) If the health condition is made worse by cold

Interviews were carried out with the 13 monitored households. Analysis of the age of all the occupants of these households showed that 43.3% of the occupants of these properties were in the age range 30 to 59 years. Figure 2.15(a) also shows that the next most common age bracket was residents over 60-69 years. In total over a third of residents (36.6%) in these properties were over 60 years. There was only a small number of children in the households with 10% of residents between 5 and 15 years.

The occupational status of the householder interviewed is shown in figure 2.15 (b). 7 of the householders were likely spend significant amounts of time at home, being retired or not working due to a health condition. 6 of the householders were working full or part-time. There were 6 of the

[18] Magic Box International https://www.magicboxinternational.com/ (Accessed 14 August 2018)

[19] PowerFlow's Energy Recovery System – ERS Advanced Solar Immersion Heating https://www.powerflowenergy.com/solar-water-heating/ (Accessed 14 August 2018)

[20] Immersun, https://www.immersun.co.uk/ (Accessed 14 August 2018)

[21] Marlex Renewable Power – About the Solar iBoost+ https://www.marlec.co.uk/product/solar-iboost/?v=79cba1185463 (Accessed 14 August 2018)

13 monitored households which had a member with a health condition. Out of these, all but 1 conditions were made worse by cold living conditions.

2.2 Affordability of energy bills

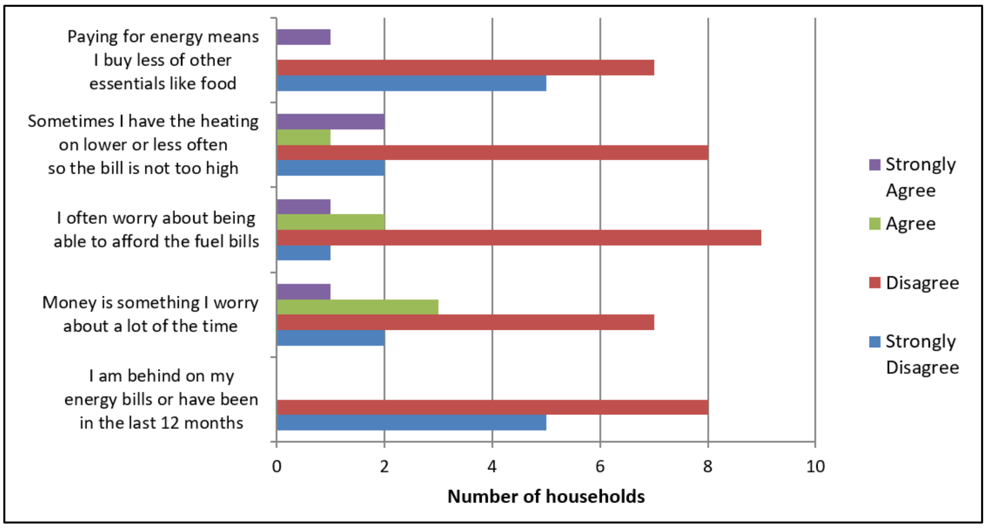

Figure 2.16 Chart illustrating the affordability of energy bills for the households interviewed

The householders interviewed were asked whether they agreed or disagreed with a series of statements. 12 households disagreed or strongly disagreed that paying for energy meant they sometimes could not afford to buy or buy less of other essentials like food (figure 2.16). Only a single householder strongly agreed with the statement and he had a medical condition. There were also 3 households who strongly agreed or agreed that they had the heating on lower or less often so that the energy bill was not too high.

There were also 3 households who worried about being able to afford their energy bills. In contrast, 9 households disagreed that they worried about being able to afford their energy bills and 1 household strongly disagreed. Slightly more households generally worried about money, with 1 household strongly agreeing that they worried about money a lot of the time and 3 households agreeing. All the households disagreed or strongly disagreed that they had been behind on paying their energy bills in the last 12 months.

Generally, the money concerns were lower among the households interviewed in this study than for a comparable study, 24/7 Solar where 40 batteries were fitted in the London Boroughs of Camden, Islington and Waltham Forest[22]. All the 10 households who were interviewed lived in socially rented homes and 2 of these noted they had been behind on their energy bills in the last 12 months.

The householders were also asked about changes since the start of the project. Figure 2.17 shows that 11 of the 13 households agreed or strongly agreed that they had reduced un-needed energy use in the home since the start of the project. All 13 households agreed or strongly agreed that they understood more about how they could save energy. Similarly, 9 households agreed that they had tried to save money on bills more and 4 households strongly agreed.

[22] Paul Rogers and Michael Hamer '24/7 Solar – London Borough of Camden' (in press)

While 7 households agreed or strongly agreed that they felt more in control of their energy bills, there were 6 households who disagreed. The 2 households who strongly agreed that they felt more in control of their energy bills both regularly monitored their energy consumption. When asked if households had seen savings on their energy payments, again, 7 agreed or strongly agreed and 6 disagreed. Out of the 2 households that strongly agreed they had seen savings, only 1 of these also strongly agreed that they felt more in control of their energy bills. However, both of these households again took meter readings at least once a week. Several households commented on how energy prices had been rising and this affected their response.

Comparing the responses with those for the 24/7 Solar study shows that more of the households in this study felt they had reduced un-needed energy use, understood more about how they could save energy and tried to save energy or money on bills more. The number that had noted savings on energy payments however were comparable in the 2 studies – 7 out of 13 here compared to 5 out of 8 in the 24/7 Solar project.

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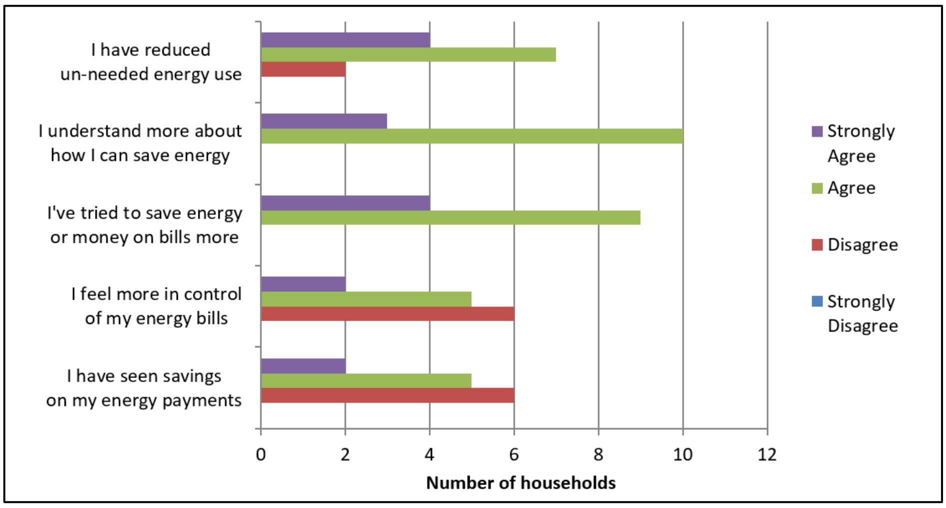

Figure 2.17 Chart illustrating changes since the start of the project

2.3 Resident acceptance and satisfaction

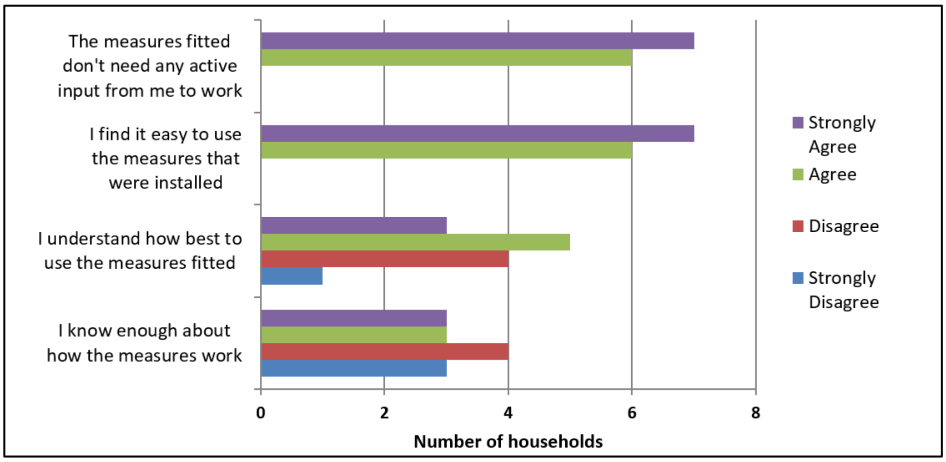

Figure 2.18 Chart illustrating ease of use of the system and knowledge of how it works

Figure 2.18 shows that all the residents felt that the battery-solar system did not require active input to work. 7 of the residents strongly agreed that the measures were easy to use and a further 6 agreed. The same numbers also found the battery installation easy to use. These positive responses on ease of use and lack of a requirement for active input were also reflected in the 24/7 Solar report.

While 8 households agreed or strongly agreed that they understood how best to use the battery, there were 4 households who disagreed and a further household that strongly disagreed with this. The picture was even more mixed when asked whether they knew enough about how the measures worked. There were 3 households that strongly agreed and 3 that agreed they knew enough about how to use the battery. However, 4 households disagreed and strongly disagreed. While the batteries required little active input, over half the households felt they did not properly understand how the battery was working. This lack of understanding of the operation of the battery system was also found in the 24/7 study.

It can be seen from figure 2.19 that all the households in the monitored battery group felt that the installers were careful and respectful in their homes, with 9 of the households strongly agreeing with the statement. Likewise, they all felt the battery system did not take up too much space and 8 households agreed with the statement.

When asked if the battery system was fitted in a suitable location, 6 households strongly agreed and 6 agreed. A single resident strongly disagreed, household T-33. In this case the resident was unhappy that the installers fitted the components of the Victron battery system lower down on the garage wall than was agreed (figure 2.19). The householder later had problems parking his car so he could get out of the vehicle due to his mobility issues. His car was scratched 3 times as a result. He noted that the installers were under a great deal of time pressure. NEA was able to get another installer to move these components to suitable position when setting up monitoring for the battery system.

While 6 households strongly agreed that the installation had no lose wires and a further 3 agreed, there were 2 households who disagreed and household T-33 strongly disagreed with the statement. Although the Victron system has multiple components, many installers would fit plastic trunking to protect and organise cables running between components. It can be seen in figure 2.20 that trunking was not used on the installation at household T-33. None was observed either on any of the monitored battery systems. It should be remembered that the installations are expected to last for 20 years.

Household T-19 noted that the installers used the way for the immersion heating on the fuse board for the battery on a temporary basis. This was not changed back later and the residents had to pay another electrician to resolve the issue. The household had no hot water for a month as a result. They commented that the installers were in a rush and didn't want to take the time to resolve the issue.

The installation of the PowerFlow battery at household T-20 was left with a loose connection on the MCB (miniature circuit breaker). This led to problems which the manufacturer had to resolve with the battery system under their guarantee.

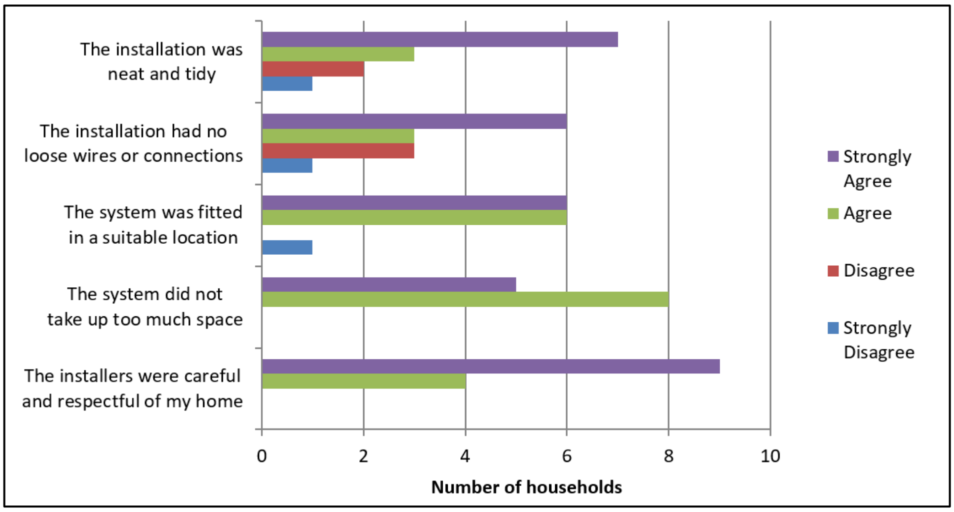

Figure 2.19 Satisfaction with the installation process

Figure 2.20 Victron system fitted low on the wall in a garage with lead acid battery in plastic box

Battery manufacturers provide minimum clearance distances between the battery and surrounding walls or ceilings. The purpose of this is to ensure there is sufficient and suitable space for heat dissipation from the battery. For the PowerFlow Sundial, the recommended clearance distance as shown in figure 2.21 is 200mm from the top, 150mm below and 100mm on either side. If the clearance distances are insufficient, the battery unit is liable to over-heat and the battery management system will turn off a battery module due to getting too hot. As a result, the discharge from the battery system would be lower.

Figure 2.22 shows a PowerFlow battery installation from this project. The separation from the ceiling and the wall on the right-hand side is below the recommended distances.

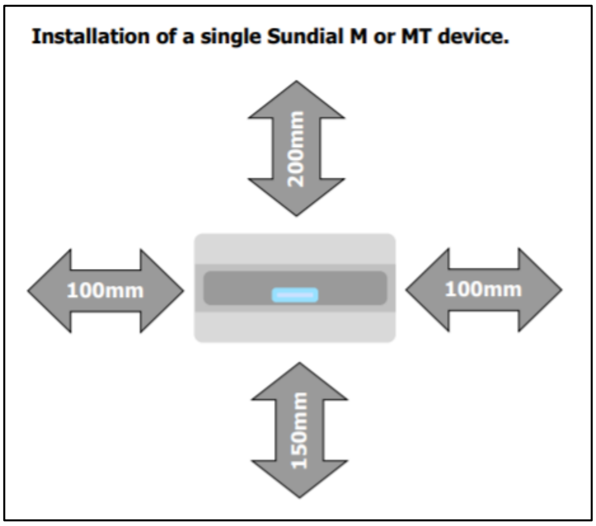

Figure 2.21 Recommended PowerFlow battery clearance[23]

Figure 2.22 PowerFlow battery installation

As well as the problems noted with the monitored battery group, there was also a Maslow battery which was installed incorrectly at a 35th property for the overall project. The problems were due to wires that were not connected on the battery. Normally during the commissioning process of a Maslow battery, the installer would run through a procedure with the battery online and the manufacturer, Moixa, would check the system was operating correctly. In this case the installers were unable to commission the battery properly as they attempted this out of office hours. As a result, they left the residents with a battery that never worked. The residents asked for the battery to be removed on several occasions and in the end got a British Gas technician to disconnect it when smart meters were fitted.

[23] PowerFlow Sundial Installation and User Manual https://www.powerflowenergy.com/files/powerflow/Sundial/PF-SD-USEINS-V2.2%20SUNDIAL%202.0kWh.pdf (Accessed 15 August 2018)

NEP Customer satisfaction survey

A customer satisfaction survey was provided to all the households on the project and these were usually posted back to Nottingham Energy Partnership (NEP) within about a week of the installation. Out of the total number of 34 completed installations, NEP was able to provide 20 surveys from the households.

The survey consisted of 6 questions relating to the quality of the work by NEP and 5 questions relating to the installer. Each of these questions were rated between 1 and 10, which allowed average responses to be obtained across all the 20 surveys as shown in table 2.23.

Out of the 20 households who completed the survey, 8 of these were in the NEA monitored group. Households T-02, T-20, T-21 and T-31 gave a very positive rating of 10 to all the questions in the NEP survey. It should be noted a problem with a loose connection to the MCB and breakdown of the PowerFlow battery for T-20 became apparent after the survey was completed.

Others in the monitored group such as households T-33 & T-34 gave a score of 9 or 10 to all questions. Household T-33 later gave more negative responses in the questionnaire carried out by NEA. Although the resident said he asked the installers to fit the system higher up on the garage wall, the system location became more of an issue later, after he changed his car and there were problems parking the car without scratching it.

The most negative customer satisfaction form came from household T-19, who had the issue where the installers used the way for the immersion heater in the consumer unit on a temporary basis. Questions on how the SunGain Battery Bank project was explained by NEP and the battery system was explained by the installer received a score of 4. They rated the quality of the workmanship at 7 and helpfulness and courteousness of the contractor at 6.

The average responses for all questions were between 9 and 10 for all but 3 questions. This is an excellent response rate and indicates the households appreciated the work of NEP and the installer. The high satisfaction ratings may also be influenced by the households being pleased to have received the battery for free as part of the project.

There was also space on the survey for comments and how NEP and the contractor could improve their services. Out of the 20 households who completed the survey, 12 included comments.
On a question about how the services of NEP had affected their quality of life, comments included:

- Has been greatly improved
- By reducing my electricity bill
- Pleased to get reduced electricity from the grid and power if a power cut (Victron system)

A further 3 households said it was too early to tell the impact. Comments on how the service could have been improved included a household noting that the storage box in which the Victron battery was fitted was damaged. Another household suggested that the fitter needed to do the survey and ensure they followed the manufacturer’s installation instructions. This comment may have been due to the PowerFlow battery not having the correct separation distances from the walls.

While 1 household noted they still didn't know how to check the performance of their Maslow battery online using their iPad, another had managed to access the Moixa portal, but commented that the website was slow.

Questions on the performance of NEP	Average	Standard Deviation	Questions on performance of the installer	Average	Standard Deviation
Explanation of SunGain battery bank scheme	8.95	1.51	Helpfulness and courteousness of contractor	9.15	1.27
Thoroughness of the survey of your property	9.05	1.32	Friendliness of Contractor	9.3	1.13
The Level of Helpfulness & Advice	8.8	1.47	Tidiness & Consideration of contractor	9.1	1.12
The Helpfulness of NEP's Technical Surveyor	9.2	0.89	Quality of work of contractor	8.9	1.21
The Helpfulness of office staff at NEP	9.1	1.07	Explanation of battery storage system	9.05	1.43
General communication received from NEP	9.15	1.27			

Table 2.23 Average response to the customer satisfaction survey by NEP with questions scored between 1 & 10

A householder noted that the information provided suggested the system would save them about £36 per year. Also, that replacement batteries currently cost about £900 which have a lifespan of about 10 years. Based on these figures the savings would be £360 over 10 years and less than the current cost of the batteries. He was concerned about this and installations like these do not currently make sense based only on the savings from solar time shifting. Battery storage is however a rapidly evolving technology. Prices for batteries are falling and additional savings and sources of income will be available for domestic batteries in the future.

2.4 Ease of use and reliability

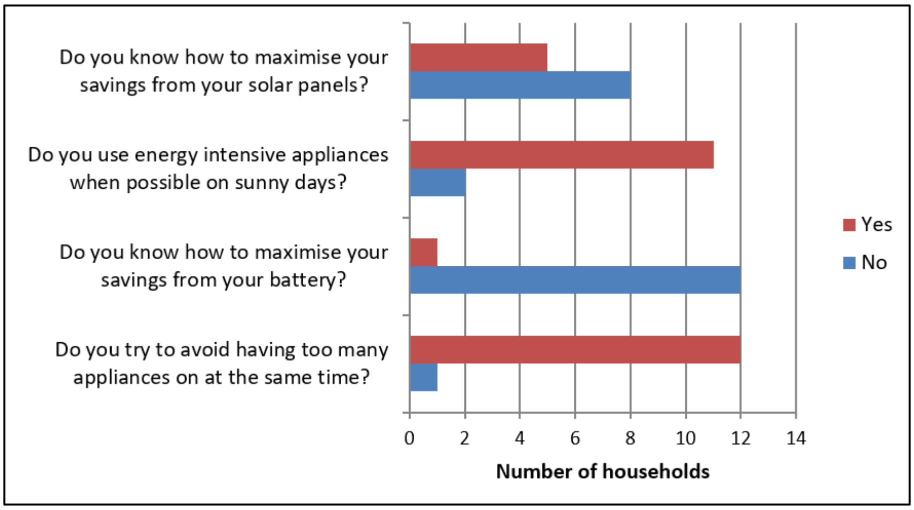

Figure 2.24 How well the households knew how to use the battery and solar systems

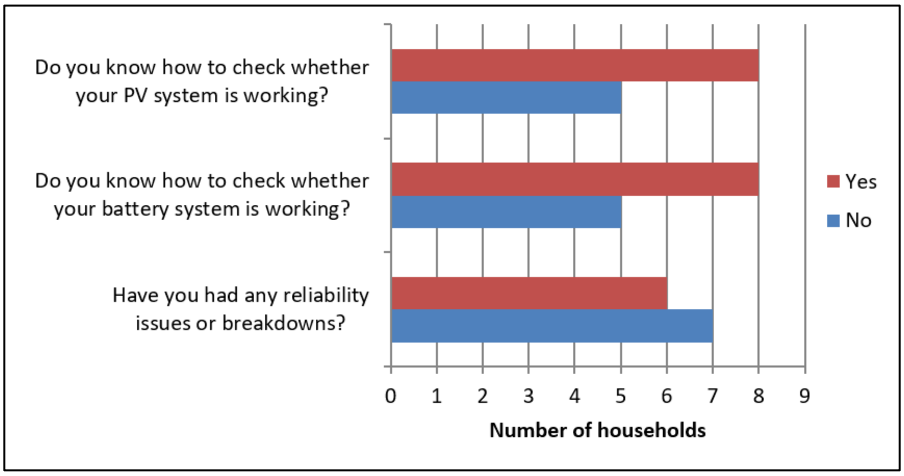

Figure 2.25 Reliability of the battery - solar systems

Questions shown in figure 2.24 investigated whether the residents in the NEA monitored group were getting the most benefit out of the battery solar system. Only 5 of the 13 households felt they knew how to maximise their savings from their solar panels. However, 11 households said they used energy intensive appliances like washing machines on sunny days whenever possible. Only a single household responded by saying they knew how to maximise savings from their battery storage system. However, 12 of the households said they tried to avoid having too many appliances on at the same time. This indicates that for the monitored group, although residents were not confident of how to maximise savings, their pattern of appliance use increased their savings. Figure 2.25 shows that 8 of the 13 households knew how to check whether their PV system was working, and the same number knew how to check whether their battery system was working. There were reliability issues or breakdowns with 6 of the 13 installations. These are summarized in table 2.26.

Household	Battery system	Reliability and breakdown issues
T-01	Maslow	System stopped working and problem resolved by an engineer with 2 weeks
T-02	Maslow	Power cuts caused the battery to go into bypass mode on 2 occasions. Once this was resolved by a visit from an engineer and once via a phone call . There was a reduction in the battery discharge in the summer of 2018 and the system was offline from July into the autumn.
T-03	Maslow	Moixa detected the Maslow battery was offline and emailed the household. The cause was the due to the household switching WiFi router and the battery losing connection and later going into bypass mode.
T-04	Maslow	The system has been down on 3 occasions, the last time being for several months. The most recent problem was likely to be due to the residents switching WiFi router and the battery later going into bypass mode. Other issues may have been caused by household rewiring and the PV system tripping.
T-20	PowerFlow	Initial issues with loose connection on MCB during installation. It was necessary to uprate the fuse in the battery and MCB over spikes in the supply. Finally resolved after 3rd unit installed.
T-32	Victron	AC isolator was accidently turned off and there have been issues with loss of connection for the monitoring system

Table 2.26 Summary of breakdown issues with the battery - solar systems

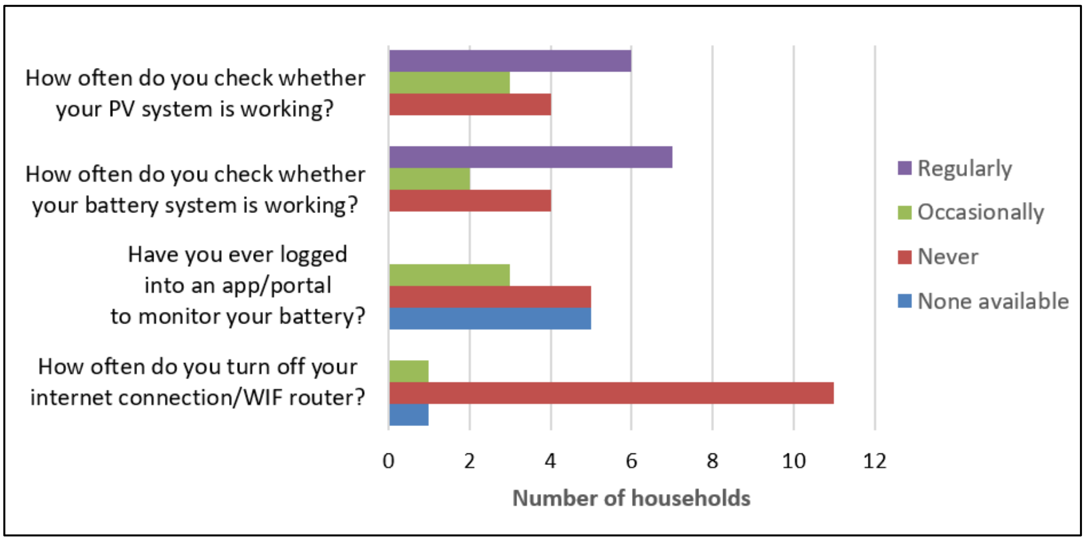

Figure 2.27 Frequency the resident checks the solar and battery system

There were 4 households in the monitored group who never checked whether their PV system was working (Figure 2.27). Out of these, 3 households had ‘rent a roof’ solar PV systems and the remaining resident interviewed was an elderly lady with less technical knowledge. 6 households regularly checked the operation of their PV system and 3 occasionally checked it.

When asked how often they checked whether their battery system was working, again 4 of the monitored group said ‘never’. In this case only 1 of 4 households had a ‘rent a roof’ solar installation. 7 of the households regularly checked the battery and were often aware of operation due to the display or the noise of a fan operating.

Portals for monitoring the battery performance were only used occasionally by 3 households:

- T-02, apparently the only household with a Maslow battery in the monitored group who used the Moixa portal.
- T-31, who regularly monitored his electricity and gas consumption and used the Victron monitoring portal after NEA arranged for an electrician to set it up in December 2017
- T-34, who paid an electrician to set up the monitoring portal for his Victron battery system shortly after the initial battery installation

The 5 households with PowerFlow batteries recorded that no portal was available. This was because a monitoring portal was only available for the PowerFlow Sundial battery from Spring 2018. The release of their Energy Gateway device[24] was too late to be fitted on batteries in the project. It would also have required an update to the battery operating system which required either for the battery to be returned to the manufacturer or for a member of their staff to carry out a site visit.

Out of the 13 households in the monitored group, 11 never turned off their WI-FI router, 1 only turned it off when on holiday and 1 household did not have a broadband connection.

[24] Sundial Energy Gateway https://www.powerflowenergy.com/battery-storage/energy-gateway/ (Accessed 16 August 2018)

Figure 2.28 explores the understanding of their PV systems for the control households living in Colchester Borough Homes (CBH) properties which did not have battery installations. Only 2 out of the 6 households felt they knew how to maximise their savings from their solar panels and used energy intensive appliances on a sunny day. These were households C-01 and C-03. Both these households had lived in the properties for over 40 years and were there when the PV systems were installed. They were likely to have been provided with documentation at the time and may have had the system explained by the installers. Out of the households that did not know how to maximise savings from the solar panels, C-02 and C-04 moved into the properties after the solar panels were installed.

Only household C-05 knew how to check whether their PV system was working. They were only able to do this by recording the solar generation meter readings. None of the households noted any reliability issues with the PV systems. Compared to the monitored households with batteries, a lower proportion of the control households used energy intensive appliances on sunny days or knew how to check whether their PV system was working. This was likely to be due to better engagement of households with the technology when they owned or organised an installation of the solar PV system.

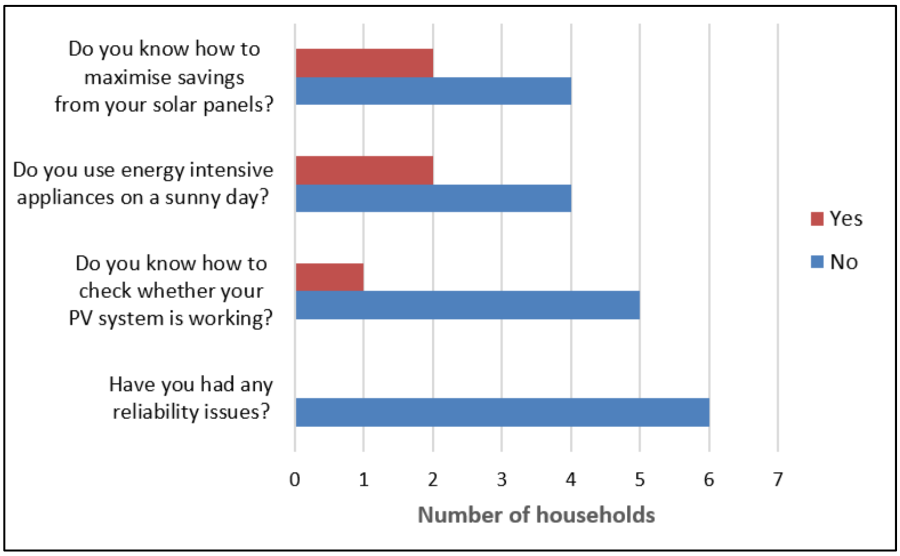

Figure 2.28 Control households – their understanding of their solar PV systems

2.5 Perceived benefits

Residents in the monitored group with the battery-solar systems were asked about whether they had experienced a series of benefits since the system was fitted. This was compared to the control households with just solar PV systems.

5 out of the 13 households with batteries said that they had seen a reduction in their energy bills over the course of the project. Out of these 5 households, 3 recorded meter readings at least once a week.

For comparison there were 4 households among the control properties who felt their PV system was reducing their energy bills. Out of the 2 households who did not think the PV system had been reducing their electricity bills, 1 of these moved in after the PV system was fitted. A factor influencing the responses of households was however, the rise in electricity prices over the last 2 years.

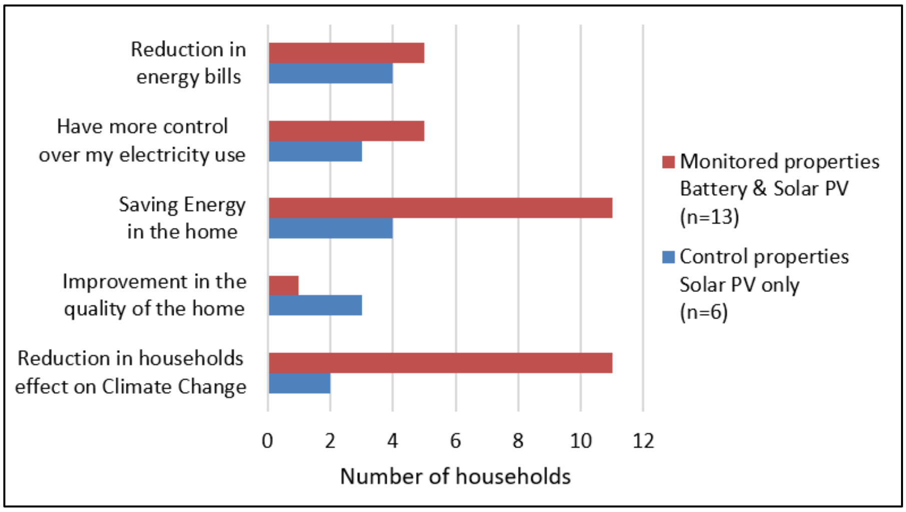

Figure 2.29 Benefits perceived by residents after installation of the solar-battery system

There were Figure 2.29 shows that 5 of the 13 households with battery and solar PV who felt they had more control over their electricity use. This compared to 3 of the 6 control properties with solar PV. A high number of the households with batteries felt they were saving energy in the home following the installation, with 11 of the 13 households noting this benefit. For the control properties, 4 out of the 6 households felt they were saving energy in the home and the 2 households who did not perceive this benefit both moved into the properties after the solar PV systems were installed.

Only a single household felt there was an improvement to the quality of their home after the battery was installed. This compared with 3 out of the 6 control households who felt there was an improvement due to installation of solar PV. For the control households, all those that noted the benefit lived in the home at the time of the installation.

There were 11 households out of the 13 in the monitored group who thought they were reducing their household effect on climate change following installation of the battery. In comparison, only 2 of the 6 control households thought that they were having this effect due to their solar PV system.

This result provides an interesting insight into the understanding about Climate Change of both groups. Installing a domestic solar PV system is of greater benefit in reducing carbon emissions than installing a domestic battery. A solar PV system can typically generate 2000-4000kWh per year of zero carbon electricity (excluding emissions due to the manufacture and transport to site). Domestic battery storage is beneficial for households by reducing export of excess solar generation, but this low carbon generation would still be consumed elsewhere. The main benefit of domestic battery storage over Climate Change is to allow greater deployment of renewable generation on the electricity grid and in the long-term to provide backup/services to the grid. This is a smaller and more subtle benefit which is harder to visualise than the clear benefits of installing a solar PV system.

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[25]. Maintenance free lead-acid batteries were developed from the 1970s such as Gel lead-acid batteries, where the electrolyte is suspended in a silica gel. Another is the AGM or Absorbent Glass Mat lead-acid battery, which has a fine fibre glass matting soaked in acid electrolyte placed between plates of the battery which are compressed.

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 starter 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[26]. Although lead acid batteries have a lower cost, they are heavy, have a relatively short lifespan, charge slowly and are not environmentally friendly.

The need for better rechargeable batteries for portable devices such as mobile phones accelerated their development from the 1980s. Lithium is an attractive material for batteries due to its low weight. Due to the instability of metallic Lithium, rechargeable batteries were developed from the 1990s using non-metallic compounds with Lithium ions. There are various compositions of Lithium-ion battery. These include oxides of Lithium with other metals such as Cobalt, Nickel and Manganese as well as Lithium Iron Phosphate[27].

Lithium-ion batteries 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' 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.

Solar panels generate and batteries store DC (direct current) electricity. With a DC coupled battery storage system, the battery and its charge controller are fitted on the same side of the solar inverter as the solar panels (figure 3.1).

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

[26] 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 August 2018)

[27] BU-205: Types of Lithium-ion, Battery University http://batteryuniversity.com/learn/article/types_of_lithium_ion (Accessed 31 May 2018)

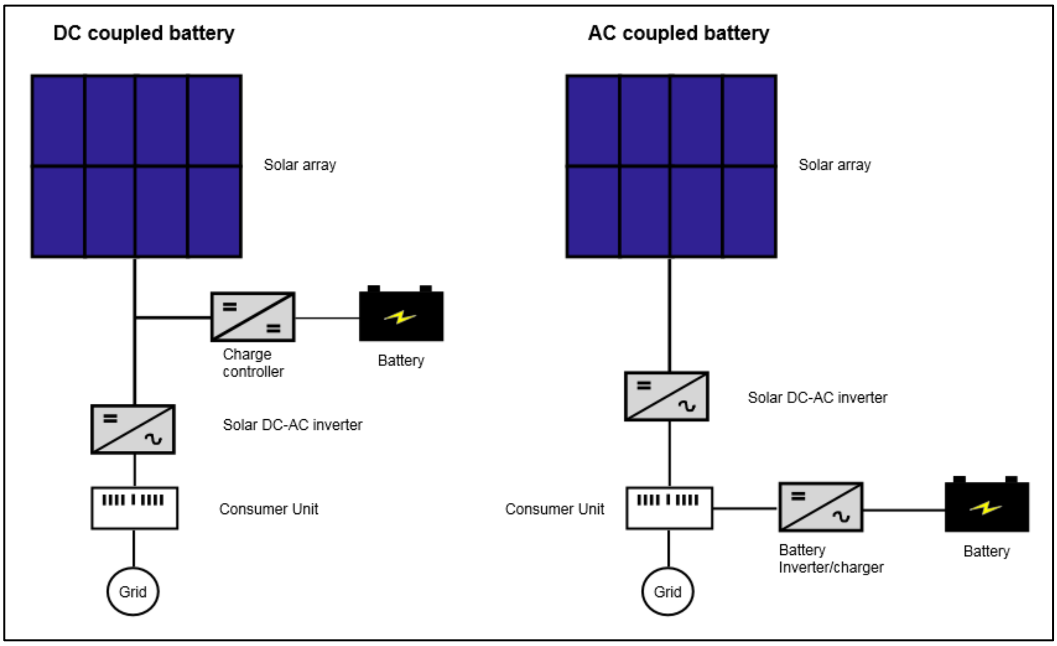

Figure 3.1 Schematic diagram showing DC and AC coupled battery systems

For an AC (alternating current) coupled battery system, the battery is fitted after the solar inverter. Here the system may be connected to the consumer unit or a sub-board.[28] In this case, the battery requires an inverter to convert the AC electricity to DC electricity which can be stored in the battery. 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 is often fitted in the loft. They can also take advantage of time of use electricity tariffs and can import electricity from the grid when it is cheaper. In this project, all 3 battery systems were AC coupled and connected to the household consumer unit.

[28] 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 Mar 2018)

Maslow

Figure 3.2 Maslow installation

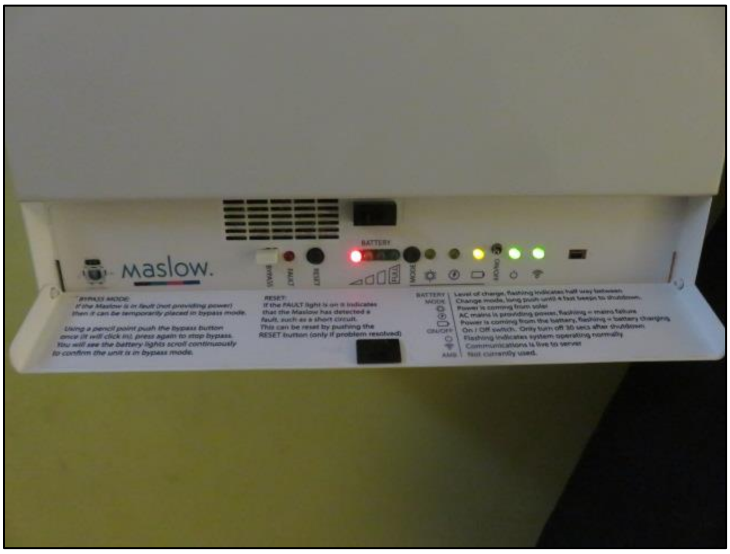

Figure 3.3 Maslow status panel

The Maslow V3 battery was manufactured by Moixa, a UK technology company that was founded in 2006 and is based in London. The Maslow used $LiFePO_4$ (lithium iron phosphate) battery cells and is an AC-coupled battery system which includes 2 micro-inverters.

16 Maslow batteries that were installed on the project with a capacity of 2kWh. Out of these, there were 4 in the monitored group. It should be noted that these batteries should only be taken to a depth of discharge (DoD) of 80%, which means a 2kWh battery has a useable capacity of 1.6kWh. The battery has an expected lifespan of over 10,000 charge and discharge cycles for less the 80% DoD. This is of the order of 20 years and the battery has a warranty of 10 years.

Figure 3.2 shows a Maslow battery installed below the box with the electricity meter near the front door of a home in the project. The battery unit shown has a height of 49cm, width of 30.8cm and depth of 19cm. There is a flap which can be pulled down at the bottom of the unit which reveals a status panel (figure 3.3). This shows the level of battery charge, whether power is coming from the solar or the battery or if the battery is charging. There is also a fault light and the ability to reset the unit.

The AC output from the battery is up to 430W while the charge is typically between 100 and 315W. The typical inverter threshold (level of consumption from the grid) at which the battery would kick in is normally set at 250W. For properties with low consumption, it can be set at a lower level, but the overall efficiency would decrease as a result.

Although the output is good for powering base-load appliances like fridge-freezers and lighting, it will only supply part of the power required by higher consuming appliances such as kettles. The unit can also provide a DC output which can be used to power appliances with a suitable DC input and DC LED down-lights (figure 3.4). In the event of a grid supply failure, the battery could continue to provide power to LED lighting for example via the DC output but would be unable to supply the household AC circuit. None of the batteries installed in this project have made use of the DC output for appliances or lighting.

In order to communicate with the Moixa servers, the battery must be connected to the internet. This is required for monitoring of performance as well as control to ensure the level of battery discharge does not exceed recommended levels. If the battery does not have an internet connection for a prolonged period, it goes into a fault condition, and stops operating.

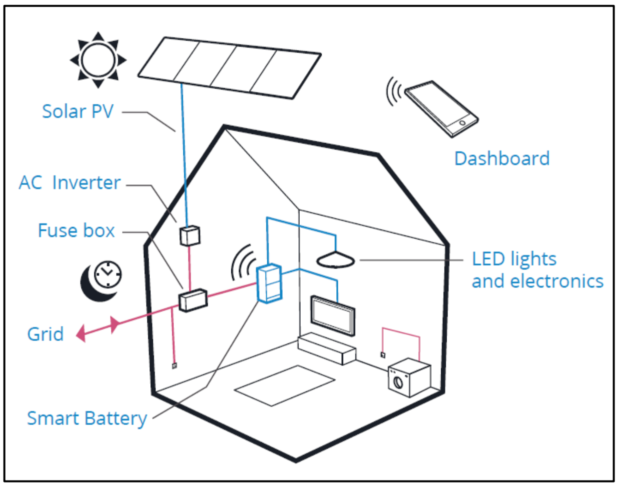

Figure 3.4 Schematic diagram showing a Moixa battery installation including connection to DC lighting and devices

The Maslow has an external WI-FI antenna on the side of the unit for communication to the household WIF router. In some cases, the signal between the two is not adequate. Rather than having a long Ethernet cable between the battery and the WI-FI router a neater option is to use power line adapters or TP Links. Here power line adapters are plugged into 13A sockets near the battery and the WI-FI router. Ethernet cables link the power line adapters to the battery and WI-FI router, while the power line adapters are able to transmit data to each other using the household 13A ring main.

Maslow batteries have been used in a number of UK trials. These include:

- Project ERIC which installed batteries in 82 households in Rose Hill, Oxford,[29] [30] with funding from Innovate UK
- Project Windy funded by Northern Powergrid and in partnership with Energise Barnsley, which installed batteries in 40 homes in Oxspring near Barnsley. The homes on the project were on the same substation and the aim was to see whether battery storage could mitigate the need for network reinforcement following clusters of renewable installations[31] [32]
- 4 battery storage trials as part of the NEA Technical Innovation Fund. These are:
    - 24/7 Solar with the London Borough of Camden[33]

[29] Project ERIC – re-energising communities https://localisedenergyeric.wordpress.com/ (Accessed 16 August 2018)

[30] Project ERIC – learnings summary document https://www.bioregional.com/wp-content/uploads/2014/10/Project-ERIC-%E2%80%93-learnings-summary-document.pdf (Accessed 16 August 2018)

[31] Home battery trial aims to increase electricity network capacity to enable more solar home and save £millions for customers, 19 Jan 2017, http://www.moixa.com/press-release/home-battery-trial-aims-increase-electricity-network-capacity-enable-solar-homes-save-millions-customers/ (Accessed 19 Mar 2018)

[32] Battery Storage Project, http://www.energisebarnsley.co.uk/battery-storage/ (Accessed 19 Mar 2018)

[33] Paul Rogers and Michael Hamer 'CP745, 24/7 Solar, London Borough of Camden' (in press)

        - Includes Maslow, sonnen and Growatt batteries
    - Sungain Battery Bank in Thurrock
        - Includes Maslow, Powerflow and Victron batteries
    - SolarMax+ in Grimsby
        - Includes Maslow, SIG Smart Energy Share for solar PV and Dimplex Quantum storage heaters
    - Optimizing infra-red in Durham
        - Includes Infra-red heating panels, Dimplex Quantum storage heaters, solar PV and Maslow batteries

Moixa has developed GridShare, which is an aggregation platform where battery owners can receive income for allowing intelligent management of their battery. Spare capacity of large numbers of batteries can be controlled together to create a virtual power plant and help balance the supply and demand of the electricity grid. Payments for households who privately purchase a battery are currently £50 for the first 3 years and are subsequently based on a profit share for any income received by the service.[34] A requirement for participation in GridShare is to maintain a constant internet connection for the Maslow battery. None of the residents taking part in the NEA trials were part of Gridshare. This ensured the performance recorded for the batteries on the trials was only influenced by the solar generation and household consumption.

Residents who received a Maslow battery as part of the SunGain Battery Bank trial will be informed about GridShare at the end of the project. Residents on the trial would only receive payments once Moixa have a contract for providing the aggregation service. However, residents would benefit from an increase from 5 to 10 years for the warranty of the battery.

At the time of writing, Moixa are offering a solar PV and battery package including a 2kW solar PV system and a 2kWh Moixa Smart Battery from £4995 including VAT. They note that their "solar panel and battery storage bundles can save you up to 60% on your energy bills"[35]. Moixa Smart Batteries are available for multiple installations for approximately £2000 excluding VAT but including installation.

Moixa have also produced a larger 3kWh Maslow V3 battery. Several of these batteries were used on the 24/7 Solar project with the London Borough of Camden. Moixa are also producing newer battery systems. The newest Moixa Smart Battery has the input power raised to a maximum 750W, which speeds up charging and also a maximum output of 460W.

The largest Moixa Smart Battery has a total capacity of 4.8kWh. The maximum input power is 700W and the maximum output power is more than double that for the Maslow V3 at 1000W.

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[34] Gridshare http://www.moixa.com/products/gridshare/ (Accessed 19 Mar 2018)

[35] Solar Panel and Battery Storage Bundle, http://www.moixa.com/products/solar-panel-battery-storage/ (Accessed 19 Mar 2018)

PowerFlow Sundial

Figure 3.5 PowerFlow Sundial SDM 2.0-500-10, 2kWh battery installed on a garage wall

PowerFlow is another UK battery manufacturer who are based in Herefordshire. The product installed was a PowerFlow Sundial M2 battery with a total capacity of 2.0kWh. At the time of writing, this retails at £2499+VAT. The battery has a standard 2-year product replacement warranty. The warranty can be extended to 5 years on the electronic components and 10 years on the battery performance or 4000 cycles if the owner registers the product.

There was a total of 14 PowerFlow Sundial SDM 2.0-500 batteries that were installed during the project and 5 of these were part of the monitored group. The battery again uses Lithium Iron Phosphate with 2 x 1kWh cells in the unit. As with the Maslow, once the maximum 80% depth of discharge (DOD) is taken into account, the battery unit has a usable capacity of 1.6kWh.

Figure 3.6 shows a typical system layout for this AC-couple device. The Sundial is a modular device. Once a Sundial M unit has been installed, it is possible to add multiple Sundial S units (e.g. the SDS 2.0-500 which is also a 2kWh unit) at a later date, up to a capacity of 96kWh.

The Sundial M unit includes a LCD display on the front panel. This shows live information about the import or export from the building as well as the battery charge/discharge status. It will also indicate the operational status of the battery and total kWh savings.

The units come in a custom made aluminium enclosure (Figure 3.5) with dimensions 44 cm x 30 cm x 28 cm. The case aids dissipation of low level heat generated during operation. During hotter days, additional automatic temperature control can be provided by 2 internal ultra-low noise fans. The cooling system ensures the internal battery packs are protected and running at their optimum.

The manufacturer recommends a minimum clearance distance away from walls and ceilings of 200mm from the top of the battery, 100mm from the sides and 150mm from below. This ensures there is sufficient and suitable space for heat dissipation. The battery should not be fitted in a loft space or in direct sunlight which can also lead to over-heating.

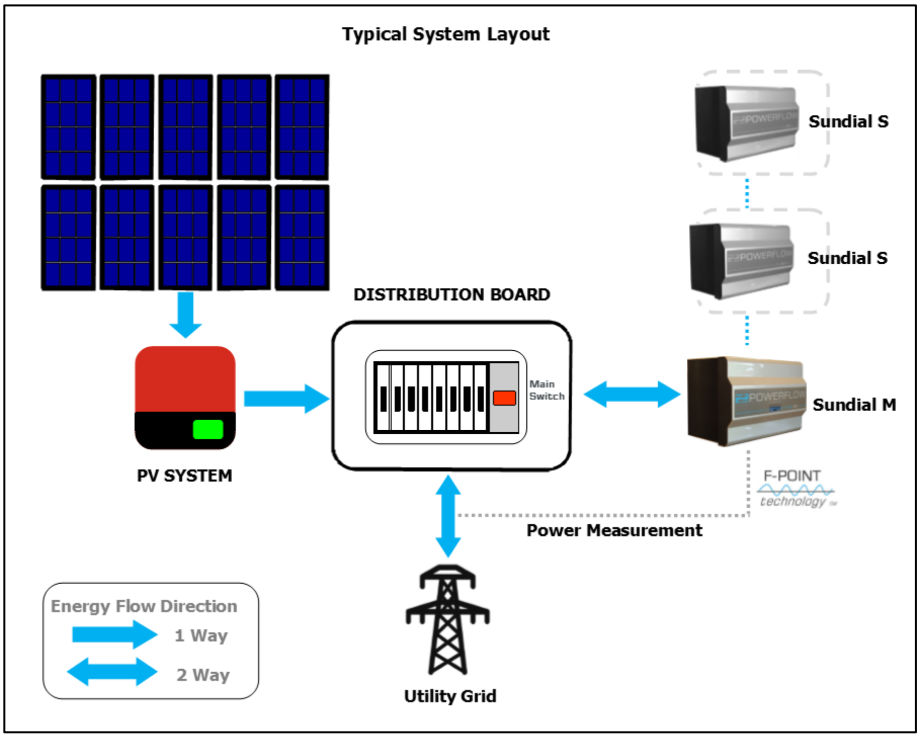

Figure 3.6 Typical system layout for a PowerFlow Sundial battery system

The input power for the PowerFlow Sundial SDM-2.0-500 can increase to a maximum of 300W in steps of 50W depending on the excess solar generation. The output power of the battery can increase in 4 steps of 125W up to a maximum of 500W[36]. The battery start-up power rating for export is 95W and 170W for import.

The battery uses the company's F-POINT technology which measures changes in the household energy consumption 5 times a second. This allows the system to automatically modulate the charge and discharge of the battery and avoid unwanted grid import during operation[37].

More recently PowerFlow has released 6kWh and 8kWh versions of the battery. This offers customers the option of a single taller case with dimensions of 44cm x 135cm x 32cm rather than a bank of 2kWh battery units. The 6.0kWh model has a usable capacity of 4.8kWh and a nominal input of up to 900W in 50W adaptive steps. There is also a dynamic discharge power output of up to 1500W in 125W adaptive steps. For the 8kWh version, the SDM-8.0-2000-10, the usable battery capacity is 6.4kWh, the maximum input is 1200W and the maximum output is 2000W.

PowerFlow have also developed an advanced solar immersion heating system which they call their Energy Recovery System (ERS)[38]. This device again uses their F-POINT technology which regularly monitors export of electricity to the grid (figure 3.7). The ERS smoothly diverts excess

[36] PowerFlow Sundial: AC Battery Storage System data sheet http://www.powerflowenergy.com/files/powerflow/Sundial/Sundial%20data%20sheet%20v2.3.pdf (Accessed 16 August 2018)
[37] Sundial M2 and S2 Features https://www.powerflowenergy.com/battery-storage/sundial-2kwh/sundial2kwhfeatures/ (Accessed 16 August 2018)
[38] PowerFlow's Energy Recovery System – ERS Advanced Solar Immersion Heating https://www.powerflowenergy.com/solar-water-heating/ (Accessed 17 August 2018)

solar generation by accurately controlling the electrical heating load. This can be the immersion heater in a hot water tank or another device like a space heater. The ERS is designed to work with the Sundial battery and excess solar generation is first used to charge the battery and only once this is charged will it then be used for water or space heating. At the time of writing, the ERS MINI retails for £299+VAT while the ERS PRO was £499+VAT. A household in the monitored group who had a PowerFlow installation had an earlier version of the ERS PRO system.

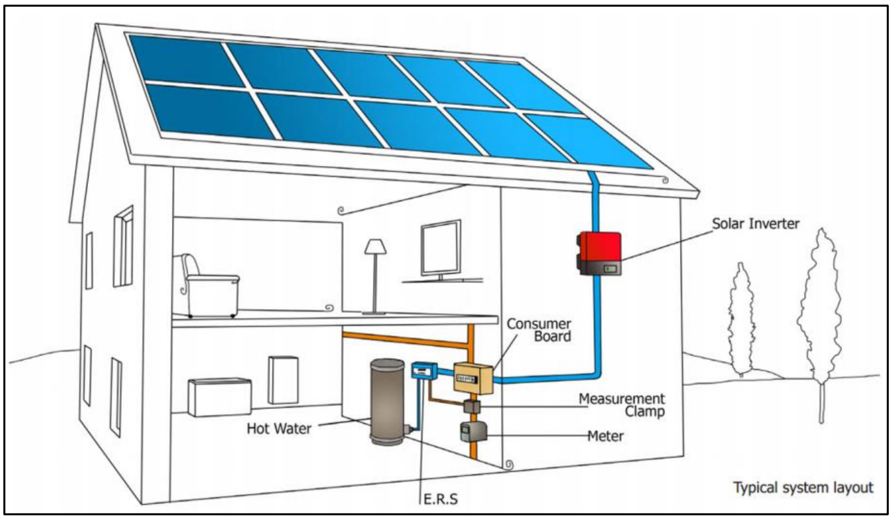

Figure 3.7 Typical system layout for a PowerFlow Energy Recovery System (ERS) solar water heating

Victron MultiPlus Compact 12/800/35 with AGM Lead Acid battery

Victron Energy is a Dutch company that was founded in 1973. Their initial focus was on providing inverters and chargers for the marine industry, but this quickly expanded to include products for land-based and automotive markets. They have a wide range of inverter/charger models sized from small 500 VA units up to 15 kVA. Their units can be used for grid-connected or off-grid battery systems. They are compatible with most brands of PV inverter. Systems are available which can be AC-coupled or DC-coupled to the solar PV system.

Many manufacturers supply their battery systems in a single unit in an attractive case. Victron typically supply the charger/inverter, battery and battery monitor in separate units. This means that customers can specify systems according to their exact needs, but the installed system has less of a stylised design and is more about function and flexibility.

There were 4 households who received Victron battery systems and all of these were part of the monitored group. The key components installed were as follows:

- Victron MultiPlus C-12/800/35 inverter/charger
- Victron Colour Control GX
- Leoch LAGM 260 Ah deep cycle AGM lead-acid battery

The Victron components were supplied by Wind and Sun. The price of the MultiPlus C-12/800/35 inverter at time of writing was £394+VAT for non-trade purchases. The non-trade price of the Colour Control GX was £386+VAT. Trade discounts for installers could be 20 to 30%.

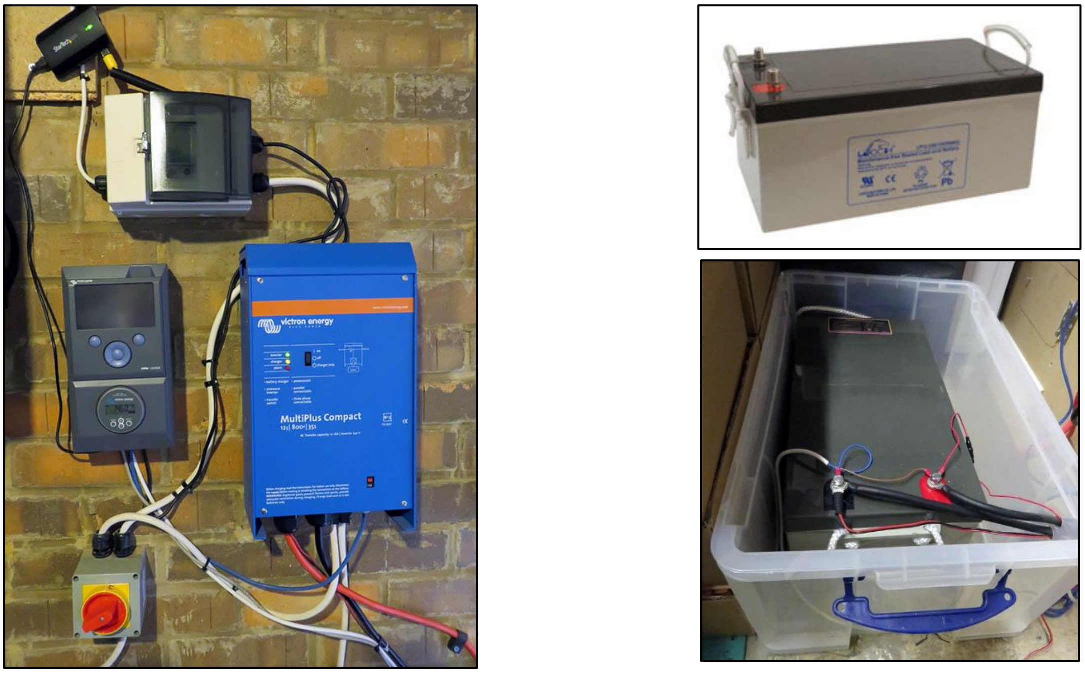

Figure 3.8 Installation with the MultPlus Compact C-12-800-35, Colour Control GX and a Leoch AGM battery

Other components (typical installation shown in figure 3.8) included:

- A wall mounted enclosure for the Colour Control GX
- A CT wired AC meter for the Victron Hub4
- Victron Precision Battery Monitor 9.0 – 90V DC
- Colour Control WI-FI Module – long range
- Appropriate cables

The Victron inverter/charger will output up to 800W, which is higher than either the Maslow or the PowerFlow Sundial. The input power is up to 400W, which is greater than for either the Maslow or SunDial battery systems. Victron also manufactures models with a higher output and input power. The system can be AC or DC coupled and can work with and without a solar PV system. Timed charging of the battery from the grid means the system is able to operate with time of use tariffs.

The Victron system can be used with a wide variety of batteries and they have worked with 3rd party battery suppliers to ensure 'plug and play' compatibility over CanBus[39]. The installers fitted AGM lead acid batteries with the Victron system on this project. Victron recommend use of Lithium-ion batteries and a battery with the same chemistry would have been better for comparison with the Maslow and SunDial batteries.

The system will operate with a 12V battery and the installers selected the Leoch LAGM 260 deep cycle battery. This will have a poorer charge efficiency than a lithium-ion battery The Leoch battery had dimensions of 50cm x 27cm x 22cm and is an AGM lead-acid battery with a 260 Ah capacity. This is equivalent to a total capacity of 3.12kWh. Since the maximum depth of discharge (DoD) recommended for the battery is 50%, the usable battery capacity is up to 1.56kWh.

[39] Victron Battery Compatibility https://www.victronenergy.com/live/battery_compatibility:start (14 Nov 2018)

The Leoch battery installed on the project has a typical maximum life of 600 cycles at 50% DoD. This would be less than 2 years at 1 cycle per day and would be within the period of the evaluation. An equivalent Leoch battery, the Xtreme 260Ah was available online from Alpha batteries for £370 incl. VAT and delivery at the time of writing. An alternative battery with superior performance is the Leoch 12V 250Ah Powerblock Tubular Gel leisure battery. This battery has a typical maximum life of 1500 cycles at 80% depth of discharge and has a 6-year warranty. The battery has tubular shaped positive plates which are more robust than the flat plates in the AGM. The combination of tubular plates and gel electrolyte allows very good deep discharge recovery. The battery cost was about £470 incl. VAT

At the time of installation, the firmware used for the Colour Control GX was Hub-4. This was updated in December 2017 to the later ESS (Energy Storage System) firmware for the Colour Control GX.

3.2 Technological monitoring

Most of the analysis for this project used data collected by the batteries using current (CT) clamps. The battery had one of the current clamps measuring solar generation and another measuring the household consumption. This data was uploaded to the internet and graphs and data were accessed through the manufacturer’s online monitoring portals.

In addition to the data from the battery systems, there was also data available from the generation meters for the solar PV systems and the meter for the electrical supply. Omega OM-CP-PULSE101A loggers were used to measure the PV generation or electrical supply on some meters which had an LED pulse output (figure 3.9). These were not always successfully attached to the meter and the sensor was occasionally not placed directly over the LED. Good data was recorded on 4 loggers with limited data on a further 3. Residents also recorded electricity and solar PV meter readings, in some cases on a daily basis. Historic meter reading data from the period of the project was also obtained from electricity bills and feed-in tariff payment statements.

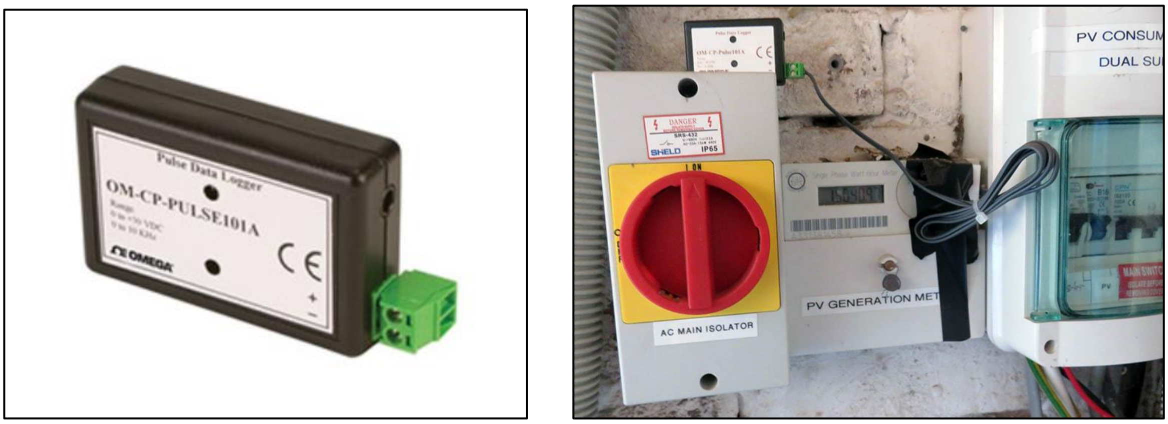

Figure 3.9 Omega OM-CP-PULSE101A logger and fitted to a Landis & Gyr E110 PV generation meter

Maslow

Raw data that had been averaged over 5-minute periods was provided by Moixa for each property. The inputs to the system were the current clamps on the solar PV and the household supply along with measurements of the battery voltage and current. The power from the solar PV and household consumption were obtained by multiplying the measurement from the current clamps by 240V. This data was also used to determine the amount of the PV that was used, the battery discharge and the grid consumption. The current clamps had an accuracy of 5 to 10%. For low currents (<1A), there was typically an error of up to 10%. However, in range 1 to 20A, the error was expected to be ±5%[40].

During the study, some batteries had small or large gaps in the data due to periods being offline. A firmware update released by Moixa in October 2018 enabled the Maslow batteries to store up to 6 months of data. This ensures the battery performance could still be recorded during periods offline and subsequently uploaded to the portal when reconnected. However, this was not available during the period of the current study.

The Moixa battery portal provides a variety of information for households. The 'My Moixa' section shows the live power flows in the property as well as the battery status/level of charge (figure 3.10). It is also possible to plot a bar chart showing the energy flows on a half hourly basis for the current day or the previous 4 days (figure 3.11).

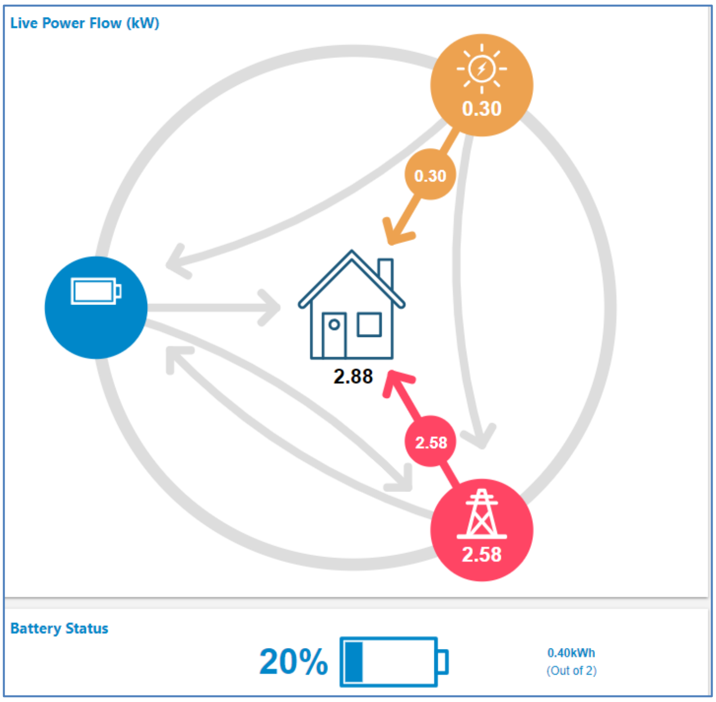

Figure 3.10 Chart showing the power flows and battery status for a Maslow battery

[40] Personal communication, Alexey Alexeev, Technical Asset Manager, Moixa (17 April 2018)

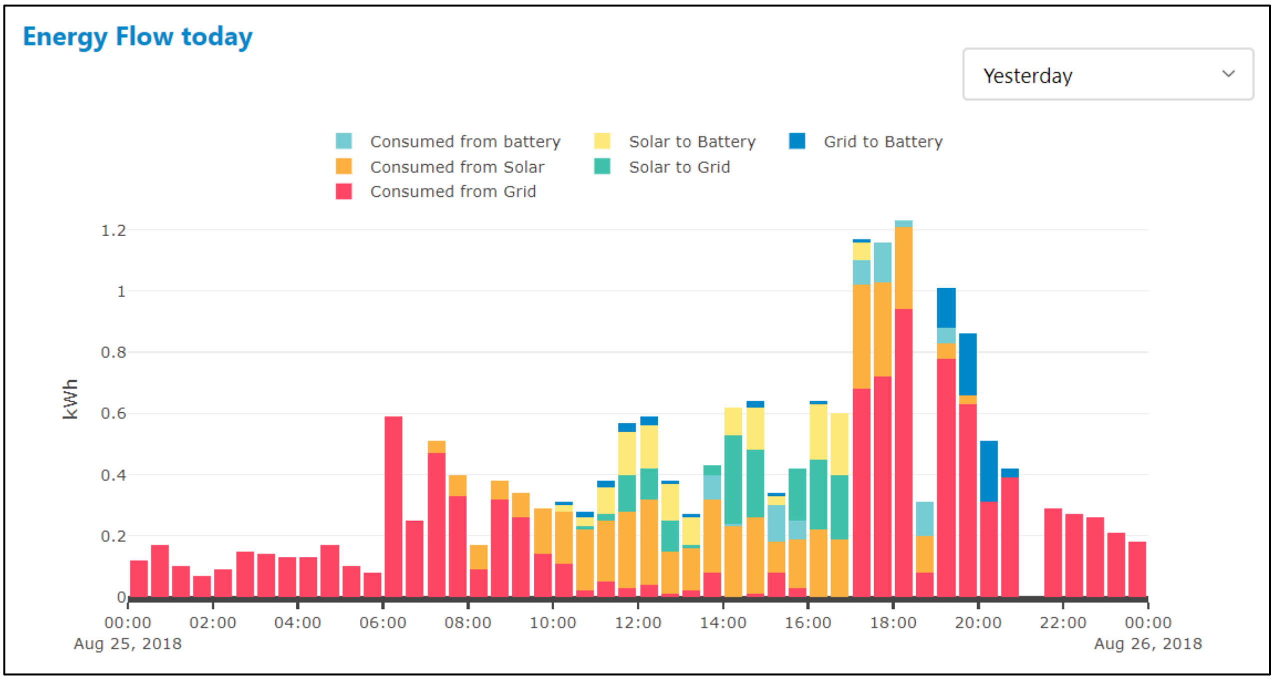

Figure 3.11 Plot showing half hourly energy flows for a Maslow battery on 25 Aug 2018

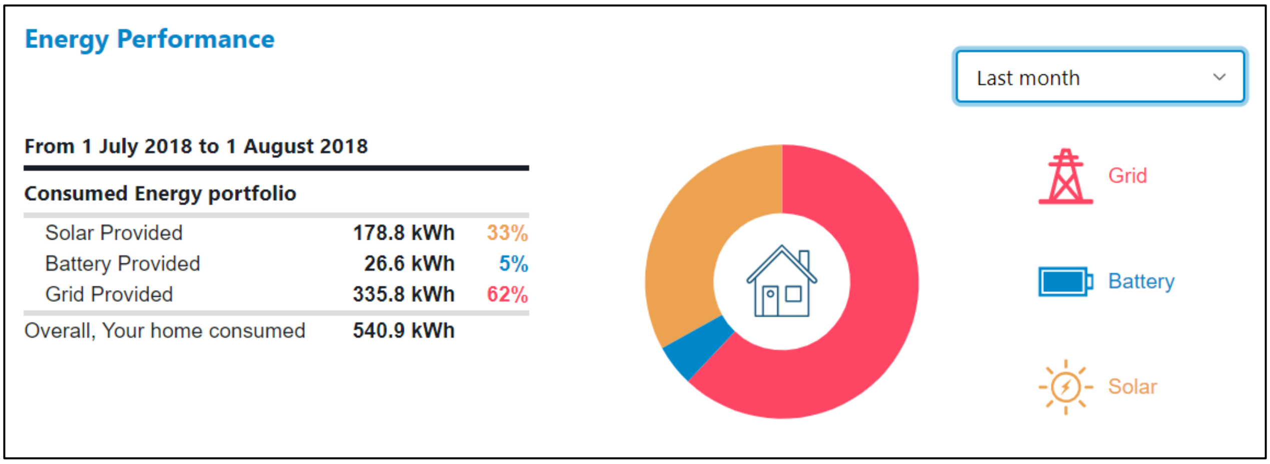

Figure 3.12 Chart showing the energy performance for a Maslow battery during July 2018

The savings section of the portal includes a chart which illustrates the percentage power that is provided to the home from the solar panels, battery and grid. This can be shown for the previous day, week or month. Figure 3.12 is a chart for July 2018 for a Maslow battery on the project and shows that the solar panels provided 33% of the power, the battery 5% and the grid 62% during the month. The battery discharged 26.6kWh towards the home consumption during the month. Similar data is also presented as a bar chart in this section, showing the home energy balance over the last 7 days, 6 weeks or 3 months.

In the data section of the portal it is possible to plot power flows between chosen dates and times. Figure 3.13 shows an example with the household consumption, solar generation and power flow to the battery (positive) and from the battery (negative). It is also possible to download this data which is provided in minute intervals. A graph can also be plotted of the battery state of charge (figure 3.14)

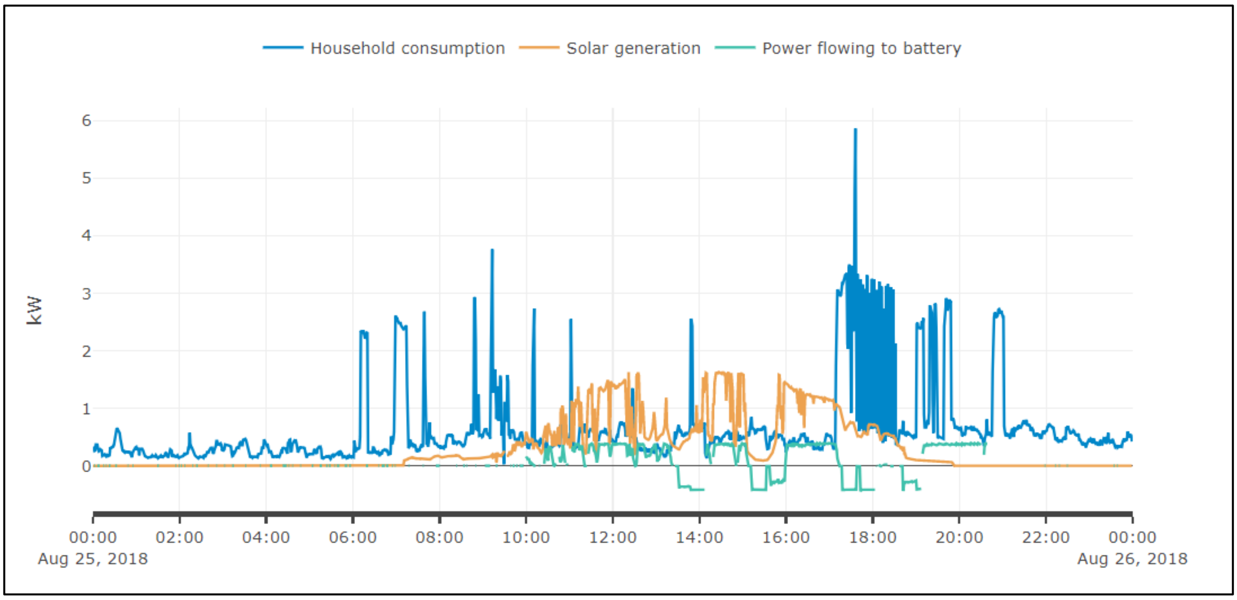

Figure 3.13 Graph showing the Household consumption (blue), Solar generation (orange) and Power flowing to and from the battery (green) for a Maslow battery on 25 August 2018

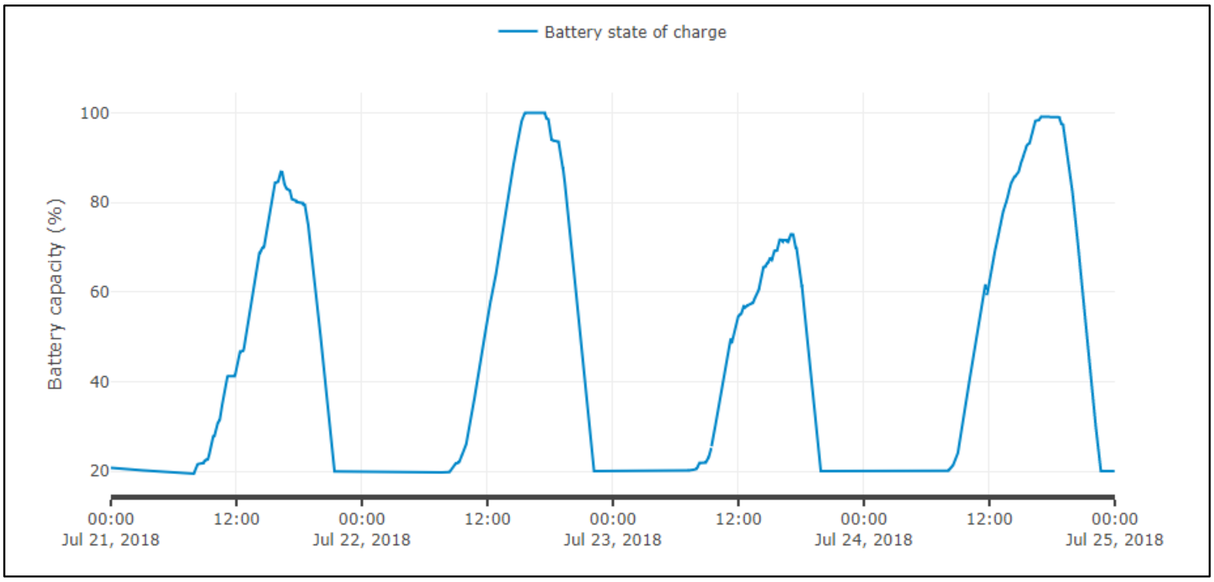

Figure 3.14 Plot of Battery state of charge for a Maslow battery between 21 July 2018 and 25 July 2018

PowerFlow

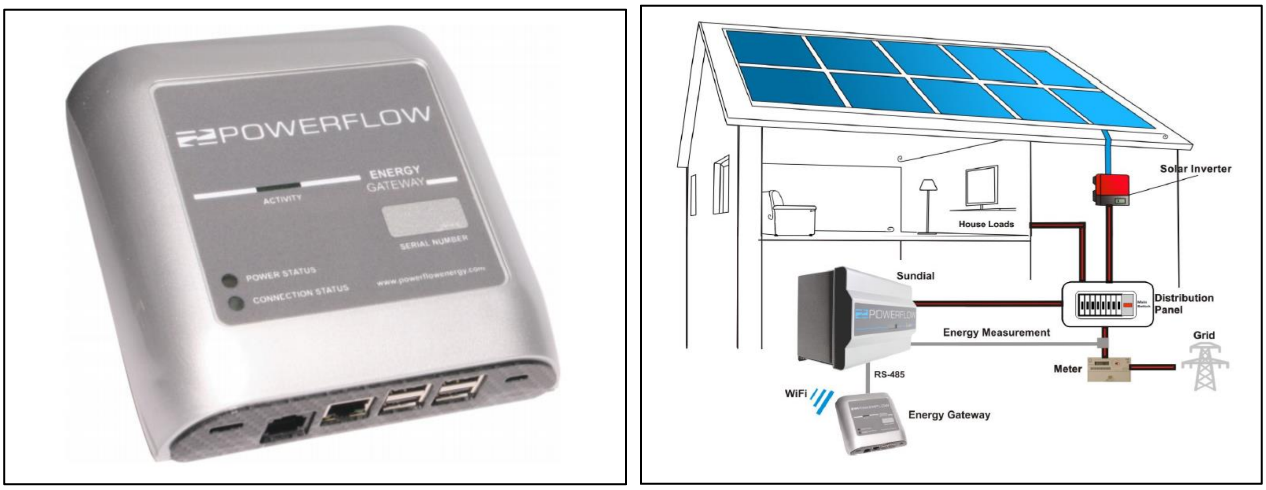

Figure 3.15 PowerFlow Energy Gateway and typical system layout

PowerFlow released their Energy Gateway device in the Spring of 2018. This links the Sundial battery unit to the internet using the household broadband connection and provides access to the PowerFlow online portal. The portal provides free online monitoring and allows control of the battery unit.[41] Figure 3.15 depicts a typical layout and image of the gateway.

The monitoring system provides live updates every 15 seconds to the household import/export as well as the battery status. It is also able to display historical data by day, month or year (figure 3.16 and 3.17). The Gateway also makes it possible to charge the battery from the grid at predefined times, which is beneficial for any household using Economy 7 or another time of use tariff. The percentage of grid charging for the battery can be set to be higher in winter than at other times.

The Gateway has dimensions 14 x 13.7 x 3.5 cm and requires a mains supply. It is linked to the Sundial battery using a RS485 data connection with a CAT5e cable. The Gateway can be connected to the internet using a hard wired RS485 connection to the household WI-FI router. Alternatively, this could be achieved by connecting the Gateway to the router via WI-FI. The unit retails for about £350+VAT

At the time of the installations, there was no monitoring system available for the PowerFlow battery. It was hoped that this could be provided to some of the monitored group at a later date. The PowerFlow Sundial battery only began sending the building's energy measurements along the data line on batteries using operating system 2.1 and later. This is necessary for the Gateway to be able to collect the energy measurements[42]. Earlier software versions also will not process external control to allow charging using off peak tariffs.

[41] PowerFlow Gateway Installation and User Manual https://www.powerflowenergy.com/files/powerflow/Gateway/PF-EGW%20Installation%20Guide%20V1.1%20(WEB%20version)%20A5.pdf (Accessed 21 August 2018)

[42] Personal communication with Ian Murray, Managing Director of PowerFlow Energy Ltd (16 March 2018)

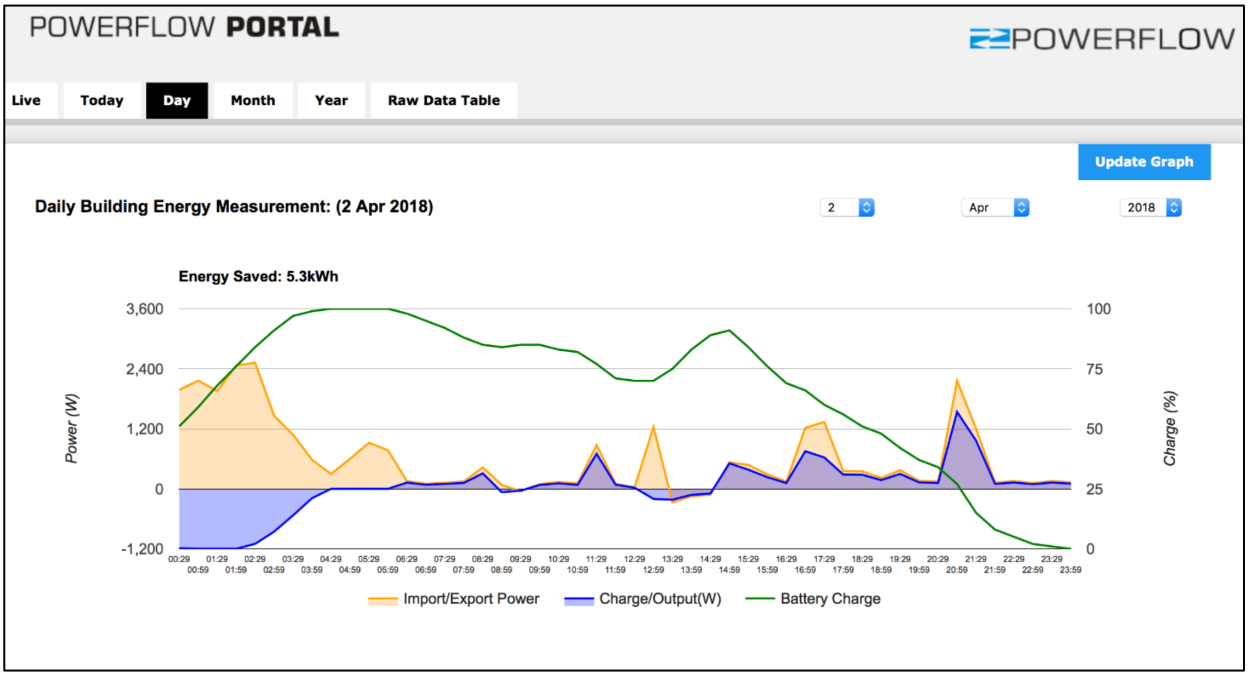

Figure 3.16 PowerFlow Portal showing system performance over a day

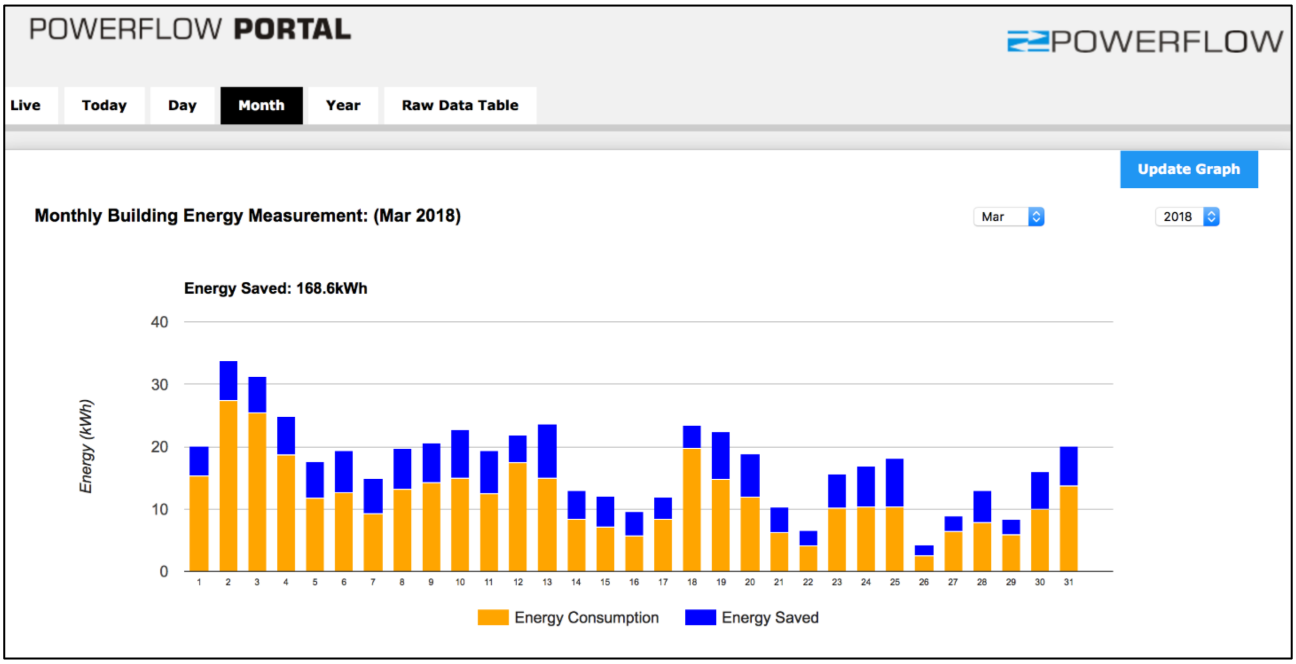

Figure 3.17 PowerFlow Portal showing system performance over a day

Since the batteries installed on this project used software version 2.0 and below, the Energy Gateway will not currently work with these batteries. It would be necessary for the battery to either be returned to PowerFlow or for one of their staff or suppliers to update the software onsite. As the project was ending a few months after the release of the Energy Gateway, it was decided not to install this monitoring device as part of the project.

PowerFlow had suggested fitting a simple Landis & Gyr E110 Watt-hour meter to measure the discharge of the batteries. Readings from this could have regularly been recorded manually or via a pulse logger to provide performance data for the battery. Unfortunately, this was not included with the installations.

Useful information from the battery is however provided if the system is restarted by turning on and off the AC isolator. During the system reboot, the LCD display shows the software version followed by the cumulative battery discharge from each of the 2 internal 1kWh battery modules (figure 3.18). However, it should be noted that in a more recent operating system update, these values have been combined together for a single reading to avoid confusion.

Figure 3.18 Examples of battery discharge readings for each of the 1kWh battery modules a PowerFlow M2 battery

Victron

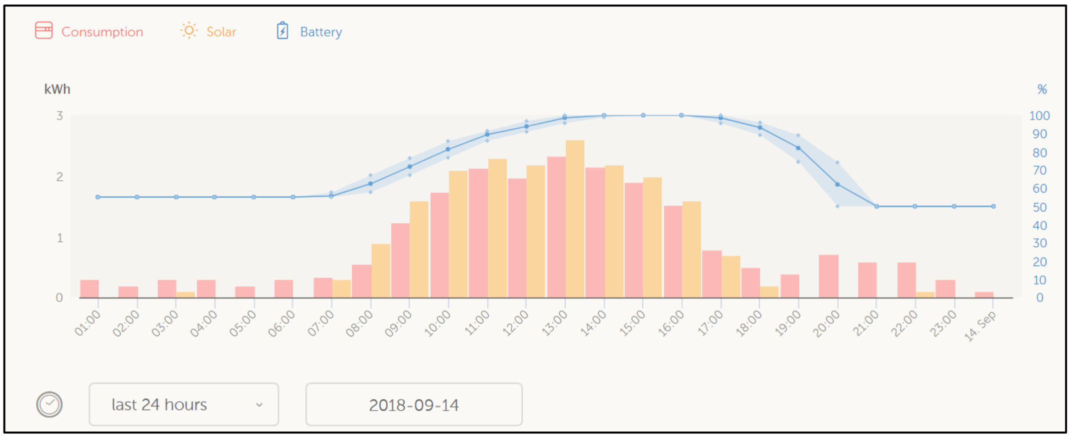

Figure 3.19 Screenshot from the Victron Energy VRM portal showing the system performance overview

The Victron Energy VRM (Victron Remote Management) portal provides a user-friendly overview of the system performance as well as a wide range of additional information which would be of interest to advanced users. The main screen shows a graph which can provide a system overview with details of the consumption, solar generation and percentage battery charge over the last 24 hours, last 7 days, last 30 days or last year. Figure 3.19 shows an example of the 'system overview' over 24 hours.

The main screen also shows the instantaneous values of household consumption, solar yield and how much is being imported or exported from the grid as well as the percentage battery charge.

It is also possible to use a drop-down menu to select graphs showing more information on the ‘consumption’ or ‘solar’. Figure 3.20shows an example of the ‘consumption’ and the bar chart shows the contribution from the grid, battery and solar. Values of the contribution for a particular time can be obtained by hovering over the graph. The percentage contribution to the consumption from the grid, battery and solar is also shown in the form of pie charts for the last 24 hours, 7 days, 30 days and last year. Figure 3.21 shows an example of the consumption over the last year.

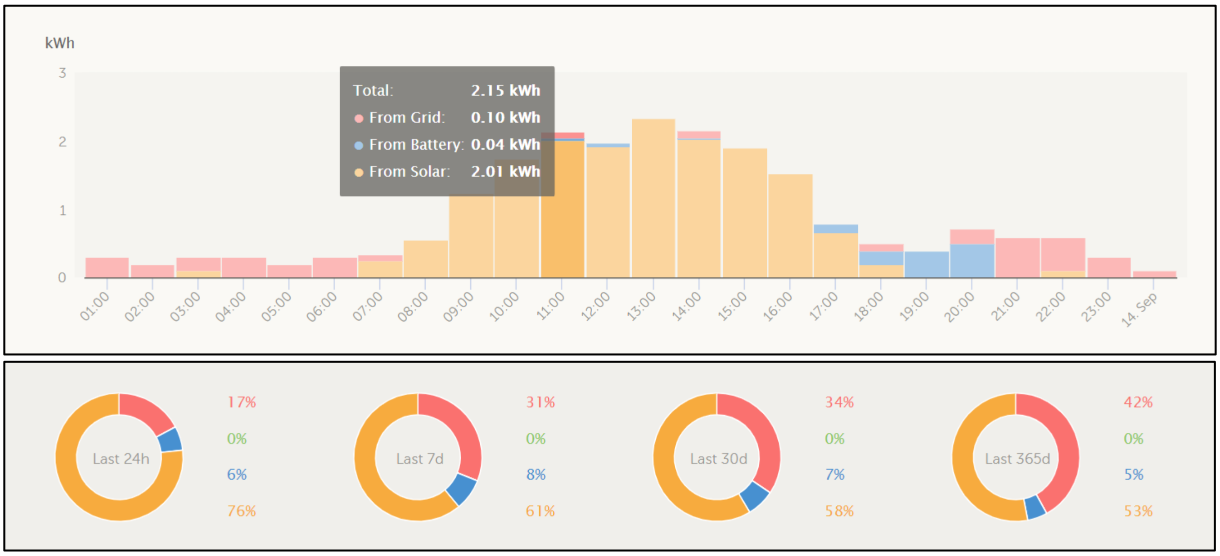

Figure 3.20 Screenshot from the Victron Energy VRM portal showing the consumption over the last 24 hours

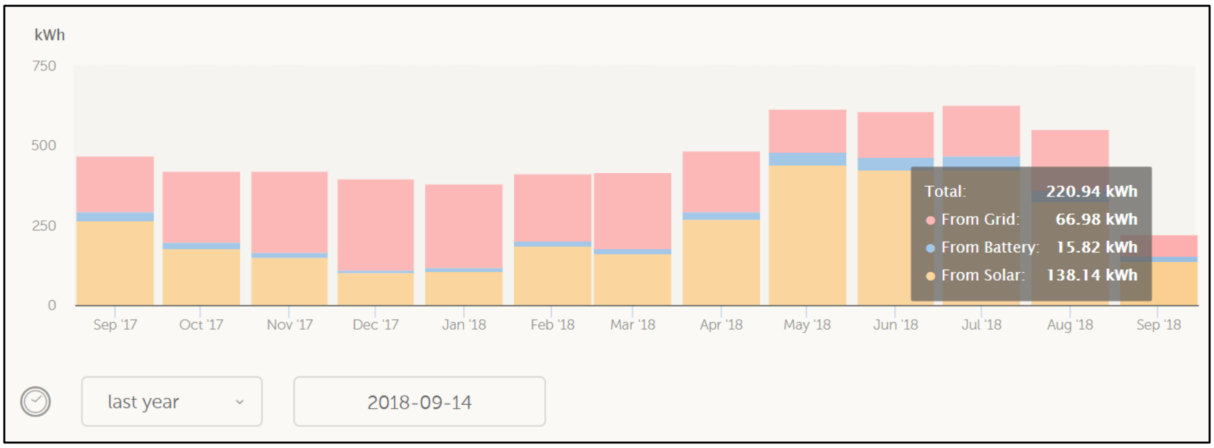

Figure 3.21 Screenshot from the Victron Energy VRM portal showing the consumption over the last year

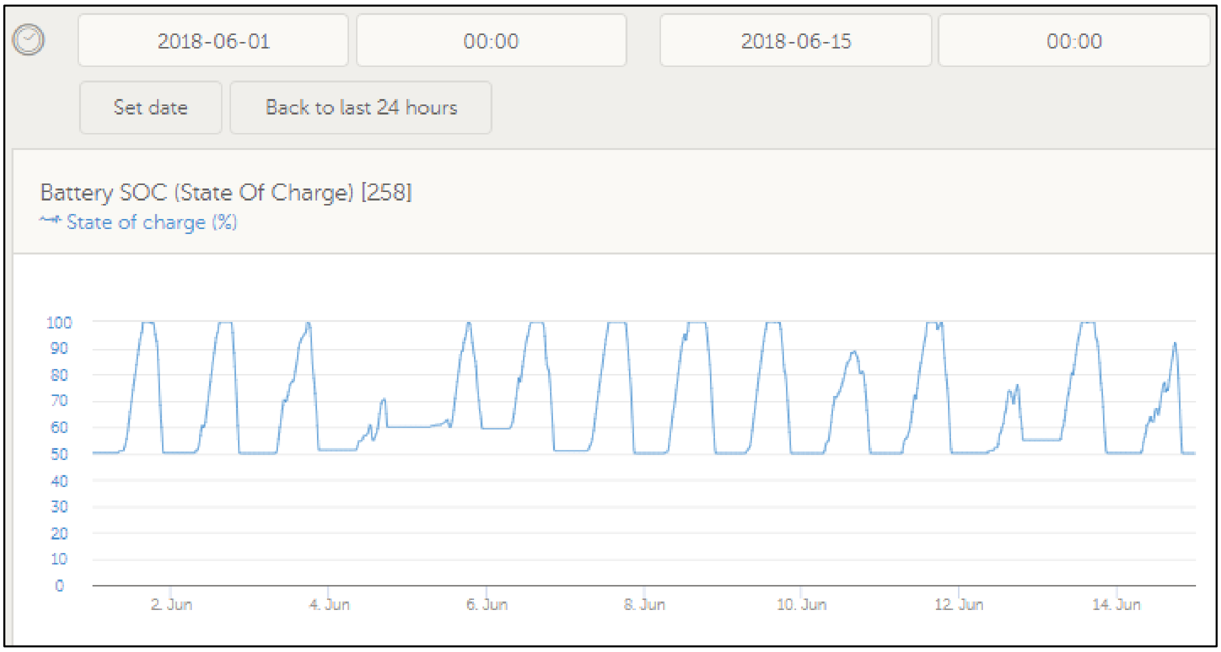

Figure 3.22 Screenshot from the Victron Energy VRM portal showing Battery State of Charge (SOC)

It is also possible to obtain a wide variety of other graphs showing system performance information using the Advanced section of the portal. The graphs can be plotted between chosen start and end date/times. Figure 3.22 shows the variation in Battery State of Charge (%) between 1 June 18 and 15 June 18. Other graphs which can be plotted include: Battery Voltage and Current, AC Input Voltage and Current, AC Input Power and AC Output Power, AC Input frequency and AC Output frequency as well as System PV Yield. Figures 3.23 and 3.24 show examples of plots of AC Consumption and PV inverter yield.

It should be noted that 3 of the 4 Victron battery systems that were tested were not wired to collect data from the solar system. As a result, for these systems, the plots of consumption like figure 3.21, would only include the amount from the grid and the amount from the battery. Also, it was not possible to plot the PV inverter yield. Detailed data is only stored on the system for 6 months and the advanced graphs could only be plotted for the previous 6 months.

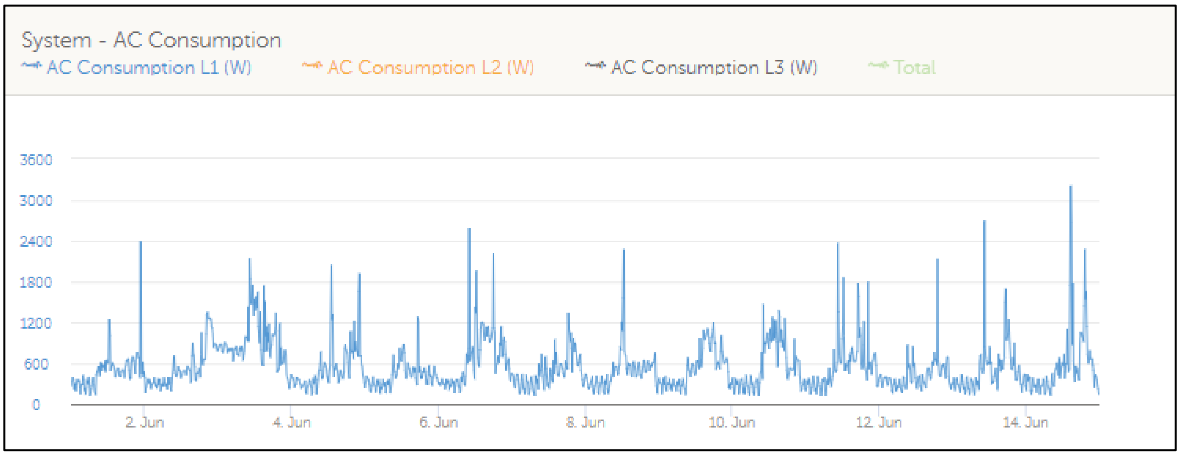

Figure 3.23 Screenshot from Victron Energy VRM portal showing System AC consumption

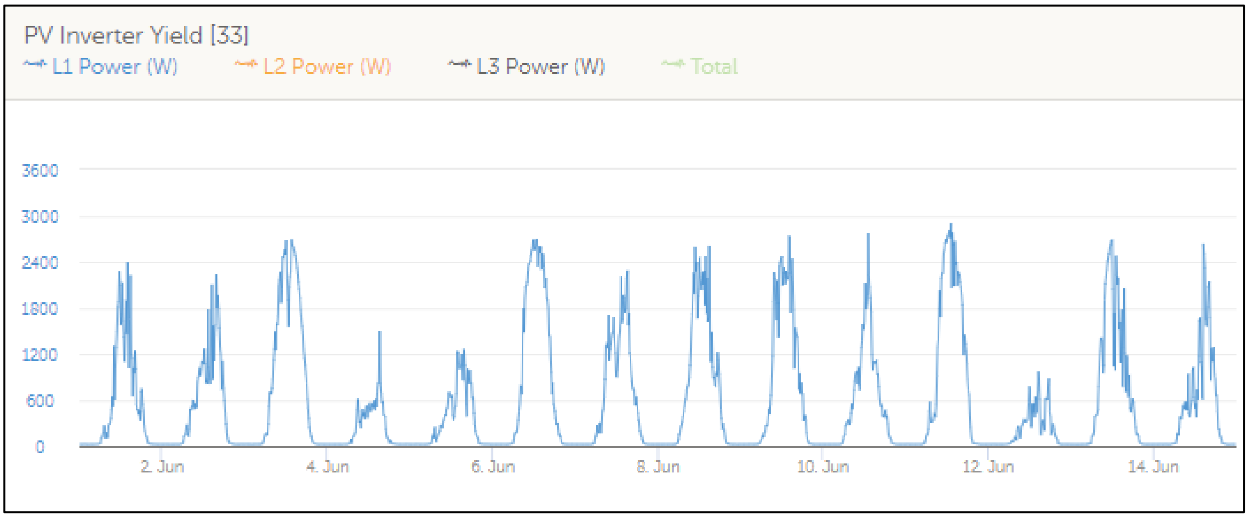

Figure 3.24 Screenshot from Victron Energy VRM portal showing PV inverter yield

As well as being able to plot graphs on the Advanced section of the Victron Energy VRM portal, it is possible to download data. There are 2 options which are available in either CSV or Excel formats. The first provides detailed data and information covering about 70 different parameters on a per minute basis going back up to 6 months. The second option provides consumption data in kWh going back to the date of installation for the following:

- Grid to battery
- Grid to consumers
- PV to battery
- PV to grid
- PV to consumers
- Battery to consumers
- Battery to grid

The data is either every 15 minutes or every hour. However, gaps in data can occur, most likely due to periods where the connection of the system to the internet are lost.

3.3 Control solar PV systems

There were 6 control properties used in this study for comparison to the properties which had batteries fitted to their solar systems. These properties were owned by Colchester Borough Homes (CBH) and had PV systems that were installed between July 2014 and January 2016. Table 3.25 shows details of these PV systems along with estimated values for the annual PV generation using the MCS method[43] and the system size provided by CBH along with a roof inclination of 30°. No assessment of shading was made.

Monthly values of PV generation from the smart generation meters are shown in Table 3.26. For household C-01 there was a period when the system was not operational between February and May 2017, which led to the reduced generation in 2017. The actual generation of households C-03 and C-05 is higher than might otherwise be expected for those system sizes based on the MCS method of estimating generation. On a domestic PV system, a suitable match of good quality PV panels and quality inverter can generate a few hundred kWh more than low cost components. This might account for the difference in generation.

Tech Ref	System size (kW)	Installation date	Direction of panels	Estimated annual generation (kWh)
C-01	3	09-Jul-14	East/West (115°/295°)	2316
C-02	3.75	03-Jun-15	South (some shading)	3574
C-03	3	16-Mar-15	South (160°)	2829
C-04	3.5	27-Mar-15	East (93°, some shading)	2772
C-05	2.9	30-Nov-15	South West (240°)	2514
C-06	2.25	06-Jan-16	South (192°)	2378

Table 3.25 Details of the solar PV systems installed at the control properties

Tech Ref	Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
C-01	2016	53.1	93.1	177.4	261.0	320.8	283.8	317.8	284.1	181.3	122.1	66.1	38.9	2199.6
C-01	2017	54.0	23.0	0.0	0.0	163.7	336.0	295.3	250.3	176.7	113.6	70.2	40.1	1522.8
C-01	2018	48.4	102.6	118.5	198.7	320.7	332.5	306.6						1428.0
C-02	2016	109.1	196.8	336.3	307.7	93.5	408.1	484.7	484.1	336.3	239.7	125.6	76.4	3198.3
C-02	2017	116.7	120.3	334.9	454.5	434.0	489.5	449.0	391.0	295.4	169.8	91.6	60.0	3406.8
C-02	2018	80.5	180.7	197.5	330.5	538.4	504.2	528.8						2360.4
C-03	2016	108.6	172.2	292.3	395.1	443.7	360.7	440.3	425.4	294.7	231.8	157.4	100.3	3422.4
C-03	2017	128.6	118.3	279.6	380.3	363.5	421.1	381.6	337.6	267.4	183.6	139.8	91.0	3092.4
C-03	2018	95.6	186.4	169.1	270.8	445.1	415.7	443.4						2026.1
C-04	2016	60.5	110.8	219.9	342.0	417.3	358.4	435.8	380.3	171.5	158.9	60.7	47.4	2763.6
C-04	2017	66.9	84.0	219.0	358.9	390.3	456.2	380.5	332.5	225.8	144.5	87.4	47.6	2793.5
C-04	2018	57.6	119.2	153.2	255.6	453.5	443.9	475.8						1958.8
C-05	2016	70.5	134.0	234.6	322.6	400.9	353.9	398.8	371.4	251.4	172.0	90.4	55.0	2855.6
C-05	2017	79.5	88.3	253.2	341.9	368.8	422.0	384.1	310.0	237.9	146.7	95.1	52.8	2780.4
C-05	2018	64.2	129.9	154.1	261.7	447.9	445.9	448.5						1952.3
C-06	2016	57.9	124.1	200.8	269.3	322.9	264.5	319.8	303.5	202.2	159.5	89.0	49.5	2362.8
C-06	2017	71.7	82.0	209.0	286.6	287.3	324.5	299.8	255.0	195.8	139.7	91.0	51.3	2293.6
C-06	2018	60.5	141.2	128.5	207.2	358.5	347.6	358.7						1602.2

Table 3.26 Monthly and annual values of solar PV generation (kWh) for the control properties without batteries

The monthly PV generation between January 2016 and July 2018 for household C-03 is shown in figure 3.27. This illustrates the variation over the year and between years.

[43] Guide to the Installation of Photovoltaic Systems (MCS, 2012) https://www.microgenerationcertification.org/images/PV%20Book%20ELECTRONIC.pdf (Accessed 13 Sept 18)

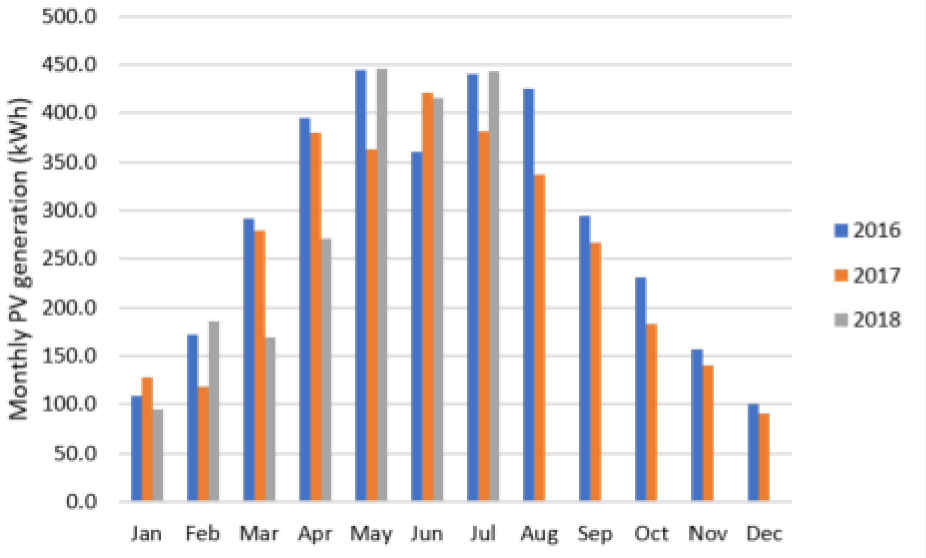

Figure 3.27 Monthly values of PV generation for control property C-03

Households were asked to regularly record their electricity meter readings. Tables 3.28 to 3.30 show the electricity consumption from the grid and PV generation for households C-01, C-03 and C-05.

Start date	End date	Consumption (kWh)	Consumption (kWh/day)	Month	Generation (kWh/day)
05-Jan-17	02-Feb-17	529	18.89	Jan-17	1.74
02-Feb-17	02-Mar-17	444	15.86	Feb-17	0.82
02-Mar-17	30-Mar-17	333	11.89	Mar-17	0.00
30-Mar-17	27-Apr-17	249	8.89	Apr-17	0.00
27-Apr-17	23-May-17	211	8.12	May-17	5.28
23-May-17	20-Jun-17	146	5.21	Jun-17	11.20
20-Jun-17	01-Aug-17	193	4.60	Jul-17	9.53
01-Aug-17	30-Aug-17	187	6.45	Aug-17	8.07
30-Aug-17	26-Sep-17	200	7.41	Sep-17	5.89
26-Sep-17	25-Oct-17	236	8.14	Oct-17	3.66
25-Oct-17	05-Dec-17	583	14.22	Nov-17	2.34
05-Dec-17	02-Jan-18	502	17.93	Dec-17	1.29

Table 3.28 Electricity consumption from the grid and PV generation for household C-01 in 2017

Household C-01 has space and water heating provided by an Air Source Heat Pump (ASHP) and this is likely to be the reason for the large daily grid consumption (table 3.28), particularly in winter. The household had 2 residents who are retired. They used an electric cooker or microwave every day and a washing machine once a week. They had a separate fridge and a freezer. As noted before, the PV system was offline between February and May 2017, leading to increased consumption.

Table 3.29 shows that the daily electricity grid consumption for household C-03 was significantly lower than for C-01. Here there was a single retired resident and the heating is supplied by mains gas. The electric cooker and/or microwave was used most meal times and the washing machine was used 3 to 4 times a week. There was a fridge freezer and a separate chest freezer.

Start date	End date	Consumption (kWh)	Consumption (kWh/day)	Month	Generation (kWh/day)
06-Jan-17	03-Feb-17	110	3.93	Jan-17	4.15
03-Feb-17	03-Mar-17	119	4.25	Feb-17	4.23
03-Mar-17	13-Apr-17	123	3.00	Mar-17	9.02
13-Apr-17	09-May-17	70	2.69	Apr-17	12.68
09-May-17	09-Jun-17	77	2.48	May-17	11.73
09-Jun-17	10-Jul-17	65	2.10	Jun-17	14.04
10-Jul-17	10-Aug-17	88	2.84	Jul-17	12.31
10-Aug-17	08-Sep-17	87	3.00	Aug-17	10.89
08-Sep-17	12-Oct-17	113	3.32	Sep-17	8.91
12-Oct-17	26-Oct-17	52	3.71	Oct-17	5.92
26-Oct-17	19-Nov-17	95	3.96	Nov-17	4.66
19-Nov-17	02-Jan-18	214	4.86	Dec-17	2.94

Table 3.29 Electricity consumption from the grid and PV generation for household C-03 in 2017

Start date	End date	Consumption (kWh)	Consumption (kWh/day)	Month	Generation (kWh/day)
05-Jan-17	03-Feb-17	276	9.52	Jan-17	2.57
03-Feb-17	02-Mar-17	228	8.44	Feb-17	3.15
02-Mar-17	13-Apr-17	244	5.81	Mar-17	8.17
13-Apr-17	09-May-17	178	6.85	Apr-17	11.40
09-May-17	08-Jun-17	78	2.60	May-17	11.90
08-Jun-17	10-Jul-17	143	4.47	Jun-17	14.07
10-Jul-17	03-Aug-17	126	5.25	Jul-17	12.39
03-Aug-17	31-Aug-17	166	5.93	Aug-17	10.00
31-Aug-17	28-Sep-17	165	5.89	Sep-17	7.93
28-Sep-17	09-Nov-17	256	6.10	Oct-17	4.73
09-Nov-17	05-Dec-17	192	7.38	Nov-17	3.17
05-Dec-17	07-Jan-18	265	8.03	Dec-17	1.70

Table 3.30 Electricity consumption from the grid and PV generation for household C-05 in 2017

Household C-05 (table 3.30) was also heated by gas, however there was an electric shower which was used daily and an electric fan heater was used briefly on winter mornings. The property had 2 residents, with 1 retired. There was a gas cooker, but the microwave was rarely used. The washing machine was used 2 to 3 times a week. There was a fridge/freezer and another large freezer. The TVs and computers in the house were always left on standby.

It is apparent that the consumption in household C-05 was higher in 2017 than for C-03. While there were 2 residents in C-05 compared to just 1 in C-03, the factor most likely to cause the higher grid consumption was likely to be the daily use of an electric shower. These devices often draw 8 to 10 kW of power. Therefore, a 15-minute shower could consume 2kWh or more.

3.4 Maslow V3 batteries

	Percentage time the battery was online															
Period	T-01	T-02	T-03	T-04	T-05	T-06	T-07	T-08	T-09	T-10	T-11	T-12	T-13	T-14	T-15	T-16
Jun-16	0.0%	0.0%	0.0%	53.0%	42.8%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	47.6%
Jul-16	37.4%	54.0%	9.2%	49.2%	34.4%	15.0%	10.1%	8.2%	15.1%	7.6%	29.0%	0.5%	3.1%	32.1%	0.0%	42.5%
Aug-16	95.6%	96.6%	0.0%	0.0%	0.0%	96.3%	78.5%	96.3%	14.1%	96.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Sep-16	48.7%	96.1%	0.0%	49.0%	0.0%	89.4%	79.6%	94.8%	44.0%	97.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Oct-16	0.0%	98.1%	0.0%	90.2%	0.0%	83.1%	4.4%	99.1%	0.0%	96.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Nov-16	0.0%	96.5%	8.0%	90.9%	8.0%	94.9%	0.0%	95.4%	0.0%	90.0%	8.0%	0.0%	7.9%	0.0%	0.0%	8.0%
Dec-16	0.0%	2.0%	18.4%	91.1%	18.4%	18.4%	0.0%	18.4%	56.5%	17.9%	18.4%	0.0%	18.4%	0.0%	0.0%	17.7%
Jan-17	40.4%	0.0%	0.0%	94.7%	0.0%	0.0%	0.0%	0.0%	100.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Feb-17	100.0%	0.0%	0.0%	98.3%	0.0%	0.0%	0.0%	0.0%	99.9%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Mar-17	100.0%	73.8%	74.1%	22.9%	73.5%	73.6%	0.0%	66.4%	99.9%	73.2%	74.2%	52.4%	74.0%	73.8%	74.0%	74.1%
Apr-17	98.5%	96.6%	97.7%	0.0%	59.1%	97.9%	47.0%	54.6%	98.5%	96.6%	98.4%	97.9%	98.3%	98.3%	91.5%	98.2%
May-17	96.2%	93.0%	81.9%	45.8%	70.8%	81.8%	71.4%	83.2%	94.0%	91.4%	93.7%	92.6%	93.6%	94.3%	96.0%	93.9%
Jun-17	64.0%	98.8%	3.1%	10.5%	21.2%	0.0%	0.0%	0.0%	99.9%	100.0%	99.9%	99.0%	98.3%	99.5%	98.1%	100.0%
Jul-17	0.0%	98.7%	100.0%	96.7%	41.3%	11.6%	0.0%	0.0%	99.9%	59.3%	99.4%	99.2%	99.8%	99.7%	99.8%	99.8%
Aug-17	31.0%	98.6%	99.9%	83.6%	28.6%	99.9%	0.0%	0.0%	99.9%	0.0%	99.4%	99.2%	99.8%	99.0%	99.7%	99.9%
Sep-17	99.7%	99.6%	99.6%	89.5%	4.8%	99.7%	0.0%	41.1%	99.7%	0.0%	99.7%	99.5%	99.5%	99.6%	99.5%	99.6%
Oct-17	97.3%	97.2%	57.1%	0.0%	0.0%	97.2%	0.5%	97.2%	97.0%	17.7%	96.4%	96.4%	96.9%	96.7%	96.6%	97.2%
Nov-17	98.3%	98.0%	98.3%	0.0%	0.0%	98.3%	1.2%	98.2%	98.2%	49.8%	97.9%	89.7%	98.1%	98.3%	94.9%	94.8%
Dec-17	97.7%	97.6%	97.7%	0.0%	0.0%	97.6%	0.0%	89.1%	97.6%	0.0%	97.3%	95.9%	97.4%	97.3%	96.0%	88.4%
Jan-18	98.8%	98.5%	98.7%	0.0%	0.0%	98.8%	0.0%	98.7%	98.7%	27.5%	98.1%	90.5%	98.4%	98.4%	92.3%	75.3%
Feb-18	96.6%	96.7%	96.7%	0.0%	0.0%	96.6%	0.0%	96.3%	96.6%	33.6%	94.7%	95.7%	96.6%	96.7%	96.7%	0.0%
Mar-18	93.4%	100.0%	100.0%	0.0%	0.0%	99.6%	0.0%	99.2%	99.9%	0.0%	99.9%	99.5%	55.0%	87.4%	99.3%	0.0%
Apr-18	99.7%	93.5%	99.5%	0.0%	0.0%	7.9%	0.0%	97.6%	99.7%	0.0%	67.7%	99.2%	99.4%	18.3%	98.8%	0.0%
May-18	99.9%	99.9%	99.9%	0.0%	0.0%	0.0%	0.0%	99.9%	99.9%	0.0%	0.0%	99.8%	99.9%	99.9%	99.9%	0.0%
Jun-18	99.6%	66.5%	99.7%	0.0%	0.0%	0.0%	0.0%	99.5%	99.7%	0.0%	0.0%	99.8%	99.5%	99.6%	99.6%	0.0%
Jul-18	95.7%	71.6%	96.3%	0.0%	0.0%	0.0%	0.0%	96.3%	9.5%	76.6%	0.0%	94.3%	94.6%	96.5%	96.4%	0.0%
2017	**76.6%**	**79.8%**	**67.9%**	**40.0%**	**25.2%**	**63.5%**	**10.1%**	**44.47%**	**98.7%**	**40.77%**	**80.13%**	**77.2%**	**80.1%**	**80.1%**	**79.6%**	**79.3%**

Table 3.31 Percentage time the Maslow batteries were online, with interviewed households shaded darker

There were 16 Maslow V3 batteries installed in this project. All had a total battery capacity of 2kWh. Among these installations, those at households T-01 to T-04 were part of the monitored group where the residents were interviewed at the start and end of the project.

The batteries typically only recorded performance data when they had an online connection. In some cases a battery was offline for many days with no data recorded. Sometimes there were also gaps in the data of a few minutes. Moixa have more recently added a firmware update which aims to provide a week of data storage. Not all of the systems have been updated and it was not effective in every situation.

Table 3.31 shows the percentage of the time each month that these batteries were online, recording performance data and able to charge or discharge. The batteries usually first came online at the time of installation. It can be seen that 11 of the batteries were online for greater than 60% of the time during 2017. Out of the monitored group, T-04 was online for only 40% of 2017. Reasons for this include the PV system tripping and sending the battery into bypass mode, rewiring of the house and switching internet service provider so the battery lost WI-FI connection.

A summary the best performing Maslow battery/solar systems is shown in table 3.32. This is for the period 1 July 2017 to 30 June 2018 and covers the second year of operation. These batteries were online and recording data for between 79.2 and 98.9% of that period.

	T-01	T-02	T-03	T-09	T-11	T-12	T-13	T-14	T-15
PV system size (kW)	4	4	2.45	2.4	3	1.88	2.4		2.5
Moixa battery size (kWh)	2	2	2	2	2	2	2	2	2
Percentage online during period (%)	84.0%	95.4%	95.5%	98.9%	79.2%	97.0%	95.0%	91.0%	98.0%
Sum of PV (kWh)	2573.2	3140	2284.7	2512.1	2081.7	2007	2019.8	1624.1	2667.6
Sum of household consumption (kWh)	3427.5	9999.7	4440.8	3127.3	4789.7	2540.4	6508.6	5217.2	4371.3
Sum of PV used (kWh)	823.2	2431.5	1339	994.5	1162.7	947.2	1302.6	1097.4	2346.7
Sum of battery discharge (kWh)	218.4	179.7	293.8	340.8	303.2	199.2	197.8	207.5	152.4
Sum of grid consumption (kWh)	2401	7400.7	2820.2	1816.3	3327.0	1411.2	5017.12	3914.4	3072.1

Table 3.32 Summary of the 9 best performing Maslow batteries between 1 Jul 17 and 30 Jun 18

The amount of annual battery discharge is influenced by a range of factors:

- Excess solar PV generation – in order to charge the battery there must be periods where the solar generation is greater than the household consumption (excess generation).
- Household consumption – to maximise battery discharge, the consumption needs to be sufficiently high overnight to regularly discharge the battery.
- Patterns of generation and consumption – If consumption is too high during the day, the battery may not fully charge. Short periods of high consumption discharge the Maslow battery less than longer periods of medium consumption.

Household T-15 had a battery discharge of 152.4 kWh, which was lowest for the systems shown in table 3.32 This was primarily due to the low excess solar generation as indicated by the small difference between the PV generated and PV used. Household T-09 had the highest battery discharge (340.8kWh). This is can be explained by a high excess solar generation. Here the difference between the total amount generated by the PV system and the amount of PV generation consumed by the household was one of the highest for the households in table 3.32, ensuring the battery was regularly charged.

The issue of excess solar generation is clearly illustrated in another NEA battery storage study, 24/7 Solar, in collaboration with the London Borough of Camden[44]. Here a Maslow battery was fitted on a small 1.36kW PV system facing north which generated 937kWh over the year. The household consumption was high (8359kWh) and most of the PV generation was consumed by the household leaving little to charge the battery. This resulted in a low annual battery discharge of only 31kWh.

Household T-01 with a Maslow 2kWh battery

[44] 24/7 Solar NEA available at http://www.nea.org.uk/hip/24-7-solar-london-borough-camden/ [Accessed 03/01/2019]

Household T-01 had 2 residents, with one retired and the other working full time. They had a privately owned 4kW solar PV system which was split across roofs facing approximately east and west. It was installed in July 2014 and the MCS certificate estimated the annual PV generation to be 3132kWh. The property was a mid-terraced house with gas central heating.

The performance of the battery-solar system is shown in table 3.33. The battery discharge between July 2017 and June 2018 was 218.4kWh. This was about average for the Maslow systems which were online for in excess of 80% of the year. It should be noted that there were issues with the system between July 2017 and September 2017. The battery was offline for all of July 2017 and most of August 2017. The battery discharge was also abnormally low in September 2017. Had the system been performing correctly between July and September 2017, the annual discharge would have been among the highest for the Maslow batteries on this project.

Date	% Online	Battery discharge (kWh)	Solar PV Production (kWh)	Solar PV Consumed (kWh)	Household Consumption (kWh)	Consumption from grid (kWh)	Battery discharge (kWh/day)	Consumption from grid (kWh/day)
Jul-17	0.0%	0.0	0.0	0.0	0.0	0.0	0	0
Aug-17	31.0%	0.5	120.2	27.8	53.8	25.8	0.05	2.68
Sep-17	99.7%	1.4	281.1	89.4	263.5	173.3	0.05	5.79
Oct-17	97.2%	20.9	183.4	63.6	306.5	223.1	0.69	7.40
Nov-17	98.3%	29.3	118.8	68.1	395.6	299.5	0.99	10.16
Dec-17	97.7%	13.8	84.8	63.6	560.1	483.0	0.46	15.95
Jan-18	98.8%	24.3	98.1	54.8	460.6	382.0	0.79	12.47
Feb-18	96.6%	13.8	153.0	43.4	171.6	115.6	0.51	4.28
Mar-18	93.7%	35.3	184.7	67.7	439.8	338.1	1.21	11.63
Apr-18	99.7%	38.4	311.6	101.0	361.6	224.3	1.28	7.50
May-18	99.9%	20.9	512.3	115.3	206.5	74.0	0.67	2.39
Jun-18	99.6%	19.9	525.3	128.7	207.9	62.5	0.67	2.09
Totals		**218.4**	**2573.2**	**823.3**	**3427.5**	**2401.0**		

Table 3.33 Performance of Maslow battery system at household T-01 between July 2017 and June 2018

Figure 3.34 shows a bar chart illustrating the energy flows in kWh every half hour for the battery solar system for household T-01 between 9 Oct 18 and 10 Oct 18. It is apparent there was discharge of the battery between midnight and 01:30 due to high levels of household consumption. In the middle of the day the PV system generated significantly more power than the household was consuming. This meant the battery charged between 07:30 and 13:00, with additional excess generation exported to the grid. From 18:00, the household consumption increased, and the solar generation fell away. The battery supplied part of the household demand from 18:30 until 23:30.

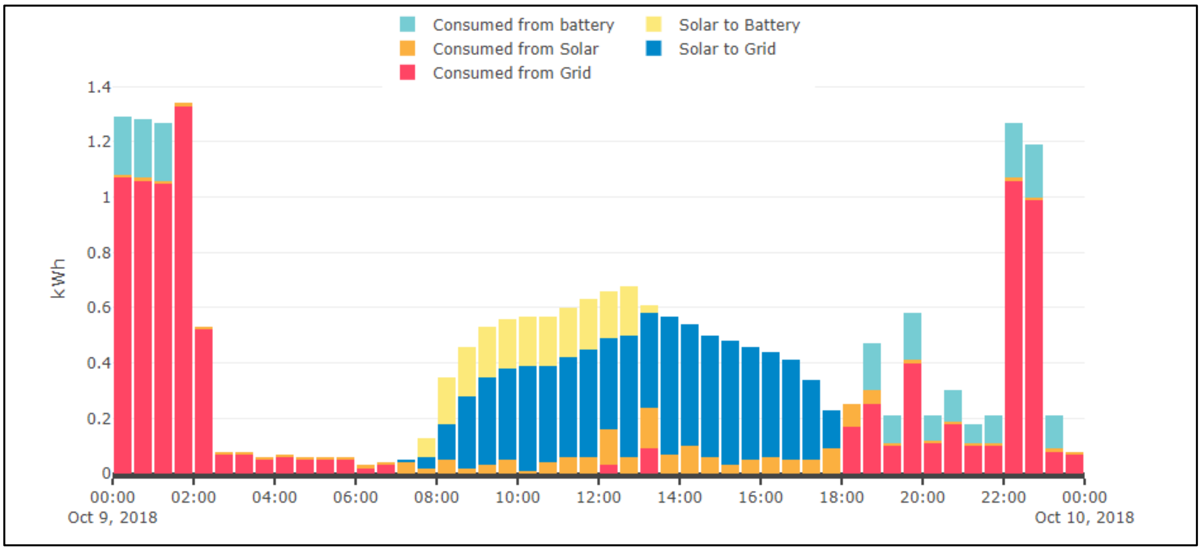

Figure 3.34 Plot of energy flows for Household T-01 with a Maslow battery and 4kW solar PV system on 9 Oct 18

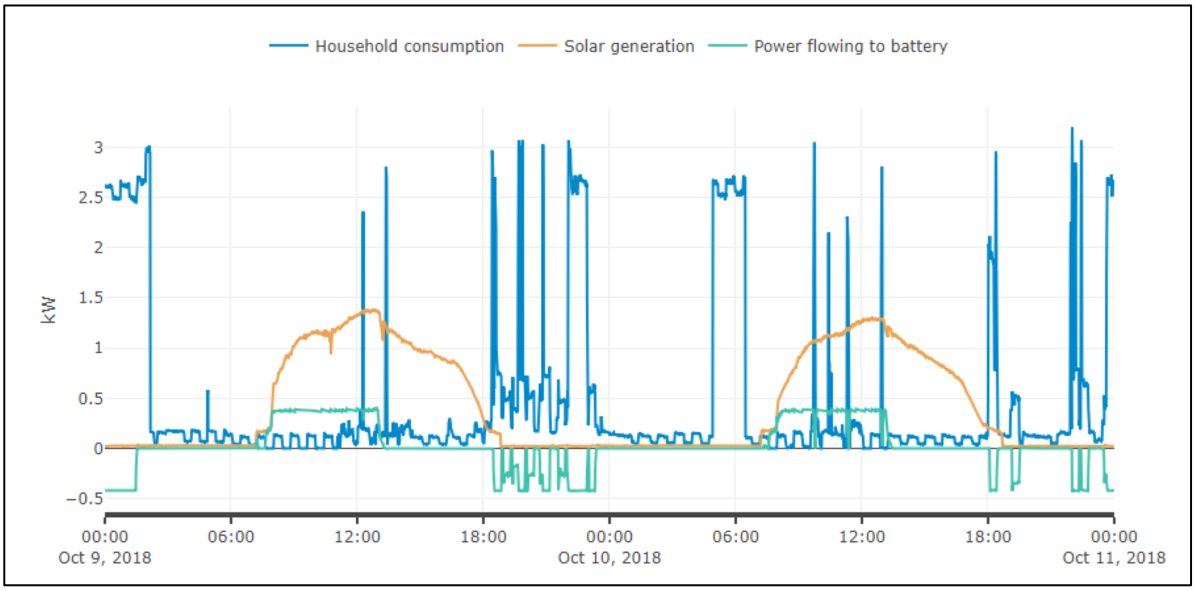

Figure 3.35 Plot of energy flows for Household T-01 between 9 Oct 18 and 11 Oct 18

A plot of power against time illustrating household consumption, solar generation and battery input/output is shown in figure 3.35 for the period between 9 Oct 18 and 11 Oct 18. The power flowing to and from the battery is shown in green, with the battery charge being positive and discharge being negative. The consumption for household T-01 is typified be a series of spikes of 3 to 5kW. There was also a variation in the baseload power consumption between less than 100W about 200W. This is most likely due to the fridge turning on an off during the day. The Maslow battery does not supply power for this baseload consumption, but only about 430W towards periods with higher consumption.

Household T-02 with a Maslow 2kWh battery

Household T-02 was made up of 2 adults and 2 children. There was again a 4kW solar PV system which was split across approximately east and west-facing roofs. This was installed in October 2014 and the estimated annual generation on the MCS certificate was 3300kWh. Space heating for the mid-terraced property was provided by storage heaters at the start of the project, but these were replaced by gas central heating in July/August 2017. The residents noted that their energy bills had become more affordable since switching from storage heaters to gas. Water heating was provided by a 3kW immersion heater along with a Solar iBoost system which diverted excess solar PV generation for use by the immersion heater.

Table 3.36 shows the performance of the battery solar system between July 2017 and June 2018. The household electricity consumption was almost 10,000kWh despite switching from electric to gas space heating. The high electricity consumption was due to regular use of high consuming appliances: there was a 8.5kW electric shower, which was used 4 times a day. The cooker had an electric hob and oven, while the washing machine and tumble drier tended to be used daily. There were several TVs and also a number of old arcade machines which were used for parties at weekends.

The solar PV generation was the highest among the 9 better performing Maslow systems. This meant that despite the high household consumption, there was excess solar PV generation to charge the battery and power the Solar iBoost immersion heater. In July and August 2017, the monthly battery discharge was in excess of 30kWh. By May 2018 it had fallen to 15.3kWh and to only 2kWh in June 2018. A few weeks later, the battery system went offline.

Date	% Online	Battery discharge (kWh)	Solar PV Production (kWh)	Solar PV Consumed (kWh)	Household Consumption (kWh)	Consumption from grid (kWh)	Battery discharge (kWh/day)	Consumption from grid (kWh/day)
Jul-17	98.7%	37.6	432.7	326.4	826.9	465.0	1.23	15.19
Aug-17	98.6%	34.2	386.4	296.4	783.8	455.4	1.12	14.90
Sep-17	99.6%	22.2	268.5	230.6	802.1	550.3	0.74	18.43
Oct-17	97.2%	11.3	176.4	129.6	548.0	407.9	0.37	13.53
Nov-17	98.0%	7.6	110.9	100.0	798.8	691.5	0.26	23.53
Dec-17	97.6%	3.0	79.6	78.0	1055.7	974.8	0.10	32.22
Jan-18	98.5%	5.8	93.6	89.7	1024.4	929.2	0.19	30.44
Feb-18	96.7%	8.2	145.6	135.1	919.4	776.3	0.30	28.67
Mar-18	100.0%	12.5	193.7	172.9	936.1	751.2	0.40	24.24
Apr-18	93.5%	19.9	268.0	220.7	760.7	521.9	0.71	18.61
May-18	99.9%	15.3	497.5	328.4	783.4	441.8	0.49	14.27
Jun-18	66.5%	2.0	487.2	323.6	760.5	435.3	0.10	21.83
Totals		**179.7**	**3140.0**	**2431.5**	**9999.7**	**7400.7**		

Table 3.36 Performance of Maslow battery system at household T-01 between July 2017 and June 2018

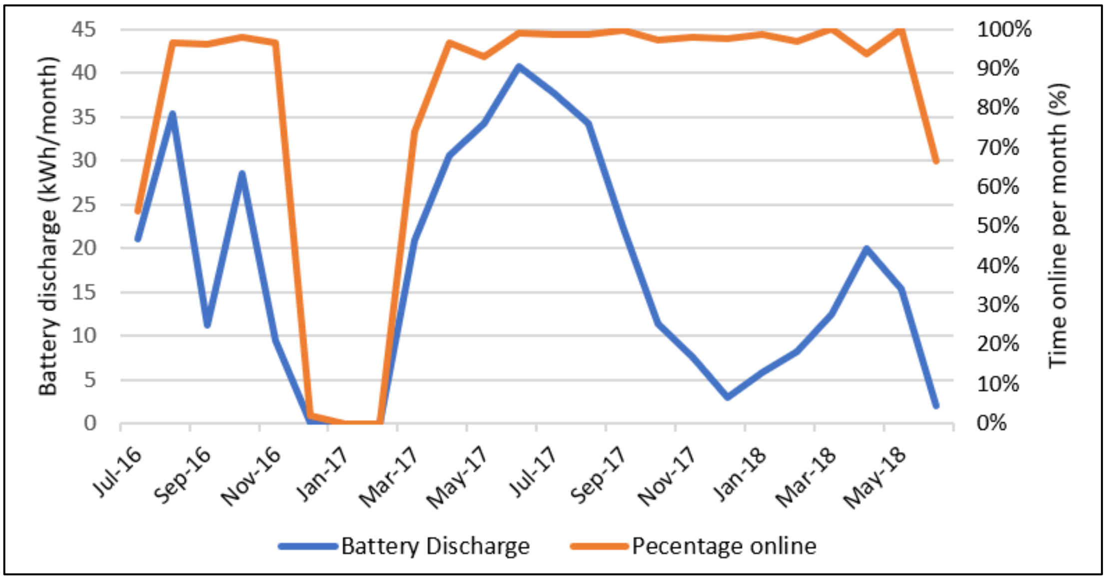

Figure 3.37 Variation in monthly battery discharge for household T-02 with a Maslow battery

Figure 3.37 illustrates how the monthly battery discharge varied from installation in July 2016 up to June 2018. When the battery system was not online, the battery discharge was not recorded, and this accounts for the low values between December 2016 and March 2017 and also in June 2018.

A peak in the battery discharge is expected in the summer when there is higher generation. However, this peak is clearly lower in summer 2018 than summer 2017. This is despite there being little significant difference in the household consumption and PV generation between the 2 periods. The reason for this variation is unclear, but it is likely to be the result of a hardware fault. The battery was offline at the time of writing and it was not possible to plot graphs to investigate the reason for this behaviour further.

Household T-03 with a Maslow 2kWh battery

Household T-03 consisted of 2 adults and a young adult living at home part time. The property was at the end of a terrace and had gas centrally heating, although it previously had storage heaters and was still on an Economy 7 tariff. There was a 2.4kW solar PV system which was facing 165° south. This was funded by a rent a roof scheme and was installed in December 2013. The annual PV generation was estimated to be 2176kWh on the MCS certificate.

The shower in the property was a mixer shower, with water heating from the gas boiler. The washing machine was used daily, and a tumble drier was used in winter. There was a plasma TV with a consumption of 255W, which was regularly used during the day and evenings. Table 3.38 shows that the household consumption was 4441kWh, which was less than half the value for T-02. There was a high difference between the solar PV production and the amount of solar PV consumed, ensuring the battery was regularly charged.

Date	% Online	Battery discharge (kWh)	Solar PV Production (kWh)	Solar PV Consumed (kWh)	Household Consumption (kWh)	Consumption from grid (kWh)	Battery discharge (kWh/day)	Consumption from grid (kWh/day)
Jul-17	100.0%	44.5	295.8	171.5	377.2	161.5	1.44	5.21
Aug-17	99.9%	43.4	270.5	152.0	380.1	185.0	1.40	5.97
Sep-17	99.6%	33.8	202.9	117.8	345.6	194.3	1.13	6.51
Oct-17	57.0%	17.0	91.5	52.3	194.1	125.1	0.96	7.07
Nov-17	98.3%	9.0	95.9	74.8	427.3	343.8	0.31	11.66
Dec-17	97.7%	6.7	66.5	54.8	450.8	389.5	0.22	12.86
Jan-18	98.7%	6.9	73.9	59.1	413.4	347.5	0.23	11.36
Feb-18	96.7%	13.6	125.1	90.1	382.8	279.9	0.50	10.34
Mar-18	100.0%	12.2	132.3	93.2	409.0	303.9	0.39	9.81
Apr-18	99.5%	25.5	220.8	126.2	366.5	216.6	0.85	7.25
May-18	99.9%	41.0	353.7	161.7	330.6	131.5	1.32	4.24
Jun-18	99.7%	40.1	355.9	185.5	363.5	141.5	1.34	4.73
Totals		**293.8**	**2284.7**	**1339.0**	**4440.8**	**2820.2**		

Table 3.38 Performance of Maslow battery system at household T-03 between July 2017 and June 2018

Figures 3.39 and 3.40 illustrate the energy flows in kWh and kW for household T-03. The 9th and 10th of October were sunny days and excess solar generation during the middle of the day charged the Maslow battery by about 15:00. The household consumption was more consistent during the day and early evening for T-03 compared to T-01. This meant that the battery fully discharged by about 21:00. Regularly fully charging and discharging the battery is likely to have led to the annual battery discharge being one of the highest for the Maslow battery systems that were installed.

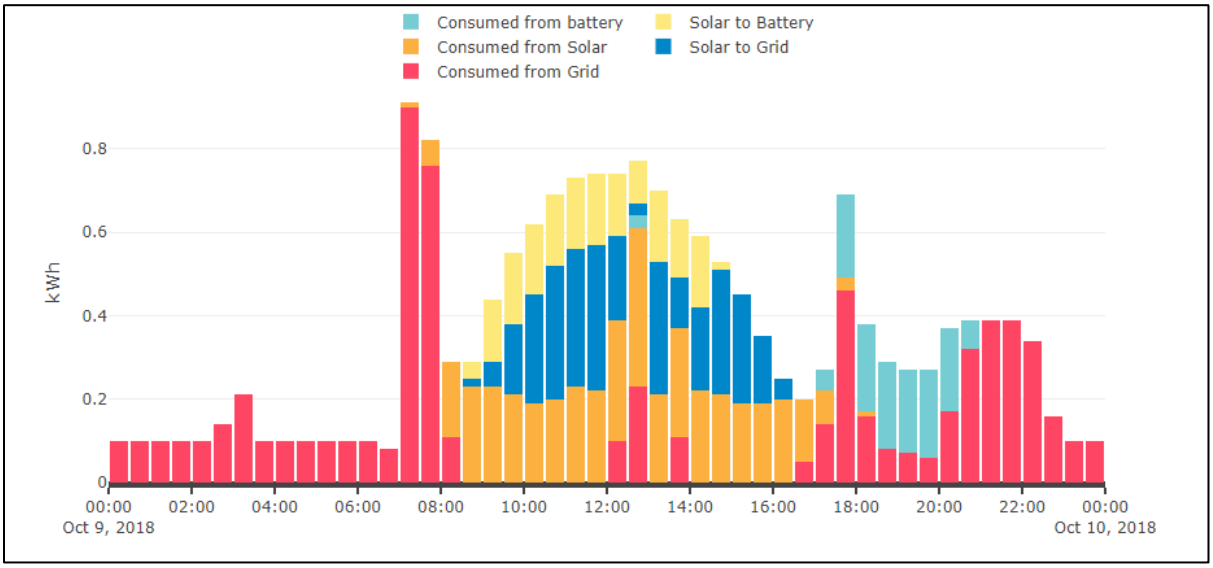

Figure 3.39 Plot of energy flows for Household T-03 with a Maslow battery and 2.4kW solar PV system on 9 Oct 18

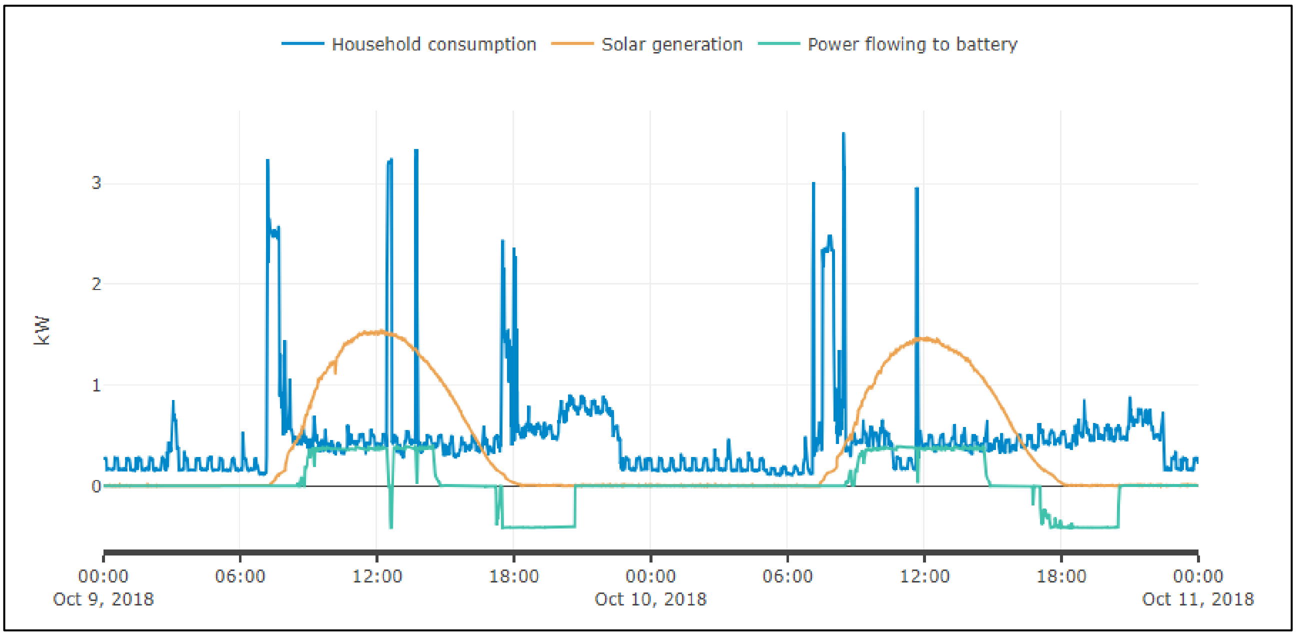

Figure 3.40 Plot of energy flows for Household T-03 between 9 Oct 18 and 11 Oct 18

Electricity meter readings and generation meter readings were recorded by the household. These are presented in table 3.41 for comparison with the data recorded by the Maslow system in table 3.38. Meter reading data was also available for previous years and this is presented in table 3.42. The solar PV system was fitted in December 2013. The period prior to the PV installation is shaded light in the table, with the period with battery and solar shaded darkest. Prior to the PV installation, the daytime grid consumption was between 9 and 9.8kWh/day. In 2015, after the PV system was installed, but before the battery, the daytime consumption had fallen to 6.89kWh/day. After the battery was fitted, the grid consumption was 6.3 to 7.2kWh/day. There are usually variations in household consumption between years due to changes in behaviour. This makes it harder to determine the impact of energy saving technologies from energy bill data alone.

Start Date	End date	Number of days	Total Grid consumption (kWh)	Solar PV Generation (kWh)	Average PV generation (kWh/day)	Average Grid consumption (kWh/day)
11-Jul-17	08-Aug-17	28	159	264	9.43	5.68
08-Aug-17	05-Sep-17	28	161	229	8.18	5.75
05-Sep-17	03-Oct-17	28	185	218	7.79	6.61
03-Oct-17	31-Oct-17	28	227	115	4.11	8.11
31-Oct-17	28-Nov-17	28	294	91	3.25	10.50
28-Nov-17	26-Dec-17	28	356	60	2.14	12.71
26-Dec-17	23-Jan-18	28	291	60	2.14	10.39
23-Jan-18	20-Feb-18	28	271	112	4.00	9.68
20-Feb-18	20-Mar-18	28	273	115	4.11	9.75
20-Mar-18	17-Apr-18	28	243	178	6.36	8.68
17-Apr-18	22-May-18	35	154	386	11.03	4.40
22-May-18	19-Jun-18	28	131	297	10.61	4.68
19-Jun-18	12-Jul-18	23	111	315	13.70	4.83
Total		**366**	**2856**	**2440**		

Table 3.41 Grid consumption and PV generation for household T-03 between July 2017 and July 2018

Start Date	End date	Number of days	Day Grid consumption (kWh)	Night Grid consumption (kWh)	Average day consumption (kWh/day)	Average night consumption (kWh/day)
24-Sep-09	27-Sep-10	368	3336	1213	9.07	3.30
27-Sep-10	27-Sep-11	365	3578	1213	9.80	3.32
27-Sep-11	03-Oct-13	737	6653	1962	9.03	2.66
27-Dec-14	30-Dec-15	368	2535	442	6.89	1.20
23-Aug-16	22-Aug-17	364	2609	549	7.17	1.51
11-Jul-17	12-Jul-18	366	2302	554	6.29	1.51

Table 3.42 Grid consumption for T-03 between Sept 2009 and Jul 2018. The solar PV system was fitted in December 2013 and the Maslow battery in July 2016.

Financial benefit for households from the Maslow battery solar systems

Technical Reference Number	Period	Household consumption (kWh)	PV generation (kWh)	PV generation used (kWh)	Financial benefit from electricity savings from Solar PV (£)*	Battery discharge (kWh)*	Financial benefit from Battery Discharge (£)
T-01	1 Jul 17 to 30 Jun 18	3427.5	2573.2	823.2	£131.71	218.4	£34.94
T-02	1 Jul 17 to 30 Jun 18	9999.7	3140.0	2431.5	£389.04	179.7	£28.75
T-03	1 Jul 17 to 30 Jun 18	4440.8	2284.7	1339.0	£214.24	293.8	£47.01
T-09	1 Jul 17 to 30 Jun 18	3127.3	2512.1	994.5	£159.12	340.8	£54.53
T-11	1 Jul 17 to 30 Jun 18	4789.7	2081.7	1162.7	£186.03	303.2	£48.51
T-12	1 Jul 17 to 30 Jun 18	2540.4	2007.0	947.2	£151.55	199.2	£31.87
T-13	1 Jul 17 to 30 Jun 18	6508.6	2019.8	1302.6	£208.42	197.8	£31.65
T-14	1 Jul 17 to 30 Jun 18	5217.2	1624.1	1097.4	£175.58	207.5	£33.20
T-15	1 Jul 17 to 30 Jun 18	4371.3	2667.6	2346.7	£375.47	152.4	£24.38
	Maximum	9999.7	3140.0	2431.5	£389.04	340.8	£54.53
	Minimum	2540.4	1624.1	823.2	£131.71	152.4	£24.38
	Average	4935.8	2323.4	1382.8	£221.24	232.5	£37.21

* - This analysis assume the financial benefit fro a household on a single rate tariff of 16p/kWh

Table 3.43 Household financial benefits for Maslow battery-solar installations using a cost of 16p/kWh for electricity

Since the introduction of the Feed-in tariff for solar PV systems, an owner benefits financially from an installation in the following ways:

- Feed-in Tariff payment = Total PV generation x Feed-in tariff rate
- Export Tariff payment = 50% of Total PV generation x Export tariff rate (deemed export)
- Ability to consume any electricity generated by the PV system for free

The rate of the Feed-in Tariff and Export Tariff depends on the date of installation of the solar PV system. They increase with inflation and will be paid for a duration for 20 years (or 25 years if installed before 1 Aug 2012). The combination of electricity savings and FiT payments means that the cost of many installations would be repaid in 5 to 10 years. The Feed-in Tariff scheme for solar PV is due to close on 31 Mar 2019 for new PV installations, but existing installations will continue to receive payments over 20 or 25 years[45]. Households with ‘rent a roof’ solar PV systems only benefit from the ability to consume the electricity generated for free. The electricity savings would increase however if a battery is fitted and export to the grid is reduced. The Feed-in tariff and export tariff payments go to the company which paid for and owns the PV system.

Table 3.43 examines the financial benefit of the electricity savings from the solar PV system and the Maslow battery for the 9 battery systems that were online for over 75% of the time between 1 Jul 17 and 30 Jun 18. A single rate electricity price of 16p/kWh was used for all the households to aid fair comparison. The financial benefit of the electricity savings from the solar PV system was calculated by multiplying the amount of the solar PV generation that was consumed by the household by 16p/kWh. Savings for the solar PV systems ranged from £131 to £389. Household T-02, which made the greatest savings from the PV system was a high electricity consumer. As well as the Maslow battery, they also had a Solar iBoost which diverted excess electricity to power an electric immersion heater. The battery discharge for these Maslow battery systems ranged from 152.4kWh to 340.8kWh over the year. This equated to annual savings of between £24.38 and £54.53. The 2 households with the lowest savings from the Maslow battery had the greatest savings from the solar PV systems.

[45] BEIS confirms intent to cull export tariff alongside FiT in future solar proposals, Solar Power Portal, https://www.solarpowerportal.co.uk/news/beis_confirms_intent_to_cull_export_tariff_alongside_fit_in_future_solar_pr (Accessed 23 Oct 2018)

3.5 PowerFlow Sundial M2

Household T-17 with a PowerFlow 2kWh battery

Start Date	End date	Number of days	Grid consumption (kWh)	Average consumption (kWh/day)
28-Dec-16	24-Jan-17	27	416	15.41
24-Jan-17	20-Feb-17	27	367	13.59
20-Feb-17	22-Mar-17	30	336	11.20
22-Mar-17	26-Apr-17	35	245	7.00
26-Apr-17	24-May-17	28	180	6.43
24-May-17	21-Jun-17	28	173	6.18
21-Jun-17	19-Jul-17	28	251	8.96
19-Jul-17	16-Aug-17	28	227	8.11
16-Aug-17	27-Sep-17	42	350	8.33
27-Sep-17	29-Oct-17	32	279	8.72
29-Oct-17	28-Nov-17	30	348	11.60
28-Nov-17	04-Jan-18	37	868	23.46
TOTAL		**372**	**4040**	**10.86**

Table 3.44 Approximately monthly grid consumption for household T-17 after installation of the PowerFlow Sundial battery

The solar PV system for household T-17 was fitted in 2012 under a rent a roof scheme. This was a 2.82kW system facing about 170° south and having an inclination of about 30°. Using these figures and the MCS irradiance dataset for London (Zone 1), indicates an annual PV generation of about 974kWh/ kW_p or 2747kWh.

The PowerFlow Sundial M2 battery was installed on 26 July 2016. The total discharge from the battery unit by 12 July 18 was 534.6kWh. This was on average 0.75kWh/day. There were 2 x 1kWh battery cells in the unit and these discharged 163.8kWh and 370.8kWh respectively.

The electricity consumption between 27 July 2016 and 12 July 2018 was 7020kWh, with an average consumption of 9.82kWh per day. Table 3.44 shows approximately monthly values for the household electricity consumption during 2017. The resident used a dishwasher every morning and a washing machine 3 times a week. A hot tub was used during the summer from May 2017, which might have contributed to the higher summer electricity consumtion from 21 June 17.

Household T-18 with a PowerFlow 2kWh battery

The solar PV system for household T-18 was fitted in 2012 and had a total installed capacity of 2.88kW. The installation was facing approximately 100° East with an inclination of about 30°. Using the MCS irradiance dataset for Zone 1 (London), the annual generation is estimated to be about 2385kWh.

The PowerFlow battery was installed on 12 Jul 2016 and the battery had discharged a total of 281.8kWh by 11 Jul 2018, almost 2 years later. This was equivalent to 0.39kWh/day which was considerably lower than for Household T-17. The discharge from the individual 1kWh battery cells was 259.8kWh and 22kWh respectively. The difference in performance between cells is substantial. The battery was fitted below the stairs along with the consumer unit and electricity meter (figure 3.45). It is possible that there was some overheating of the battery unit due to a lack of space and ventilation and this led to the system partially shutting down. However, it is more likely that the poorly performing cell was from a substandard batch of Lithium-ion battery cells.

The property had gas central heating and a Solar Thermodynamic Box system contributed to the water heating. This had an aluminium collector on an external wall which absorbed heat for a thermodynamic assisted heat pump[46].

Figure 3.45 PowerFlow battery and electricity meters for household T-18

During the period of the study, the household was on an Economy 7 tariff. This was likely to be due to having electric storage heaters in the past and never switching to a single rate tariff. The residents were on a particularly competitive tariff until June 2018 where the Economy 7 day rate was cheaper than many single rate tariffs.

Table 3.46 shows the variation of electricity consumption between October 2012 and October 2016. It can be seen there was an increase in electricity consumption in more recent years and that the daytime consumption was several times that at night. Table 3.47 shows the approximately monthly grid consumption and PV generation for household T-18 after the battery was fitted. This is also illustrated in figure 3.48 over nearly 2 years. It can be seen there was little variation in the night-time consumption between months during the year. The day-time grid consumption varied between 17.19kWh/day in December 2016 to 5.42kWh/day in June 2017. A significant factor in this variation was the higher solar PV generation in summer.

Start Date	End date	Number of days	Day Grid consumption (kWh)	Night Grid consumption (kWh)	Average day consumption (kWh/day)	Average night consumption (kWh/day)
22-Oct-12	27-Nov-13	401	2637	765	6.58	1.91
27-Nov-13	23-Oct-14	330	1889	662	5.72	2.01
23-Oct-14	26-Oct-15	368	2680	705	7.28	1.92
26-Oct-15	28-Oct-16	368	3672	1009	9.98	2.74
TOTAL		**1467**	**10878**	**3141**	**7.42**	**2.14**

Table 3.46 Grid consumption for household T-18 after the solar PV system was fitted

46 What is a thermodynamic solar assisted heat pump https://www.magicboxinternational.com/hot-water/thermodynamic-solar-assisted-heat-pump/ (Accessed 5 October 2018)

Start Date	End date	Number of days	Day Grid consumption (kWh)	Night Grid consumption (kWh)	Average day consumption (kWh/day)	Average night consumption (kWh/day)	Solar PV Generation (kWh)	Average PV Generation (kWh/day)
23-Aug-16	29-Sep-16	37	247	90	6.68	2.43	162	4.38
29-Sep-16	28-Oct-16	29	247	70	8.52	2.41	203	7.00
28-Oct-16	04-Dec-16	37	478	101	12.92	2.73	79	2.14
04-Dec-16	05-Jan-17	32	550	92	17.19	2.88	36	1.13
05-Jan-17	08-Feb-17	34	449	100	13.21	2.94	59	1.74
08-Feb-17	05-Mar-17	25	287	65	11.48	2.60	73	2.92
05-Mar-17	04-Apr-17	30	267	74	8.90	2.47	189	6.30
04-Apr-17	03-May-17	29	270	67	9.31	2.31		
03-May-17	02-Jun-17	30	208	62	6.93	2.07		
02-Jun-17	05-Jul-17	33	179	74	5.42	2.24		
05-Jul-17	08-Aug-17	34	198	80	5.82	2.35		
08-Aug-17	07-Sep-17	30	212	80	7.07	2.67		
TOTAL		**380**	**3592**	**955**	**9.45**	**2.51**		

Table 3.47 Grid consumption and solar generation for household T-18 after the PowerFlow battery was installed

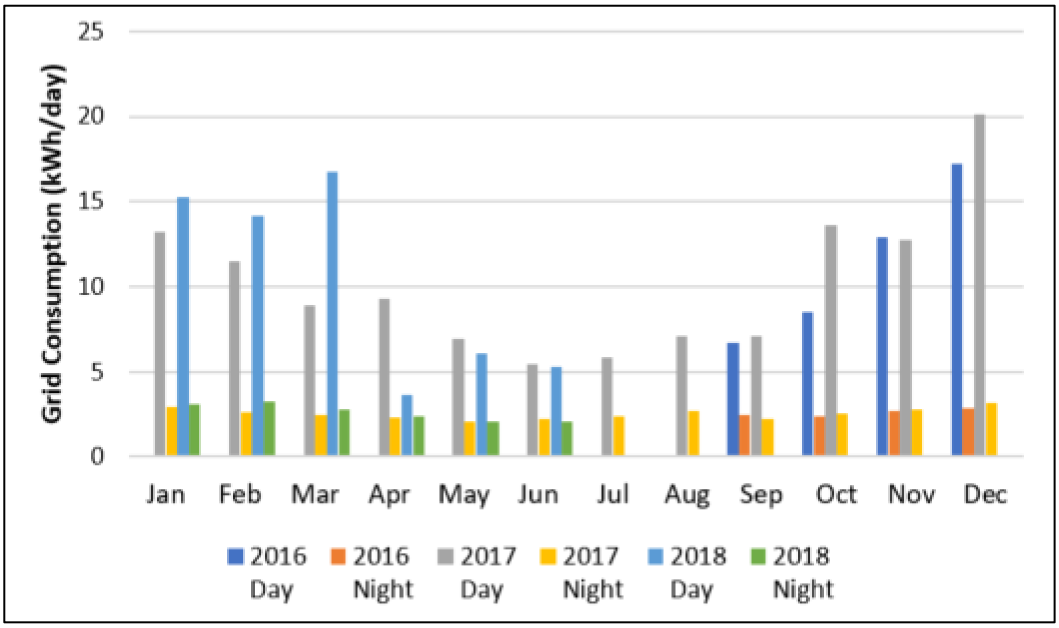

Figure 3.48 Plot of the grid consumption for household T-18 after the PowerFlow battery was installed

The household had a higher baseload electricity consumption, having 2 fridge freezers, a chest freezer and an mini fridge. There was a washing machine that was used 3 times a week in the morning. The electric hob and the dishwasher were used daily in the early evening. It is possible that the high household electricity consumption limited the excess solar generation which could be used to charge the PowerFlow battery.

Household T-19 with a PowerFlow 2kWh battery

Household T-19 comprised of 2 residents over 60 years old. The property was an end-terraced house with night storage heaters. The 4kW solar PV system was installed in July 2012, with half the array facing south east and the other half facing north west. The estimated annual generation on the MCS certificate was 2787kWh. The 7.5kW electric shower was used twice a day. The washing machine was used 4 times a week, early in the morning or when it was sunny outside. The cooker was all electric and a microwave was also used daily. Along with a fridge-freezer, there was a full sized larder freezer and a small chest freezer. These fridges and freezers are likely to have resulted in a higher baseload of electricity than some other properties. A 3kW kettle was used about 4 times a day.

The PowerFlow battery was installed on 19 Jul 16. The installers used the fuseway for the immersion heater in order to connect the battery on a temporary basis during battery installation. This issue was not however resolved and the residents were left without hot water for nearly a month until they appointed an electrician to resolve the issue.

Start Date	End data	Number of days	Battery Module 1 Discharge (kWh)	Battery Module 2 Discharge (kWh)	Total Battery Discharge (kWh)	Average discharge (kWh/day)
19-Jul-16	13-Jul-18	724	429	407.4	836.4	1.16

Table 3.49 Discharge from the PowerFlow Sundial SDM 2.0-500 battery installed at household T-19

Table 3.49 shows that the battery discharged a total of 836.4kWh over neary 2 years. This was the best performance of all the PowerFlow batteries in the study. The PV generation over a similar period in table 3.50 averaged at 8.44kWh/day. The PV generation was sufficiently high and the daytime consumption low enough to ensure there was excess solar generation to regularly charge the battery. The household consumption in the evening and overnight ensured the battery was also likely to regularly fully discharge.

Start Date	End data	Number of days	Day Grid Consumption (kWh)	Night Grid consumption (kWh)	Average day consumption (kWh/day)	Average night consumption (kWh/day)	Solar PV Generation (kWh)	Average PV Generation (kWh/day)
05-Jun-16	13-Jul-18	768	2550	9578	3.32	12.47		
31-Jul-16	13-Jul-18	712					6007	8.44

Table 3.50 Grid consumption and solar generation for household T-19 over the period of the study

Household T-20 with a PowerFlow 2kWh battery

Figure 3.51 PowerFlow Sundial battery installation with solar PV generation meter and electric utility meter

Household T-20 in Basildon had a 1.96 kW solar PV system installed on 1 Dec 2011. The installers predicted an annual generation of 2068kWh on the MCS certificate. The roof was orientated about 25° from south and had an inclination of about 30°. Using the MCS Irradiance data set for East Anglia (Zone 12) indicates that the estimated annual generation for the system was about 937kWh/kW$_p$ or 1837kWh.

The PowerFlow battery system was fitted on 29 Jun 2016 (Figure 3.51). There were initially issues with a loose connection on the MCB from the installation and spikes in the AC which led a fuse to blow in the first and a subsequent battery unit that was installed. A third battery was fitted on 22 Oct 2016.

The resident also purchased a PowerFlow ERS (Energy Recovery System) unit which was fitted on 24 Jul 2016 (Figure 3.52). Excess solar generation was first used to charge the Sundial battery. Any further excess generation was diverted by the ERS unit to power the immersion heater for the hot water tank and an Elnur 800W storage heater. This did not affect the performance of the battery system but will have reduced gas consumption.

Figure 3.52 PowerFlow Energy Recovery System (ERS) and Elnur SH6M 800W storage heater

Start Date	End date	Number of days	Grid consumption (kWh)	Average consumption (kWh/day)
28-Jun-04	16-Jun-05	353	3324	9.42
16-Jun-05	11-Jun-06	360	3378	9.38
11-Jun-06	08-May-07	331	3544	10.71
08-May-07	17-Jul-08	436	4062	9.32
29-Jul-08	28-May-09	303	2571	8.49
28-May-09	29-May-10	366	2535	6.93
29-May-10	15-May-11	351	2238	6.38
08-Jul-12	03-Jul-13	360	1206	3.35
03-Jul-13	29-Apr-14	300	1193	3.98
24-Apr-14	03-Jun-15	405	1438	3.55
03-Jun-15	03-Jun-16	366	1255	3.43
03-Jun-16	03-Jun-17	365	893	2.45
03-Jun-16	12-Jul-17	404	1004	2.49

Table 3.53 Grid consumption for household T-20. The different shading colours illustrate the periods before and after installation of solar PV on 1 December 2011 and for the installation of the battery on 29 Jun 2016

The resident was careful with his use of electrical appliances. He used the washing machine once a week and dishwasher twice a week, usually when the sun shined. The cooker had a gas hob and he rarely used the electric oven, instead using the microwave most evenings. There was a single fridge/freezer, but the TV was a plasma screen model which had a higher consumption. The resident however was diligent in turning off appliances left on standby.

Electricity meter readings had been regularly recorded by household T-20 since 2003. This allowed approximately annual values of electricity consumption to be determined along with the average electricity consumption per day. The period before the solar panels were installed in December 2011 is shaded lighter in table 3.53. The consumption was as high as 10.71 kWh/day in 2006/07 but decreased to 6.38kWh/day prior to the PV installation. Following the installation of the solar PV system, the average electricity consumption was in the range 3.35 to 3.98kWh/day. The PowerFlow battery was installed on 29 Jun 2016 and the average electricity consumption reduced to a range of 2.45kWh/day to 2.49kWh/day. Table 3.53 indicates that there was a reduction in average electricity consumption of about 3kWh/day following the installation of the solar PV system this was reduced by approximately a further 1kWh/day after the battery was installed.

The generation of the PV system at household T-20 between 2012 and 2018 is shown in table 3.54. The values of annual generation were close to 1837kWh/year, estimated by the MCS method. The average PV generation ranged from 4.74 to 5.23kWh/day.

Start Date	End date	Number of days	PV Generation (kWh)	Average PV generation (kWh/day)
05-Jun-12	03-Jun-13	363	1744	4.80
03-Jun-13	03-Jun-14	365	1879	5.15
03-Jun-14	03-Jun-15	365	1910	5.23
03-Jun-15	03-Jun-16	366	1787	4.88
03-Jun-16	03-Jun-17	365	1797	4.92
03-Jun-17	25-May-18	356	1689	4.74

Table 3.54 Annual generation from the 1.96kW solar PV since installation in December 2011

Table 3.55 shows discharge readings from the PowerFlow battery. Between 22 Oct 16 and 11 Oct 18 the average discharge was 0.70kWh/day.

Start Date	End Date	Number of days	Battery Module 1 Discharge (kWh)	Battery Module 2 Discharge (kWh)	Total Battery Discharge (kWh)	Average Discharge (kWh/day)
22-Oct-16	05-Mar-18	499	172.5	194.3	366.8	0.74
22-Oct-16	12-Jul-18	628	199.2	248.6	447.8	0.71
22-Oct-16	11-Oct-18	719	217.3	283.5	500.8	0.70

Table 3.55 Discharge from the PowerFlow Sundial SDM 2.0-500 battery installed at household T-20

Household T-21 with a PowerFlow 2kWh battery

Household T-21 had a 3kW solar PV system which was installed in 2012 under a ‘rent a roof’ scheme. The installers estimated the annual generation at the site, which had some shading, was 2682kWh. The generation meter was in the loft, so it was not easy to keep a record of the solar generation. The resident however, regularly recorded electricity meter readings and approximately monthly consumption data over the course of the study is shown in tables 3.56 and 3.57.

There was single retired resident in Household T-21, as with household T-20. Here the average consumption over the year was 3.79 and 4.32kWh per day compared to 2.45 and 2.49kWh/day for household T-20. There was an electric cooker, but the oven was only used at Christmas. A 1300W Halogen Oven was used instead on a daily basis. There was a single large fridge/freezer and the washing machine and tumble drier were used once a week.

Start Date	End date	Number of days	Grid consumption (kWh)	Average consumption (kWh/day)
10-Jun-16	03-Aug-16	54	156	2.89
03-Aug-16	03-Sep-16	31	79	2.55
03-Sep-16	01-Oct-16	28	90	3.21
01-Oct-16	01-Nov-16	31	107	3.45
01-Nov-16	01-Dec-16	30	149	4.97
01-Dec-16	01-Jan-17	31	206	6.65
01-Jan-17	01-Feb-17	31	170	5.48
01-Feb-17	01-Mar-17	28	140	5.00
01-Mar-17	01-Apr-17	31	103	3.32
01-Apr-17	05-May-17	34	88	2.59
05-May-17	10-Jun-17	36	95	2.64
TOTAL		**365**	**1383**	**3.79**

Table 3.56 Grid consumption for household T-21 in the first year after the PowerFlow battery was installed

The PowerFlow battery was installed on 20 Jul 2016. Table 3.58 shows that by 11 Jul 2018, the battery had discharged a total of 562kWh. This consisted of 269kWh and 293.3kWh in each of the 1kWh lithium-ion battery cells. Over the period of the installation, the average discharge was 0.78 kWh/day. This was similar to Household T-20, which averaged 0.70kWh/day between 22 Oct 16 and 11 Oct 18. There may have been greater discharge from the battery at Household T-21 because it had a larger 3kW solar PV system compared to the 1.96kW system at Household T-20, with a greater excess solar generation which was available to charge the battery.

Start Date	End date	Number of days	Grid consumption (kWh)	Average consumption (kWh/day)
10-Jun-17	08-Jul-17	28	71	2.54
08-Jul-17	05-Aug-17	28	61	2.18
05-Aug-17	02-Sep-17	28	89	3.18
02-Sep-17	30-Sep-17	28	106	3.79
30-Sep-17	28-Oct-17	28	122	4.36
28-Oct-17	02-Dec-17	35	206	5.89
02-Dec-17	31-Dec-17	29	186	6.41
31-Dec-17	03-Feb-18	34	202	5.94
03-Feb-18	04-Mar-18	29	162	5.59
04-Mar-18	04-Apr-18	31	156	5.03
04-Apr-18	03-May-18	29	115	3.97
03-May-18	09-Jun-18	37	114	3.08
TOTAL		**364**	**1571**	**4.32**

Table 3.57 Grid consumption for household T-21 in the second year after the PowerFlow battery was installed

Start Date	End data	Number of days	Battery Module 1 Discharge (kWh)	Battery Module 2 Discharge (kWh)	Total Battery Discharge (kWh)	Average discharge (kWh/day)
20-Jul-16	11-Jul-18	721	269	293.3	562.3	0.78

Table 3.58 Discharge from the PowerFlow Sundial SDM 2.0-500 battery installed at household T-21

Financial benefit for households from the PowerFlow battery systems

Household	Date of Battery Installation	Date of Battery Reading	Household Consumption (kWh/day)	PV Generation (kWh/day)	Battery Discharge (kWh)	Battery Discharge (kWh/day)	Financial Benefit from Battery Discharge (£) *	Financial Benefit from Battery Discharge (£/year) *
T-17	26-Jul-16	12-Jul-18	9.82		534.6	0.75	£85.54	£43.60
T-18	12-Jul-16	11-Jul-18	12.72	5.51	281.8	0.39	£45.09	£22.57
T-19	19-Jul-16	13-Jul-18	15.79	8.44	836.4	1.16	£133.82	£67.47
T-20	22-Oct-16	11-Oct-18	2.45	4.94	500.8	0.70	£80.13	£40.68
T-21	20-Jul-16	11-Jul-18	4.10		562.3	0.78	£89.97	£45.55
T-30	01-Aug-16	09-Aug-18			535.9	0.73	£85.74	£42.41

* - This analysis assumes the financial benefit for a household on a single rate tariff of 16p/kWh

Table 3.59 Household financial benefits from PowerFlow battery-solar installations using a cost of 16p/kWh for electricity

Table 3.59 summarises the battery discharge from the 5 households with PowerFlow batteries that were in the monitored group along with T-30, where the household provided a battery discharge reading. The period for the battery discharge was about 2 years in all cases, although for household T-20, the battery was installed on 22 Oct 16 and the final reading taken in 11 Oct 18.

The household consumption and PV generation were calculated using the difference between readings taken on the day the battery discharge was measured and a date close to when the battery was installed (usually within a month). It was not possible to calculate the average PV Generation for T-17 and T-21 as the PV systems fitted there were ‘rent a roof’ systems where the generation meter was in the loft and an initial generation meter reading was not recorded. For household T-30 no other meter readings were available.

Households T-18 and T-19 were both on Economy 7 tariffs. While household T-19 used night storage heaters, T-18 had gas central heating. The average daytime consumption for T-18 was 10.18kWh/day compared to a total average household electricity consumption of 12.72kWh/day. Although household T-19 had a higher total average household consumption of 15.79kWh/day, the average daytime consumption was only 3.32kWh/day, with the rest used at night, primarily by the storage and water heaters.

Most of the PowerFlow batteries in the study discharged between 0.70 and 0.78kWh/day. For household T-18 it was only 0.39kWh/day with one cell discharging 259.8kWh and the other 22.0kWh. It is possible that the poor performance of the second battery cell was due to a substandard batch of battery cells. The highest battery discharge was from the system at household T-19. Here there was a low average daytime consumption of 3.32kWh/day and a high average PV generation of 8.44kWh/day. This meant there was likely to be greater excess solar generation which could be used to charge the battery and led to the greater battery discharge.

To simplify the calculation of the financial benefit from the PowerFlow battery, it was assumed that all the households were on a single rate tariff of 16p/kWh. Most households saved between £40 and £45 per year, but household T-19 saved £67.47.

3.6 Victron battery system

Installation and operational issues

The Victron system installed included a Victron Multicompact C-12/800/35 inverter/charger, a Victron Colour Control GX and a Victron Colour Control Long Range WI-FI Module. The battery fitted to the system was a Leoch 260Ah AGM battery. This had a total capacity of 3.12kWh, but it is recommended that this AGM battery is only taken to 50% Depth of Discharge (DoD) and so the usuable capacity was about 1.56kWh. This is comparable to the 2kWh Maslow and PowerFlow Lithium-ion batteries, which can be taken to 80% DoD and so have a 1.6kWh usable capacity.

When the original installers fitted the systems, they did not set up the monitoring for the Victron VRM Portal. Household T-34 arranged for another electrician to set up the monitoring system soon after the installation. This included collecting data from both the battery and the solar PV system. The monitoring for the other 3 Victron systems was set up in December 2017. However this did not include wiring in the solar circuit. Also there were problems with the quality of the data collected by the portal for these systems.

Household T-34 with a Victron Multicompact C-12/800/35 and Leoch LAGM-260 battery

The solar PV system at household T-34 was installed in October 2013. It was a 3.5kW system which faced 185° south and had Enecsys 240-60MP microinverters on each solar panel. The Victron battery system was installed on 12 Jul 2016 with the system subsequently set up to allow monitoring via the Victron VRM Portal. During the study, the resident took daily readings from the PV generation meter and the Economy 7 electricity meter. There was also an Omega 101 pulse logger on the PV generation meter.

Figure 3.60 illustrates the variation in grid consumption over a year for both the peak (day) and off-peak (night) tariff periods for household T-34. There was no significant increase in off peak electricity consumption during the winter. This was because the household had gas central heating and not night storage heaters. Electric convector heaters were only used for supplementary heating on the coldest days in winter, which might account for the peak in daytime consumption between November and January.

Table 3.61 shows the ‘Grid to consumer’ measured by the battery systems and the ‘Measured Grid Consumption’ taken from daily meter readings. For most of the monthly grid consumption readings, the difference between the two forms of measurement was less than 10%. The difference between the values of the PV generation recorded by meter readings and the Omega pulse logger was less than 5% and frequently under 2%.

There was a greater difference between the ‘PV to consumer’ measured by the battery system and the ‘PV Generation meter’ readings. However, for all but 2 months, this difference was under 10%. The greater difference might be due to not taking into account PV export to the grid. According to the VRM portal, this was only 0.26kWh between Jul 17 and Jun 18. This seems very low and the system may not have recorded all the PV export.

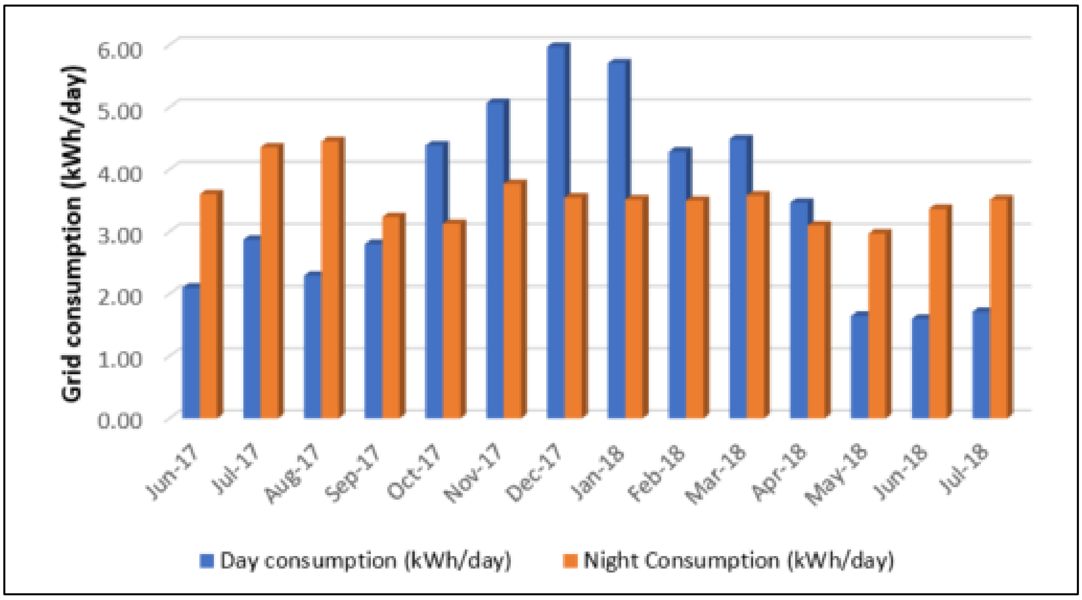

Figure 3.60 Variation in grid consumption between June 2017 and July 2018

Date	PV to consumer (kWh)	PV Generation meter (kWh)	Omega Logger PV Generation (kWh)	Grid to consumer (kWh)	Measured Grid Consumption (kWh)	PV Generation meter (kWh/day)	Measured Grid Consumption (kWh/day)
Jul-17	363.5	398	401.8	216.76	224	12.84	7.23
Aug-17	347.5	379	378.6	248.7	259	12.23	8.35
Sep-17	266.7	300	295.6	173.64	181	10.00	6.03
Oct-17	177.9	199	193.9	222.83	233	6.42	7.52
Nov-17	149.9	158	160.8	253.42	265	5.27	8.83
Dec-17	101.6	106	103.9	283.62	300	3.42	9.68
Jan-18	107.5	107	110.7	264.02	286	3.45	9.23
Feb-18	186.2	202	200	208	218	7.21	7.79
Mar-18	161.6	168	171.9	238.14	260	5.42	8.39
Apr-18	271.0	293	293.2	189.66	201	9.77	6.70
May-18	438.9	480	485.9	134.24	140	15.48	4.52
Jun-18	425.0	460	470.1	143.34	149	15.33	4.97
Total	2997.2	3250.0	3266.4	2576.4	2716.0		

Table 3.61 Solar PV generation and grid consumption for Household T-34 with a Victron battery system

The battery charge and discharge for household T-34 is shown in table 3.62. ‘PV to battery’ shows the amount of excess solar generation that was used to charge the battery, while ‘Grid to battery’ indicates how much electricity was required from the grid to maintain an adequate level of charge for the battery. ‘Battery to consumer’ is the amount of electricity provided by the battery into the home.

The battery efficiency is output of the battery divided by the total input (from solar PV and the grid). For the period shown, the battery efficiency ranged from 61.90% in July 2017 to 45.45% in December 2017. The battery discharge for the period shown ranged from 0.31kWh/day in December to 1.30kWh/day in May 2018.

Date	PV to battery (kWh)	Grid to battery (kWh)	Battery to consumer (kWh)	Battery Efficiency (%)	Battery to consumer (kWh/day)
Jul-17	56.81	0.56	35.51	61.90%	1.15
Aug-17	49.82	0.86	31.03	61.23%	1.00
Sep-17	46.38	0.76	28.61	60.69%	0.95
Oct-17	33.05	1.69	19.68	56.65%	0.63
Nov-17	27.47	1.74	15.26	52.24%	0.51
Dec-17	18.47	2.54	9.55	45.45%	0.31
Jan-18	20.34	2.5	11.33	49.61%	0.37
Feb-18	29.57	1.76	17.88	57.07%	0.64
Mar-18	27.69	2.06	16.11	54.15%	0.52
Apr-18	40.11	1.21	23.93	57.91%	0.80
May-18	67.35	0.48	40.31	59.43%	1.30
Jun-18	64.44	0.39	38.15	58.85%	1.27
Total	**481.5**	**16.55**	**287.35**		

Table 3.62 Charge and discharge of the battery for Household T-34

2 years of data was available for this household via the Victron VRM portal. Table 3.63 summarises the performance of the system for each year and indicated the average daily performance. Figure 3.64 shows how the battery state of charge varied between 1 June 2018 and 10 June 2018. This was a sunny period and the battery regularly charged to 100% in the morning. By about 21:00, the battery had discharged down to about 50%. Since the 260 Ah AGM battery had a capacity of 3.12kWh, 50% depth of discharge corresponds to a discharge of 1.56kWh. Table 3.62 shows that the average battery discharge during June 2018 was 1.27kWh/day.

Period	PV to consumer (kWh)	PV to battery (kWh)	Grid to battery (kWh)	Battery to consumer (kWh)	Battery efficiency (%)	Grid to consumer (kWh)
Aug 16 to Jul 17	3011.7	504.97	12.07	308.08	59.59%	2468.95
Aug 17 to Jul 18	3060	494.28	16.41	295.31	57.83%	2517.01
Total	6071.7	999.25	28.48	603.39		4985.96
Average	8.32 kWh/day	1.37 kWh/day	0.04 kWh/day	0.83 kWh/day		6.83 kWh/day

Table 3.63 Annual and average performance of the solar PV and Victron battery system at household T-34

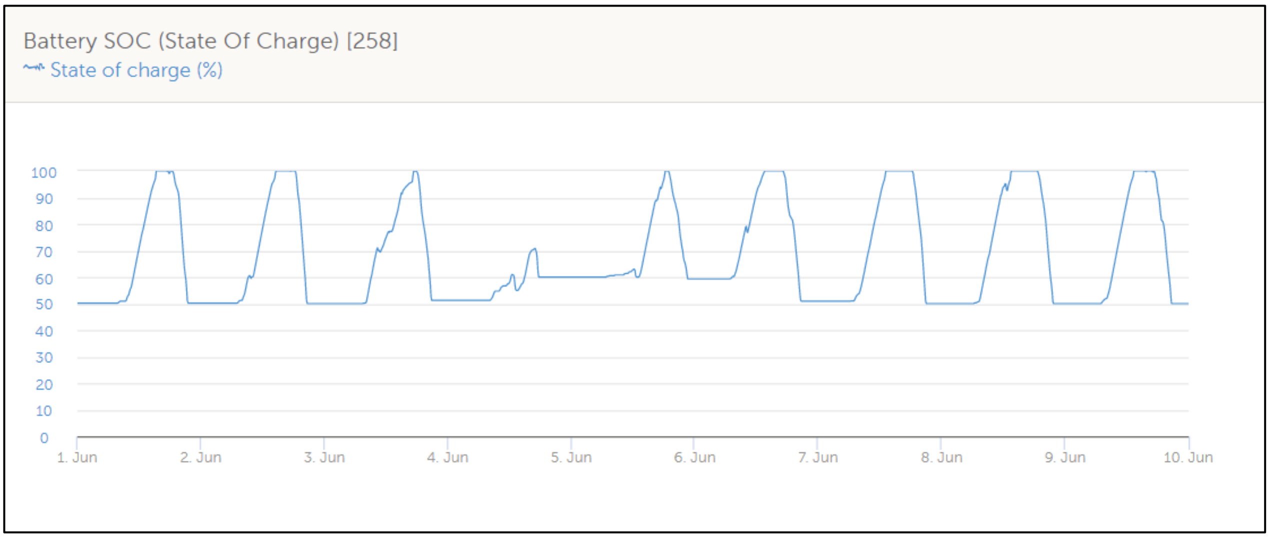

Figure 3.64 Plot of the battery state of charge (SOC) between 1 June 2018 and 10 June 2018 for household T-34

Households T-31 to T-33 with a Victron battery systems

Households T-31, T-32 and T-33 had comparable Victron battery systems installed to T-34. As mentioned earlier, the original installers did not set up the monitoring system for these batteries. The monitoring was set up in December 2017, however it was not possible to wire in the solar circuit as for household T-34. Data was not recorded for long periods for households T-31 and T-32 when these systems went offline. Even when the systems were online, it was common for a few hours of data to be missing on the portal on some days. This may have been due to poor connectivity between the WI-FI module and the WI-FI router. As a result, detailed information on the battery performance for these households will not be presented.

Household T-31 had a 3.2kW solar PV system that was fitted in 2013. Using meter readings over a 5 year period, the average annual generation for the PV system was 2699kWh or an average of 7.4kWh/day. This compared to the estimate on the MCS certificate of 2733kWh/year. Table 3.65 shows the grid consumption for household T-31 between July 2014 and July 2018. There was a large reduction in electricity consumption for the period July 2017 to July 2018. This was likely to be due to family members moving out of the house. The reduction in consumption in 2016/17 could not necessarily be attributed to the battery system as the consumption was lower in 2014/15.

Start Date	End date	Number of days	Grid consumption (kWh)	Average consumption (kWh/day)
26-Jul-14	27-Jul-15	366	3135	8.57
27-Jul-15	25-Jul-16	364	3312	9.10
25-Jul-16	24-Jul-17	364	3223	8.85
24-Jul-17	11-Jul-18	352	1935	5.50
AVERAGE			**2901.25**	**8.00**

Table 3.65 Electricity consumption based on meter readings for household T-31

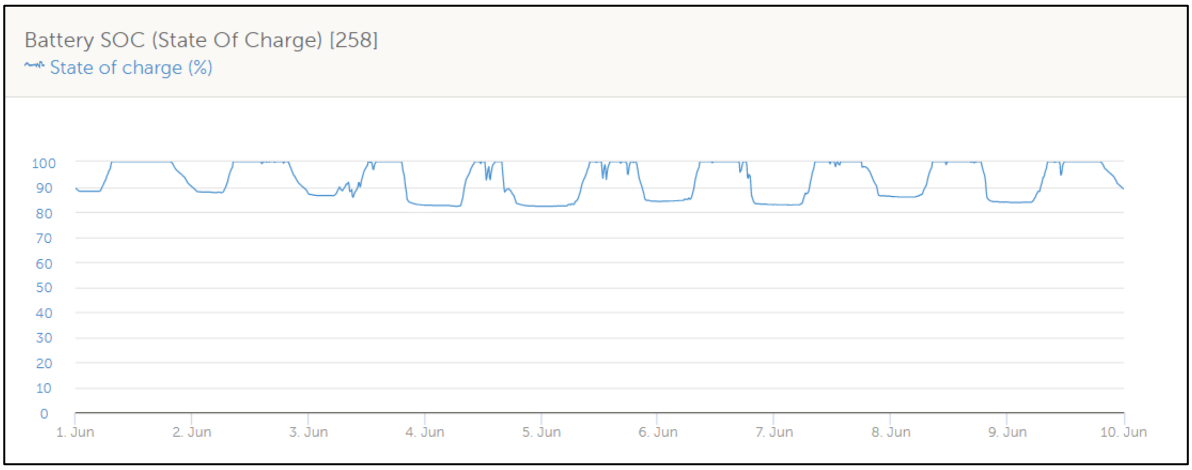

Figure 3.66 Plot of the battery state of charge (SOC) between 1 June 2018 and 10 June 2018 for household T-31

Although it was not possible to get accurate monthly values for the discharge of the battery, it was however possible to compare the performance of household T-31 with T-34. Figure 3.66 shows the battery state of charge for household T-31 for the same period as the plot for T-34 in figure 3.64. It was apparent that the state of charge for the battery at household T-31 only reached a minimum of about 82% on discharge. This was equivalent to a maximum discharge of 0.56kWh. The low value for the discharge from this battery may be due to the battery coming to the end of its useful lifespan. AGM lead acid batteries of this type have a typical lifespan on 600 cycles at 50% depth of discharge.

It is possible to set up the Victron system to assist with battery longevity. The Hub 4 and ESS firmware for the Colour Control GX has a BatteryLife setting. This feature prevents the battery state of charge falling to a harmful level for an extended period of time. It is unclear whether this setting had been used on this installation and if other settings were also optimised[47] [48].

The solar PV system for household T-32 was installed in February 2014. This was a 3.78kW system with the panels split between the north and south facing roofs. The annual PV generation was 2866kWh from November 2016 to November 2017. This compared to 3440kWh on the MCS certificate. The Victron battery system was installed on 5th July 2016.

Start Date	End date	Number of days	Day Grid consumption (kWh)	Night Grid consumption (kWh)	Average Daytime consumption (kWh/day)	Average Night time consumption (kWh/day)
25-Jun-14	06-Jun-15	346	1622	4695	4.69	13.57
06-Jun-15	16-Jun-16	376	2179	4945	5.80	13.15
16-Jun-16	01-Jul-17	380	2574	4242	6.77	11.16
01-Jul-17	11-Jul-18	375	3350	6213	8.93	16.57
AVERAGE			**2431.25**		**6.55**	**13.61**

Table 3.67 Electricity consumption based on meter readings for household T-32

As a result of household T-32 having storage heaters, the property was on an Economy 7 tariff. Table 3.67 shows the household consumption from June 2014 to July 2018. There was no apparent reduction in consumption following the installation of the battery system in July 2016 and in fact the annual consumption increased. This was due to the household purchasing an electric car in March 2017 and their electricity consumption increasing as a result.

The plot of battery charge in figure 3.68 for household T-32, shows that during discharge, the battery state of charge decreased to about 65%. This was equivalent to a battery discharge of about 1.09kWh. The battery performed better than household T-31, but was not as good as T-34. The residents in this household worked full time, while the residents in the households that had the other Victron battery systems were retired.

Household T-33 had an approximately south-facing 3.0kW solar PV system installed during 2012. The PV system was installed under a 'rent a roof' scheme and no meter readings were available. However it is possible to estimate the annual PV generation to be approximately 2922kWh. The Victron battery system was fitted on 28 June 2016. Between 8 Jul 2017 and 11 Jul 2018, the electricity consumption was 1895kWh.

[47] Hub 4 Old Manual, 9 Colour Control configuration, Battery Life https://www.victronenergy.com/live/system_integration:hub4_grid_parallel#old_manual (Accessed 14 Nov 2018)
[48] ESS Design & installation manual, 6.2 BatteryLife, https://www.victronenergy.com/live/ess:design-installation-manual#batterylife (Accessed 14 Nov 18)

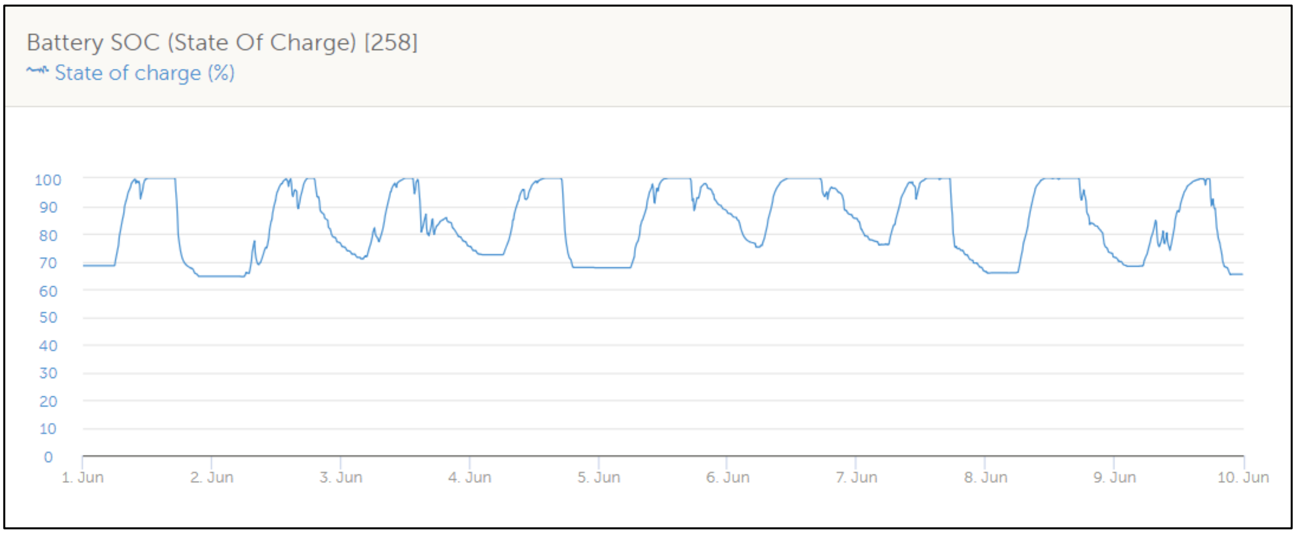

Figure 3.68 Plot of the battery state of charge (SOC) between 1 June 2018 and 10 June 2018 for household T-32

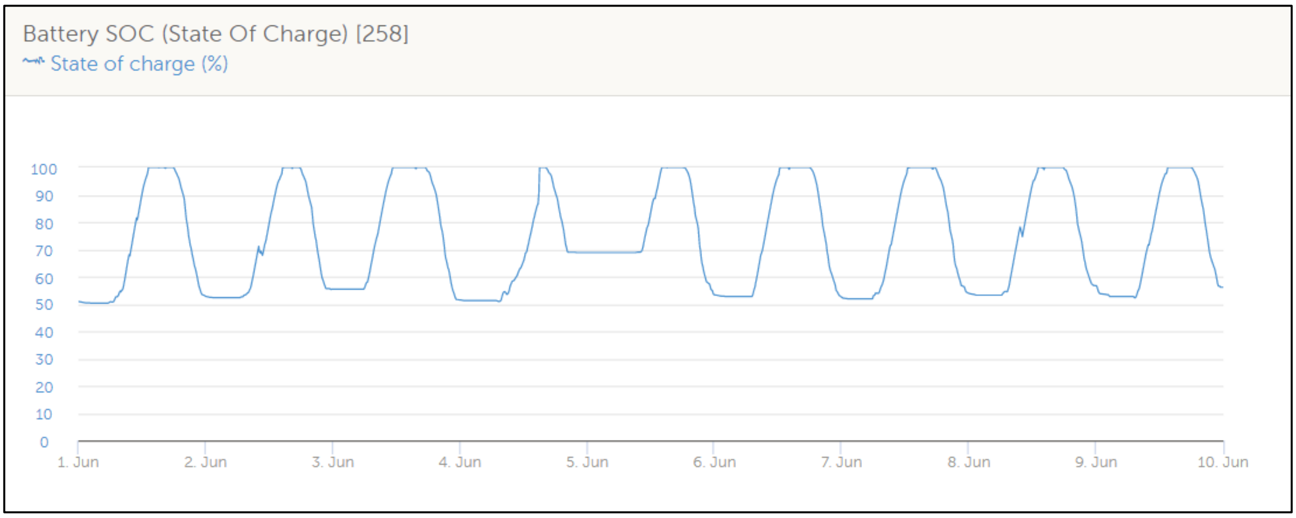

Figure 3.69 Plot of the battery state of charge (SOC) between 1 June 2018 and 10 June 2018 for household T-33

Figure 3.69 plots the variation in the battery state of charge for the same period in June as for the other households with Victron systems. This plot is closest to the plot for household T-34 in figure 3.64. In this case the battery discharged to a value of about 52.5% charge. This is equivalent to a discharge of about 1.48kWh. For comparison, the typical daily discharge of household T-34 was about 1.56kWh over the same period.

Financial benefit for household with a Victron battery system

Household	Start date	End date	Grid to battery (kWh)	Battery to consumer (kWh)	Financial Benefit from Battery Discharge (£) *	Financial Benefit from Battery Discharge (£/year) *
T-34	01-Aug-16	31-Jul-18	28.48	603.39	£91.99	£45.99

* - This analysis assumes the financial benefit for a household on a single rate tariff of 16p/kWh

Table 3.70 Assessing the financial benefit of the Victron battery system to Household T-34

Table 3.70 shows that over the 2 years of the study, household T-34 was supplied with 603.4kWh by the Victron battery system. Over this period, the battery consumed 28.48kWh from the grid, so the net benefit was 574.92kWh or 287.46kWh/year. Using a single rate tariff of 16p/kWh, this equates to a financial benefit of about £46 per year. T-34 was the best performing of the Victron battery systems. Household T-33 was likely to have received a similar benefit, while the other Victron systems performed less well, particularly household T-31. The finanicial benefit of £46/year was comparable to some of the better performing Maslow batteries on the study with savings ranging from £24 to £55.

4. Conclusions and recommendations

4.1 Conclusions

Solar PV systems can reduce daytime electricity costs while batteries can store electricity that would otherwise be exported to the grid for consumption later in the day. This project aimed to install 35 batteries in households with pre-existing solar PV systems in the Thurrock area and:

- Assess the performance of the 3 different battery technologies used:
  - Maslow V3 manufactured by Moixa, PowerFlow Sundial SDM 2.0 500 and a Victron Multicompact charger/inverter with a Leoch AGM lead acid battery.
- Assess levels of resident satisfaction with the battery and solar technologies
- Determine the performance of the battery system over 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

A total of 34 batteries were correctly installed and operated during the project. These comprised:

- 16 Maslow V3, 14 PowerFlow Sundial and 4 Victron systems

A subset of 13 households along with 6 controls without batteries were recruited to be part of a monitored group where the residents were interviewed and the performance of the battery systems assessed. These consisted of the following households

- 4 Maslow V3, 5 PowerFlow Sundial and all 4 Victron installations

Resident satisfaction

- All the residents in the monitored group thought that the batteries didn't need any active input to work and found the systems easy to use.
- A majority of households felt they knew how best to use the battery with 8 out of 13 agreeing or strongly agreeing. However, a minority of households felt they knew enough about how the battery worked.
- Only 5 out of 13 households in the monitored group thought there was a reduction in their energy bills after the battery was installed, while 11 thought they were saving energy in the home. Rising prices and direct debit payments are likely to have made it harder to perceive any savings.

Installation and reliability issues

- Apart from the Maslow battery that was incorrectly installed and later removed, other issues were also noted during the installation phase of the project.
- A loose connection on the MCB from installation and spikes in the supply caused a PowerFlow battery to require replacement on two occasions.
- Installers temporarily used the way in the consumer unit for the immersion heater and left the household without water heating for a month.
- Batteries were not always fitted with the correct separation distances and this may have led to overheating and poorer performance in some cases.
- Wires to and from the battery were not routinely fitted in plastic trunking and were sometimes left loose.
- Maslow and Victron battery systems connected to portals had problems with the systems going offline. Reasons included PV systems tripping out and sending the Maslow battery

into bypass mode, issues with TP Links connecting the battery to the household WI-FI and residents switching internet service provider.

Maslow V3 batteries

- Among the 16 Maslow battery installations, only 9 were online for more than 75% of the time during 2017.
- For these 9 Maslow batteries, between 1 Jul 17 and 30 Jun 18, the battery discharge was in the range 152kWh to 341kWh or 0.42kWh/day to 0.93kWh/day.
- The household with the lowest battery discharge also had the highest self-consumption of the solar PV (88%). This indicated there was limited excess PV generation available to charge the battery which led to the low battery discharge.
- The level of PV self-consumption was only 40% for the household with the highest battery discharge. Here the excess PV generation was able to regularly charge the battery.
- Among the monitored properties, the battery at household T-03 discharged 294kWh between 1 Jul 17 and 30 Jun 18. This was the highest for the monitored Maslow batteries. There was sufficient excess PV generation to charge the battery and consumption early in the evening to regularly fully discharge the battery.
- There was a significant decrease in the battery discharge between 2017 and 2018 for household T-02. This was most likely to be due to a hardware fault.
- Electricity savings from the batteries with better online connections ranged from £24 to £55 per year. The household which saved the least from the battery, had high savings of £375 from consuming electricity from their solar PV system. The household with greatest battery discharge consumed less of the solar generation, saving £159.

PowerFlow Sundial SDM 2.0 500 battery

- Online monitoring of the PowerFlow battery was not possible during the project as the PowerFlow Energy Gateway device was only released in Spring 2018. However, it was possible to get battery cell discharge readings from 6 of the PowerFlow systems after about 2 years of operation.
- The battery discharge over about 2 years ranged from 282kWh to 836kWh or 0.39kWh/day to 1.16kWh/day. This equated to savings of between £22.57/year and £67.47/year based on a single rate tariff of 16p/kWh.
- The worst performing of the monitored batteries had a discharge of 260kWh and 22kWh from the 2 cells in the battery system. The poor performance of the second cell might have been due to the battery cell coming from a substandard batch. Other factors influencing performance may have been high daytime household consumption and limited ventilation around the battery.
- A household in the monitored group had previously been regularly monitoring electricity consumption. Between 2004 and 2011, the annual household consumption was between 6.38 and 10.71kWh/day. After installation of a1.96kW PV system, the average consumption was from 3.35 to 3.98kWh/day. After the PowerFlow battery was fitted the consumption was 2.45 and 2.49kWh/day for the 2 years of the study. The battery discharge over a period of about 2 years was 500.8kWh or an average of 0.7kWh/day.
- Out of the 6 batteries where readings were recorded after 2 years, 4 had an average

discharge of between 0.70 and 0.78kWh/day which corresponded to a saving of about £40 to £46/year.

- The best performing PowerFlow battery had a discharge of 1.16kWh/day and was fitted on a 4kW solar PV system split across an east-west roof. Household consumption was low in the day, which allowed the battery to charge. There was electric water and space heating overnight, which ensured the battery regularly fully discharged.

Victron Multicompact C-12/800/35 and Leoch LAGM-260 battery

- All 4 of the Victron systems that were installed were part of the monitored group. However, a detailed assessment was only possible for a single system where good quality monitoring data was available.
- Between July 2017 and June 2018, the battery discharged 287kWh. The solar PV system provided 482kWh to charge the battery while 17kWh came from the mains supply.
- The battery round trip efficiency ranged from 45.5% in December 2017 to 61.9% in July 2017.
- The net battery discharge over 2 years was 575kWh, which equated to £46/year based on a single rate tariff at 16p/kWh.
- While the 2 best performing Victron systems regularly saw the battery discharge to nearly 50%, the state of charge for another system was only reaching a minimum of about 82% on discharge during June 2018. This was likely to be due to this AGM battery reaching the end of its life span.

4.2 Recommendations for potential future installations

Domestic solar PV is an effective technology for reducing electricity bills for residents as well as for increasing SAP ratings. With the demise of the Feed-in tariff in April 2019, these considerations along with lowering carbon emissions will drive PV installations. Domestic battery storage can increase the self-consumption of PV generated electricity saving households money. Social landlords planning multiple PV installations in a small area may find it difficult to obtain a grid connection from the Distribution Network Operator (DNO) for a large number of PV systems. Installing domestic batteries could limit export of PV generated electricity and allow more solar PV systems on the network in that area.

Domestic battery storage technology is advancing rapidly and the business case for installations is still developing. Customers should research the technologies to determine whether the battery capacity or battery power output is likely to meet their needs while being at an affordable price. Installers should have a good reputation, have been on the battery manufacturer's training course and have previous installation experience. As for solar PV, customers should obtain 2 or 3 quotations from different installers. A MCS accredited installer is not required for batteries, but shows they have experience and a quality assurance system in place. An experienced local renewable energy installer is normally a better option. Installers who are based a long distance away will be reluctant to return for any maintenance issues and installations may be rushed.

For social landlords and others carrying out larger scale battery installations it is important to allow sufficient time for customer recruitment. It may take 3–6 months, with communications provided by email and letter as well as community engagements events to build trust. Understanding the households and collecting accurate details helps determine suitability and improves the customer experience.

A full survey is necessary to ensure the battery can be fitted in a suitable location with adequate ventilation and the separation distances required from the walls by the manufacturer. It must be easy for the customer to determine the battery is operating correctly, but the location shouldn't be anywhere that fan noise would be unacceptable. A sensible cable route is required between the battery location and consumer unit, with all wiring fitted in plastic trunking for protection.

During the survey an assessment should be made of the household energy consumption and patterns of use to check for household suitability and allow correct sizing of the battery. The ideal household for a battery is a medium electricity consumer with peak usage in the morning and evening, but limited consumption of solar PV during the day. A challenge for social landlords however is the regular turnover of customers.

Where new PV systems are to be installed, it is important to ensure the PV array is large enough to charge the battery. Domestic battery systems can be installed in a few hours. To minimize disruption to households, installation of solar PV and the battery should be co-ordinated. A battery system requires good internet connectivity and 3G cannot be relied on to provide a consistent service. Project planners need high levels of customer engagement to confirm that households have Wi-Fi installed, will allow the battery access to their Wi-Fi and they will not switch off the router. A hard-wired connection is best between the router and the battery as TP Links and Wi-Fi connections are not robust enough to maintain long term connections. Households should be provided with advice on what to do if they switch internet service provider.

A large-scale roll-out of battery systems requires a project management team who are familiar with the technology and have clearly defined roles and responsibilities. Regular meetings are necessary with the frequency increased during critical phases such as customer recruitment and installation. Good communication is required with project partners such as the installers and manufacturer. Customer recruitment and post installation liaison can be carried out by energy champions or tenant liaison officers. If expertise is not available in house, a suitable partner for energy audits and customer recruitment may be an energy advice organisation or community energy group.

Customers need to receive advice at the time of installation and in documentation which explains the relationship between their pattern of energy use, the battery performance and expected savings. 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.

The project described in this report had are wide range of house types, locations and PV system sizes. For a study which is more focused on evaluating the technology it would be better to have installations taking place on an estate of similar sized homes where there has been widespread installation of solar PV. The PV systems should ideally have similar sized arrays and orientation.

4.3 Impact on fuel poverty

A domestic solar PV array can produce significant amounts of electricity between March and October. This can reduce the daytime electricity consumption of households, but a proportion of the electricity generation is usually exported to the grid. Households who live in rented properties or have a solar PV system which was funded under a 'rent a roof' scheme only benefit from savings due to consuming the free electricity from the solar array. Finding a way to increase self-consumption can improve these savings.

Domestic batteries storing excess solar generation for use in the evening can improve electricity savings. These are particularly beneficial for households where the residents are out during the day and have fairly high evening consumption.

Savings measured for the better-connected Maslow batteries in this study ranged from £24 to £54 per year. Households with the PowerFlow Sundial saved between £22 and £67 per year while a Victron systems resulted in savings of £46 per year. These savings are currently too low to produce a payback for the battery system cost. The payback and ways that the next generation of batteries are likely to improve savings and provide additional benefits are discussed further in section 4.5

4.4 Performance comparison against manufacturer's/manufacturers' claims

Moixa have advertised installations of a 2kW solar PV system with a 2kWh battery for £4995 +VAT. They noted savings of up to 60% on energy bills. It is possible to compare this with the savings from some of the better performing Maslow battery solar systems on this project.

For the analysis period between 1 Jul 2017 and 30 Jun 18, the savings for 9 better performing solar systems with Maslow batteries ranged from 23% to 57%. It should be noted that nearly all of these systems had PV arrays larger than 2kW.

Household T-15 with a 2.5kW array showed the largest percentage savings with 53.7% (£375) coming from the solar PV system and 3.5% from the Maslow battery (£24). It is possible that the high rate of consumption of the PV generation was due to use of a solar immersion heater device as for household T-02.

Household T-09 had an annual battery discharge of 341kWh with only a 2.4kW PV array. The battery discharge for this household was the largest among the Maslow batteries in this study and corresponded to 10.9% of the household consumption or a saving of £55. A further 31.8% was saved by the solar PV system, taking the total to 42.7%.

In an article which mentions the 2kW solar PV and 2kWh battery system they have been supplying, Moixa noted that their technology helped customers make savings of up to £350 on their energy bills[49]. The total financial savings of the best performing Maslow battery solar systems in the project ranged from £167 to £418 per year. The system with the greatest savings had high levels of self-consumption of the electricity generated by the PV system. Household T-02 saved £389 from

[49] 'Will future homes come with a solar battery already installed?', Moixa, 14 May 2018 https://www.moixa.com/future-homes-come-with-solar-batteries/ (Accessed 21 May 2018)

the PV system and £29 from the battery. The high levels of savings from the solar PV system were likely to be due to the Solar iBoost immersion heating device that had been also installed.

4.5 Economic business case for installation of measures

Measure	Capital Cost	Installation Costs	Total	Annual energy saving (from this study)	Indicative annual payback (yrs)	Assumptions
Maslow V3 2kWh	£2,000		£2,000	£55	36.7	•Cost of £2000+VAT includes installation •Using the maximum value of battery discharge of 341kWh/year •No savings included from the Moixa Gridshare scheme •Electricity price of 16p/kWh which remains static
PowerFlow Sundial 2kWh	£2,500	£400	£2,900	£68	42.8	•Cost of £2900+VAT includes installation •Using the maximum value of battery discharge of 423kWh/year •Electricity price of 16p/kWh which remains static
Victron system with AGM Lead Acid battery	£1,700	£400	£2,100	£46	45.7	•Cost of £2100+VAT includes installation and a Leoch AGM battery •Battery capacity of 260Ah or 3.12kWh •AGM battery taken down to 50% DoD •Using a net battery discharge of 287.5kWh/year •Electricity price of 16p/kWh which remains static

Table 4.1 Business case for the batteries systems installed in this study

The business case for the installation of Maslow V3, PowerFlow Sundial and Victron energy storage systems is presented in table 4.1. The prices are excluding VAT and assume installation on a system with a pre-existing solar PV array or where the cost of the PV system is accounted for separately. It should be noted that the battery costs were higher at the time of installation.

The annual energy savings are based on the best performing systems in the study and use an electricity price of 16p/kWh which is assumed to remain constant. To keep things simple, discount rates and energy price inflation are not considered.

It can be seen that for the systems tested at the current prices and with the savings measured, the payback time for the batteries exceeded 35 years and would exceed the lifespan of the battery systems. This would be due to the lifespan of the battery cells and also the electrical components.

The battery cells for the Maslow have a predicted life of 10,000 cycles. This is equivalent to about 27 years based on a discharge of 1 cycle per day. The Maslow has a 10-year warranty, but this is extendable for residents who are members of Moixa's Gridshare scheme.

GridShare is an aggregation platform developed by Moixa where battery owners can receive income from allowing Moixa to intelligently manage their battery. Spare capacity of large numbers of batteries can be controlled together to create a virtual power plant and help balance electricity supply and demand of the electricity grid. The battery system may only be used for only a few minutes a day with a likely low impact on savings from the system.

Customers who buy a Moixa battery and join GridShare receive fixed payments of £50/year for the first 3 years and would subsequently be offered a share in the profits of any future income generated by grid services, but it is unclear what that amount might be. If the annual payments for GridShare were maintained at £50/year, the payback time would be reduced to 19 years.

Residents who received a Maslow battery through a trial are not eligible for the initial £50 payments for joining GridShare but would be eligible for an extended warranty and a share in future profits from GridShare.

The Lithium Iron Phosphate battery cells for the PowerFlow system are also likely to have a lifespan of about 10,000 cycles. The warranty for the battery is however 4000 cycles or 10 years and it is 5 years for the electronics.

The installer used a Leoch 260Ah AGM lead acid battery with the Victron energy storage system. This had a typical maximum life of 600 cycles at 50% depth of discharge. For a battery going through a charge and discharge cycle every day, this would be less than 2 years or within the project lifespan. After 2 years the battery at household T-31 only discharged to about 82% of capacity, suggesting it was near the end of its lifespan. A replacement 260Ah AGM battery would be about £370, but the savings after 2 years would only be about £92.

A tubular gel lead acid battery with a capacity of 250Ah would have a typical maximum cycle life of 1500 cycles at 80% depth of discharge (DoD). Such a battery would cost about £470 incl. VAT and might be expected to have a lifespan of over 4 years at 1 cycle per day. The total battery capacity in this case would be 3kWh and with an 80% DoD, the usable battery capacity would be 2.4kWh. The savings should be greater for this battery than for the AGM model tested with a usable capacity of 1.56kWh. While the economics for the tubular gel battery are better than for the AGM, the payback for the system is significantly beyond the lifespan of the battery.

Battery manufacturers are aware that the payback time for their systems is beyond the lifespan of the battery. It is possible that mass production and greater installations could reduce costs in a similar manner as seen for solar PV systems. However, manufacturers are looking at other ways to reduce payback times and offer additional services. This includes the following developments:

- Higher battery charge rate
  - This will reduce the electricity exported to the grid and increase the amount stored in the battery
- Higher power outputs
  - More of the power consumed by higher power devices like cookers, washing machines and kettles can be supplied by the battery
- Greater battery capacities
  - Less of the electricity generated by the solar array will be exported and the household demand can be supplied for a longer period. A larger capacity battery allows further benefits like grid charging and extra income from grid services like Moixa Gridshare.
- Grid charging
  - A larger capacity battery allows a household to switch to a time of use tariff such as economy 7 or more advanced tariffs. The battery can charge during off-peak periods and supply power to get the household through peak rate periods. Solar charging can provide more of the power in summer with grid charging suppling cheap power in winter.

- Grid services
  - Combining large numbers of batteries to act together in a virtual power plant can be beneficial to the electricity grid and provide additional income for owners. This might mean supplying power for a few minutes during a period of high demand in the early evening or charging at low cost when there is excess renewable generation on the electricity grid. A larger battery can supply more electricity and earn more income.
- Other benefits
  - A number of manufacturers are introducing battery systems which can continue to provide household power during a grid outage. This would be of particular benefit to households living in rural areas with frequent power cuts who rely on critical appliances.
  - Monitoring of 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 Matt*
CBH	*Colchester Borough Homes*
DC	*Direct Current*
DOD	*Depth of Discharge*
EPC	*Energy Performance Certificate*
ESS	*Energy Storage System*
HIP	*Health and innovation Programme*
LED	*Light Emitting Diode*
MCB	*Miniature Circuit Breaker*
MCS	*Microgeneration Certification Scheme*
NEA	*National Energy Action – the National Fuel Poverty Charity*
NEP	*Nottingham Energy Partnership – the project manager*
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*

Appendix 2: Nottingham Energy Partnership promotional materials

SunGAIN

nep nottingham energy partnership

Nottingham Energy Partnership
5th Floor, Castle Heights
72 Maid Marian Way
Nottingham
NG1 6BJ

0300 688 0808
www.nottenergy.com

[illegible]

Dear Householder,

SunGain Battery Bank

The smart way to store your solar energy and use it at night

We are delighted to invite you to the **SunGain Battery Bank energy storage information event on Thursday 26th May 2016 and sign up for a FREE battery storage system.** Please come along to share a glass of wine or cup of tea with the project team and we will explain the benefits of storing energy from your solar PV panels, discuss the install process, and answer any of your questions. You can see the product and meet the project partners including Project Managers Nottingham Energy Partnership winners of the Queen's Award for Sustainability, installers T4 Sustainability plus product Manufacturers, Moixa Technology.

What is available?

The SunGain Battery Bank scheme is offering the **FREE installation of a battery storage unit, worth over £4000, for 35 homeowners that have solar panels.** This ground-breaking technology works in conjunction with your PV panels by storing solar energy during the day to enable you to use more of your free electricity in the evenings and cut your electricity bill even further.

WHEN?
Thursday 26th May 2016

WHERE?
Thurrock CVS
'The Beehive Resource Centre
West Street, Grays
RM17 6XP

WHAT TIME?
Drinks from 6pm, presentation and discussion 6.15pm – 8pm.

Booking arrangements

If you are a homeowner with a solar PV system and would like to be part of this pilot project please call **NEP** on **0300 688 0808** to find out more and to book your place. Do not delay because places are limited. Ask to speak to Adam, lines are open weekdays 9am – 5pm.

I hope that you will be able to attend what promises to be an interesting evening.

Yours sincerely,

Philip Angus
Nottingham Energy Partnership - General Manager

The Queen's Awards for Enterprise: Sustainable Development 2014

NEA Action for Warm Homes TECHNICAL INNOVATION FUND

Figure 5.1 Initial letter sent to suitable households with solar PV promoting the project

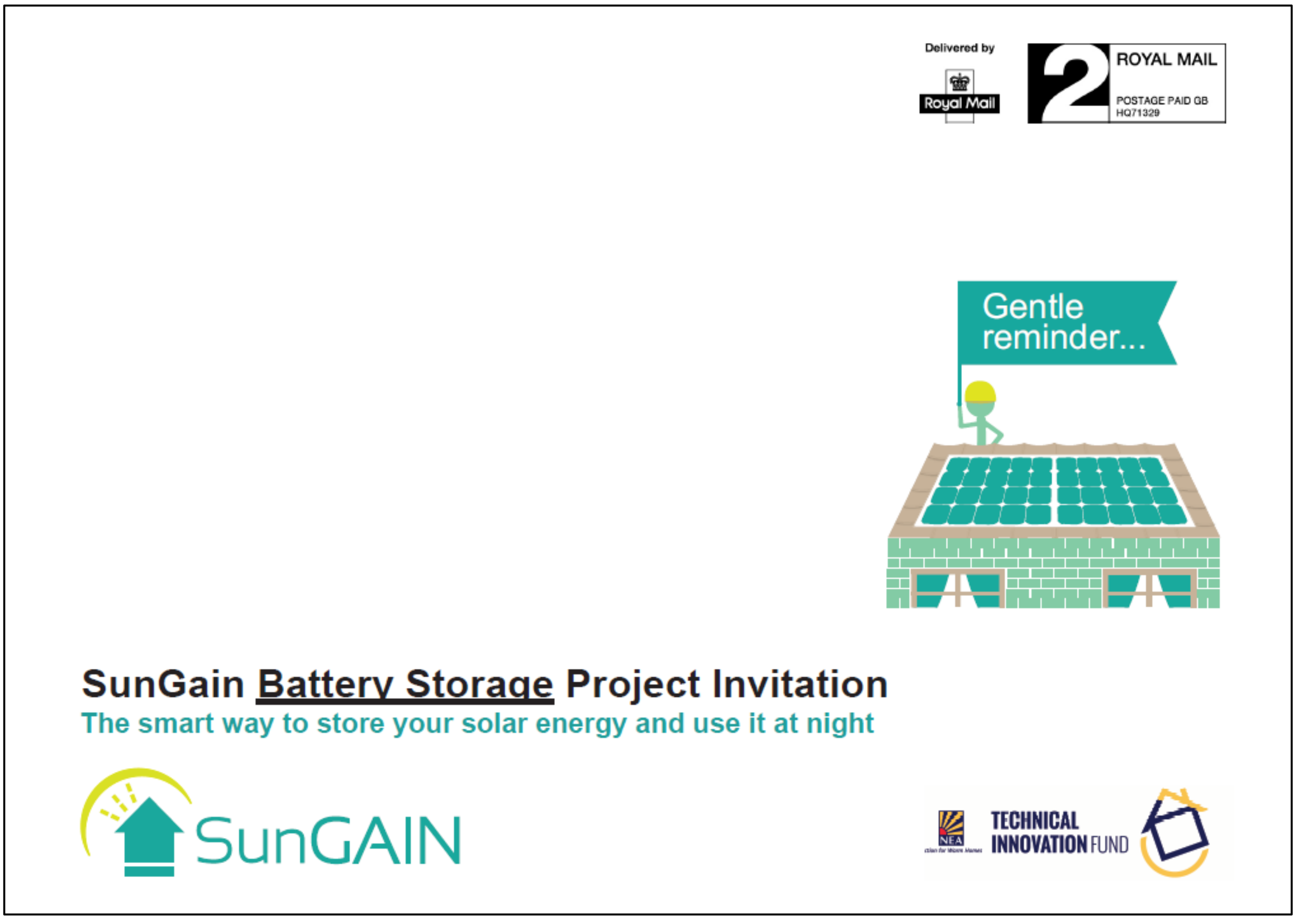

Figure 5.2 Envelope for reminder letter encouraging households to attend the community engagement event

PRESS RELEASE 19.05.2016

Contact: alison.mcguire@nottenergy.com // 0115 985 9057

Thurrock solar generation households needed for FREE battery storage project – limited spaces

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Queen's Award winning climate change charity, Nottingham Energy Partnership (NEP) is looking for 35 households with existing solar panels in Thurrock to house battery storage technology. This exciting project works on a first come first serve basis so interested households must act quickly.

This ground breaking technology will allow families to use 30% more of their free, clean electricity in the evenings, allowing them to power kitchen appliances, lights and the television at little or no cost.

NEP successfully secured funding from the Warm and Healthy Homes Fund to finance this project. It is part of a £26.2 million pound innovative UK-wide programme, designed and administered by National Energy Action, www.nea.org.uk.

Phil Angus, Nottingham Energy Partnership Manager urges people to sign up 'Without energy storage, on average, households only get to use around 30% of the energy they generate, now with battery storage they will be able to utilise up to 60%. These are fully funded systems so it really is a win win for the household. Each system would normally cost in the region of £4,000'.

With less reliance on the grid households can expect to use up to 30% more of their generated electricity. 250 battery storage systems are already in situ in domestic homes across the country so this is a tried and tested technology.

Learn more at our Information Event

If you are a Thurrock resident with a solar electricity system and your household has an Energy Performance Rating between D to G please come along to our information event to learn more and to meet the team.

Date:	**Thursday 26th May 2016**
Venue:	**Thurrock CVS, The Beehive Resource Centre, West Street, Grays, RM17 6XP**
Timings:	**Drinks will be served from 6.00pm, presentation and discussion will take place 6.15pm to 8.00pm.**

To register for this event please contact Adam 0300 688 0808
adam.revill@nottenergy.com

Unobtrusive monitoring will help DECC (Department of Energy and Climate Change) to steer future energy strategies. With little or no subsidies in domestic renewable systems, battery storage is the next big thing and this project will help to bring its need to the forefront.

All systems must be installed by the end of June 2016.

ENDS

Notes to Editors

NEP is a not-for-profit Queen's Award winning organisation in Sustainable Development. They are ISO14001 and ISO9001 accredited and have also gained the Green Level Investors in the Environment (iiE) standard; they are a Green Deal Accredited Assessor and Installer organisation.

For more information contact:
NEP's Marketing Officer, Alison Mcguire
Email: alison.mcguire@nottenergy.com
Telephone: 0115 985 9057
Website: www.nottenergy.com
Twitter: @Nott_Energy

Figure 5.3 Press release promoting the SunGain battery bank project and community engagement event.

Appendix 3: Health and Innovation Programme 2015 –

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

NEA Technical
January 2019

Action for Warm Homes