NEA Action for Warm Homes — TECHNICAL INNOVATION FUND

CP745
24/7 Solar
London Borough of Camden

Technical Evaluation Report

Paul Rogers and Michael Hamer
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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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Executive summary

Project overview

The project was led by the London Borough Council of Camden in partnership with the London Boroughs of Islington and Waltham Forest. Each of these councils have a significant portfolio of homes which they socially rent. There was a desire to reduce electricity bills of vulnerable residents in or at risk of fuel poverty by installing domestic battery storage alongside solar PV systems.

Although significant amounts of electricity can be generated by a domestic solar Photovoltaic (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, when PV generation is low or absent.

The project had the following aims;

- Install domestic battery storage in 40 homes with solar PV in Camden, Islington and Waltham Forest,
- Assess the performance of 3 different battery technologies:
  - Moixa Maslow V3 battery
  - sonnenBatterie eco 8.2
  - Growatt SP2000 controller and GBLI 5001 battery
- Assess levels of resident satisfaction with the technology
- Determine the battery performance over a year and the savings for the residents from the batteries and the solar PV systems
- Consider any barriers to further large-scale deployment of the technologies

Context

There are estimated to be 111,774 households in Camden, 108,001 in Islington and 107,583 in Waltham Forest in 2017[1]. The London Borough of Camden socially rents 33,418 properties. Out of these, there are 734 properties which provide a single dwelling and many of these are terraces of older buildings. Islington Council owns about 25,000 properties with a further 10,000 owned by housing associations. Waltham Forest Housing socially rents 10,130 properties and 3,802 of these are houses. The fuel poverty rates in Camden and Islington are similar with values of 9.9% and 9.8% respectively. In Waltham Forest the rate is noticeably higher at 13.2%. London had a total of 21,480 domestic solar PV installations at the end of 2017. In Camden there were a total of 260 domestic PV installations, while in Islington there were 377 and 1528 in Waltham Forest.

The feed-in tariff for solar PV allowed the industry to develop, mature and for PV costs to fall. Solar PV can reduce electricity costs for residents and improve the SAP rating for the property, which assists the landlord to meet targets for SAP ratings. The market for domestic battery storage is still in the early stages in the UK. At the time of writing, battery storage was not covered by the Microgeneration Certification Scheme (MCS) which provides quality assurance for renewable

[1] Table 406, 2014-based Household Projects for 2017, Department for Communities and Local Government, https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections (Accessed 5 Mar 18)

installations. While renewable energy installers are very familiar with solar PV and the benefits can be easily estimated, experience with battery storage is more limited.

There has been no financial incentive such as the feed-in tariff for domestic battery storage in the UK. However, many 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[2].

Installations 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[3]. The German manufacturer sonnen had sold 15,000 battery systems globally by October 2016[4].

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

Moixa Maslow V3 battery

The Moixa Maslow V3 battery is an AC (alternating current) coupled battery system which uses a lithium iron phosphate battery and 2 microinverters. Most of the Moixa batteries installed had a capacity of 2kWh, but a few were the larger 3kWh model. The batteries could be taken to a depth of discharge (DOD) of 80%, which 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 5 years. The system needs to be connected to the internet for monitoring to assist with battery control. The battery has an external WiFi antenna and a 3G transmitter, but most batteries were connected to the WiFi routers using power-line adapters or TP Links.

sonnenBatterie eco 8.2

The sonnenBatterie eco 8.2 is again an AC coupled battery system that uses lithium iron phosphate battery technology. The battery had a usable capacity of 2kWh and an output of up to 1500W. The battery can start to discharge once the household demand exceeds 30W. The warranty lasts for either 10 years or 10,000 complete recharge cycles, depending on which occurs

[2] 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)

[3] 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)

[4] China's Envision joins investor in German battery firm sonnen cash boost, 16 Oct 2016, https://www.pv-magazine.com/2017/09/07/suns-e3-dc-senec-and-lg-chem-dominate-german-residential-pv-storage-market/ (Accessed 19 Mar 2018)

first. The system is modular and an expansion case and further batteries can be added. The battery requires an internet connection for monitoring, to allow system updates and to maintain the guarantee.

Growatt SP2000 controller and GBLI5001 battery

The Growatt battery system is DC (direct current) coupled and so is fitted between the solar panels and the inverter. While the Moixa and sonnen systems comprise a single unit, the Growatt system includes a separate controller and battery. The Growatt SP2000 controller can work with either lead-acid or lithium-ion batteries and has a maximum charge and discharge power of 2000W. The Growatt GBLI 5001 is a lithium-ion battery with a capacity of 4.875kWh. Once the conversion efficiency of 94% of the SP2000 unit is taken into account along with the 80% DOD, the usable capacity of the battery is 3.67kWh. Monitoring for the system can be provided by installing a Wi-Fi dongle on the SP2000 controller.

The project

Camden Council recruited households through their Warm and Well programme and among those living in the hardest to treat properties. Since many of the socially rented properties in Camden are in conservation areas, houses with ‘London Valley’ or inverted pitch design of roof were targeted. This was because the roof is hidden behind a parapet and the solar panels would not be visible from the road. The housing stock in Waltham Forest was typically built later and most of the council-owned properties which received installations were built after 1929 and all had pitched roofs. The batteries fitted in Islington were installed in private properties which had pre-existing solar PV installations which had previously been funded by the council’s Climate Change Fund.

Out of the total of 40 battery systems 28 were fitted in Camden, 3 in Islington and 9 in Waltham Forest. The batteries installed in Camden were 20 x Moixa Maslow batteries (with 17 x 2kWh and 3 x 3kWh), 6 x sonnenBatterie eco 8.2 and 2 x Growatt battery system with a SP2000 controller and GBLI 5001 battery. All the batteries in Islington and Waltham Forest were Moixa Maslow 2kWh systems. Installations took place between August and November 2016. A third Growatt battery system was fitted in Camden, however the system never worked and was later removed.

Initially 7 households in Camden were recruited to be part of a monitored group. These included 1 Moixa Maslow installation with a 3kWh battery, 2 Moixa Maslow systems with 2kWh batteries, 2 sonnen installations and 2 Growatt installations. A further 3 households were recruited for interviews at the end of the project as there was limited battery data from some of the initial households. These included 1 with a sonnen battery and 2 with Moixa Maslow 2kWh batteries. As well as the monitored households with batteries and solar, there were also 3 households recruited in Waltham Forest which only had solar PV and acted as a control group.

Initial questionnaires were completed by the households between August and November 2016. An intermediate visit in June 2016 maintained contact with the households and gave the opportunity to check for any changes during the project. A final visit was carried out in February 2018 where the questionnaire assessed the benefit of the technologies, 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

- Out of the 10 households interviewed, all thought the battery-solar system did not need any active input to work and 8 found it easy to use. However, 5 of the households felt they did not know enough about how the measures worked.
- The perception of savings from the battery solar systems was not clear and likely to be affected by rising prices and some households paying by direct debit. 4 out of 9 households felt there had been a reduction in their energy bills while 6 of the 9 believed they had been saving energy in the home.

Installation and reliability issues

- Reliability of the battery solar systems was a problem with 6 of the 10 households interviewed saying they had experienced reliability issues or breakdowns.
- Problems included regular tripping of the RCD protection for the solar PV system and at least 1 system where there was a partial fault of the inverter or solar PV array.
- The batteries require an internet connection for monitoring, system updates, effective operation of the battery and maintenance of the warranty.
- Out of the 32 Moixa Maslow installations, 8 were connected to the internet for less than 150 days between September 2016 and December 2017. Reasons included lack of home internet access,3G communication proving unreliable, residents declining access to their home broadband and tripping of the RCD protection causing the battery to go offline.
- TP Links were used to connect the Moixa and sonnen batteries to the household WiFi routers. Although they were considered more effective than 3G and WiFi communication, problems still developed with the TP Link connections. This resulted in several of the sonnen batteries going offline intermittently and limiting the data available to analyse.
- There were problems with the Growatt systems due to poor system design and installation by the contractors. This meant that 1 system failed to work and had to be removed. For another, it was necessary for Growatt to de-rate the SP2000 controller to enable the battery to discharge.

Moixa Maslow V3 batteries

- Out of the 32 Moixa Maslow batteries installed, 15 were online for a sufficient period to allow an assessment of the performance between March and December 2017.
- The battery discharge was typically in the range 120kWh to 280kWh.
- Some systems performed less well, such as an installation with a 1.36kW PV array and an annual household consumption of 8359kWh. Here there was little excess solar generation to charge the battery and the discharge over the period was only 31kWh.
- The best performing battery discharged 290kWh between 9 Mar 2017 and 31 Dec 2017. The solar PV system generated 1786kWh in 2017 while the household consumption was 980kWh between 31 Mar 2017 and 23 Dec 2017. The relatively low daytime consumption and larger PV array meant there was frequently excess solar generation which allowed the battery to regularly charge. The battery was then able to supply a significant proportion of the electricity demand in the evening.

- The financial benefit for residents was assessed for 8 Moixa battery solar systems which had a good internet connection and performed well over the period 9 Mar 17 to 31 Dec 17. The households saved up to £141.60 on their electricity from the solar PV systems. The batteries saved households between £18.56 and £46.39 during the same period.

sonnenBatterie eco 8.2

- There was a single sonnen battery that was online throughout 2017 and this discharged 407kWh over the year. The annual grid consumption for the household was 4700kWh and the generation from the solar PV system 1958kWh.
- 5 of the 6 sonnen battery systems were online during March 2017. The battery discharge during the month ranged from 28.9kWh to 37kWh.
- The battery inverter on the sonnen system can operate with an input as low as 30W. This is likely to increase the level of battery discharge. However, the inverter is less efficient at low power and this affects the battery round trip efficiency, which is low in winter.
- During an extended period without solar generation, such as dark winter days or after a PV system fault, the battery can consume 0.59kWh per day to power the battery system and maintain charge.
- For the household that was online throughout 2017, the financial benefit from the sonnen battery was £65.06 and the electricity savings from the solar PV system was £188.35.
- It was possible to compare better performing sonnen and Moixa batteries between April and December 2017. The best performing sonnen battery discharged 362kWh during this period compared to 273kWh for the best performing Moixa Maslow

Growatt SP2000 and GBLI 5001 battery

- There were installation issues with all these batteries, perhaps due to the contractors having limited experience with the Growatt battery system. Monitoring for the system was fitted in October 2017. This revealed that a Growatt battery had not been discharging since installation.
- The period for monitoring was limited due to a number of contributory factors; monitoring equipment was not fit at install and therefore delayed the commencement of the monitoring period, the technical issue outlined above where the battery was not discharging and household electrical work causing one of the batteries to go offline.
- It was not possible to make long-term comparisons with the Moixa and sonnen systems. However, the battery discharge recorded for a Growatt system ranged from 0.27kWh/day in December 2017 to 0.82kWh/day in February 2018, which was higher than for the Moixa and sonnen batteries.
- Differences between the PV generation recorded by the Growatt system and a smart generation meter along with differences in the battery discharge and charge determined by different methodologies raised concerns about the accuracy of the data recorded.
- When the battery was discharging, some of this was exported to the grid when there were changes in the household consumption. Power was also discharged to the grid during periods when the household consumption was 100-200W. This indicates that not all the battery discharge was used by the household.

Conclusions and recommendations

- Solar PV is a mature technology which is effective at reducing electricity bills for residents and also increasing SAP ratings for the property. It shouldn't however be considered as a 'fit and forget' technology. A number of issues occurred during this study ranging from regular RCD trips to at least 1 system where an inverter or PV array fault led to a reduction in generation. Remote monitoring of systems along with regular checks in performance are to ensure there is not a loss of feed-in tariff income for the PV system owner and electricity savings for the residents.
- Domestic battery storage is a technology still under development and is currently at the stage of undergoing large-scale trials and purchases from early adopters and specialist users. Problems with installations can occur due to the contractors having limited experience with the technology and there being no quality management for installations such as with the Microgeneration Certification Scheme (MCS).
- A continuous internet connection is important for monitoring batteries, providing system updates as well as maintenance of effective operation and extended guarantees. WiFi connections to broadband routers along with 3G have generally provided ineffective. TP Links or powerline adapters are generally more successful but have also proved problematic in this study with many systems losing the connection. To ensure a continuous connection, manufacturers now prefer a hard-wired connection between the battery and the WiFi router. Social landlords must check there is broadband at a property and the resident is willing to provide internet access before considering an installation.
- 3 battery technologies were trialled from Moixa, sonnen and Growatt. A sonnenBatterie eco 8.2 system was able to discharge 406.6kWh in 2017, providing a saving of £65 to the residents. The best performing Moixa installation discharged 290kWh between March and December 2017, with a saving of £46.
- When compared over the same April to December period, the Moixa battery discharged 273kWh (saving £43.70) compared to 362kWh (saving £57.90) for the sonnen system.
- Installation and operational issues with the Growatt batteries limited the monitoring period for the system. However, an installation appeared to perform better in winter than Moixa and sonnen installations.
- Before considering a battery installation, an assessment should determine whether there would be sufficient excess solar PV generation to charge the battery with the level of household consumption. Some batteries in the study had a small solar PV array and high household electricity consumption. This led to little charging of the battery and provided minimal extra benefit to the household.
- At present the payback time of the residential batteries trialled exceeded their lifespan. However, battery technology is rapidly developing, 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, offering grid balancing services and providing backup power during power cuts.

1. Project overview

1.1 Introduction

The project was led by the London Borough Council of Camden in partnership with the London Boroughs of Islington and Waltham Forest. Each of these councils have a significant portfolio of homes which they socially rent. There was a desire to reduce electricity bills of vulnerable residents in or at risk of fuel poverty by installing domestic battery storage alongside solar PV systems.

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.

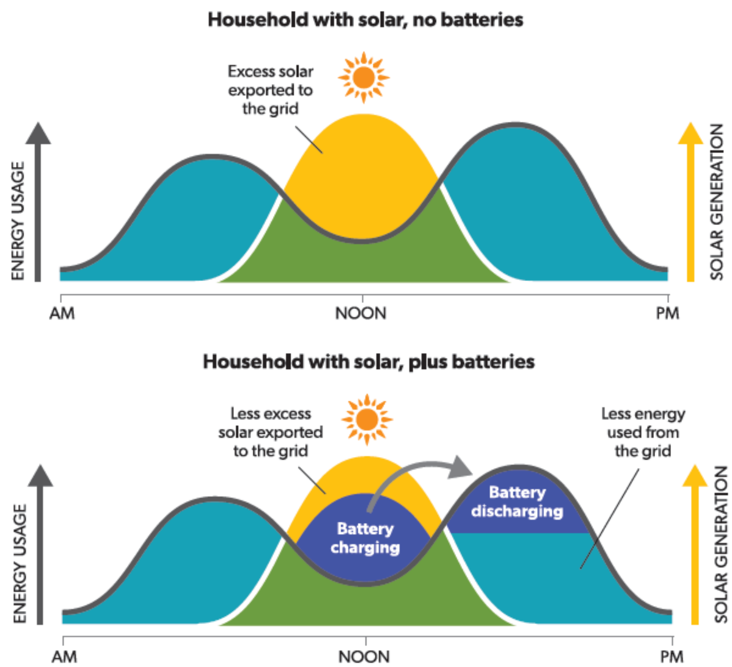

Figure 1.1 Illustration of the benefits of energy storage on a solar PV system[5]

A total of 40 batteries were installed with financing from the NEA Technical Innovation Fund, while the solar PV systems were funded by the councils. The batteries chosen were manufactured by Moixa, sonnen or Growatt. A total of 28 were installed in Camden, 9 in Waltham Forest and 3 in Islington. Project management was provided by Lakehouse. Solgain was chosen as the installer and they sub-contracted to ALG Home Services in Flintshire. The office of the Mayor of London has published a case study which summarises the project[6]

[5] 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)
[6] Solar energy and battery storage trial, Mayor of London, https://www.london.gov.uk/sites/default/files/renew_solar_energy_case_study2.pdf (Accessed 1 Mar 2018)

1.2 Aims

The project had the following aims;

- Install domestic battery storage in 40 homes with solar PV in the London Boroughs of Camden, Islington and Waltham Forest.
- Assess the performance of 3 different battery technologies:
  - Moixa Maslow V3 battery with capacities of 2kWh and 3kWh
  - sonnen eco 8.2 with a usable capacity of 2kWh
  - Growatt SP2000 controller and GBLI 5000 battery with a capacity of 4.875kWh
- Assess levels of resident satisfaction with the technology
- Determine the battery performance over a year 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 111,774 households in Camden, 108,001 in Islington and 107,583 in Waltham Forest in 2017[7]. The London Borough of Camden socially rents 33,418 properties. Out of these, there are 734 properties which provide a single dwelling and many of these are terraces of older buildings. Islington Council owns about 25,000 properties with a further 10,000 owned by housing associations. Waltham Forest Housing socially rents 10,130 properties and 3,802 of these are houses. The fuel poverty rates in Camden and Islington are similar with values of 9.9% and 9.8% respectively. In Waltham Forest the rate is noticeably higher at 13.2%.

London had a total of 21,480 domestic solar PV installations at the end of 2017. The rate per 10,000 households was 59, the lowest rate for a region in the UK[8]. In Camden there were a total of 260 domestic PV installations, while in Islington there were 377 and 1528 in Waltham Forest.

It has been noted that one reason for the low rate of solar PV installations in London is that it has a cityscape of thin, tall buildings as well as terraced housing with little roof space[9]. Also, a significant number of these homes are in conservation areas where there can be confusion over whether solar panels require planning permission. In Camden for example, 75% of developed areas are designated as 'conservation areas', but the council has produced retrofitting planning guidance for conservation areas[10]. Over half of London residents live in rented accommodation where PV installations are less common than for owner occupiers. Also, a significant number of households live in flats and apartments where PV installations are less straightforward[11].

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[7] Table 406, 2014-based Household Projects for 2017, Department for Communities and Local Government, https://www.gov.uk/government/statistical-data-sets/live-tables-on-household-projections (Accessed 5 Mar 18)

[8] Sub-regional Feed-in Tariff Statistics, December 2017, https://www.gov.uk/government/statistical-data-sets/sub-regional-feed-in-tariffs-confirmed-on-the-cfr-statistics (Accessed 5 Mar 2018)

[9] Bring me sunshine! How London's homes could generate more solar electricity, London Assembly, October 2015 https://www.london.gov.uk/sites/default/files/07a_environment_committee_-_domestic_solar_report_-_final.pdf (Accessed 6 Mar 18)

[10] Energy Efficiency Planning Guidance for Conservation Areas, Camden Council, Sept 2014 https://www.camden.gov.uk/ccm/navigation/environment/planning-and-built-environment/planning-policy/supplementary-planning-documents--spds-/ (Accessed 5 Mar 2018)

[11] London Councils' Response to the London Assembly Investigation on Solar Power, June 2015 https://www.londoncouncils.gov.uk/our-key-themes/environment/energy-and-climate-change/energy-efficiency (Accessed 6 Mar 2018)

From 2010, the expansion of solar PV installations was driven by the feed-in tariff. Prior to that limited grants were available from Central Government and local authorities. In 2008, Islington Borough Council set up a £3m Climate Change Fund to support green energy projects that would reduce CO_2 emissions throughout the borough. Islington residents were able to apply for funding to install technologies such as solar PV, solar thermal, wind turbines, ground source heat pumps and biomass boilers in their homes. By 2010, the scheme had funded 100 solar installations.[12]

In the period between 2010 and 2016, the feed-in tariff was sufficiently high to encourage social landlords to install solar PV on their properties on a large scale. Some like Mid-Devon Council used ‘rent-a-roof’ schemes where the council received rental income from the financer and tenants had access to any electricity generated by the system. By 2015, Mid-Devon Council had installed PV panels on 1,175 units (38%) of their housing stock, many of which were bungalows and well suited to solar panels[13]. This programme accounted for about one third of all PV systems in the local authority area, which has the second highest rate of installations per 10,000 households in the country.

In 2012, the London Borough of Waltham Forest funded the installation of about 1000 solar PV systems on homes managed by their then arms-length social landlord, Ascham Homes[14]. The council benefited from the feed-in tariff income and residents were estimated to save up to £140 per year from use of the free electricity generated by the solar panels. This was the largest scheme of its kind in London and meant that the council was responsible for about two thirds of the domestic PV installations in Waltham Forest. Currently Waltham Forest Housing owns 1006 PV systems installed on socially rented houses and 39 where tenants have purchased the house via right-to-buy.

There was a significant reduction in solar PV installations after the 2016 feed-in tariff cuts. However, interest in solar PV from social landlords is returning. Although returns on investment are now lower, the technology can provide a cost-effective method of improving SAP ratings as well as reducing residents’ electricity bills, alleviating fuel poverty levels and lowering carbon emissions[15]. Whereas previous funded solar offers enabled residents to use electricity from the solar panels for free, ones currently offered may require a tenant contribution in the form of a monthly payment or an energy supply contract where the electricity is purchased at a lower rate than from a normal electricity supplier.

The market for domestic battery storage is still in the early stages of development in the UK. At the time of writing, battery storage is not covered by the Microgeneration Certification Scheme (MCS) which provides quality assurance for renewable installations. While renewable energy installers are very familiar with solar PV and the benefits can be easily estimated, experience with battery

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12 Islington receives 100th rooftop solar installation, Solar Power Portal, 1 Nov 2010, https://www.solarpowerportal.co.uk/news/islington_recieves_100th_rooftop_solar_installation (Accessed 4 Apr 2018)

13 Mid Devon District Council Draft Housing Strategy 2015-2020, Mid Devon District Council https://democracy.middevon.gov.uk/documents/s3650/MDDC%20Housing%20Strategy%20v4%20kd%2006102015%20Decent%20and%20Affordable%20Homes%20Policy%20Development%20Group.pdf (Accessed 6 Mar 2018)

14 Solar PhotoVoltaic Installations on Council Housing, London Borough of Waltham Forest (2011), http://democracy.walthamforest.gov.uk/documents/s17231/Solar%20Panels%20Revised%20281111%20final.pdf (Accessed 6 Mar 2018)

15 Is Solar PV on a comeback?, Jamie Abbott, Mayor of London, October 2017, https://www.london.gov.uk/sites/default/files/october_solar_pv_blog.pdf (Accessed 6 Mar 2018)

storage is more limited. The Renewable Energy Consumer Code (RECC) has written guidance on battery storage for sellers and installers following a significant number of complaints about mis-selling of the technology[16]. The BRE National Solar Centre in collaboration with RECC has also produced guidance for those considering purchasing battery storage systems[17]. 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[18].

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[19]. Other manufacturers such as sonnen are likely to have installed hundreds of battery storage systems in the UK to date[19]. Globally, and primarily in its home market of Germany, sonnen had sold 15,000 battery systems by October 2016[20].

As manufacturers develop new products, there is a trend towards larger capacity batteries with greater output power. Prices per kWh of storage are predicted to fall. The economics for domestic battery storage will be further improved by batteries 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 earn a fixed income of £50 per year from the scheme[21].

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16 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)

17 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)

18 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)

19 Moixa expansion continues with £2.5 million investment and plans for 100,000 battery Virtual Power Plant to balance grid, Moixa press release, 18 Jul 2017 http://www.moixa.com/press-release/moixa-expansion-continues-2-5-million-investment-plans-100000-battery-virtual-power-plant-balance-grid/ (Accessed 7 Mar 2018)

20 China's Envision joins investor in German battery firm sonnen cash boost, 16 Oct 2016, https://www.pv-magazine.com/2017/09/07/suns-e3-dc-senec-and-lg-chem-dominate-german-residential-pv-storage-market/ (Accessed 19 Mar 2018)

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

1.4 Project timeline

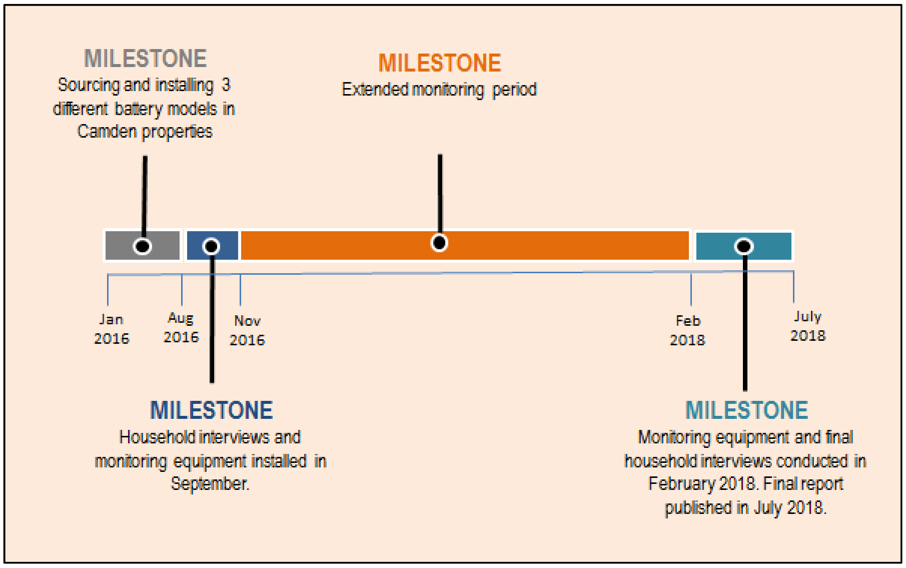

Figure 1.2 Project timeline

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 1.3 Solar PV installation on a property in Camden with a London Valley roof

- Camden Council identified social tenants for recruitment through their Warm and Well programme and among those living in the hardest to treat properties[22].
- Many of the socially rented street properties in Camden are in conservation areas. This restricts retrofits which change the character or appearance of the area. Houses with a 'London Valley' or inverted pitch design of roof were targeted as the roof was hidden behind a parapet and the solar panels would not be visible from the road (figure 1.3).
- An initial letter was sent to several hundred tenants by Camden Council after successfully passing the first stage of the NEA Technical Innovation Fund application. Further contact was made following confirmation of the project by NEA and financing for the solar PV from the councils.
- Home visits were also carried out to explain to residents how the solar PV would provide free electricity during the day and the batteries would store further electricity they could use in the evenings.
- The ambition was that tenants would remain engaged with the project throughout. Some withdrew before installation, however, other residents asked to be added to the project once they saw installations were going ahead.
- Out of a total of 40 battery installations, 28 of these were in properties owned by the London Borough of Camden and 9 by Waltham Forest. The 3 properties where the batteries were fitted in Islington were privately owned and had solar PV systems that had been financed by the Climate Change Fund set up by the London Borough of Islington in 2008.
- Initially 7 of the households in Camden with battery installations were recruited for a monitored group where the residents were interviewed. A further 3 households in Waltham Forest were recruited as controls. These properties had pre-existing solar PV systems, but no batteries were fitted. All these households received shopping voucher incentives for taking part in the project.
- Later in the project, an additional 3 households were recruited for the monitored group. These were recruited because they had better quality battery monitoring portal data available. Each of these households completed the final project questionnaire.

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[22] Solar energy and battery storage trial, Mayor of London, https://www.london.gov.uk/sites/default/files/renew_solar_energy_case_study2.pdf (Accessed 1 Mar 2018)

1.6 Factors affecting the planned evaluation methodology

Issue	Description and mitigation
Project delays	Originally, it was intended for the new solar PV systems to be funded by a ‘rent-a-roof’ scheme. However, this fell through after cuts to the feed-in tariff. To ensure the project went ahead, Camden Council self-funded the new solar PV systems on their sites. Delivery of batteries from Europe also caused delays and meant changes to the battery brands used for the project. Since the installations took place between August 2016 and November 2016, the project was extended to allow a full 12-month monitoring period including the summer when PV generation was highest.
Suitable houses for installing solar PV	Islington Council investigated installing solar PV systems for the project but faced several challenges with their housing stock. • Issues with planning due to houses in conservation zones • The presence of asbestos • Insufficient space in the roof to fit an inverter They decided to fit 3 batteries in private properties which had solar PV systems funded by the Islington Climate Change Fund in 2008.
Size of battery system	Some residents were unhappy with the size of the batteries and refused to have particular models.
Removal of Growatt battery system	Originally 3 Growatt battery systems were installed but 1 of these was later removed. The contractor was meant to conduct surveys to assess suitability ahead of installations. In this case the battery was fitted on the initial visit at a site with a pre-existing 1.075kW PV system. This installation was problematic and caused the PV system to stop working. The contractor subsequently bypassed the battery to get the PV system working again. They later claimed the problems were due to the array being too small to charge the battery. The issue was not resolved by the contractor and the resident requested that the battery was removed.
Other issues with the installation of Growatt batteries	There were issues with the other Growatt battery installations. At 1 site, the DC input to the controller was initially fitted with reversed polarity. It was later determined the SP2000 controller was an inappropriate sized for the inverter. At the other, the battery was fitted on the ground floor of a 3-storey building, while the SP2000 controller was in the loft. There was no communication cable between the battery and controller and the DC cables were undersized for the length of cable run. This problem was later resolved by reinstalling the battery in the loft.

Poor connection of batteries to the internet	It was necessary for the batteries to have a consistent connection to the internet to provide good monitoring data for the battery portal and also control and updates for the batteries. This was usually done using TP Links/power line adapters connected to the battery and the WiFi router, but a WiFi or a 3G transmitter could also be used. In some cases, there was a poor signal or residents regularly turned off their WiFi router and there were gaps in the data. A sonnen battery went offline for a few weeks and this was resolved by replacing the TP Links.
Technical problems with the solar PV systems	Some PV systems had technical issues such as the system occasionally tripping out. Where residents did not understand the technology or regularly check the generation meter, the PV system could be offline for an extended period before this was noticed. Here it was necessary to reset the RCD switch. It was noticed by NEA staff that the PV generation from a sonnen system had decreased substantially, possibly due to an inverter fault. This highlights how an understanding of the system, coupled with remote monitoring and automatic fault reporting can be important for quick identification and remedy of issues which could in turn limit the potential household benefits.
London Valley Roof	Camden Council targeted households living in properties with London Valley roofs. This was because it was possible to fit solar panels on homes despite them being in a conservation area as the roof was hidden by a parapet. When the solar PV systems were fitted by the contractor, they also put solar panels over the hatch which provides access to the roof from the loft space. The maintenance team at Camden Council were concerned there was no longer access to the roof using the hatch. The panels which covered the hatches may have to be removed at a later date to restore access.
Changes of tenancy	There is potential for problems if the tenant in the property changes. The new tenant would not have been advised on the operation of the battery solar system and the internet connection for the battery would have been lost during the void period. Camden Council are planning to add information to their asset register to ensure the issue is properly addressed in future when there is a change of tenancy.
Battery data from monitored group	Households where the batteries had a consistent connection to the internet during the study were recruited into the monitored group at the stage of the final interviews. This overcame the problem of some households in the initial group where data from the batteries was poor. It was intended that all the batteries would be connected to the internet. This allowed an assessment of the performance of some of the other batteries that were outside the monitored group.

2. Social evaluation and impacts

2.1 Details of properties

Batteries installed

Type of battery	All installations	Camden installations	Islington installations	Waltham Forest installations	Camden households questioned
Moixa	32	20	3	9	5
sonnen	6	6	0	0	3
Growatt	2	2	0	0	2
Total	**40**	**28**	**3**	**9**	**10**

Table 2.1 Summary of types of battery installed in the 24/7 Solar project

Overall, there were a total of 40 battery systems installed and a summary of the types is shown in table 2.1 and figure 2.2. In the London Borough of Camden, there were 28 battery systems fitted in council-owned houses. These comprised 20 Moixa batteries, 6 sonnen batteries and 2 Growatt batteries. There were 2 sites which had pre-existing PV systems while all the others were installed along with the batteries.

In the London Borough of Islington, batteries were fitted in 3 privately-owned properties. These all had pre-existing solar PV systems that were installed in 2008 with funding from Islington's Climate Change Fund. Out of these properties, 2 also had a pre-existing solar thermal system. Each of these properties had Moixa batteries fitted.

There were 9 Moixa batteries fitted in socially-rented properties in the London Borough of Waltham Forest. There was a single property with a pre-existing solar PV system, while all the rest were installed with the batteries.

A monitored group was initially recruited with 7 households who received batteries in Camden. These households were interviewed, and their energy bills were analysed. These included 3 with Moixa batteries, 2 with sonnen and 2 with Growatt. A further 3 households were recruited towards the end of the project who were noted to have good quality data on the battery portals. These included 2 households with Moixa batteries and 1 with a sonnen battery.

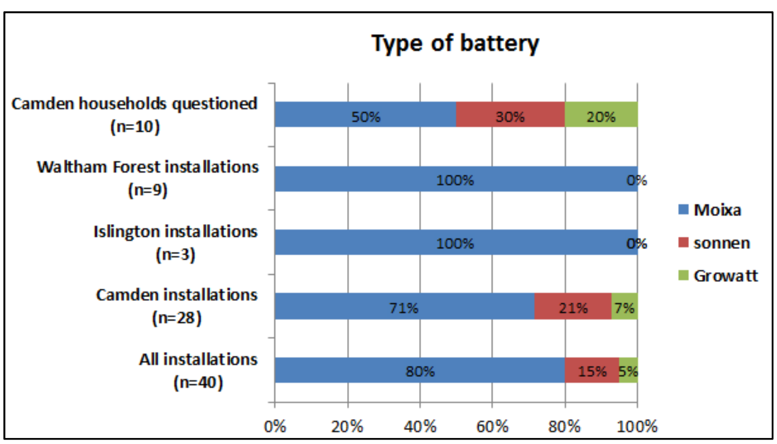

Figure 2.2 Summary of types of battery installed in the 24/7 Solar project

Location of installations

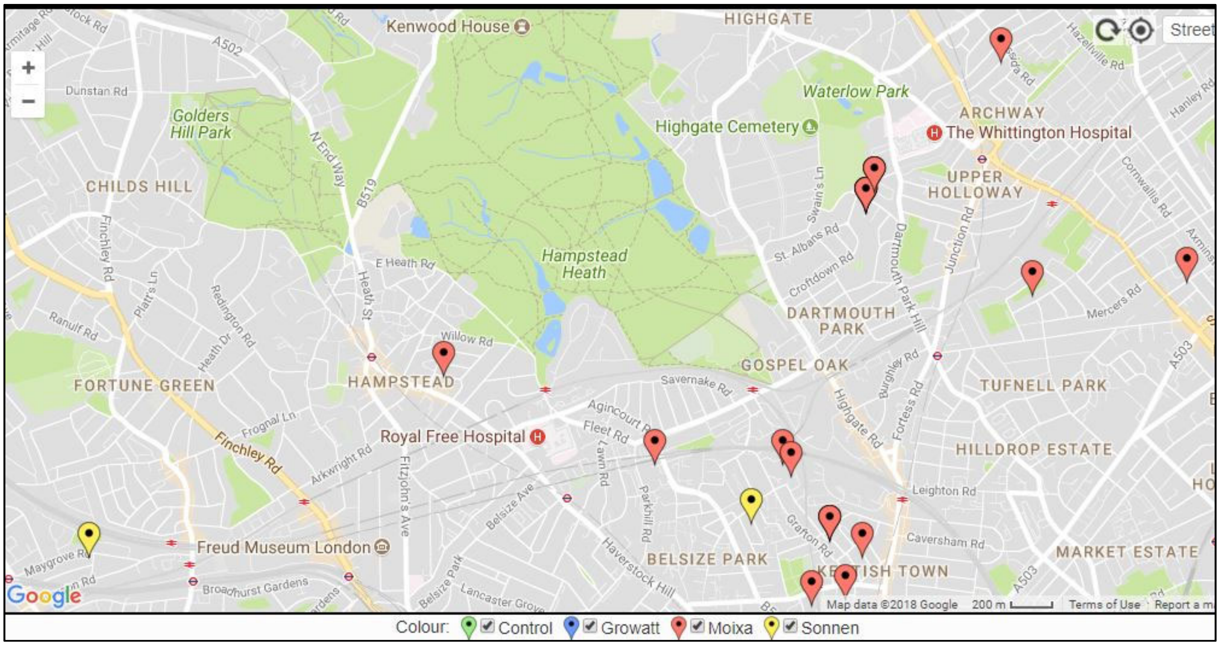

Figure 2.3 Map showing locations of north Camden and Islington battery installations

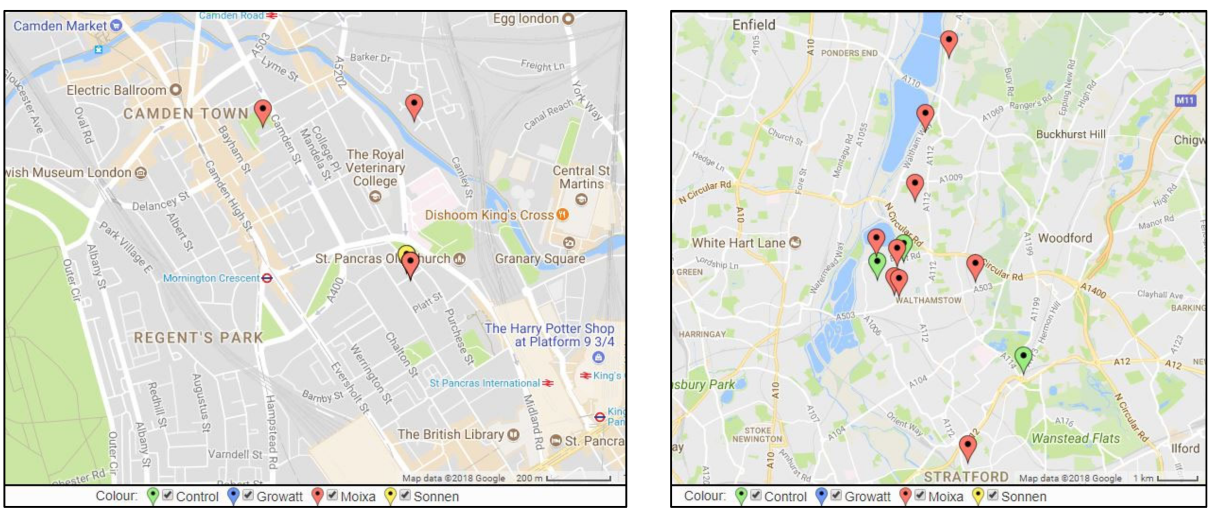

Figure 2.4 Maps showing the locations of southern Camden battery installations (left) and Waltham Forest battery installations (right) along with Waltham Forest control properties

Figure 2.3 shows where the batteries were installed in north Camden and Islington, while figure 2.4 shows those in southern Camden (left) and the installations and controls in Waltham Forest (right).

Characteristics of properties with battery installations

Technical Reference Number	Dwelling type	Date band	Floor area (m^2)	Wall type	Heating type	SAP rating before	SAP rating after	SAP improvement from PV
T-01	Mid-terrace	1900-1929	96	Solid	Mains gas	64	77	13
T-02	Mid-terrace	Pre-1920	105	Solid	Mains gas	64	78	14
T-03	Mid-terrace	Pre-1920	104	Solid	Mains gas	65	76	11
T-04	Mid-terrace	Pre-1920	93	Solid	Mains gas	61	69	8
T-05	Mid-terrace	1900-1929	114	Solid	Mains gas	58	69	11
T-06	End-terrace	Post 1982	79	Cavity	Mains gas	69	85	16
T-07	Mid-terrace	Post 1982	87	Cavity	Mains gas	74	84	10
T-08	Mid-terrace	Pre-1920	111	Solid	Mains gas	65	76	11
T-09	Mid-terrace	Pre-1920	111	Solid	Mains gas	65	70	5
T-10	Mid-terrace	1900-1929	103	Solid	Mains gas	58	69	11
T-11	Mid-terrace	Post 1982	80	Cavity	Mains gas	-	73	
T-12	Mid-terrace	Post 1982	80	Cavity	District heating	-	68	
T-13	Mid-terrace	Pre-1920	95	Solid	Mains gas	67	79	12
T-14	Mid-terrace	Pre-1920	111	Solid	Mains gas	62	73	11
T-15	Mid-terrace	Pre-1920	111	Solid	Mains gas	60	71	11
T-16	Mid-terrace	Pre-1920	97	Solid	Mains gas	63	75	12
T-17	Mid-terrace	Pre-1920	93	Solid	Mains gas	65	72	7
T-18	Mid-terrace	1950-1965	67	Cavity	Mains gas			
T-19	Mid-terrace	Pre-1920	94	Solid	Mains gas	59	72	13
T-20	Mid-terrace	Pre-1920	95	Solid	Mains gas	66	78	12
Average			96.3			63.8	74.9	11.1

Table 2.5 Details of properties in Camden which received Moixa batteries

Technical Reference Number	Dwelling type	Date band	Floor area (m^2)	Wall type	Heating type	SAP rating before	SAP rating after	SAP improvement from PV
T-21	Mid-terrace	1920-1929	140	Solid	Mains gas	59	68	9
T-22	End-terrace	Pre-1920	111	Solid	Mains gas	45	56	11
T-23	Mid-terrace	Pre-1920	95	Solid	Mains gas	66	78	12
T-24	Mid-terrace	Pre-1920	95	Solid	Mains gas	67	75	8
T-25	Mid-terrace	Pre-1920	133	Solid	Mains gas	56	67	11
T-26	End-terrace	Pre-1920	94	Solid	Mains gas	57	65	8
Average			111.3			58.3	68.2	9.8

Table 2.6 Details of Camden properties which received sonnen batteries

Technical Reference Number	Dwelling type	Date band	Floor area (m^2)	Wall type	Heating type	SAP rating before	SAP rating after	SAP improvement from PV
T-27	Mid-terrace	Pre-1920	93	Solid	Mains gas	66	73	7
T-28	Mid-terrace	Pre-1920	111	Solid	Mains gas	65	76	11
Average			102			65.5	74.5	9

Table 2.7 Details of Camden properties which received Growatt batteries

Details of the Camden Council properties which received battery installations are shown in tables 2.5 to 2.7. The properties in Islington and Waltham Forest are shown in tables 2.8 and 2.9. The households receiving Moixa batteries that were interviewed were T-03, T-08, T-12, T-14 and T-18. Half of the households receiving sonnen batteries were interviewed and these were T-21, T-22 and T-25. Both T-27 and T-28 who received Growatt batteries were interviewed.

Technical Reference Number	Dwelling type	Date band	Floor area (m^2)	Wall type	Heating type	SAP rating before	SAP rating after	SAP improvement from PV
T-29	Mid-terrace	Pre-1920	141	Solid	Mains gas			
T-30	Mid-terrace	Pre-1920	124	Solid	Mains gas	-	67	
T-31	Mid-terrace	Pre-1920	125	Solid	Mains gas	-	59	
Average			124.5					

Table 2.8 Details of properties in Islington which received Moixa batteries

Technical Reference Number	Dwelling type	Date band	Floor area (m^2)	Wall type	Heating type	SAP rating before	SAP rating after	SAP improvement from PV
T-32	Mid-terrace	1900-1929						
T-33	Semi-detached	1930-1949	76	Solid	Mains gas	64	78	14
T-34	Semi-detached	1900-1929	86	Solid	Mains gas	52	61	9
T-35	Mid-terrace	1950-1966	77	Solid				
T-36	End-terrace	1930-1949	67	Solid	Mains gas	63		
T-37	Semi-detached	1950-1966	85	Cavity	Mains gas	65	81	16
T-38	Mid-terrace	1900-1929	86	Solid/EWI	Mains gas	73	91	18
T-39	Mid-terrace	Post 1982	118	Solid	Mains gas	46	54	8
T-40	Semi-detached	1950-1966	82	Cavity	Mains gas	73	89	16
Average			84.6			62.3	75.7	13.5

Table 2.9 Details of properties in Waltham Forest which received Moixa batteries

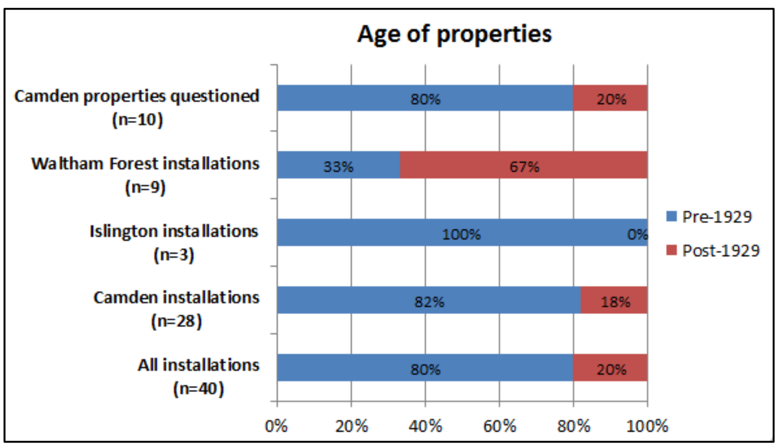

Figure 2.10 Chart illustrating the age of properties which received batteries

Figure 2.10 illustrates that the majority (82%) of battery installations in Camden took place in older properties that were built before 1929. In contrast 67% of the installations in Waltham Forest were in properties built after 1929. The higher proportion of installations in Camden being in pre-1929 properties is not surprising given that 75% of the developed areas in the Borough are 'conservation zones'.

Figure 2.11 shows the different dwelling types which had installations. In Camden, 89% of the properties receiving batteries were mid-terraced. While there were no semi-detached properties in Camden, 44.4% of those which had batteries fitted in Waltham Forest were semi-detached.

The types of roofs where the solar PV systems were fitted are illustrated in figure 2.12. In Camden, 67.9% of the properties had London Valley roofs. This type of property was targeted by the Council as there would be less visual impact in conservation zones with the solar panels hidden behind a parapet. Figure 2.13 shows older streets in Camden with London Valley roofs where PV systems and batteries were installed. In Waltham Forest, where the properties were more modern and not in conservation zones, all the PV installations were on pitched roofs.

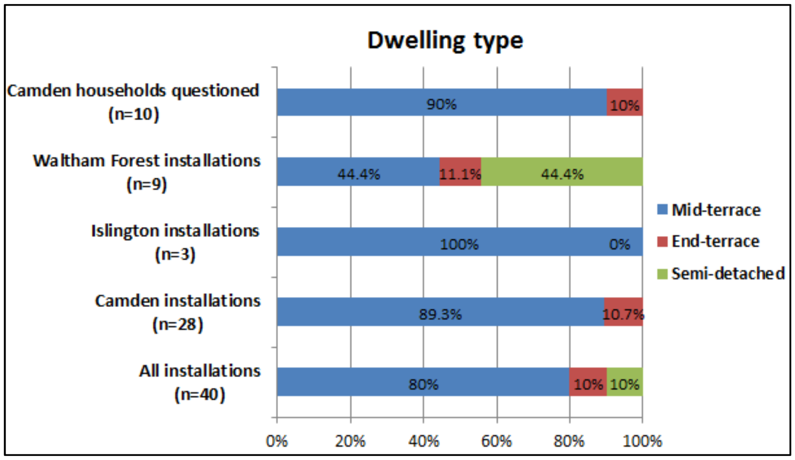

Figure 2.11 Chart illustrating the types of properties which received batteries

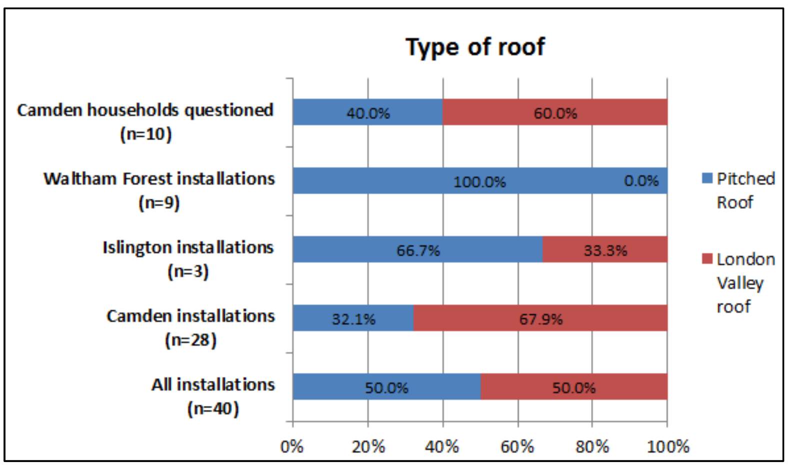

Figure 2.12 Chart illustrating the types of roofs where solar panels were installed

Figure 2.13 Examples of streets in Camden with London Valley roofs which received installations

Details of solar PV and battery installations

Technical Reference Number	Install Date	Battery	Storage capacity (kWh)	PV System size (kW)	Inverter	Roof type
T-01	24-Aug-16	Moixa	2	3.24	SolaX SL-TL3300T	London Valley - E/W
T-02	31-Aug-16	Moixa	2	3.78	SolaX SL-TL3300T	London Valley SW/NE
T-03	25-Aug-16	Moixa	2	3.24	SolaX SL-TL3300T	London Valley - SE/NW
T-04	05-Sep-16	Moixa	2	1.62	SolaX MINI1500	Pitched - South West
T-05	03-Nov-16	Moixa	2	3.24	SolarX SL-TL3600T	London Valley - SE/NW
T-06	25-Aug-16	Moixa	2	3.24	SolaX SL-TL3300T	Pitched South
T-07	05-Sep-16	Moixa	2	2.16	SolaX MINI1000	Pitched - South East
T-08	02-Sep-16	Moixa	2	3.24	SolaX SL-TL3300T	London Valley - NE/SW
T-09	02-Sep-16	Moixa	2	1.62	SolaX MINI1500	London Valley - NE/SW
T-10	01-Sep-16	Moixa	2	3.24	SolaX SL-TL3300T	London Valley - SE/NW
T-11	09-Sep-16	Moixa	2	1.14		Pitched - South West
T-12	20-Sep-16	Moixa	2	1.88		Pitched - South West
T-13	22-Sep-16	Moixa	2	3.24	SolaX SL-TL3300T	London Valley - SW/NE
T-14	21-Sep-16	Moixa	2	3.24	SolaX SL-TL3600T	London Valley - NE/SW
T-15	25-Oct-16	Moixa	2	3.24	SolaX SL-TL3300T	London Valley - NE/SW
T-16	01-Sep-16	Moixa	2	3.24	SolaX SL-TL3300T	London Valley - SE/NW
T-17	09-Nov-16	Moixa	2	1.62	SolaX SL-TL2200	Pitched - South West
T-18	24-Aug-16	Moixa	3	2.16	SolaX SL-TL2200	Pitched - South
T-19	31-Aug-16	Moixa	3	3.24	SolaX SL-TL3300T	London Valley - NE/SW
T-20	06-Sep-16	Moixa	3	3.24	SolaX SL-TL3300T	London Valley - SW/NE

Table 2.14 Details of the 20 solar PV and Moixa battery installations in Camden

Table 2.14 shows details of the solar PV systems and Moixa batteries fitted to properties in Camden. A Technical Reference Number was assigned to each property, which provides a means of anonymising data from each household. The date the battery was installed, the size of the solar PV array and the model of inverter used are also shown. Details of whether the roof at the property was pitched or had a London Valley are shown along with approximate orientations. There were 17 Moixa 2kWh batteries and 3 Moixa 3kWh batteries. These sizes were the total capacity. The usable capacity of the battery was about 80% of this size. Details of the solar PV systems and batteries for the 6 sonnen and 2 Growatt systems that were installed in Camden are shown in Table 2.15. Here the sonnen battery had a useable capacity of 2kWh while the Growatt battery had a total capacity of 4.875kWh.

Technical Reference Number	Install Date	Battery	Storage capacity (kWh)	PV System size (kW)	Inverter	Roof type
T-21	06-Sep-16	sonnen	2	3.24	SolaX SL-TL3300T	London Valley - SE/NW
T-22	09-Sep-16	sonnen	2	3.24	SolaX SL-TL3000	London Valley - SW/NE
T-23	08-Sep-16	sonnen	2	3.24	SolaX SL-TL3300T	London Valley - SW/NE
T-24	08-Sep-16	sonnen	2	2.16	SolaX MINI1000	London Valley - SW/NE
T-25	08-Sep-16	sonnen	2	2.7	SolaX SL-TL3000	Pitched - East
T-26	13-Sep-16	sonnen	2	2.16	SolaX SL-TL3300T	London Valley - SW/NE
T-27	07-Sep-16	Growatt	4.875	1.62	SolaX MINI1500	Pitched - South West
T-28	21-Sep-16	Growatt	4.875	3.24	SolaX SL-TL3300T	London Valley - NE/SW

Table 2.15 Details of the 6 sonnen and 2 Growatt battery installations in Camden along with their solar PV systems

Technical Reference Number	Install Date	Battery	Storage capacity (kWh)	PV System size (kW)	Inverter	Roof type
T-29	2008	Moixa	2	1.296	Fronius IG15	Pitched - South East
T-30	2008	Moixa	2	1.36	Fronius IG15	London Valley - NE
T-31	2008	Moixa	2	1.296	Fronius IG15	Pitched - South East
T-32		Moixa	2	2.35	SMA Sunny Boy 2000HF	Pitched - South
T-33	10-Nov-16	Moixa	2	2.76	Solax SL-TL 2800	Pitched - SW/NE
T-34	21-Oct-16	Moixa	2	1.89	Solax SL-TL 2800	Pitched - South
T-35	20-Oct-16	Moixa	2	1.62	Solax SL-TL 2800	Pitched - South
T-36	01-Nov-16	Moixa	2	1.35	Solax SL-TL 2800	Pitched- South
T-37	21-Oct-16	Moixa	2	3.24	Solax SL-TL 2800	Pitches - West
T-38	24-Oct-16	Moixa	2	3.78	Solax SL-TL 2800	Pitched - E/W
T-39	11-Nov-16	Moixa	2	2.16	Solax SL-TL 2800	Pitched - East
T-40	08-Nov-16	Moixa	2	3.78	Solax SL-TL 2800	Pitched - E/W

Table 2.16 Details of the Moixa battery installations and solar PV systems in Islington and Waltham Forest

There were 3 Moixa battery systems installed in properties in Islington which had solar PV systems that were fitted in 2008 (table 2.16). These were small PV systems of less than 1.4kW and used Fronius IG15 inverters. There was a single Moixa battery installation in Waltham Forest which was fitted in a property with a pre-existing solar PV system. This had a SMA Sunny Boy 2000HF inverter. The other battery and solar PV systems in Waltham Forest were all fitted together, with the solar PV systems using a SolaX inverter. The handover documents from Lakehouse suggested the inverters on the Waltham Forest installations were all SolaX SL-TL-2800. This was unlikely to be the case given the range of sizes of the PV systems installed. While it was possible to obtain inverter models for the Camden installations from the serial numbers, these were not available for the Waltham Forest installations.

Details of monitored households

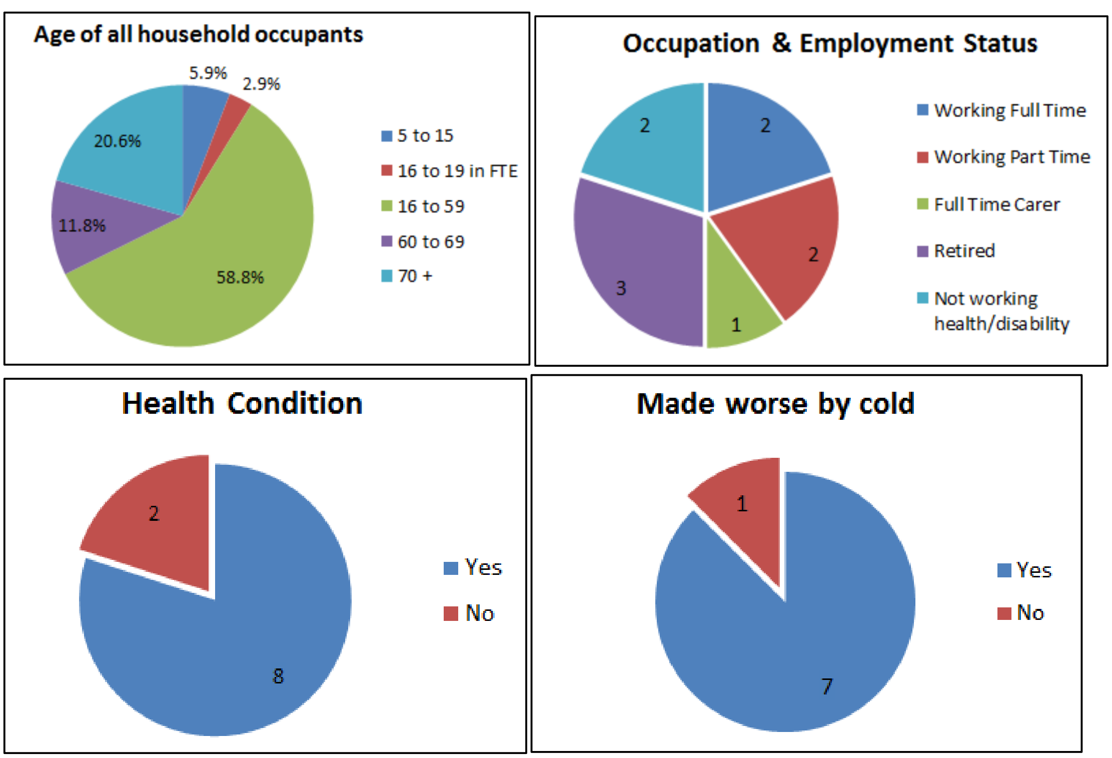

Figure 2.17 (a) Household age (b) Occupation (c) Health conditions (d) If the health condition is made worse by cold

Interviews were carried out with 10 households in Camden. Analysis of the age of all the occupants of these households showed that more than half of all the occupants (58.8%) of these properties were in the age range 16 to 59 years. Figure 2.17 (a) also shows that the next most common age bracket was residents over 70 years. In total nearly a third of residents (32.4%) in these properties were over 60 years.

The occupational status of the householder interviewed is shown in figure 2.17 (b). 6 of the householders were likely to spend significant amounts of time at home, being retired, not working due to a health condition or being a full-time carer. 4 of the householders were working full or part-time.

Figure 2.17 (c) shows that 8 of the 10 households interviewed had a member with a health condition. These included Alzheimer's disease, arthritis, asthma, autism, Crohn's disease, depression, diabetes, fibromyalgia, heart condition, Parkinson's and Reynaud's disease. Out of these, 7 out of the 8 felt that the medical condition was made worse by the cold.

2.2 Affordability of energy bills

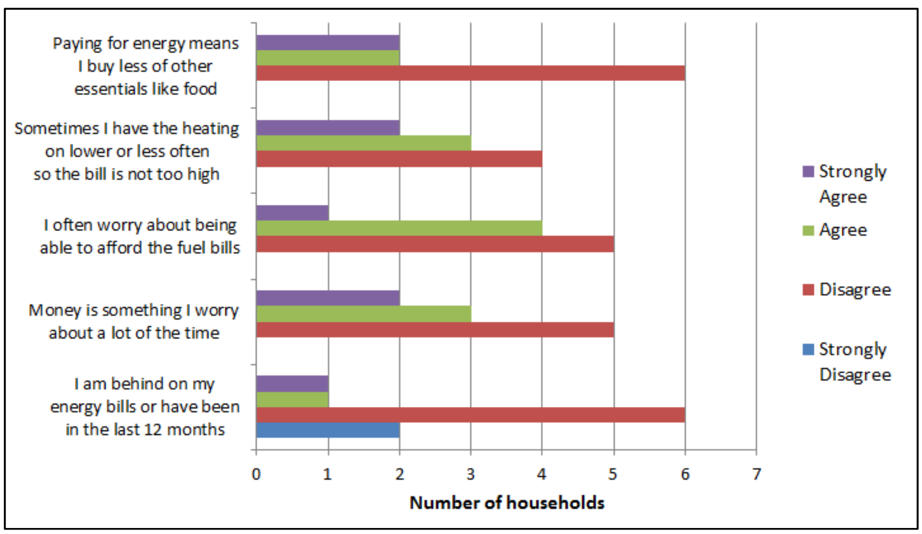

Figure 2.18 Chart illustrating the affordability of energy bills for the households interviewed

The householders interviewed were asked whether they agreed or disagreed with a series of statements. 6 households disagreed that paying for energy meant they sometimes could not afford to buy or buy less of other essentials like food (figure 2.18). However, 2 households strongly agreed, and these were residents who were not working due to a health condition or disability, while a further 2 households also agreed. There were also 5 households who had the heating on lower or less often so that the energy bill was not too high.

There was a 50:50 split between the households who did and did not worry about money a lot of the time or about being able to afford their fuel bills. However, some strongly agreed that they worried about these issues. There were 2 households who had been behind on their energy bills in the last 12 months and both of these had not been working due to a health condition or disability.

The householders were also asked whether there have been changes since the start of the project. Figure 2.19 shows that 5 of the households had reduced un-needed energy use in the home since the start of the project. Out of the 8 households that answered the questions, 5 stated that they understood more about how they could save energy and tried to save energy more.

While 2 households strongly agreed that they felt more in control of their energy bills and a further household agreed, 5 households did not feel more in control. 2 households strongly agreed that they had seen savings on their energy bills. A further 3 agreed to have seen savings, while 3 also disagreed and felt they had not seen any savings. Both the households who strongly agreed that they had seen savings on their energy bills had a sonnenBatterie installed. The 3 households interviewed who received sonnenBatteries all engaged well with the technology and were enthusiastic about the benefits.

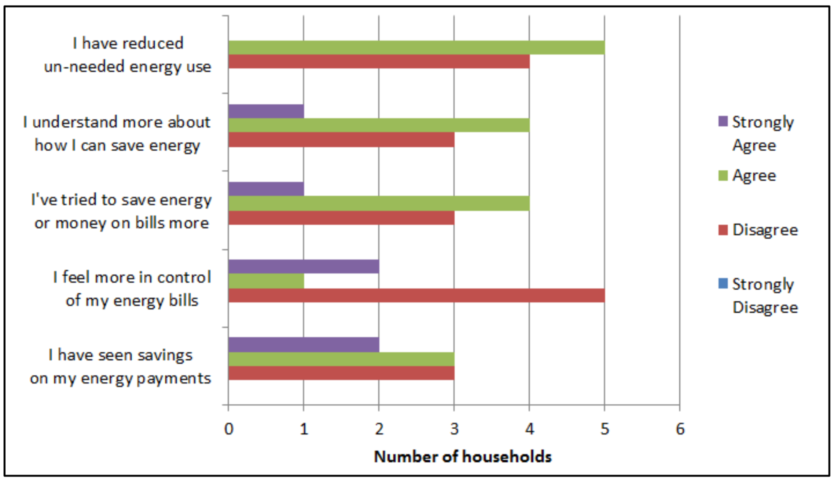

Figure 2.19 Chart illustrating changes since the start of the project

2.3 Resident acceptance and satisfaction

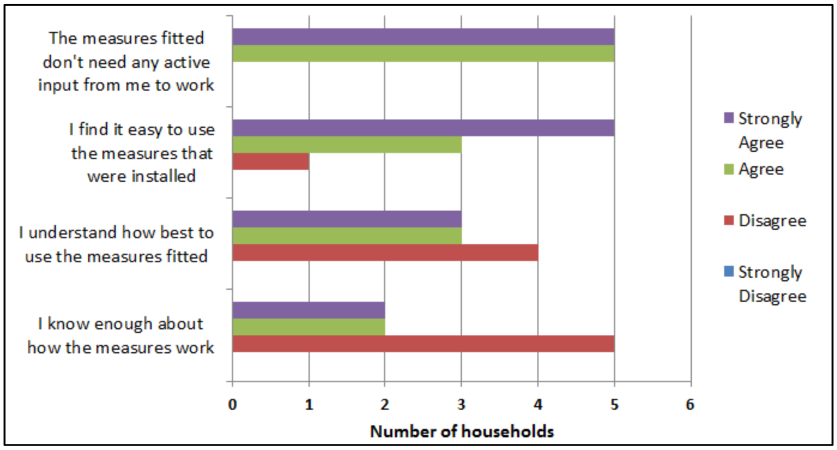

Figure 2.20 Chart illustrating ease of use of the system and knowledge of how it works

Figure 2.20 shows that all the residents felt that the battery-solar system did not require active input to work. 5 of the residents strongly agreed that the measures were easy to use and a further 3 agreed. Only 1 of the residents disagreed. This household had a Growatt battery system fitted and there had been several installer-related issues.

Most of the households felt they understood how to best use the measures fitted, with 6 of them strongly agreeing or agreeing with the statement. However, 5 of the households disagreed that they knew enough about how the measures worked.

Figure 2.21 shows that nearly all the residents thought the installation was neat and tidy. A single interviewed household felt it was not. The same resident disagreed that the installation had no loose wires or connections. He noted that the box for the Moixa battery in the hallway was not attractive and neither were all the wires. Part of the issue was due to the wires connecting the TP Links to the WiFi router. However, there were also other loose wires and the installers had not used plastic trunking for cables throughout the installation.

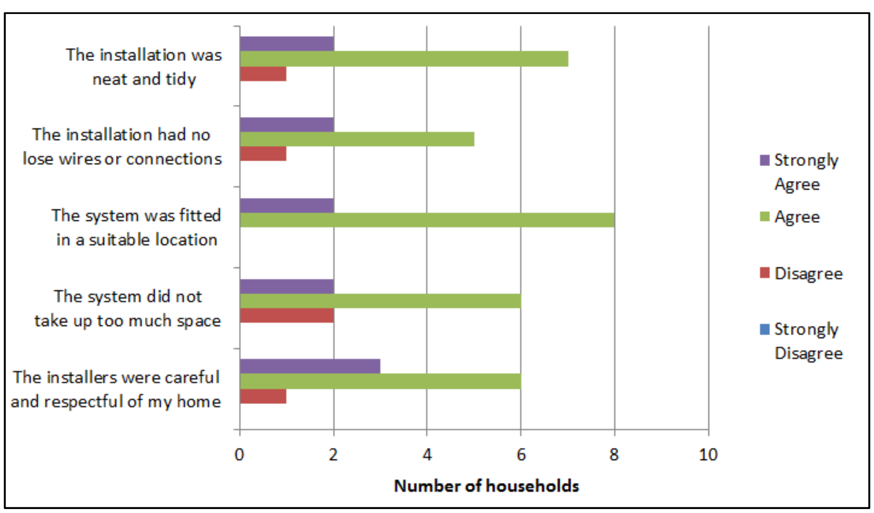

Figure 2.21 Satisfaction with the installation process

There were 8 households who felt the battery system did not take up too much space. Out of the 2 who felt it did, 1 had the larger sonnenBatterie system and the other had a Moixa battery in the hallway near the front door. When asked if the installers were careful and respectful in their home the majority either strongly agreed or agreed, only 1 resident disagreed due to damage to paintwork.

2.4 Ease of use and reliability

Questions shown in figure 2.22 investigated whether the residents were getting the most benefit out of the battery solar system. 7 of the 10 households did not know how to maximise their savings from their solar panels. The same number said they did not try to use energy intensive appliances like washing machines when it was sunny. None of the households felt they knew how to maximise the savings from their battery. However, 6 of the 10 households tried to avoid having too many appliances all on at the same time. These results suggest the residents would have benefited from receiving an advice leaflet about the battery solar systems and their use. Camden Council produced a couple of draft advice leaflets, but these were never distributed to the residents during the project. The council is planning to provide an updated leaflet to explain how the system works, troubleshooting (if required), explain the maintenance regime and provide contacts to the maintenance contractor.

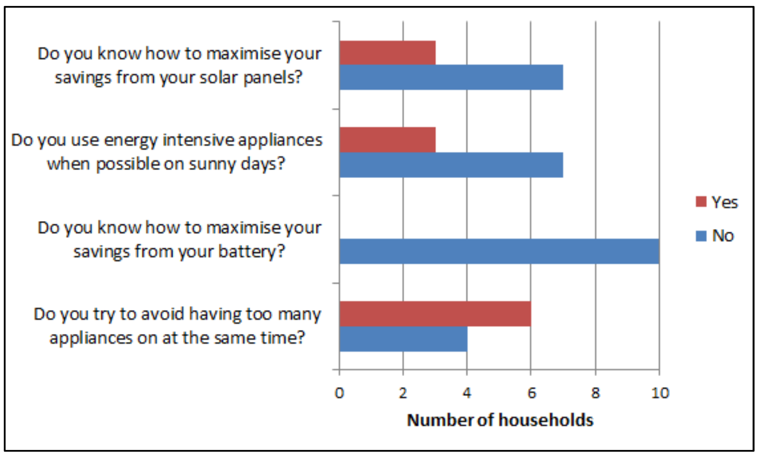

Figure 2.22 How well the households knew how to use the battery and solar systems

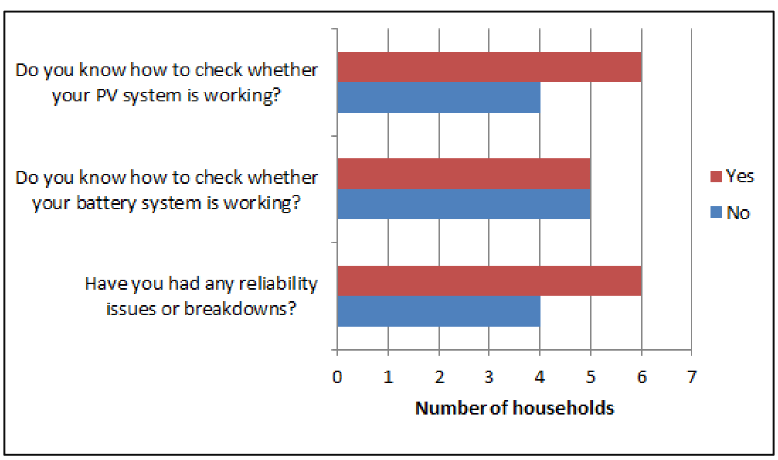

Figure 2.23 Reliability of the battery - solar systems

Figure 2.23 shows that out of the 10 monitored households with battery-solar systems, 6 knew how to check whether their PV system was working. For comparison, none of the 3 control households with only solar PV knew how to determine this. Half the households with batteries felt they knew how to check whether their battery system was working. 6 out of the 10 households had reliability issues with their battery-solar systems. For the control properties, 2 said they had no reliability issues with their solar PV system and a further resident did not comment. Although the numbers here are small the responses suggest there are greater reliability issues when a battery is fitted with a system.

There were 4 households in the monitored group who regularly checked if the PV system was working and 3 who never checked (figure 2.24). This compared to 3 households who regularly checked if their battery system and 6 who never checked. Many of the residents were aware the PV system was working by the flashing of the red LED on the generation meter. However, in at least once case, this was inaccessible as it was fitted in the loft.

Residents were less aware of evidence that the battery was working. It is possible to check on the performance of the battery system using apps or web portals, but 7 of the households said they had never used one to monitor the battery. Most of the batteries require an internet connection and 8 of the 10 households said they never turned off their WiFi router.

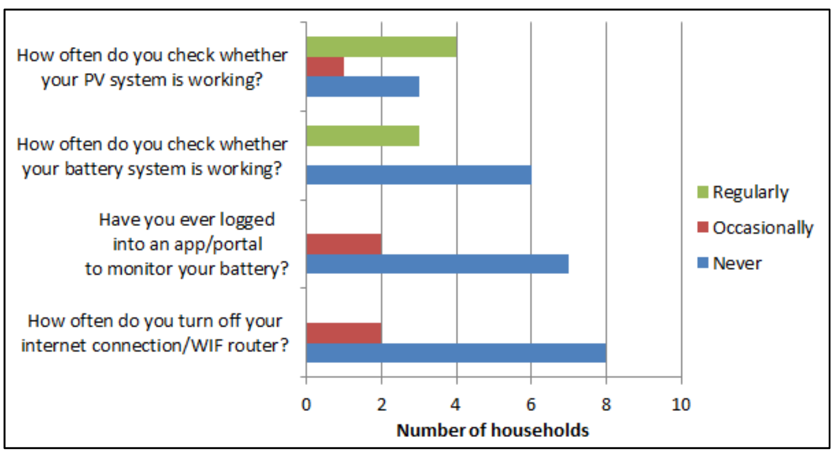

Figure 2.24 Frequency the resident checks the solar and battery system

2.5 Perceived comfort and benefits

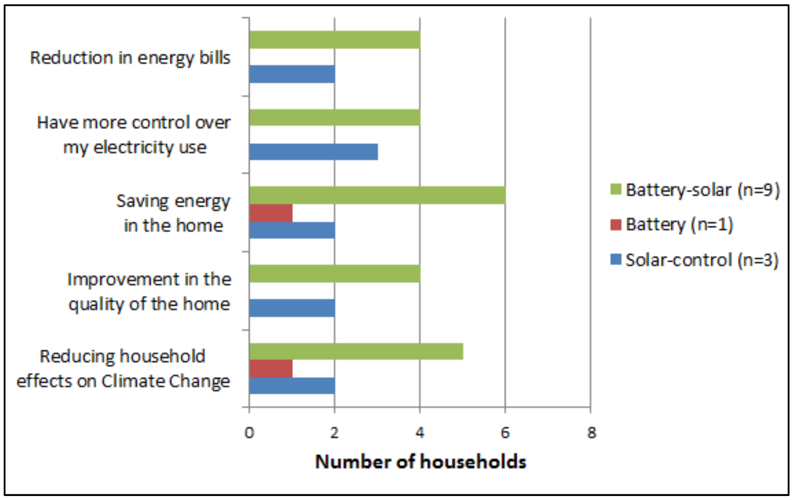

Figure 2.25 Benefits perceived by residents after installation of the solar-battery system

Residents with the battery-solar systems were asked about benefits due to the installed measures since the start of the project. Out of the 10 Camden households who were interviewed, a single household had a battery that was fitted to a pre-existing solar PV system. Therefore, the benefits since the start of the project would have been due to the addition of just the battery. For the other 9 households it was the combination of the solar PV and battery. For comparison, residents in the 3 control households in Waltham Forest were asked the same questions.

For the households who had the solar PV and battery systems installed at the same time, 6 out of the 9 felt they were saving energy in the home and 5 thought they were reducing their household effects on climate change. A reduction in energy bills was perceived by 4 households and the same number thought they had more control over their electricity and there was an improvement to their home. There were 3 households with solar and battery systems who noted no benefits. Out of these, 2 paid for the electricity by direct debit and were unsure of the benefits.

Where the battery was fitted to a pre-existing solar PV system, the resident thought she had been saving energy in the home and reducing the household effect on climate change as a result of the addition of the battery. The residents in the control properties with just solar PV all felt they had more control over their electricity use. 2 out of the 3 households also felt there was a reduction in their energy bills, they were saving energy in the home and they had been reducing their household effect on climate change.

Overall the residents who had battery solar systems noted benefits following the installation, but there was little difference compared to households who had only a solar PV system. Households are more likely to perceive benefits in situations where their solar PV system generates more electricity and where the residents closely monitor their electricity consumption.

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[23]. 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[24].

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 maintenance free deep cycle lead acid battery might have a life span of 1000 charge and discharge cycles if the Depth of Discharge (DOD) is 50%. In contrast lithium-ion batteries can be taken to a DOD of 80% while having a life span several times that of a lead acid battery. They also have a better energy density, although they are also more expensive. Mass production for applications such as electric vehicles is expected to bring the cost of lithium ion-batteries down.

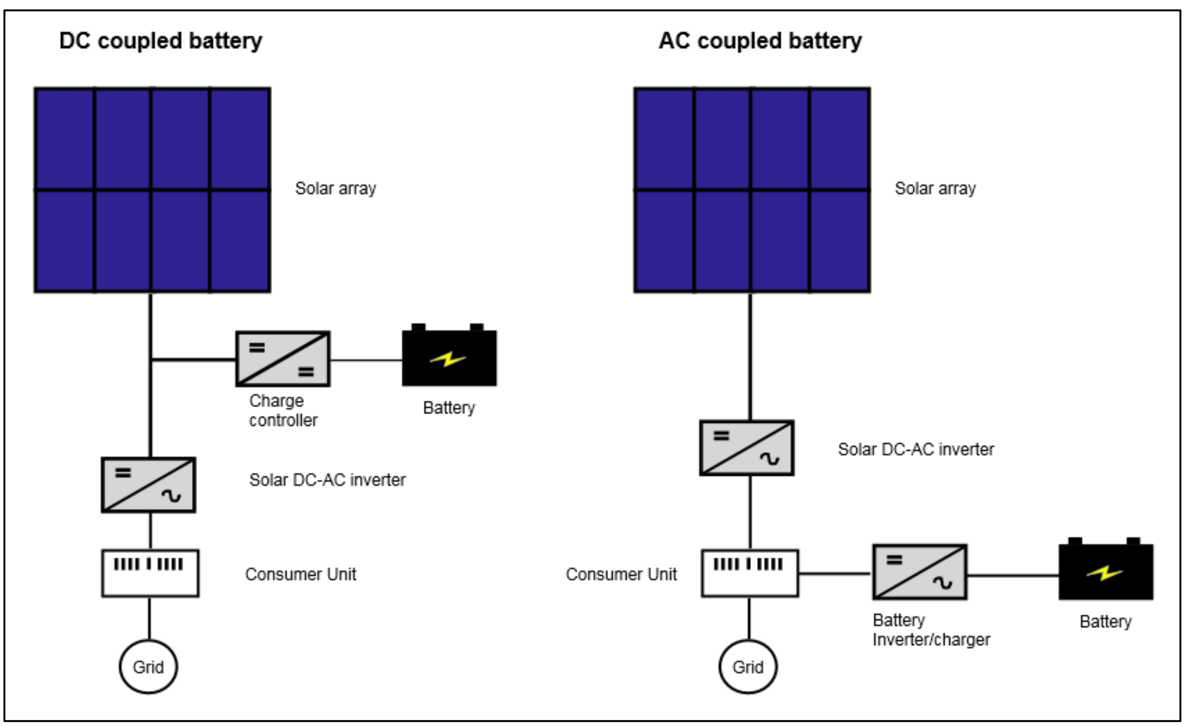

Figure 3.1 Schematic diagram showing DC and AC coupled battery systems

[23] BU-201: How does the Lead Acid Battery Work?, Battery University http://batteryuniversity.com/learn/article/lead_based_batteries (Accessed 31 May 2018)
[24] BU-205: Types of Lithium-ion, Battery University http://batteryuniversity.com/learn/article/types_of_lithium_ion (Accessed 31 May 2018)

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). 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.[25] 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.

Moixa Maslow

Figure 3.2 Moixa Maslow V3 installation

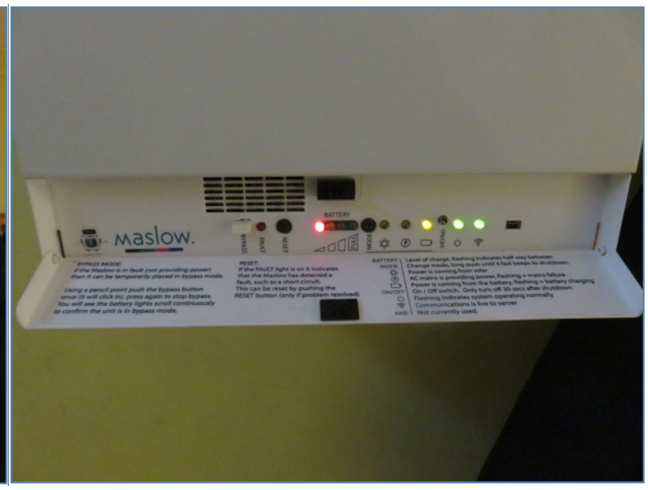

Figure 3.3 Moixa Maslow status panel

Moixa is a UK technology company that was founded in 2006 and is based in London. It designed and manufactured the Moixa Maslow V3 battery which was used for the majority of installations on this project. The Maslow uses $LiFePO_4$ (lithium iron phosphate) batteries and is an AC-coupled battery system which includes 2 micro-inverters.

Out of the 32 Moixa batteries that were installed on the project, 29 were 2kWh batteries and 3 had a capacity of 3kWh. It should be noted that these batteries could 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 5 years.

Figure 3.2 shows a Maslow battery installed below the consumer unit near the front door of a home in the project. The 2kWh unit shown has a height of 49cm, width of 30.8cm and depth of 19cm. The 3kWh unit is slightly bigger with a depth of 23cm. 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.

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25 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)

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.

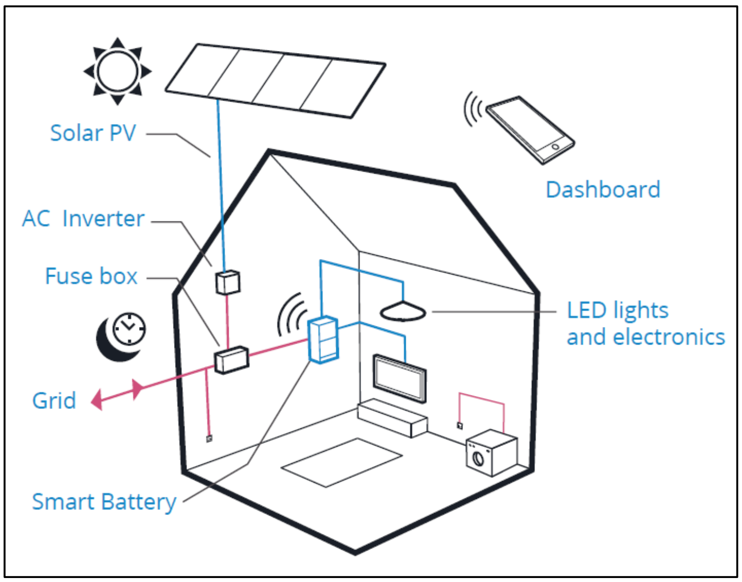

Figure 3.4 Schematic diagram showing a Moixa battery installation including connection to DC lighting and devices

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.

The Maslow has an external WiFi antenna on the side of the unit for communication to the household WiFi router. In some cases, the signal between the two is not adequate. Rather than having a long Ethernet cable between the battery and the WiFi 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 WiFi router. Ethernet cables link the power line adapters to the battery and WiFi router, while the power line adapters are able to transmit data to each other using the household 13A ring main.

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

- Project ERIC which installed batteries in 82 households in Rose Hill, Oxford,[26] [27] 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[28] [29]
- 4 battery storage trials as part of the NEA Technical Innovation Fund. These are:
    - 24/7 Solar with the London Borough of Camden
        - Includes Moixa, sonnen and Growatt batteries
    - Sungain Battery Bank in Thurrock
        - Includes Moixa, Powerflow and Victron batteries
    - SolarMax+ in Grimsby
        - Includes Moixa, 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 Moixa batteries

Moixa has developed GridShare, which is an aggregation platform where battery owners can receive income for 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 the supply and demand of the electricity grid. Payments currently start from £50.[30] 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 was due to management challenges among the project partners, and involvement would have complicated NEA's analysis of the performance of the battery. Camden Council is however planning to look at this again to explore a suitable method of administration which would allow them to include this and maximise the savings for residents.

At the time of writing, Moixa are offering a solar PV and battery package including a 2kW solar PV system and a 2kWh Moixa Maslow 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"[31]. Moixa Maslow V3 batteries are available for multiple installations for approximately £2000 excluding VAT but including installation.

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[26] Energy saving community project wins prestigious Energy Awards, 2 December 2016, https://www.brookes.ac.uk/about-brookes/news/energy-saving-community-project-wins-prestigious-energy-awards/ (Accessed 19 Mar 2018)

[27] Project ERIC – re-energising communities https://localisedenergyeric.wordpress.com/ (Accessed 19 Mar 2018)

[28] 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)

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

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

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

sonnen

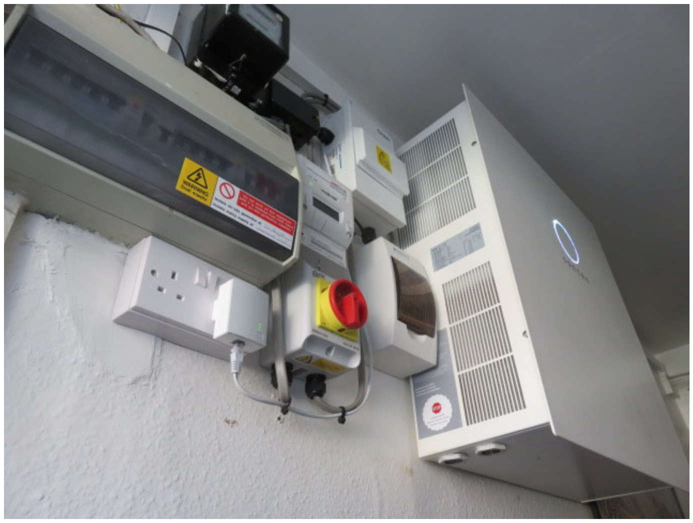

Figure 3.5 sonnen 2kWh battery installed in the hallway of one of the homes

The German battery manufacturer sonnen was founded in 2010 and their battery system is the market leader in many countries. By October 2016, the company had already sold 15,000 battery systems[32]. In the first half of 2017 market analysis showed 16,800 battery storage systems were installed in Germany, with sonnen the lead supplier with a 23% market share.[33] Sales in Germany represented about 75% of the total in Europe.

There were 6 sonnenBatterie eco 8.2 systems installed in residential properties owned by Camden Council. The system again uses $LiFePO_4$ cells and is an AC-coupled device. It has a warranty which lasts for either 10 years or 10,000 complete recharge cycles, depending on which occurs first[34]. For this warranty to be valid, the unit must be connected to the internet and have received software updates from sonnen. Power line adapters (TP Links) were used with these installations to ensure a good connection to the WiFi router.

The eco 8.2 units installed on this project had a usable capacity of 2kWh. The inverter in the unit had a rated power of 1500W. This means the maximum output power from sonnen system is more than 3 times greater than that from the Moixa Maslow V3. For example, if a household was running a 1kW electric fire and a 250W fridge, this could all be powered by a charged sonnenBatterie unit. However, with the Moixa Maslow, only 430W could be supplied, with the rest coming from the grid.

The 2kWh system comes in a unit which is 70cm x 64cm x 22cm, which is larger than the Moixa Maslow. The sonnenBatterie system is modular and larger capacities are available by fitting extra batteries in an extension case. The unit size for a system with a capacity of between 4kWh and

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[32] China's Envision joins investor in German battery firm sonnen cash boost, 16 Oct 2016, https://www.pv-magazine.com/2017/09/07/suns-e3-dc-senec-and-lg-chem-dominate-german-residential-pv-storage-market/ (Accessed 19 Mar 2018)
[33] Sonnen, E3 / DC, Senec and LG Chem dominate German residential PV storage market https://www.pv-magazine.com/2017/09/07/suns-e3-dc-senec-and-lg-chem-dominate-german-residential-pv-storage-market/ (Accessed 19 Mar 2018).
[34] Operating instructions sonnenBatterie eco 8.2 http://www.sonnensupportaustralia.com.au/uploads/2/9/8/5/29857561/sonnen_-_eco_8.2_-_user_manual_1-ph_-_kd-225-en-52186_-_x02.pdf (Accessed 19 Mar 2018)

10kWh is 137cm x 64cm x 22cm. The 4kWh system has an inverter with a rated power of 2000W, while for the systems between 6 and 10kWh the inverter power is 2500W[35].

The current guide price for trade purchases of the sonnenBatterie eco8.2 (2kWh) is £3000+VAT. For the sonnenBatterie eco8.4 (4kWh) system it is £4100+VAT and this includes the additional battery module and extension cabinet. Some trade customers receive greater discounts and reductions would also be available for bulk purchasing.

An updated battery from sonnen, the eco 9 is to be released soon. The wall mounted unit can have either a 2.5kWh or 5kWh battery capacity. With an extension cabinet, the capacity can be increased to 15kWh.

In 2015, sonnen launched the sonnenCommunity in Germany. This is a peer-to-peer energy-sharing network for owners of sonnen batteries. Large numbers of batteries are linked to form a 'virtual energy pool' and central software monitors performance of the systems and balances supply and demand of the electricity. Members who are generating excess electricity can supply it to others who are unable to produce enough to supply their homes due to bad weather[36]. It is also possible to become part of a battery pool which provides grid balancing services. Members are financially rewarded for both services. The service has evolved and now allows members to pay a cheaper flat monthly rate and for electric vehicles to be part of the scheme turning their batteries into a flexible load as part of the virtual power plant[37]. The sonnenCommunity has been expanding into other countries such as Austria, Switzerland and Australia[38]. It is not currently available in the UK and issues like regulation and having a sufficient number of sonnen battery installations are hurdles to be overcome.

Growatt

Figure 3.6 Installation with a Growatt SP2000 controller and GBLI5001 battery

[35] Technical Data sonnenBatterie, https://sonnenbatterie.de/sites/default/files/161018_datasheet_sonnenbatterie.pdf (Accessed 19 Mar 2018)

[36] sonnenCommunity, https://sonnenbatterie.de/en/sonnenCommunity (Accessed 19 Mar 2018)

[37] Sonnen adds EVs to Virtual Power Plant 'community', https://www.energy-storage.news/news/sonnen-adds-evs-to-virtual-power-plant-community (Accessed 19 Mar 2018)

[38] Sonnen tries different virtual power plant models in Germany, Australia and America, 21 Mar 2017, https://www.greentechmedia.com/articles/read/sonnens-new-virtual-power-plant-model-differs-by-country#gs.sLVUC18 (Accessed 19 Mar 2018)

Growatt is a Chinese company that was founded in 2010. The company initially focused on manufacture of solar inverters and quickly became a popular supplier of inverters and now has sales in more than 100 countries. More recently the company has added battery storage and smart energy solutions to its portfolio of products. They have sold more than 5000 DC battery storage systems, mainly in the UK and Italy and have been expanding into other storage solutions such as AC storage and hybrid storage[39].

There were 2 Growatt battery systems installations in homes rented by Camden Council. The inverters for these solar PV systems were manufactured by SolaX as for all the other new PV systems. The Growatt battery system is DC coupled and so was fitted between the solar panels and the inverter. The system comprised of a Growatt SP2000 controller and a GBLI 5001 battery (figure 3.6).

The SP2000 unit can operate with either a lead-acid or lithium-ion battery. Its maximum charge and discharge power is 2000W and so is higher than both that for the Moixa Maslow and sonnenBatterie eco8.2. The unit has dimensions of 48.2cm x 35.5cm x16.6cm. The GBLI 5001 battery has a 4.875kWh capacity, weighs 46.5kg and has dimensions of 80cm x 61cm x 16.7cm. Taking into account the maximum depth of discharge of 80% and the conversion efficiency of 94% of the SP2000 unit, the useable capacity of the battery is 3.67kWh. There is a manufacturer's warranty for 5 years for product defects and a performance guarantee for 10 years with 70% of the original capacity after 5000 cycles.

There were originally 3 Growatt battery systems fitted on the project. The third system was a retrofit to an existing PV system with a 1.075kW array. The system stopped working after the battery was fitted by the installer. To resolve the problem the installer bypassed the battery system and it was eventually removed.

There were installation issues with the other Growatt battery systems on the project. The system in figure 3.6 had problems with the battery not discharging. This was because the SolaX MINI1500 inverter fitted by the installer was a poor match for the Growatt SP2000 controller. This was resolved by Growatt technical staff altering the settings of the SP2000 controller to effectively work as a smaller SP1000 controller.

For the other site, the battery was fitted on the ground floor of a 3-storey building and the SP2000 controller was installed in the loft. There was no communication cable between the battery and controller and the DC power cables were undersized for the length of cable run. The battery was later re-installed with the controller in the loft.

The trade price for a Growatt SP2000 controller is currently £375+VAT and a GBLI 5001 battery is £1250+VAT.

[39] Personal communication, Scott Feng, General Manager, Growatt New Energy UK (17 May 2018)

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. Smart generation meters were typically installed by the councils as these could provide meter readings for feed-in tariff payments without requiring visits. Also, performance of the PV system could be assessed and faults detected.

Camden Council had smart generation meters fitted at sites where new PV systems were installed with the battery. Data was available from 22 of these systems, but there were technical problems with the meters at 4 of the sites. There were standard generation meters at the 2 sites with pre-existing PV systems. Household T-12 which had a pre-existing system was in the monitored group and had a pulse logger fitted on the generation meter.

Among the 9 properties at Waltham Forest which had battery installations, 8 of these had new solar PV installations. These included smart generation meters which recorded half-hourly generation meter data. The 3 installations in Islington were in private homes and were not monitored. As a result, there was no generation meter data available.

Electricity bill data was available for some of the Camden properties in the monitored group. This included readings recorded by the residents in a log-book and meter readings from the electricity supplier. In some cases, this data included periods before the battery solar installation.

Moixa

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].

On installations for owner-occupiers, Moixa often calibrate the current clamps by comparing meter readings over a period of 2 weeks with data derived from the current clamps. This was not carried out on this project due to the challenges of obtaining information from tenants. Camden and Waltham Forest Councils however, had smart generation meter data available from the solar PV systems which would have allowed this to be done.

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

Project Windy in Oxspring near Barnsley, which had more recently installed Moixa batteries, used small electricity meters instead of current clamps. Here a small meter was fitted on the meter tail and a solar meter in a spare fuse position within a household consumer unit. Each of these was connected into the battery for communications. This arrangement improved accuracy of readings and avoided the risk of tampering from tenants or maintenance staff moving the current clamps.

The Moixa battery portal for multiple system owners can provide graphs and data from individual batteries or performance of the group as a whole. Figure 3.7 shows a snapshot of the performance of all the Moixa batteries on the 24/7 solar trial that were online. The system also provides an indication of the status of the connection for the battery and can plot graphs of the historical performance of the battery for a large range of parameters. Graphs can be plotted with raw data or aggregation over periods ranging from 5 minutes to 1 day.

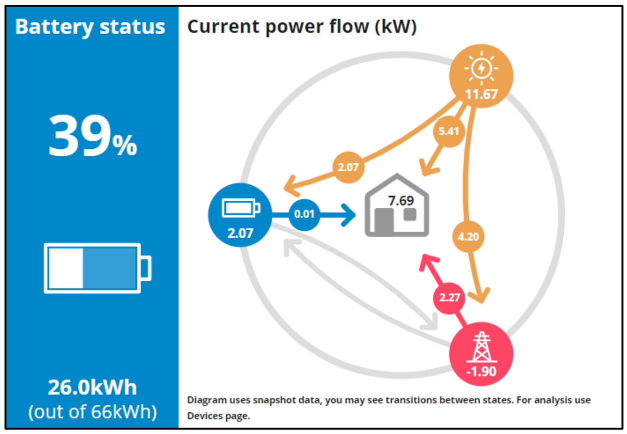

Figure 3.7 Chart showing the different values of power flow, aggregated across all the 24/7 solar Moixa batteries

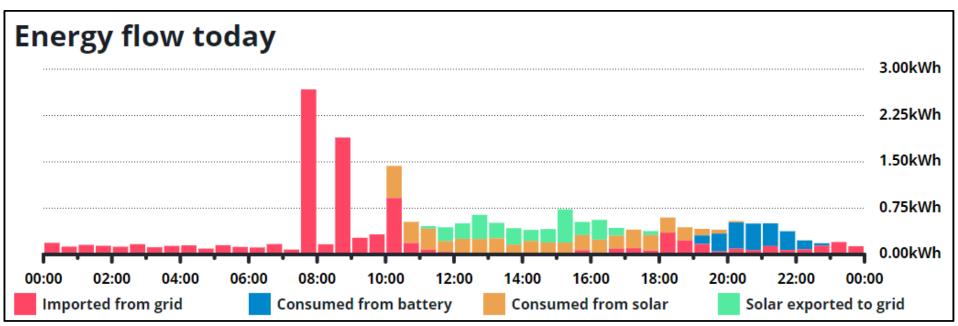

Figure 3.8 Plot showing energy flows, aggregated across all the 24/7 solar Moixa batteries on 16 Apr 2018

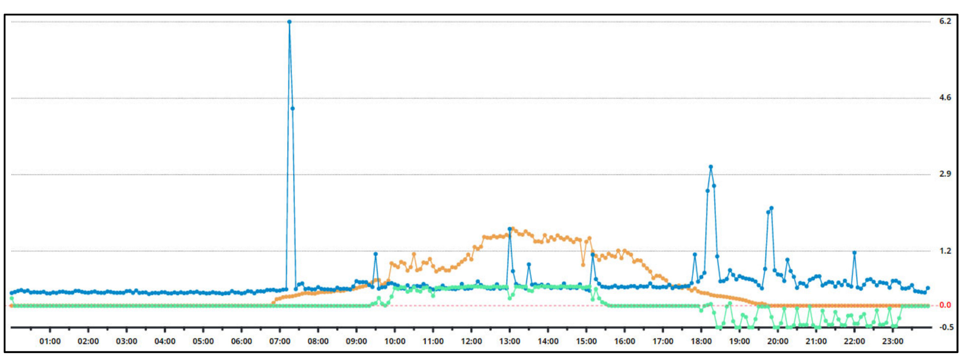

Figure 3.9 Plot of Power (kW) against time for property T-16 on 6th April 2018
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Since the project started, Moixa have introduced a firmware update which enables the battery to save a week of data. If the battery goes offline this can up be uploaded when reconnected. Some of the batteries on the project have received this update. However, improvements are still needed. The WiFi router at household T-03 was turned off each night and the gaps in the data were still apparent. This may be due to the system being unaware there would be a data gap as the TP Links maintained their connection with the battery.

There was a gap in the data between 7 Dec 2016 and 9 Mar 2017 for the Moixa batteries. This was because the battery current was not included in the original data provided due to issues downloading it off the Moixa server. This meant it was not possible to include the battery discharge for this period.

sonnen

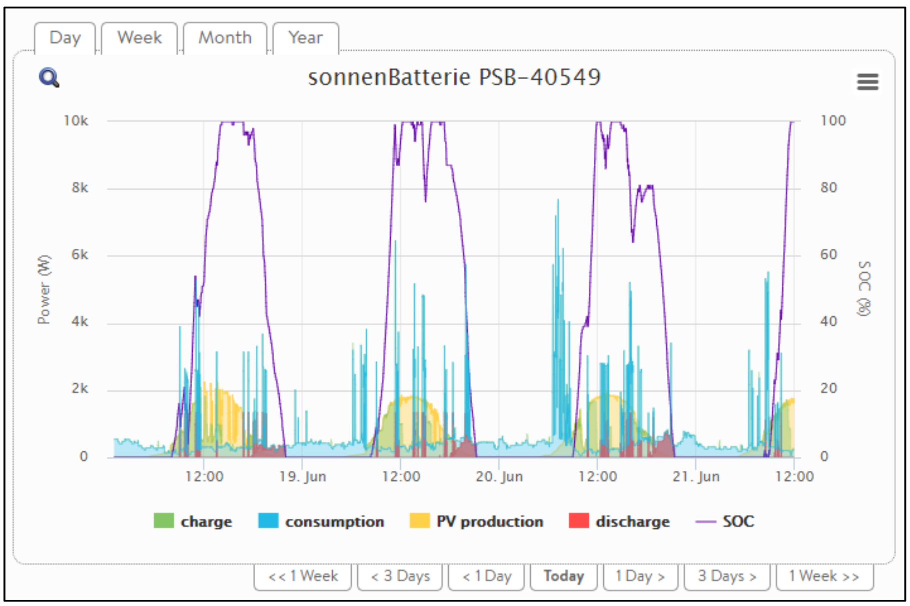

Figure 3.10 History graph over a period of a week from the sonnen portal for one of the installed sonnen batteries

Most of the technical analysis of the sonnen battery installations was carried out using graphs and data from the sonnen online-portal. The sonnen battery system recorded this data using current clamps. The accuracy from data derived with these current clamps was expected to typically be about ±5%.

The history section of the web-portal allowed graphs to be plotted over a period of a day, week, month or year. The graphs such as figure 3.10 can display the battery charge (green) and discharge power (red), the household electricity consumption (blue), the PV production (yellow) and the state of charge (SOC) of the battery (purple).

It was possible to use the download section to obtain data that was recorded by the battery system every minute (figure 3.11). Measurement data provided the power in watts for discharge, charge, production (from the solar panels) and consumption (electricity consumed by the household). Work data provided the energy in Watt hours for battery discharge and charge, solar production, the electricity consumed by the household, the feed-in electricity to the grid (export) and the amount of electricity consumed from the grid (electricity import).

The sonnen data was consistent and a reading was recorded every minute. The battery included memory which could store up to about 2 months of data. If the battery went offline for a short period, data would be uploaded to the portal once the battery was back online. It was however not possible to collect continuous data over the monitoring period for most of the sonnen batteries due to other technical issues. These included loss of a continuous internet connection for long periods due to problems with the TP links which provided a connection to the WiFi router. There were also problems with 2 of the solar systems such as the RCD cut-out tripping and a PV system developing a partial fault.

Systems which maintained a good internet connection showed occasional gaps of data of just over 24 hours. These occurred when the battery had a system refresh and the battery went offline and performance data was not recorded. The work data was used to obtain performance for each month that the battery was online. Data was presented with the total kWh for the month and the number of kWh/day.

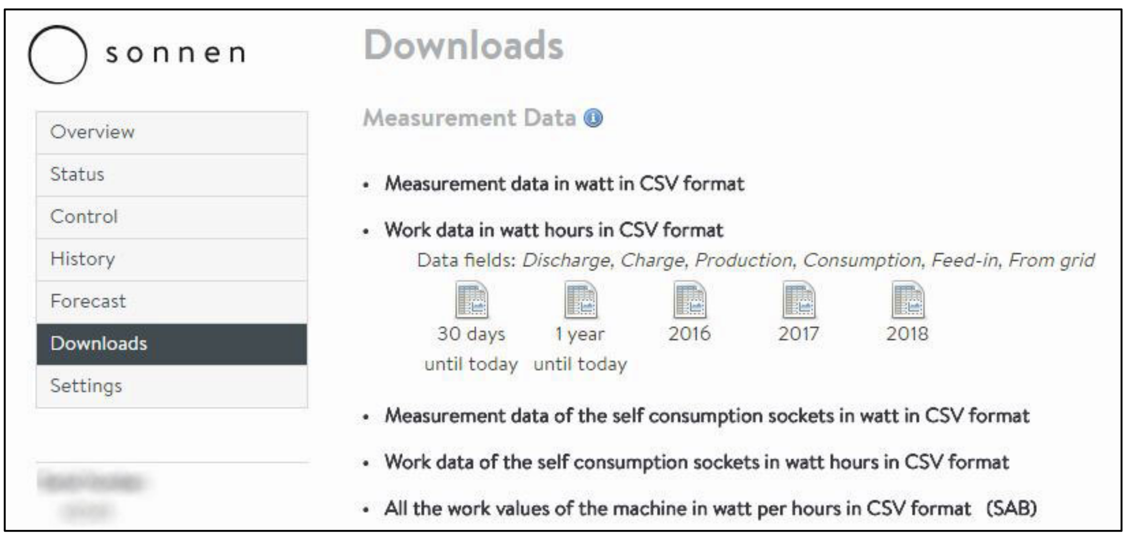

Figure 3.11 Downloads of data available from the sonnen battery portal

Growatt

Figure 3.12 Growatt WiFi dongle which provides communication for the Growatt battery system

Monitoring for the Growatt batteries was not set up when the systems were installed by the contractor in September 2016. It was possible to add this feature with the addition of a WiFi dongle (figure 3.12) which plugs into the SP2000 controller. This provides monitoring and historic performance data via an online portal or mobile phone app.

WiFi dongles were obtained from Growatt and these were installed by Camden Council and NEA staff in October 2016. During the setup, it was necessary to connect to the dongle using a mobile phone and enter the household WiFi router password to allow the module to connect to the internet. If the household switches internet service provider, the connection for the monitoring would be lost until the system has been setup again with the new WiFi password.

More recently Growatt has released an improved monitoring solution called ShineLink. This comprises a ShineRFStick which plugs into the SP2000 controller and a ShineLanBox which plugs into the WiFi router. Should the resident switch broadband provider and WiFi router, all that is required with the new system is to plug the ethernet cable from the ShineLanBox into the new router. The new system uses RF433 wireless communication which extends the maximum communication range from 100m to 200m.

The Growatt online portal uses graphics and charts to illustrate the performance of the battery system along with providing access to raw data with 5-minute intervals. This includes an illustration of power flows in the battery solar system (figure 3.13), and plots of energy production and consumption over 24-hour periods (figure 3.14) on the portal dashboard. It is also possible to plot parameters including charging power and discharging power on the Plant data menu (figure 3.15).

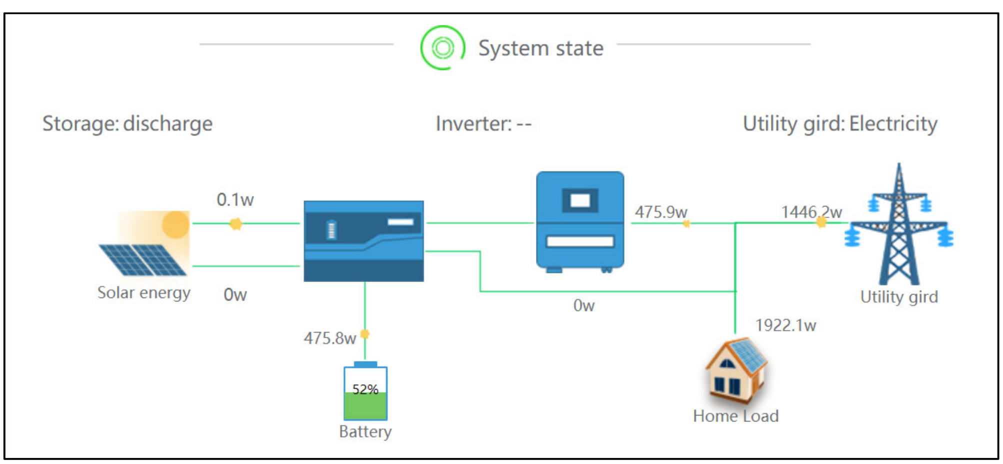

Figure 3.13 Power flows illustrated on the dashboard of the Growatt web portal

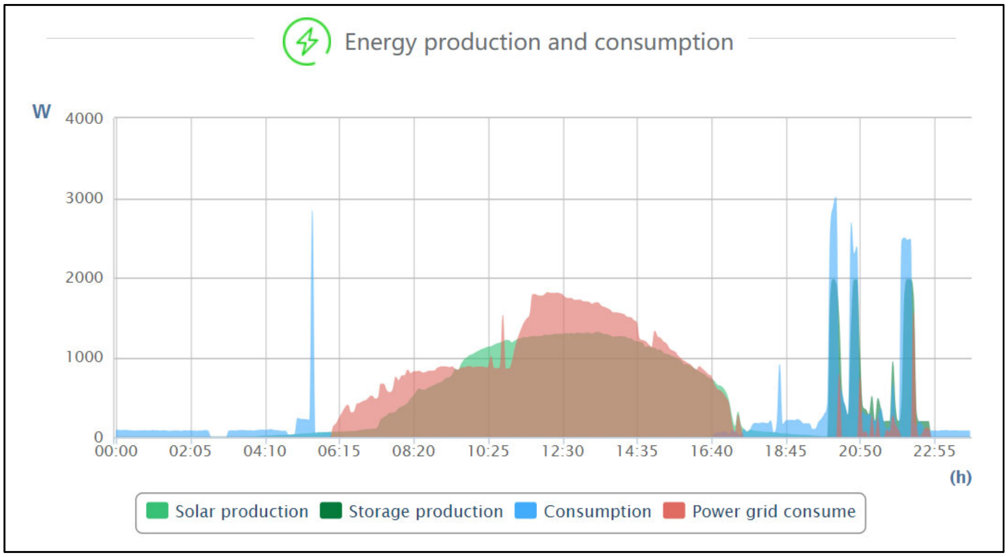

Figure 3.14 Plot showing energy production and consumption from the dashboard of the Growatt web portal

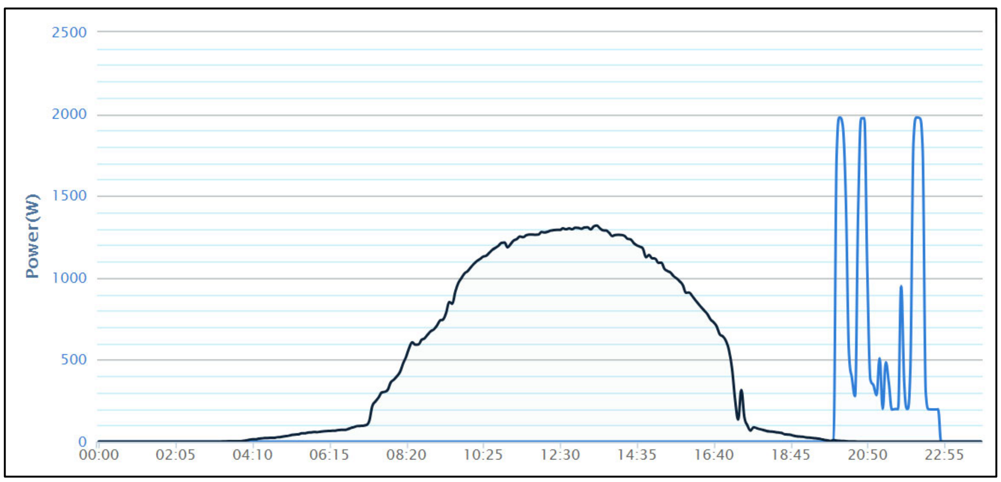

Figure 3.15 Plots of charging power (black) and discharging power (blue) from the Plant data tab on the Growatt web portal

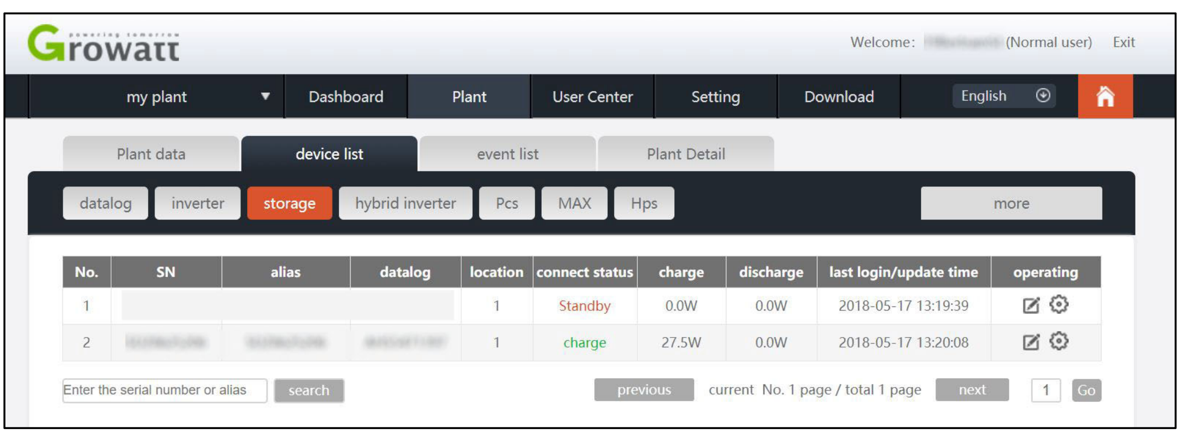

Figure 3.16 Accessing raw data via the Growatt web portal

Raw data can also be accessed and downloaded via the Growatt portal. In order to do this, it is necessary to select the 'Plant' tab', 'device list' and then 'storage', which brings up details of the battery installation(s) (figure 3.16). Clicking the text below 'connect status' brings up a window with data at 5-minute intervals. As well as being able to view this on screen, it is possible to export this as an Excel spreadsheet.

Data provided by the system includes: time, battery status, charge power (W), discharge power (W), PV voltage (V), AC voltage (V), AC power consumed by the household (W), AC power exported to the grid (W), PV generation (today and total in kWh), battery charge (today and total in kWh) and battery discharge (today and total in kWh). This data is useful for analysing performance and for checking for faults.

3.3 Control solar PV systems

3 control properties were selected for the study for comparison to the properties which had battery solar systems installed. These properties were owned by Waltham Forest Housing and had solar PV systems that were installed several years earlier. Details of these PV systems are shown in table 3.17 and the monthly generation from the systems is shown in table 3.18. An illustration of how the PV generation varies between years for control property C3 is shown in figure 3.19. The solar PV generation meter reading data for these systems was obtained from a web-portal with half-hourly meter readings from a smart generation meter.

Property reference	Size of PV system (kW)	Orientation of PV array (degrees from South)	Inclination of PV array (degrees)	Type of roof
C1	1.88	52	30	Pitched
C2	2.35	5	30	Pitched
C3	2.35	60	30	Pitched

Table 3.17 Details of the solar PV systems installed at the control properties

Period	Control C1 Generation (kWh)	Control C1 Generation (kWh/day)	Control C2 Generation (kWh)	Control C2 Generation (kWh/day)	Control C3 Generation (kWh)	Control C3 Generation (kWh/day)
Oct-16	87.05	2.81	76.82	2.48	98.65	3.18
Nov-16	57.56	1.92	97.28	3.24	68.16	2.27
Dec-16	31.27	1.01	57.16	1.84	36.16	1.17
Jan-17	45.82	1.48	77.04	2.49	49.42	1.59
Feb-17	50.92	1.82	70.43	2.52	57.27	2.05
Mar-17	133.76	4.31	182.53	5.89	144.94	4.68
Apr-17	194.43	6.48	239.60	7.99	197.23	6.57
May-17	188.75	6.09	237.87	7.67	213.91	6.90
Jun-17	229.39	7.65	284.99	9.50	259.83	8.66
Jul-17	200.46	6.47	251.38	8.11	261.99	8.45
Aug-17	185.95	6.00	238.88	7.71	242.49	7.82
Sep-17	136.49	4.55	177.54	5.92	170.16	5.67
Oct-17	85.53	2.76	117.33	3.78	97.59	3.15
Nov-17	57.93	1.93	89.83	2.99	64.84	2.16
Dec-17	33.69	1.09	56.50	1.82	36.78	1.19
Jan-18	37.87	1.22	61.02	1.97	42.65	1.38
Feb-18	83.12	2.97	123.29	4.40	92.97	3.32
Mar-18			118.31	3.82	109.24	3.52
2017 total	**1543.1**		**2023.9**		**1796.5**	

Table 3.18 Monthly values of solar PV generation for the control properties without batteries

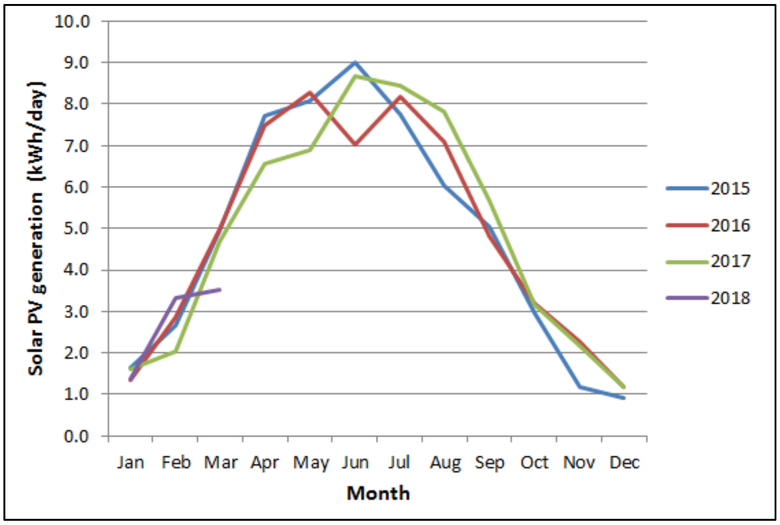

Figure 3.19 Monthly values of PV generation for control property C3 with a 2.35kW solar PV array

3.4 Moixa Maslow V3 batteries

Technical Reference Number	Sep-16	Oct-16	Nov-16	Dec-16	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17	Total Days
T-01	29	6	30	31	31	28	31	30	30	23	26	31	30	31	29	5	421
T-02	23	31	30	31	20	28	31	5	24	30	31	31	30	31	30	31	437
T-03	24	31	18	31	31	27	31	29	31	30	31	29	28	30	30	31	462
T-04	4	31	30	31	31	28	31	30	31	30	31	31	30	31	30	31	461
T-05	0	4	13	31	1	0	0	0	23	30	31	31	30	31	25	25	275
T-06	0	0	0	0	0	0	29	29	21	0	0	0	0	6	0	0	85
T-07	19	31	30	31	25	25	0	1	19	0	0	14	0	0	0	0	195
T-08	26	31	30	31	31	28	31	30	31	30	31	31	30	31	30	31	483
T-09	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12
T-10	11	0	0	0	0	28	31	14	23	30	31	31	30	31	11	0	271
T-11	3	10	8	31	26	28	29	23	31	30	2	0	0	0	0	0	221
T-12	11	31	30	31	31	28	31	30	31	30	31	31	30	31	30	31	468
T-13	0	16	19	31	31	28	31	30	31	30	4	23	19	31	30	31	385
T-14	10	31	30	31	31	28	31	30	31	30	31	31	30	31	30	31	467
T-15	1	9	30	31	31	28	31	30	31	30	31	31	30	31	24	0	399
T-16	0	7	30	5	22	28	31	30	31	30	31	31	30	31	30	31	398
T-17	1	1	0	1	22	17	0	0	14	0	0	0	0	29	30	23	138
T-18	13	5	7	0	0	0	0	0	0	0	0	0	0	0	0	0	25
T-19	30	31	14	31	16	0	0	0	0	0	0	9	0	8	30	31	200
T-20	24	18	2	31	31	28	31	30	31	30	31	31	30	19	0	0	367
T-29	2	5	30	31	31	28	31	30	31	30	31	31	30	26	30	30	427
T-30	8	20	30	31	31	28	31	30	31	30	31	31	30	31	30	31	454
T-31	9	31	30	31	31	28	31	30	31	24	31	31	30	31	30	31	460
T-32	5	0	30	31	28	0	0	0	0	0	0	0	0	0	0	0	94
T-33	2	0	20	31	31	28	31	30	31	30	31	31	30	31	24	0	381
T-34	3	8	29	20	0	3	0	0	0	2	3	1	0	0	0	7	76
T-35	2	7	15	0	0	12	31	30	31	30	31	31	30	31	30	31	342
T-36	1	0	5	17	31	28	31	30	30	30	31	12	24	31	24	25	350
T-37	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
T-38	2	9	30	19	0	23	31	22	0	0	0	0	0	0	0	0	136
T-39	0	3	20	31	31	28	31	30	31	30	31	31	30	31	30	31	419
T-40	2	0	14	23	31	28	31	30	22	1	31	31	30	21	30	3	328

Table 3.20 Days per month when each of the Moixa batteries were online, with interviewed households highlighted

There were 32 Moixa Maslow batteries which were installed in this project. The batteries installed in Camden were fitted to households T-01 to T-20. All were 2kWh batteries apart from T-18, T-19 and T-20, which had 3kWh batteries. The batteries fitted in Islington were T-29 to T-31 and those in Waltham Forest were T-32 to T-40.

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, and occasional gaps of a few minutes were also noted.

As mentioned above, since participation in the project Moixa have 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 3.20 shows the number of days in each month that each of these batteries were online and recorded at least some performance data. This gives no indication of how long the battery was online during any of these days. The batteries usually first came online at the time of installation. Moixa engineers were available to assist the contractors during the installation process. In the weeks after the installation, a number of the PV systems had problems with the RCD (residual current device) protection tripping leading to the solar PV system cutting out. This also led the Moixa batteries to go offline. The contractor resolved the tripping issue by increasing the rating of the RCD cut out.

Other problems included residents unplugging TP Link connectors while using appliances such as vacuum cleaners and the battery going offline as a result. There was a wired conection between the nearest TP Link and the WiFi router. Switching Internet Service Provider (ISP) would have resulted in the battery going offline if the ethernet cable was not plugged back in after the WiFi router was swapped over. Sometimes a problem developed with the TP Links and they needed reparing or replacing. Despite the problems with TP Links, Moixa have found that they provide a more reliable connection than 3G mobile or WiFi from the battery to the router. Moixa now prefer a wired connection between the battery and the router, with TP Links fitted as a backup.

Household T-18 did not have the internet and the connectivity of that battery was poor due to the 3G transmitter being ineffective with the battery installed under the stairs. The battery installed at household T-09 had periods online for 12 days in September 2016 and none since due to an intermittent 3G connection. The household said they were unaware that the battery would need to use their internet connection before they signed up and refused use of their broadband. Camden Council was notified and the problem was not resolved during the project.

Unfortunately the households in Waltham Forest which had the best performing PV systems in the project had batteries which were only online for short periods of time, providing little or no data to assess the battery performance. These were households T-37 and T-38 where the annual PV generation was 2632kWh and 2703kWh respectively in 2017. Household T-37 did not have broadband and a WiFi router at the time the battery and solar system was installed in October 2016. The resident only had broadband fitted in April 2018 and a request has been made for Moixa to carry out a service visit and ensure the system is connected online.

Table 3.21 shows the performance over 2017 for some of the battery-solar system in Camden and table 3.22 for others in Islington and Waltham Forest. The battery for household T-03 had periods online for 462 days between September 2016 and December 2017. However in 2017, the system was online for only 58.4% of the time. This was because the resident turned off his WiFi router every night. While online, the PV recorded by the battery was 257kWh less than the accurate value from the smart generation meter. The battery discharge from this property was the largest recorded for the Moixa installations at 290kWh.

The solar PV generation recorded by the battery current clamp was typically closer to the value recorded by the smart generation meter when the battery was online more than 90% of the time. The accuracy of all the battery data was likely to be higher for these batteries where the solar PV generation from the generation meter and battery current clamps are close. An example of this is T-39, which was online for 99% of 2017. The solar PV generation meter in 2017 recorded 1743kWh compared to 1744kWh measured by the battery system between February and December. Less accurate however was T-14 where the generation meter recorded 1816kWh and the battery current clamp 1943kWh, despite being online for 99.4% of the time in 2017. This was an error of between 5 and 10% and the system would have benefited from callibration of the current clamp.

	T-01	T-02	T-03	T-08	T-12	T-14	T-15	T-16	T-20
PV system size (kW)	3.24	3.78	3.24	3.24	1.88	3.24	3.24	3.24	3.24
Moixa battery size (kWh)	2	2	2	2	2	2	2	2	3
PV Generation in 2017 (kWh)	1203	908	1786			1816	2043	2143.47	1605
Percentage Moixa battery online during 2017 (%)	75.9%	86.6%	58.4%	98.5%	91.9%	99.4%	89.1%	96.7%	79.5%
Sum of PV in 2017 (kWh)	992.7	1064.9	1529.1	1443.3	1953.0	1943.8	2113.7	2181.1	2171.4
Sum of household consumption in 2017 (kWh)	2072.7	3660.5	1974.7	5965.4	3295.2	7382.7	6762.2	4374.5	3347.5
Sum of PV used in 2017 (kWh)	411.3	746.0	745.3	1108.3	1089.1	1050.2	1347.7	1296.2	1025.1
Sum of battery discharge in 2017 (kWh)	166.7	89.7	290.0	116.0	250.9	274.1	250.1	282.3	36.0
Sum of grid consumption in 2017 (kWh)	1516.2	2828.9	981.4	4749.0	1976.6	6075.4	5177.8	2805.7	2291.9

Table 3.21 Performance of the Camden solar systems with Moixa batteries that were online for greater periods in 2017

	T-29	T-30	T-31	T-33	T-35	T-39
PV system size (kW)	1.296	1.36	1.296	2.76	1.62	2.16
Moixa battery size (kWh)	2	2	2	2	2	2
PV Generation in 2017 (kWh)				1778	1324	1743
Percentage Moixa battery online during 2017 (%)	97.4%	99.3%	97.5%	89.3%	86.3%	99.0%
Sum of PV in 2017 (kWh)	1506.3	936.5	1516.1	1819.4	1525.3	1744.2
Sum of household consumption in 2017 (kWh)	4024.7	8358.8	3264.5	2151.5	1861.1	4085.3
Sum of PV used in 2017 (kWh)	1167.7	925.0	980.9	727.2	732.3	884.9
Sum of battery discharge in 2017 (kWh)	165.2	31.0	157.2	194.3	123.9	280.3
Sum of grid consumption in 2017 (kWh)	2698.1	7403.3	2149.8	1258.7	1024.3	2929.5

Table 3.22 Performance of Moixa batteries and solar systems in Islington and Waltham Forest

The battery discharge typically ranged from about 120kWh to 280kWh during 2017. Some systems performed less well. This included household T-02 where the solar PV generation was only 908kWh in 2017 despite having one of the largest PV arrays. Here the battery only discharged 89.7kWh. Household T-30 had a small 1.36kW PV system which faced north east and only generated 925kWh. The household consumption was 8359kWh and nearly all the solar generation was used to power household appliances with little left over for charging the battery. As a result in 2017 this battery discharged only 31kWh. Household T-20 was the only property amoung those which had 3kWh Moixa Maslow batteries where the battery was online for a significant proportion of the year (79.8%). Here there was a large error between the value of PV generation measured by the generation meter (1605kWh) and the battery current clamp (2171kWh). Household consumption at 3348kWh was average and there should have been periods which allowed charging of the battery. However the system recorded a battery discharge in 2017 of only 36kWh. Household T-19 also had a 3kWh battery, but was not online during the summer months of 2017 and so the performance was not monitored. However the resident told council staff that her electricity account was significanly in credit following the installation of the battery solar system. Several of the better performing batteries will be discussed below in more depth.

Household T-03 with a Moixa Maslow 2kWh battery

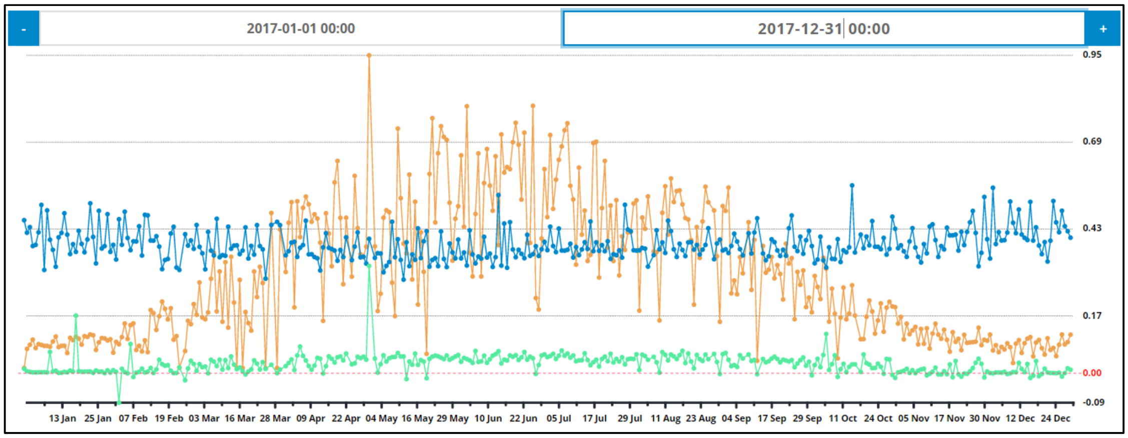

Figure 3.23 Plot of Power (kW) against time for property T-03 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Figure 3.23 shows a plot of power against time for household T-03 in 2017 using data which was averaged over 1 day. It indicates there were no long gaps in data as was also shown by table 3.20. There was a single resident in the household who was at home a lot of the time due to a health condition. The electricity consumption was typically in the range 175 to 500W.

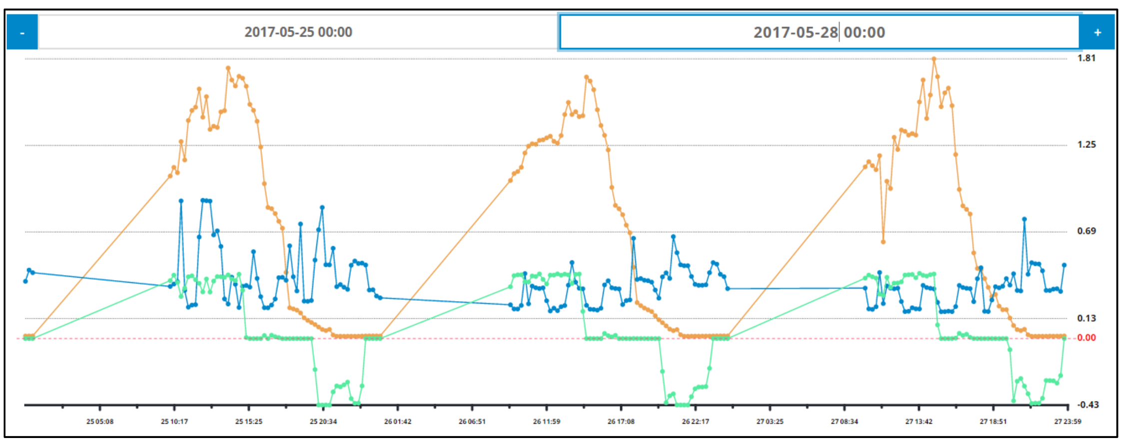

Figure 3.24 Plot of Power (kW) against time for property T-03 between 25 May 2017 and 28 May 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Between April and September, the 24-hour aggregate electricity generation from the 3.24kW PV system was frequently greater than the 24 hour aggregate household consumption in the property. Figure 3.24 illustrates typical summer performance on 3 consecutive days in May 2017. It should be noted that each night, the resident turned off the WiFi router and no data was recorded until it was turned back on between about 08:00 and 10:00. This led to the discontinuities where straight lines join the data points between the evening and the morning. This behaviour reduced the number of readings recorded by the battery system. However, a lot of the solar generation and most of the battery discharge was likely to have been recorded.

On 26th May 2017, the PV generation had exceeded 1kW by the time the WiFi router had been switched on at 08:30. The household consumption was 330W at this time. The excess solar generation allowed the battery to charge until 14:45. As the solar generation decreased below the household consumption, the battery started discharging once the grid import reached 250W at 20:00. The battery continued to discharge at up to 430W, lowering the grid import until 23:30 when it became depleted, having used up the 1.6kWh useable capacity of the battery.

Table 3.25 provides monthly performance data from the battery solar system at household T-03. Although values are presented from December 2016, battery current readings were not included in the data from Moixa for the period between 7 Dec 2016 and 9 Mar 2017. This meant the battery discharge readings were reduced in December and March and 0 in January and February. This affected readings from all the Moixa batteries in the same way.

As stated earlier, this resident turned off the WiFi router every night. As a result, the solar PV production measured by the battery system at 1529kWh was noticeably lower than the accurate value of 1786kWh measured by the smart generation meter. The household and grid consumption measured were also likely to be significantly lower as the battery system was only recording data 58.4% of the time in 2017. Utility meter readings showed the grid consumption was 980kWh between 31 Mar 17 and 23 Dec 17. In comparison, data from the battery recorded a grid consumption of 981kWh over the whole of 2017.

The battery discharge was likely to be more accurate as the battery usually would have become depleted by the time the WiFi router was turned off in the evening before the resident went to bed. Despite these issues, it was apparent that the household was a lower electricity consumer and the battery discharge was the highest recorded among the Moixa batteries. The relatively low daytime consumption and larger PV array meant there was frequently excess solar generation which allowed the battery to regularly charge.

Date	Battery discharge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	PV generation consumed (kWh)	From Grid (kWh)
Dec-16	0.4	36.3	183.6	32.9	150.3
Jan-17	0.0	41.7	182.3	36.9	145.3
Feb-17	0.0	51.1	151.9	37.5	114.4
Mar-17	16.8	89.8	140.6	47.2	78.5
Apr-17	40.4	181.2	157.0	74.6	47.3
May-17	39.9	214.9	161.8	83.6	44.9
Jun-17	41.1	239.9	157.2	89.3	33.9
Jul-17	44.2	231.6	175.9	100.0	37.9
Aug-17	39.4	184.0	161.6	80.4	47.6
Sep-17	30.8	125.6	155.7	65.0	63.8
Oct-17	22.5	84.6	165.9	56.8	89.5
Nov-17	9.3	48.3	174.4	40.1	126.5
Dec-17	5.5	36.4	190.5	33.7	151.9
Jan-18	7.8	40.9	187.4	38.1	142.3
Total 2017	**290.0**	**1529.1**	**1974.7**	**745.3**	**981.4**

Table 3.25 Monthly performance of the Moixa battery solar system for household T-03

Household T-08 with a Moixa Maslow 2kWh battery

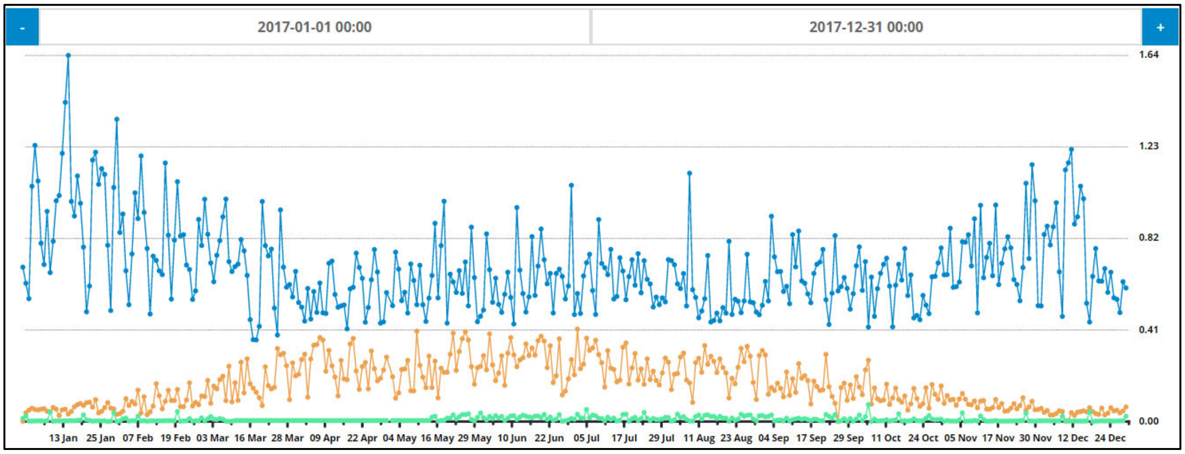

Figure 3.26 Plot of Power (kW) against time for property T-08 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Figure 3.26 shows a plot of household consumption, solar generation and battery charge/discharge over 2017. The 24-hour aggregation of the data meant that the full peaks for household consumption and solar generation were apparent in the plot. However, it can be seen that the average household consumption is high and also typically greater than the solar generation even during the summer.

Although there were 2 permanent residents in the property, a further 4 lived there during weekdays. There was an electric shower which was used about 8 times per week and required about 8kW of power. The electric oven was used on a daily basis in the afternoon. The washing machine and tumble dryer were used 2 evenings a week. In winter, supplementary electric heating was used in the evenings during the week. This explained the higher household electricity consumption and multiple peaks during the day. Figure 3.27 shows the battery solar performance on 25 May 17, which was sunny, particularly in the afternoon. The battery charged in the morning and between 13:00 and 15:00. A peak in consumption at 15:00 led to a short period of discharge. The main period of battery discharge occurred between about 19:00 and 22:00.

Table 3.28 shows the monthly performance of the battery-solar system. Household consumption was more than double that for property T-03. The solar production was also lower. As a result, there was less excess solar generation for charging the battery and the battery discharge amounts were lower for household T-08. The values of 0 for January and February 2017 were due to the battery current not being recorded on the Moixa server between 7 Dec 16 and 9 Mar 17. There was also very limited battery discharge in March and April 2017. This was likely to be due to the battery being put into bypass mode, possibly by mistake.

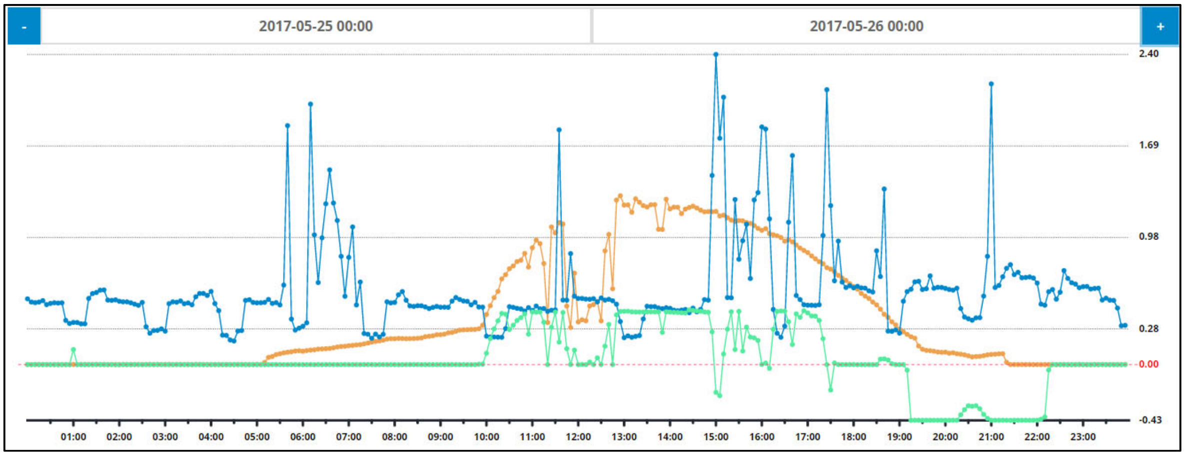

Figure 3.27 Plot of Power (kW) against time for property T-08 on 25 May 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Date	Battery discharge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	PV generation consumed (kWh)	From Grid (kWh)
Sep-16	4.8	17.5	399.2	13.1	381.4
Oct-16	4.7	30.3	486.4	26.8	455.4
Nov-16	8.3	53.4	621.5	48.6	565.0
Dec-16	0.2	37.1	549.1	37.0	512.0
Jan-17	0.0	43.6	720.2	41.0	679.1
Feb-17	0.0	60.5	530.8	55.2	475.7
Mar-17	0.2	133.2	517.9	95.4	422.3
Apr-17	0.1	178.6	401.8	117.7	284.1
May-17	13.3	177.8	458.5	133.5	312.8
Jun-17	25.6	197.6	463.2	146.3	293.1
Jul-17	22.8	190.2	468.5	145.1	301.9
Aug-17	23.4	174.4	433.9	128.3	284.3
Sep-17	13.7	112.5	431.9	90.0	329.0
Oct-17	8.9	88.7	446.9	74.6	363.9
Nov-17	5.4	55.5	539.7	50.8	483.7
Dec-17	2.6	30.6	552.0	30.3	519.2
Jan-18	4.9	43.5	632.3	41.4	586.1
Total in 2017	**116.0**	**1443.3**	**5965.3**	**1108.3**	**4749.0**

Table 3.28 Monthly performance of the Moixa battery solar system for household T-08

Household T-12 with a Moixa Maslow 2kWh battery

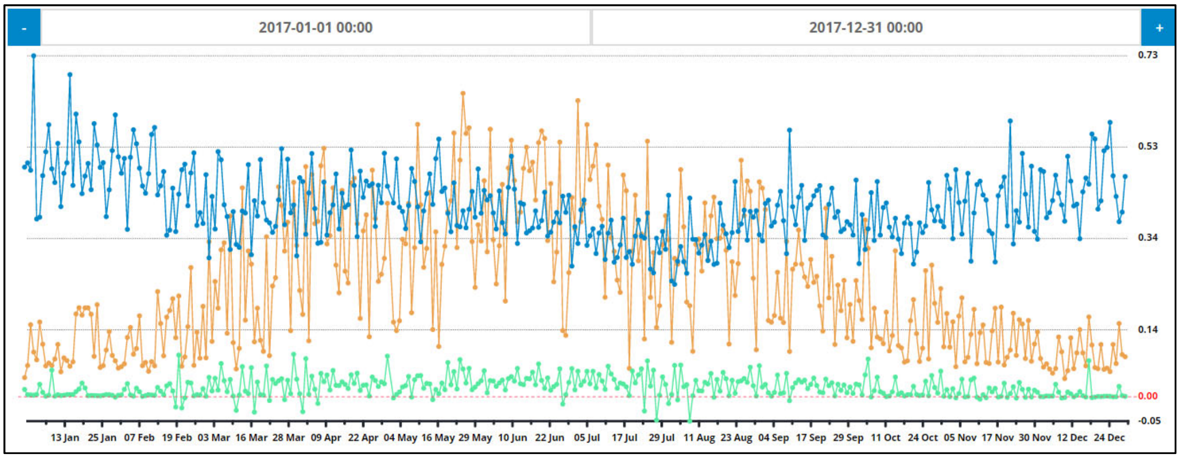

Figure 3.29 Plot of Power (kW) against time for property T-12 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

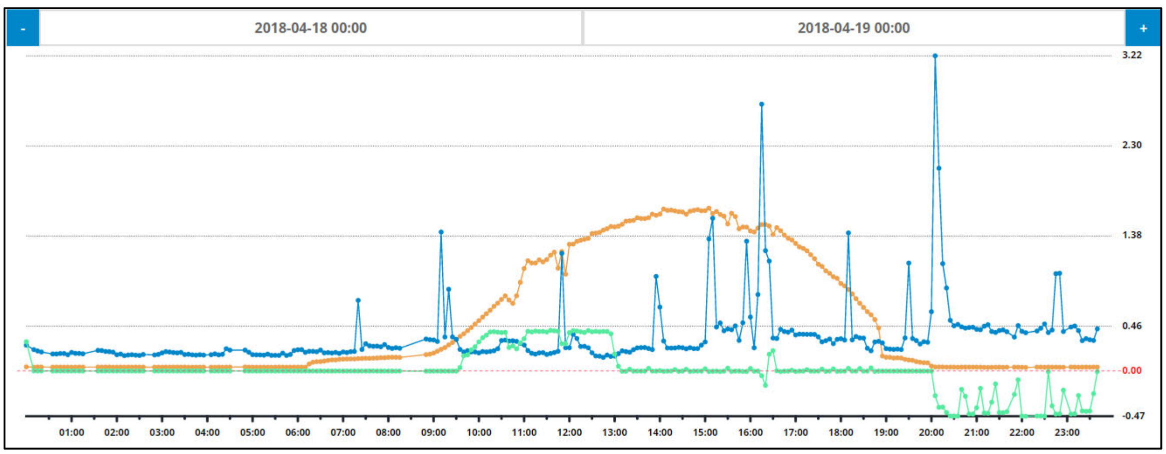

Figure 3.30 Plot of Power (kW) against time for property T-12 on 18 Apr 2018
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

The maximum PV generation for household T-12 was typically about 1.7 kW. Figure 3.29 shows that the daily average PV generation was higher than the household consumption between around May and August, which was a shorter period than for household T-03. An example of the performance on a sunny day is shown in figure 3.x. It can be seen there are more peaks with higher power consumption than for household T-03. The battery charged between 09:30 and 13:00 and discharged between 20:00 and about midnight. The plot shows there were no large gaps in data as for T-03 when the WiFi router was turned off. However, there were some smaller gaps such as between 08:15 and 08:45, where the lines of the plot can be seen to be thinner.

There were 2 residents in this household and the person interviewed worked part time. They used appliances during the day such as their washing machine 4 times per week and their dish washer 2 times per week. These appliances along with use of kettles are likely to have contributed to peaks in daytime electricity consumption.

Date	Battery discharge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	PV generation consumed (kWh)	From Grid (kWh)
Oct-16	20.0	133.9	316.0	86.2	211.2
Nov-16	10.6	80.8	343.7	65.2	268.4
Dec-16	2.3	64.0	366.3	57.7	306.3
Jan-17	0.0	78.3	364.3	65.4	298.9
Feb-17	0.0	79.1	286.5	62.1	224.4
Mar-17	20.1	164.3	271.0	88.7	163.9
Apr-17	31.5	224.3	274.8	114.5	131.3
May-17	30.9	233.4	279.6	123.3	127.4
Jun-17	39.8	291.0	282.6	141.4	104.8
Jul-17	39.0	256.1	233.6	118.5	79.9
Aug-17	32.0	216.3	228.9	103.0	97.3
Sep-17	25.5	164.1	267.7	95.4	148.5
Oct-17	16.3	111.2	246.8	72.0	160.1
Nov-17	9.2	78.1	258.8	56.6	193.7
Dec-17	6.5	56.9	300.7	48.3	246.3
Jan-18	4.7	61.6	284.4	50.7	229.6
Total in 2017	**250.9**	**1953.0**	**3295.2**	**1089.1**	**1976.6**

Table 3.31 Monthly performance of the Moixa battery solar system for household T-12

Table 3.31 shows performance data from the battery solar system as measured by the Moixa battery. In 2017, the system showed the grid consumption to be 1977kWh. Utility meter readings showed the grid consumption between 31 Oct 16 and 27 Oct 17 to be 2234kWh. Using data from the battery system between these same dates, the grid consumption recorded was 2091kWh. This was an error of 6.4%, with contributions from the measuring error of the current clamp and the battery recording data during 91.9% of 2017.

The PV generation during 2017 was higher for household T-12 than for T-03, but the battery discharge recorded of 250.9kWh was lower that for T-03. The higher household consumption was likely to have affected this, in particular the greater daytime consumption.

It should be noted that no battery discharge was recorded for January and February 2017 for T-12 or the other Moixa batteries. As noted before, this was due to an issue on the Moixa server which meant that the battery current was not recorded between 7 Dec 16 and 9 Mar 17. Values of battery discharge in these months were likely to have been about 5 and 10kWh.

Household T-14 with a Moixa Maslow 2kWh battery

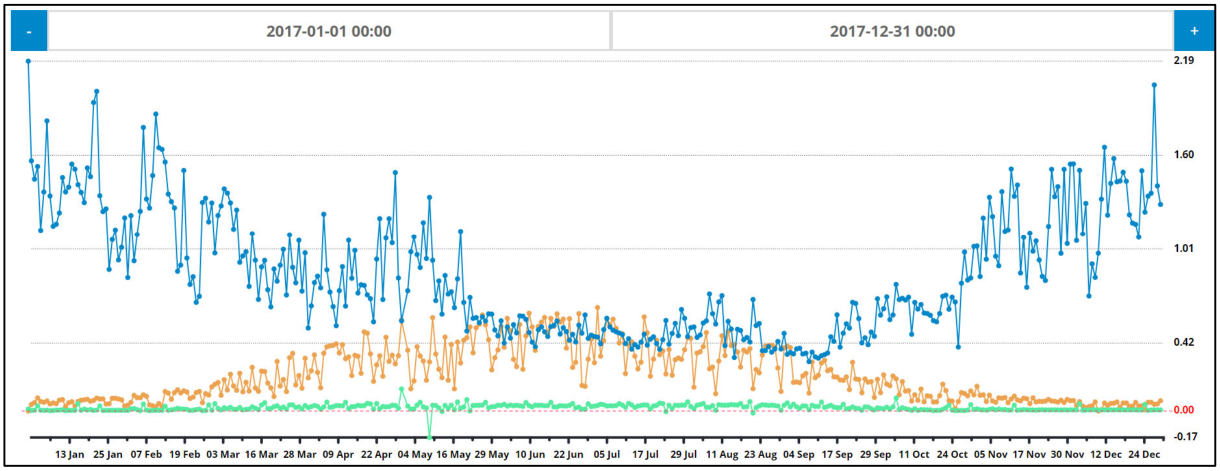

Figure 3.32 Plot of Power (kW) against time for property T-14 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Household T-14 was one of the highest electricity consumers in the study and the plot in figure 3.32 illustrates the high average daily electricity consumption (in blue) during 2017. There was a high baseload consumption as the residents had a fridge-freezer, a fridge and a mini freezer.

Figure 3.33 shows a plot for 5th May 2018, which was a sunny day. The battery started charging from 7:00 once the PV generation exceeded the household consumption. However, there were several peaks in consumption during the morning and early afternoon. These led to the power going into the battery either reducing or decreasing to zero while more of the solar generation supplied the household demand. The battery had charged by 15:00 and by 18:30, the household demand had exceeded the solar generation. This led the battery to provide about 430W until 21:45 and the battery was depleted at about 22:00.

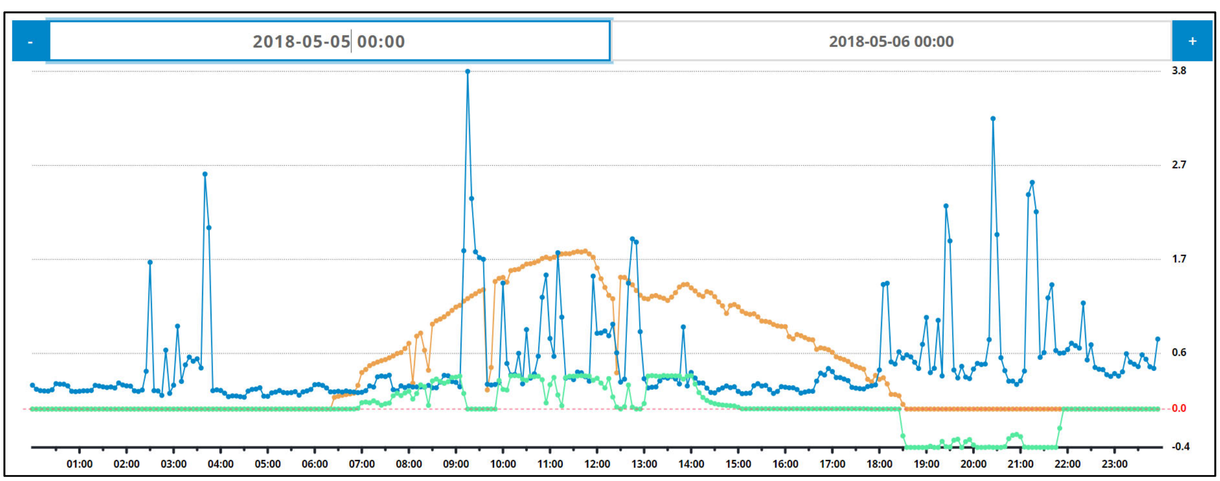

Figure 3.33 Plot of Power (kW) against time for property T-14 on 5 May 2018
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Table 3.34 shows that the household consumption measured by the battery system in 2017 was 7383kWh. While the monthly consumption in winter was high, the electricity consumption during summer months like June to September were lower. Consumption also tended to be higher in the evening. This combined with higher generation from the PV system at this site, led to a higher value of battery discharge of 274kWh in 2017.

Where there was good quality data, it was possible to also determine the battery charge from the raw Moixa data and calculate a round trip efficiency value. This ranged between 66.9% and 87.7%. These higher values are most likely due to the inverter used by Moixa requiring a grid import of 250W before the battery begins to discharge, allowing the inverter to run more efficiently. However, if the inverter threshold was set lower, there would be potential for additional charge and discharge.

Date	Battery discharge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	PV generation consumed (kWh)	From Grid (kWh)	Battery charge (kWh)	Battery Round Trip efficiency
Sep-16	7.8	44.1	301.0	30.0	263.1	9.7	80.7%
Oct-16	12.5	99.6	1471.2	76.5	1382.1	16.1	77.9%
Nov-16	5.7	52.1	1388.7	45.3	1337.8	8.5	66.9%
Dec-16	1.8	35.2	931.7	32.0	897.9	2.2	82.3%
Jan-17	0.0	44.4	1011.0	38.5	972.5	0.0	
Feb-17	0.0	58.4	815.8	48.7	767.0	0.0	
Mar-17	20.6	141.6	719.5	89.3	610.4	24.7	83.2%
Apr-17	36.3	242.0	618.8	120.5	463.5	45.7	79.4%
May-17	38.0	269.7	564.9	142.0	386.9	43.4	87.7%
Jun-17	42.9	325.1	360.9	138.2	182.8	51.2	83.9%
Jul-17	44.7	293.8	351.0	139.8	169.8	52.3	85.4%
Aug-17	41.3	250.1	371.1	115.2	218.1	47.9	86.4%
Sep-17	29.9	157.5	319.4	85.8	205.8	35.8	83.5%
Oct-17	12.4	81.3	491.3	58.8	420.6	15.6	79.2%
Nov-17	3.9	51.0	798.9	45.4	749.7	4.8	81.1%
Dec-17	4.0	28.9	960.1	28.1	928.1	5.2	78.2%
Jan-18	3.0	36.6	894.8	35.0	856.9	4.3	68.7%
Total 2017	**274.1**	**1943.8**	**7382.7**	**1050.2**	**6075.3**	**326.5**	**83.9%**

Table 3.34 Monthly performance of the Moixa battery solar system for household T-14

Household T-16 with a Moixa Maslow 2kWh battery

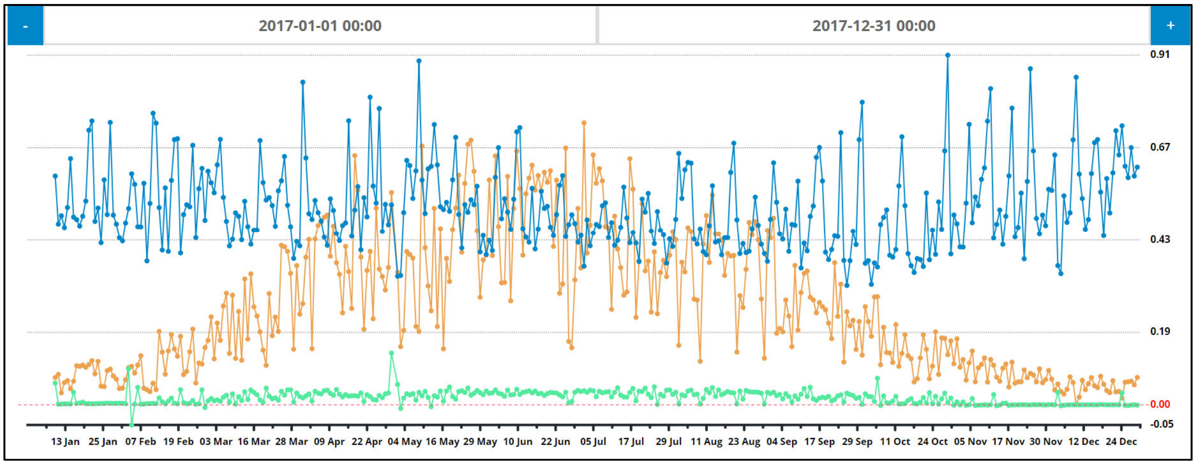

Figure 3.35 Plot of Power (kW) against time for property T-16 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

The solar PV generation for the system at household T-16 was the highest for the Camden PV systems where generation meter data was available. The value recorded by the smart generation meter was 2143kWh compared to 2181kWh recorded by the battery current clamp. The household consumption was mid-ranged and did not tend to be significantly higher in winter months as for household T-14. The levels of battery discharge are among the best for the Camden Moixa batteries, along with T-03 and T-14.

Date	Battery discharge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	PV generation consumed (kWh)	From Grid (kWh)
Jan-17	0.0	39.4	275.0	37.7	237.3
Feb-17	0.0	70.5	360.6	62.1	298.5
Mar-17	23.6	176.0	384.1	115.3	245.6
Apr-17	37.8	270.8	390.3	151.2	201.8
May-17	39.5	298.7	393.1	165.7	189.6
Jun-17	43.4	347.6	367.3	173.7	151.8
Jul-17	44.9	317.4	340.4	156.0	141.3
Aug-17	40.4	269.1	355.8	147.5	169.5
Sep-17	28.6	184.8	347.0	117.1	202.5
Oct-17	15.4	109.5	338.6	79.8	244.0
Nov-17	4.6	61.5	389.2	55.2	329.5
Dec-17	4.0	35.7	433.0	34.9	394.1
Jan-18	2.5	44.5	457.6	42.7	412.4
Total 2017	**282.3**	**2181.1**	**4374.5**	**1296.2**	**2805.7**

Table 3.36 Monthly performance of the Moixa battery solar system for household T-16

Households T-29 and T-30 with Moixa Maslow 2kWh batteries

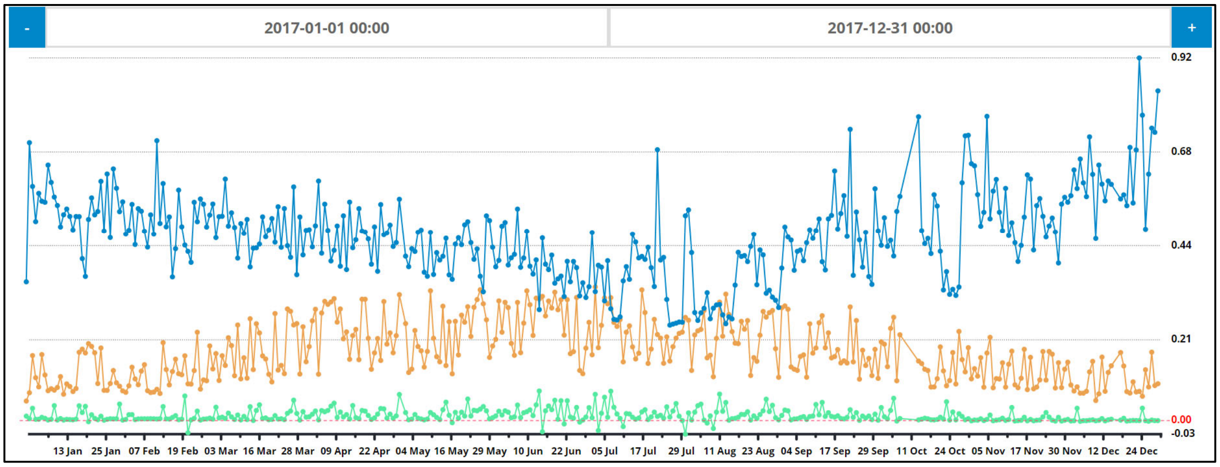

Figure 3.37 Plot of Power (kW) against time for property T-29 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

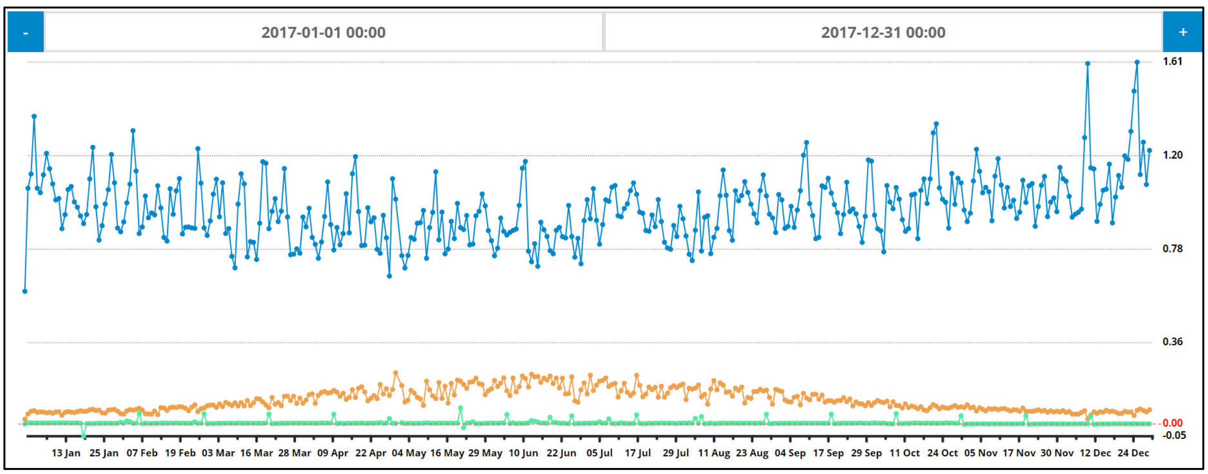

Figure 3.38 Plot of Power (kW) against time for property T-30 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

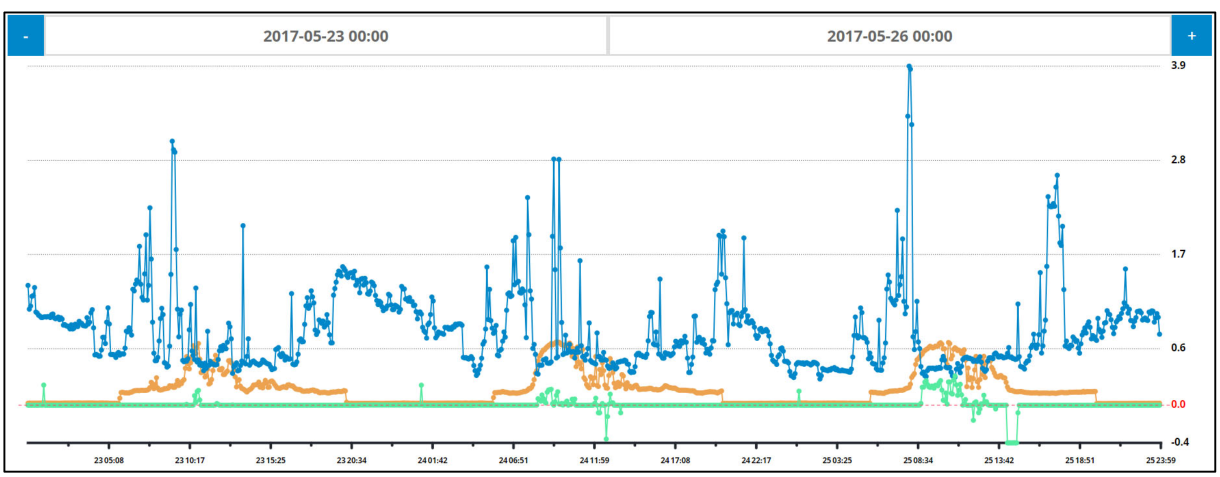

Figure 3.39 Plot of Power (kW) against time for property T-30 between 23 May 2017 and 26 May 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

The 3 Moixa battery systems installed for households in Islington were all fitted on pre-existing solar PV systems that were about 1.3kW in size. These were the smallest PV systems that batteries were fitted on in this study. Despite this, the PV generation for T-29 was 1506kWh, which was larger than for some of the Camden installations with small PV arrays (which may have suffered from shading) or those with technical problems. Household T-29 was the best performing of the Islington installations with a battery discharge of 165kWh in 2017 (table 3.22).

The worst performing system was T-30 with a battery discharge of only 31kWh. The solar PV generation was only 925kWh between March and December 2017. This was because the 1.3kW array was facing north east. The household consumption was also high, being more than double that of T-29 at 8359kWh. Figure 3.39 illustrates 3 sunny days in May 2017 and maximum output of the PV array for T-30 was only just over 700W. The household consumption was high throughout the 3 days and there were few times when the solar PV generation was sufficiently high to charge the battery. Away from periods of higher PV generation, this situation would have been even worse.

Date	Battery discharge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	PV generation consumed (kWh)	From Grid (kWh)
Nov-16	9.5	90.5	383.6	79.0	295.1
Dec-16	0.2	73.2	435.5	70.6	364.7
Jan-17	0.0	84.8	405.3	76.1	329.2
Feb-17	0.0	77.8	339.6	70.7	268.8
Mar-17	12.2	131.0	360.4	101.8	246.7
Apr-17	23.0	165.0	341.0	123.8	194.9
May-17	21.0	160.3	319.8	120.7	178.9
Jun-17	29.6	182.4	284.6	124.8	131.7
Jul-17	22.4	167.2	273.4	115.4	136.6
Aug-17	24.1	162.3	254.8	108.2	123.8
Sep-17	14.6	130.5	341.7	105.5	222.0
Oct-17	8.4	88.7	291.9	75.6	208.1
Nov-17	5.2	88.6	375.8	80.2	290.5
Dec-17	4.8	67.5	436.5	64.9	366.8
Jan-18	3.4	76.1	461.4	73.6	384.5
Total 2017	165.2	1506.3	4024.7	1167.7	2698.1

Table 3.40 Monthly performance of the Moixa battery solar system for household T-29

Household T-33 with a Moixa Maslow 2kWh battery

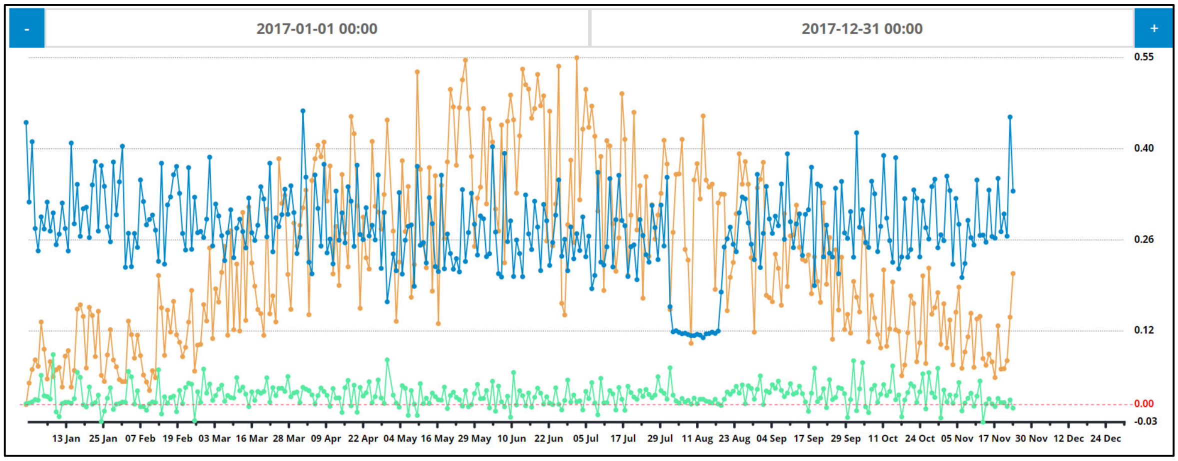

Figure 3.41 Plot of Power (kW) against time for property T-33 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Figure 3.41 shows a plot for household T-33 in Waltham Forest in 2017. The battery was offline and did not record data from 24 Nov 2017 until1 Feb 2018. The connection was again lost on 20 Apr 2018 and this problem persisted into May 2018.

The daily average household consumption in figure 3.41 was often below the solar generation between April and September 2017. There was also an extended period of low household consumption in August 2017, when the residents were most likely away. One of the days during this period is illustrated in figure 3.42. The grid consumption was typically below 100W, with regular small rises in consumption, most likely due to periodic operation of the fridge compressor. Between about 07:00 and 18:30 all the power required by the home was supplied by the solar PV system.

As the household demand only exceeded the normal 250W start-up threshold for the battery inverter once during the day, the system only supplied power briefly during the day apart from a steady output of 15W, which most likely was due to powering the battery system. This suggests the Maslow battery may have limited impact reducing the evening consumption where household demand is consistently below about 150W.

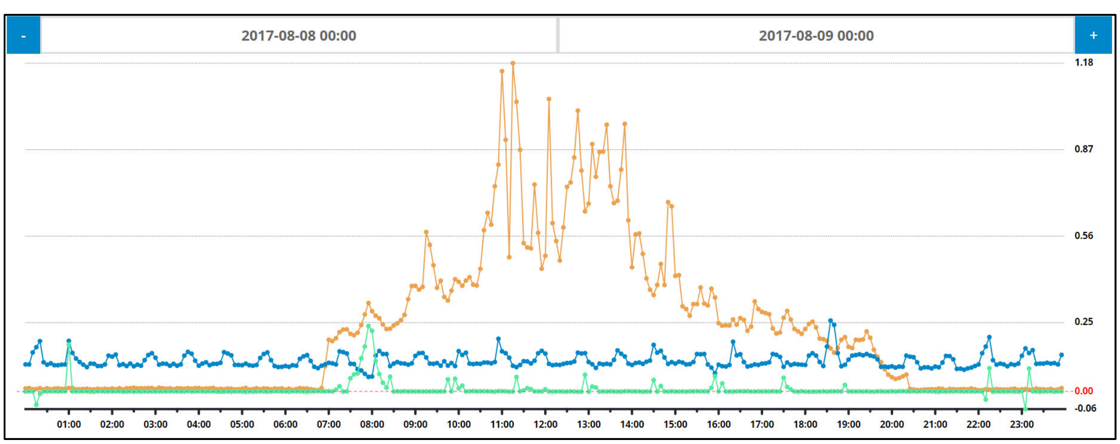

Figure 3.42 Plot of Power (kW) against time for property T-33 on 8 Aug 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

During June 2017, the household consumption was typically low during the daytime and evenings apart from sharp peaks in consumption, perhaps caused by use of an electric shower. Again, there was lower discharge from the Moixa battery despite significant solar generation. These factors may explain the lower values for battery discharge during June 2017 and August 2017 which are apparent in Table 3.43.

Date	Battery discharge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	PV generation consumed (kWh)	From Grid (kWh)
Nov-16	11.4	40.0	145.4	21.9	112.4
Dec-16	2.7	43.2	225.6	29.6	193.4
Jan-17	0.0	58.5	229.1	35.7	193.4
Feb-17	0.0	65.1	197.5	37.9	159.6
Mar-17	23.3	152.4	216.1	63.6	130.9
Apr-17	25.0	221.1	208.0	83.5	102.8
May-17	18.8	247.1	195.1	90.1	90.0
Jun-17	17.2	281.1	192.5	97.5	82.4
Jul-17	24.3	256.9	193.8	98.7	76.0
Aug-17	21.7	221.9	140.0	66.5	57.3
Sep-17	26.6	159.0	206.1	71.1	111.0
Oct-17	24.4	102.0	211.6	51.2	137.1
Nov-17	12.9	54.3	161.7	31.2	118.2
Total in 2017	**194.3**	**1819.4**	**2151.5**	**727.2**	**1258.7**

Table 3.43 Monthly performance of the Moixa battery solar system for household T-33

Household T-39 with a Moixa Maslow 2kWh battery

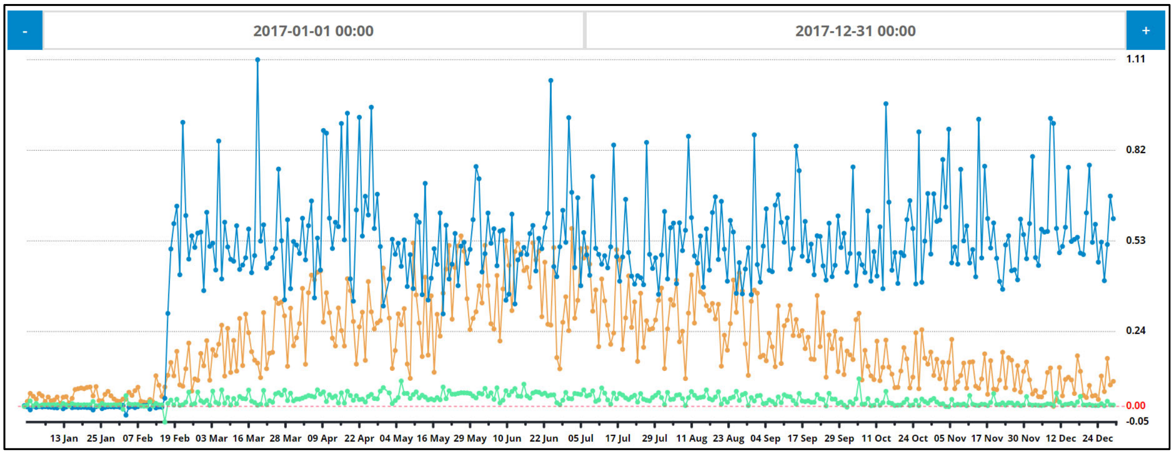

Figure 3.44 Plot of Power (kW) against time for property T-39 between 1 Jan 2017 and 31 Dec 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Household T-39 was the best performing of the Moixa battery systems in Waltham Forest in 2017. However, this battery system went offline on 14 Jan 2018. The solar PV system was operating during the period January to May 2018, which suggests it may be a problem with the battery system, most likely due to the TP Link connection.

Figure 3.44 shows typically the 24-hour aggregate household consumption in 2017 did not vary significantly between months. An exception to this was January and February 2017 when the consumption of very low. This may have been due to the property being vacant at the time. Figure 3.45 shows another plot on 26 May 2017. This was a sunny day and for much of the time during the day the PV generation was greater than the household consumption, allowing the battery to be charged. There were periods in the morning and at lunchtime when the household consumption approached 9kW. These may be due to use of an 8.5kW electric shower. This may also explain the range of values for the average household consumption in figure 3.44. Battery discharge data for 2017 was available between 9 Mar and 31 Dec 2017.

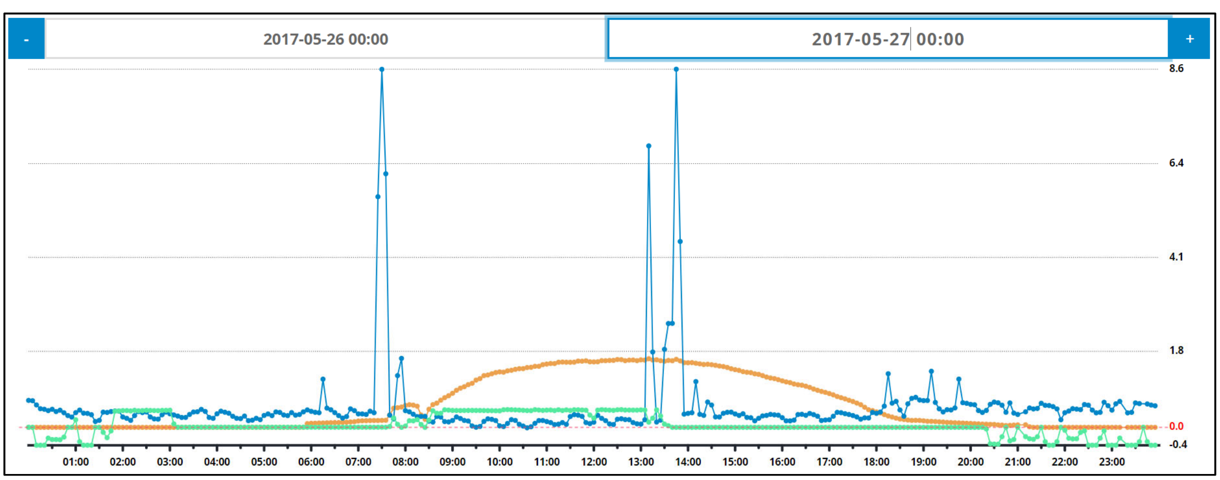

Figure 3.45 Plot of Power (kW) against time for property T-39 on 27 May 2017
Household consumption is in blue, solar PV generation in orange and battery charge/discharge in green

Date	Battery discharge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	PV generation consumed (kWh)	From Grid (kWh)
Feb-17	0.0	46.5	157.7	18.6	139.1
Mar-17	23.0	148.2	391.8	71.3	298.0
Apr-17	35.3	211.3	436.8	96.3	305.9
May-17	39.7	226.3	364.1	98.7	227.2
Jun-17	44.4	270.5	382.1	116.5	222.7
Jul-17	39.2	242.5	383.7	118.0	227.8
Aug-17	36.2	216.0	381.6	109.1	237.7
Sep-17	25.8	158.2	387.7	97.8	265.1
Oct-17	16.7	102.5	386.7	68.7	301.8
Nov-17	12.0	73.6	393.9	51.9	330.5
Dec-17	7.8	48.6	419.4	38.0	373.8
Jan-18	2.7	18.2	180.5	15.5	162.3
Total in 2017	280.3	1744.2	4085.3	884.9	2929.5

Table 3.46 Monthly performance of the Moixa battery solar system for household T-39

Financial benefit for households from the Moixa battery solar systems

Technical Reference Number	Period	Household consumption (kWh)	PV generation (kWh)	PV generation used excluding battery (kWh)	Financial benefit from solar PV excluding battery storage (£)	Battery discharge (kWh)	Financial benefit from Battery Discharge (£)
T-03	9 Mar 17 to 31 Dec 17	1595.0	1410.5	367.1	£58.73	290.0	£46.39
T-08	9 Mar 17 to 31 Dec 17	4554.6	1311.0	871.7	£139.47	116.0	£18.56
T-12	9 Mar 17 to 31 Dec 17	2570.4	1758.0	687.9	£110.07	250.9	£40.15
T-14	9 Mar 17 to 31 Dec 17	5317.3	1810.3	667.2	£106.75	274.1	£43.86
T-16	9 Mar 17 to 31 Dec 17	3631.6	2033.1	885.0	£141.60	282.4	£45.18
T-29	9 Mar 17 to 31 Dec 17	3179.3	1314.3	830.0	£132.79	165.2	£26.43
T-33	9 Mar 17 to 24 Nov 17	1669.5	1662.3	444.2	£71.07	194.3	£31.09
T-39	9 Mar 17 to 31 Dec 17	3824.4	1666.0	568.7	£90.98	280.3	£44.84
	Maximum	5317.3	2033.1	885.0	£141.60	290.0	£46.39
	Minimum	1595.0	1311.0	367.1	£58.73	116.0	£18.56
	Average	3292.8	1620.7	665.2	£106.43	231.6	£37.06

Table 3.47 Household financial benefits for Moixa 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

For the installations in Camden and Waltham Forest, the solar PV installations are owned by the councils. They receive the feed-in tariff payments and export tariff payments which repay their investment in the solar installations. The householders benefit from the potential to consume any solar-generated electricity for free, but consumption in the home may be low when PV generation is high and much of the free electricity could be exported to the grid. Batteries provide the opportunity to store some of the free solar generated electricity (which would otherwise be exported) for use in the evening when household electricity demand will be higher.

Table 3.47 summarises performance data from the 8 batteries reviewed and provides an indication of the financial benefit the households have received. The period covered is between 9 Mar 17 and 31 Dec 17 as battery discharge data was not available between 7 Dec 16 and 9 Mar 17 due to an issue with the Moixa server. The data provided for household consumption, PV generation and battery discharge were derived from the current clamps for the battery systems and errors of 5 to 10% are possible. Also, there were gaps in the data for the period covered. In most cases these were small, however for T-03 they were significant as the resident turned off his WiFi router every night and data during this period was not recorded. This meant that the household consumption for T-03 was in practice higher and some of the solar PV generation in the early morning was also missed. This is likely to account for the financial benefit from the solar system for this household being the lowest among the properties discussed.

Data from the Moixa batteries included the amount of the solar PV generation that was consumed in the home. The following equation was used to calculate the PV generation used excluding the battery. In practice, it would have been more appropriate to use the value for battery charge, but accurate values for this were not available for the Moixa batteries.

$$PV\ generation\ used\ excluding\ the\ battery = PV\ generation\ used - battery\ discharge$$

The cost of electricity used for these calculations was 16p/kWh which is the same value for a single-rate electricity tariff that has been used throughout the NEA Technical Innovation Fund projects. The data shown does not include January and February 2017, but there was likely to be limited contribution from the solar and batteries during this period.

The 8 Moixa batteries in table 3.47 discharged between 116 and 290kWh between 9 Mar 17 and 31 Dec 17. This provided residents with savings of between £18.56 and £46.39. This compared to savings of between £58.73 (or £71.07 when discounting T-03) and £141.60 for the solar PV systems.

Some of the Moixa battery installations in the study performed less well. Reasons for this included

- Batteries having a poor connection to the internet and not recording performance data
- Situations where there was insufficient excess solar generation to charge the battery.
    - Systems with low PV generation due to small PV systems or faults
    - High household consumption relative to solar generation

3.5 sonnenBatterie eco 8.2

Household T-21 with a sonnen 2kWh battery

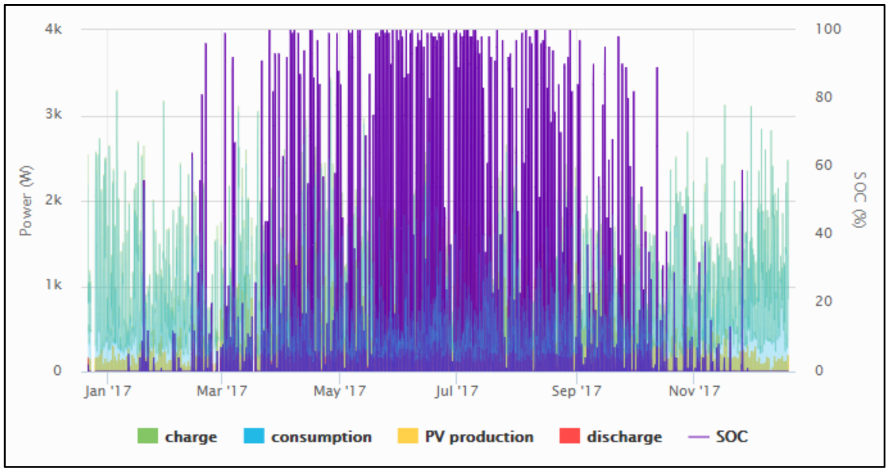

Figure 3.48 Battery history plot from the sonnen web-portal for T-21 in 2017 including state of charge (SOC)

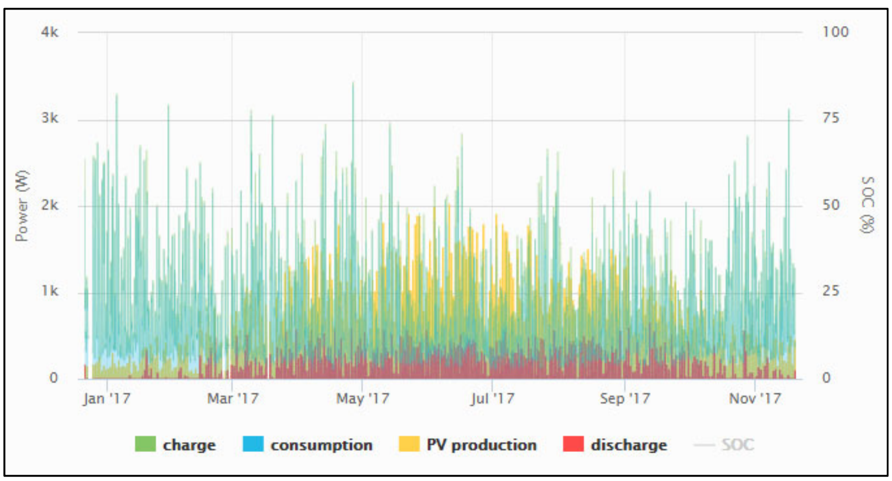

Figure 3.49 Battery history plot for household T-21 in 2017 which excludes state of charge (SOC)

Household T-21 had a solar PV system and sonnenBatterie eco 8.2 installed in September 2016. The PV array was 3.24kW and was fitted on a London Valley roof with panels facing approximately South East and North West. The battery system which has a usable capacity of 2kWh had some initial technical problems but provided regular data from the end of December 2016.

Figure 3.48 shows the consistent data throughout 2017, with household consumption in light blue and battery state of charge (SOC) in purple. The battery was able to maintain high levels of charge between March and October. When there was less solar generation, between November and February, the SOC was typically low. Figure 3.49 shows the same plot, but excluding SOC. Here it is possible to see solar PV production in yellow and battery discharge in red. This household was quite a high electricity user as can be seen by the power consumption frequently being between 1 and 2kW. The PV system could generate over 2kW, but this was frequently consumed in the home rather than used for charging the battery. The residents tended to use their dishwasher and their washing machine in the morning on a daily basis.

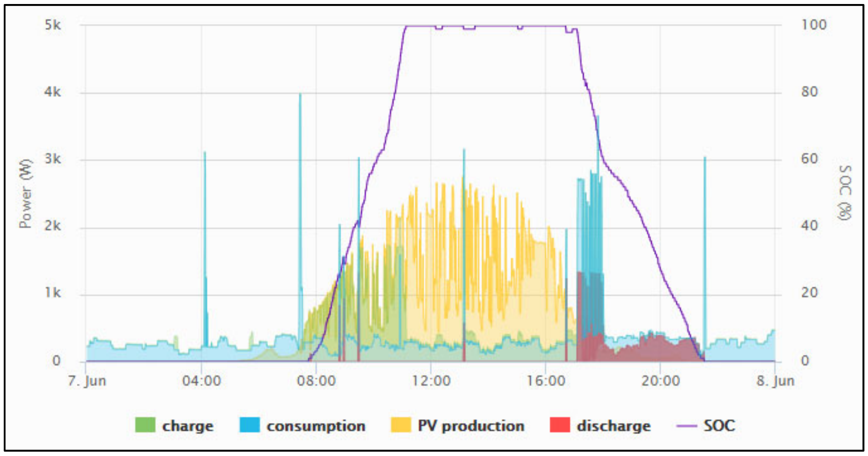

Figure 3.50 Battery history plot for T-21 on a sunny day in June 2017 with low daytime household consumption

Figure 3.50 shows a plot for the system at T-21 on a sunny day in June 2017 where there was low daytime electricity consumption. The base-load consumption overnight was typically between 100W and 300W. The battery started charging from about 08:00 and reached full charge by just after 11:00. After this point, the electricity generated by the solar panels exceeded that consumed in the property and so power was exported to the grid. There were some short spikes in consumption during the morning, perhaps due to a kettle. Between 17:00 and 18:00, the household consumption increased to about 2.7kW, most likely due to cooking an evening meal. During this period, the battery was typically supplying about 1.3kW of power. After 18:00, the battery continued to supply a significant proportion of the household consumption until 21:30 when it became depleted. On some sunny days where there was low household consumption, the battery could supply electricity to the house beyond 23:30.

Another example of a day in June 2017 is shown in figure 3.51. Here there was high household electricity consumption throughout the morning, perhaps from use of the dishwasher and washing machine. Consumption was typically higher than solar generation until about 16:00. Between 16:00 and 18:30, consumption was low which allowed the solar panels to charge the battery. Subsequently the battery was able to supply much of the power required by the home until 22:30.

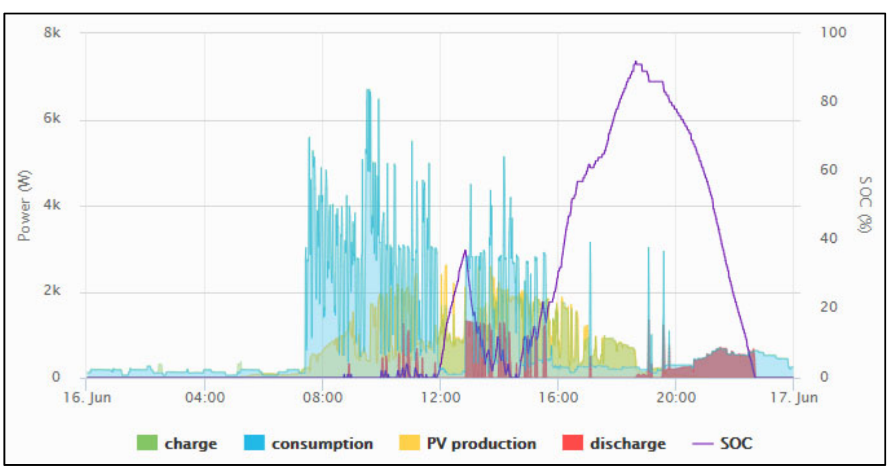

Figure 3.51 Battery history plot for T-21 on a sunny day in June 2017 with high daytime household consumption

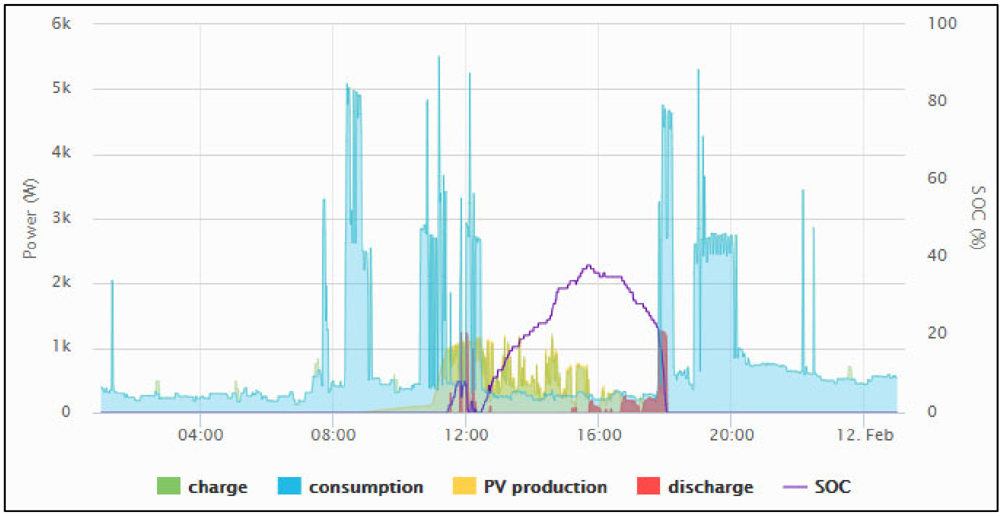

Figure 3.52 Battery history plot for T-21 on a sunny day in February 2018

On some summer days there was high household consumption throughout the day and little opportunity for charging of the battery. Figure 3.52 shows a sunny winter day in February 2018. Here the PV production only exceeded the household consumption for an extended period after 12:30. There was charging of the battery until about 16:00 and the battery state of charge (SOC) reached nearly 40%. The PV generation dropped after 16:00 and the battery provided power to the household until about 18:00. On less sunny winter days, there were few periods when the PV generation exceeded the household consumption, allowing the battery to charge. This explains why the state of charge (SOC) was so low between November and February on figure 3.48.

Data from the sonnen web-portal enabled the monthly figures for the battery solar system shown in table 3.53 to be calculated. This was the only sonnen battery which was online throughout 2017 and allowed a full year of data to be collected.

Date	Battery discharge (kWh)	Battery Charge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	Feed-in to grid (kWh)	From Grid (kWh)
1 Jan 17 to 31 Jan 17	3.05	22.79	34.49	593.12	0.01	578.38
1 Feb 17 to 28 Feb 17	10.31	30.08	52.77	434.00	0.15	401.15
1 Mar 17 to 31 Mar 17	31.32	61.00	144.89	515.04	10.12	409.97
1 Apr 17 to 30 Apr 17	54.32	92.13	244.61	510.04	39.42	342.75
1 May 17 to 31 May 17	55.97	95.72	284.22	417.52	84.35	257.47
1 Jun 17 to 30 Jun 17	64.76	106.80	325.87	397.59	99.27	213.13
1 Jul 17 to 31 Jul 17	61.53	100.13	292.32	411.25	75.37	232.96
1 Aug 17 to 31 Aug 17	60.18	92.72	249.27	397.62	47.26	228.17
1 Sep 17 to 30 Sep 17	41.27	66.34	167.99	427.11	15.65	299.84
1 Oct 17 to 31 Oct 17	16.50	32.10	92.34	523.42	1.47	448.14
1 Nov 17 to 30 Nov 17	5.70	16.09	47.86	590.75	0.59	553.87
1 Dec 17 to 31 Dec 17	1.65	9.92	20.82	746.84	0.06	734.35
Totals for 2017	**406.57**	**725.82**	**1957.45**	**5964.30**	**373.71**	**4700.19**
1 Jan 18 to 31 Jan 18	2.24	11.03	30.23	694.45	0.22	673.22
1 Feb 18 to 28 Feb 18	13.80	26.59	79.70	573.92	1.50	508.51
1 Mar 18 to 31 Mar 18	14.29	28.51	113.77	680.80	2.05	583.29
1 Apr 18 to 30 Apr 18	31.23	51.26	186.72	548.17	42.79	424.28

Table 3.53 Monthly performance of the battery solar system for household T-21

The 3.24kW solar PV array on the London Valley roof of T-21 was split with some panels facing approximately south east and the others north west and generated 1957kWh in 2017. The 2.35kW PV array on property C2 faced approximately south and generated 2024kWh. The orientation of the PV array on the control property was better for PV generation and the pitched roof was likely to suffer less from shading. This explained why the generation from the solar PV array for T-21 was lower than for C2, despite the control property having a significantly smaller PV array.

The annual feed-in to the grid in 2017 as measured by the battery system (table 3.53) was 374kWh. Using the figure for solar PV production of 1957kWh, this suggests a self-consumption rate of 80.9%.

While there were no major data gaps for battery T-21 from the end of December 2016, there were occasional gaps of 24 hours. These began at 2.29am and the battery was online again at 2.33am the following day. These were due to a system refresh taking place for the sonnen battery. This occurred for example on 24/25th February and 27/28th February 2017. Other batteries also had occasional system refreshes, but these occurred on different dates and at different times in the early morning.

Table 3.54 shows data for the battery system in kWh/day, which takes into account the number of minutes of data recorded for each month. This allows comparision between months for this battery system and for those in other households which did not have full sets of monthly data.

In June 2017, grid consumption was at its lowest at 7.11kWh/day and solar PV production at its highest at 10.87kWh/day. In contrast by December, the grid consumption is at its highest at 23.71kWh/day and PV production had fallen to its lowest rate of 0.67kWh/day. While electicity consumption from lighting and appliances is likely to be lower in summer, the primary reason for the reduction in grid consumption in summer was the generation from the solar PV system. The following equation shows how grid consumption is affected by other parameters:

$$Grid\ consumption = Household\ consumption - PV\ production + Feed\ in\ to\ grid - Battery\ discharge + Battery\ charge$$

Grid consumption goes down as there is more PV production, but goes up as more of this is exported to the grid. When there is greater discharge of the battery, the grid consumption also falls.

The monthly figures for battery charge are larger than those for discharge of the battery. The ratio of these values can provide the battery round trip efficiency and represents the percentage of the energy put into the battery which can be retrieved. The round trip efficiency for the sonnen battery at T-21 ranged from 13.4% in January 2017 to 64.9% in August 2017. There are losses in the system from converting the electricity from AC to DC in the battery and back to AC when it is to be used. The battery inverter which does this can operate from an input as low as 30W, but at low power the efficiency of the inverter is lower. In January, PV generation is less and the input for the battery inverter is likely to be lower. The battery also requires power to operate and periodically draws short bursts of power from the grid to maintain battery charge during periods without solar charging. These all contribute to the low round-trip efficiencies in winter.

Date	Battery discharge (kWh/day)	Battery Charge (kWh/day)	Solar PV Production (kWh/day)	Household Consumption (kWh/day)	Feed-in to grid (kWh/day))	From Grid (kWh/day)	Battery round trip efficiency
1 Jan 17 to 31 Jan 17	0.10	0.74	1.11	19.16	0.00	18.69	13.4%
1 Feb 17 to 28 Feb 17	0.40	1.16	2.04	16.74	0.01	15.48	34.3%
1 Mar 17 to 31 Mar 17	1.05	2.04	4.85	17.25	0.34	13.73	51.3%
1 Apr 17 to 30 Apr 17	1.81	3.07	8.16	17.01	1.31	11.43	59.0%
1 May 17 to 31 May 17	1.81	3.09	9.18	13.48	2.72	8.31	58.5%
1 Jun 17 to 30 Jun 17	2.16	3.56	10.87	13.26	3.31	7.11	60.6%
1 Jul 17 to 31 Jul 17	1.99	3.23	9.44	13.28	2.43	7.52	61.5%
1 Aug 17 to 31 Aug 17	1.94	2.99	8.05	12.84	1.53	7.37	64.9%
1 Sep 17 to 30 Sep 17	1.38	2.21	5.60	14.25	0.52	10.00	62.2%
1 Oct 17 to 31 Oct 17	0.53	1.03	2.98	16.88	0.05	14.45	51.4%
1 Nov 17 to 30 Nov 17	0.19	0.54	1.60	19.71	0.02	18.48	35.5%
1 Dec 17 to 31 Dec 17	0.05	0.32	0.67	24.11	0.00	23.71	16.7%
Averages for 2017	**1.12**	**2.01**	**5.41**	**16.50**	**1.03**	**13.00**	**56.0%**
1 Jan 18 to 31 Jan 18	0.07	0.36	0.98	22.44	0.01	21.75	20.4%
1 Feb 18 to 28 Feb 18	0.49	0.95	2.85	20.53	0.05	18.19	51.9%
1 Mar 18 to 31 Mar 18	0.46	0.92	3.68	22.04	0.07	18.88	50.1%
1 Apr 18 to 30 Apr 18	1.04	1.71	6.23	18.30	1.43	14.16	60.9%

Table 3.54 Monthly performance of the battery solar system for household T-21 with data presented in kWh/day

It should be noted that in June 2017, the average battery discharge was 2.16kWh per day. This means that the battery provided more than one charge and discharge cycle on average each day. Figure 3.51 shows how this can occur. The battery initially started to charge at midday and approached 40% SOC, but household demand subsequently increased and the battery discharged. In the late afternoon there was excess solar generation and the battery charged to over 90% SOC before discharging during the evening.

Household T-22 with a sonnen 2kWh battery

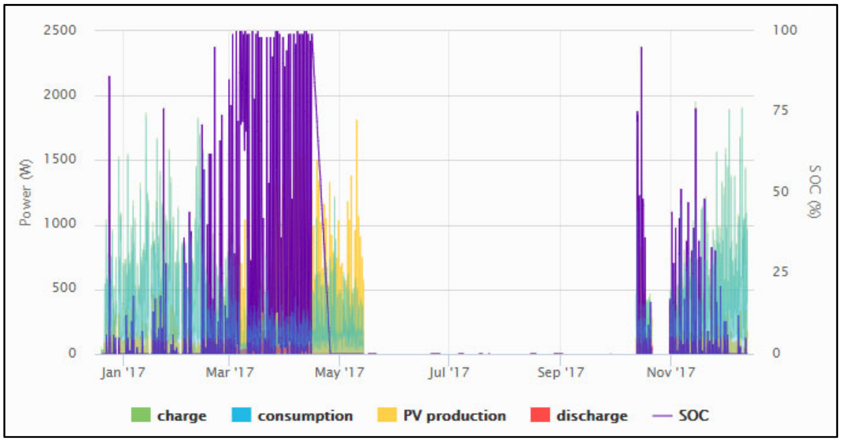

Figure 3.55 Battery history plot from the sonnen web-portal for T-22 in 2017 including state of charge (SOC)

Household T-22 had a 3.24kW solar PV system and 2kWh sonnenBatterie eco 8.2 installed in September 2016. As for household T-21, the PV array was fitted on a London Valley roof, but here the panels faced approximately South West and North East.

Figure 3.55 shows a history plot for this battery. It can be seen that no data was recorded between mid-May and mid-October. Also from mid-April, there were no charge/discharge cycles recorded for the battery and the only power measured for the charge was the self-consumption of the battery. Over the summer, daily readings from the generation meter showed that the PV system continued to operate normally. This was therefore only an issue with the battery. Camden Council and NEA staff visited the property in October 2017 and determined that a factor in the system going offline was a fault that had developed with the TP Links. These were replaced and the battery had a system refresh. There was a short period offline in late October and the system stayed online until the beginning of March 2018 when a further problem developed. During the final interview, the residents described a technical issue which occurred with the battery where it started to emit a high-pitched sound and the light on the battery went out. They subsequently contacted the Council.

Figure 3.56 shows the performance of the battery system on 13th April 2017. There was charge left in the battery from the previous day and that supplied some of the base-load power consumption until 04:00. There was a period of higher electricity consumption in the morning as the residents were getting up and having breakfast. From about 09:00, the solar generation exceeded the household consumption and the battery started charging. It became fully charged at 14:30 and subsequent excess solar generation was exported to the grid. For short peaks in consumption at 16:30 and 17:40, the battery provided about 1kW of the 1.3kW demand. From 18:00, the battery supplied the majority of the demand until about 06:00 the next morning. Similar behaviour was seen on 11th, 12th and 14th April 2017 as shown in figure 3.57. However, the fault developed on 15th April and no charge discharge cycles were then recorded by the system until October 2017.

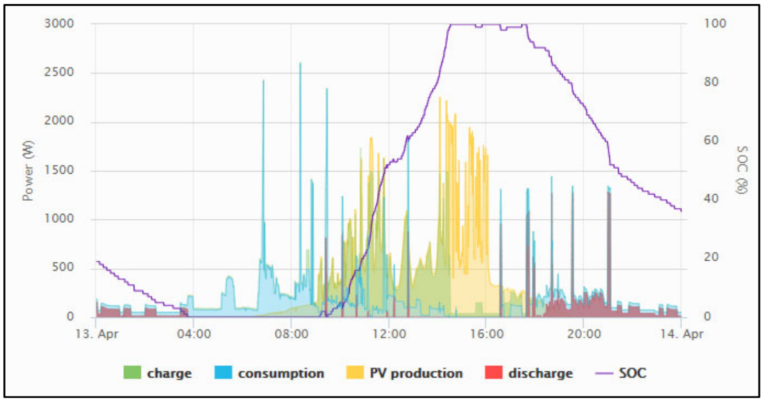

Figure 3.56 Battery history plot for Household T-22 on 13 April 2017

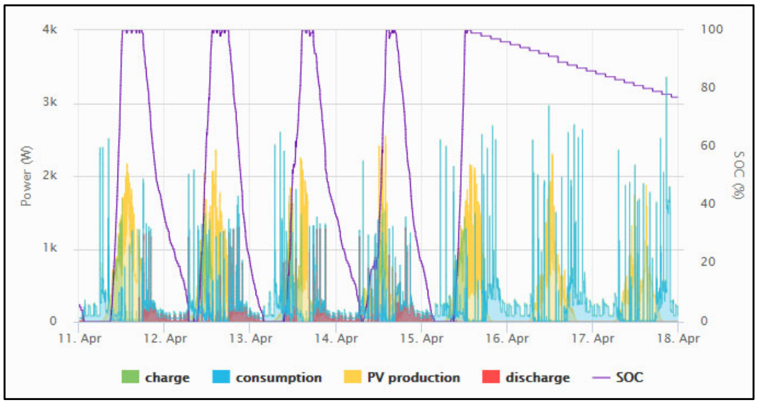

Figure 3.57 Plot for T-22 in April 2017 when the system stopped recording the battery charge/discharge cycle

Date	Battery discharge (kWh)	Battery Charge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	Feed-in to grid (kWh)	From Grid (kWh)	PV Generation meter (kWh)
1 Jan 17 to 31 Jan 17	6.91	28.07	37.94	349.27	1.44	333.92	36.92
1 Feb 17 to 28 Feb 17	15.69	38.45	54.07	253.90	2.24	224.85	53.19
1 Mar 17 to 31 Mar 17	37.04	74.24	151.98	138.06	51.80	75.08	150.57
1 Apr 17 to 14 Apr 17	19.77	38.53	107.43	55.13	54.52	20.99	106.73
1 Nov 17 to 30 Nov 17	14.59	30.91	50.87	263.64	2.81	231.91	49.4
1 Dec 17 to 31 Dec 17	4.49	15.55	26.66	396.38	1.26	382.03	25.4
1 Jan 18 to 31 Jan 18	6.85	19.30	33.95	321.54	1.73	301.77	32.8
1 Feb 18 to 28 Feb 18	17.89	34.72	69.50	302.81	13.45	263.60	68.9

Table 3.58 Monthly performance of the battery solar system (in kWh) for T-22 during periods when it was online

Date	Battery discharge (kWh/day)	Battery Charge (kWh/day)	Solar PV Production (kWh/day)	Household Consumption (kWh/day)	Feed-in to grid (kWh/day))	From Grid (kWh/day)	Battery round trip efficiency
1 Jan 17 to 31 Jan 17	0.23	0.94	1.27	11.66	0.05	11.15	24.6%
1 Feb 17 to 28 Feb 17	0.58	1.43	2.00	9.41	0.08	8.34	40.8%
1 Mar 17 to 31 Mar 17	1.20	2.41	4.94	4.48	1.68	2.44	49.9%
1 Apr 17 to 14 Apr 17	1.42	2.76	7.71	3.95	3.91	1.51	51.3%
1 Nov 17 to 30 Nov 17	0.49	1.03	1.70	8.80	0.09	7.74	47.2%
1 Dec 17 to 31 Dec 17	0.15	0.50	0.86	12.80	0.04	12.34	28.9%
1 Jan 18 to 31 Jan 18	0.22	0.63	1.10	10.43	0.06	9.79	35.5%
1 Feb 18 to 28 Feb 18	0.65	1.25	2.51	10.92	0.49	9.50	51.5%

Table 3.59 Monthly performance of the battery solar system (in kWh/day) for T-22 during periods when it was online

The performance of the system is shown in table 3.58 for the period that battery was online. Also included in the table is data derived from daily generation meter readings for the solar PV system. The solar PV production readings derived from the battery current clamp were normally within about 1kWh of the reading from the generation meter which is used for determining feed-in tariff payments.

Monthly PV production values from the array at household T-22 were typically slightly greater than for household T-21 which had the same sized PV array. The total generation for T-22 in 2017 was 1822kWh. A figure was not available for the system at T-21 as there were issues with the wireless connection on the smart generation meter.

The electricity consumption of household T-22 was considerably lower than for T-21. A factor in this was that there were 2 residents living at T-22 and 4 at T-21. In January 2017, household T-22 was consuming 11.66kWh/day compared to 19.16kWh/day for household T-22. There was greater battery charging per day in January, February, November and December for household T-22. This is likely to be due to slightly greater solar PV production with that system and lower household consumption. This may have led to the typically higher battery round trip efficiency in winter at this site.

Household T-21 had good round trip efficiencies in summer, with values higher than for T-22 in March and April. The higher household consumption is likely to have meant that the battery could fully discharge in the evening and potentially go through more than one charge-discharge cycle as in figure 3.51.

Household T-23 with a sonnen 2kWh battery

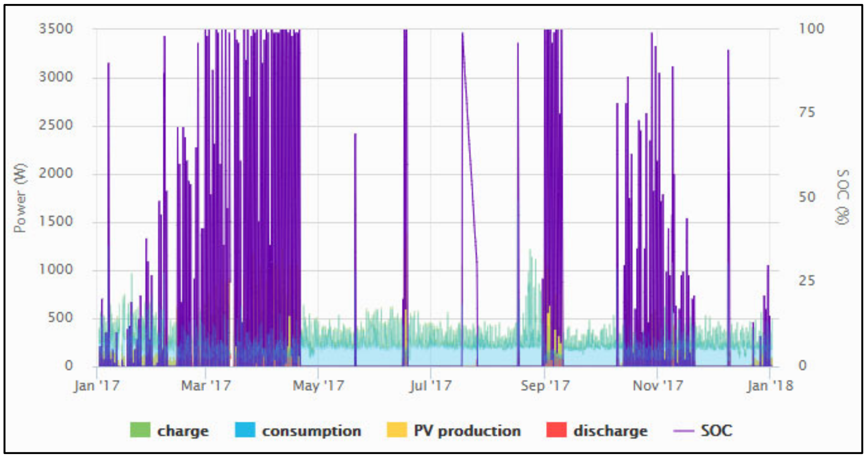

Figure 3.60 Battery history plot from the sonnen web-portal for T-23 in 2017 including state of charge (SOC)

The solar PV system for household T-23 consisted of a 3.24kW PV array on a London Valley roof with panels facing approximately South West and North East. This was the same as for household T-22, which was nearby. Figure 3.60 shows data from the sonnen web-portal. It can be seen that there was no solar production for much of the summer and the battery was not going through charge and discharge cycles. This was due to the RCD (Residual Current Device) protection switch for the PV array regularly tripping out. The PV system at this site generated 500.3kW in 2017. For comparison, the comparable system nearby for household T-22 generated 1822kWh during 2017. This suggests there was a substantial loss of generation which led to a loss of feed-in tariff income to the Council and higher electricity bills for the residents.

The council contacted Lakehouse about this situation and a member of their electrical maintenance team visited the site, but was unable to determine what was causing the regular tripping of the RCD. The residents had been advised to monitor whether the PV system was generating by checking whether the LED on the generation meter continued to flash. Also they were shown how to reset the RCD. However, there continue to be problems with this installation. Technical support for the inverter manufacturer suggested a potential cause of this problem was the installer using a 16A rated circuit breaker instead of 20A.

Figure 3.61 shows a plot from the sonnen web-portal for the battery solar system on 13th April 2017. This can be compared with the plot in figure 3.56 for household T-22 on the same day. The performance of the battery solar system for household T-23 was very similar to household T-22. Both households consumed little electricity during the day, but had occasional spikes in consumption, perhaps due to using a kettle. The household was again a lower electricity consumer.

The battery was supplying most of the baseload electricity consumption overnight until nearly 05:00. The household consumption was about 30 to 40W higher than the power delivered by the battery. Although solar PV production began from about 06:20, this was only able to charge the battery from about 08:00. The battery was fully charged by 13:20 and after that excess generation was exported. PV production began to fall around 19:00 and the battery started to discharge continously throughout the rest of the evening.

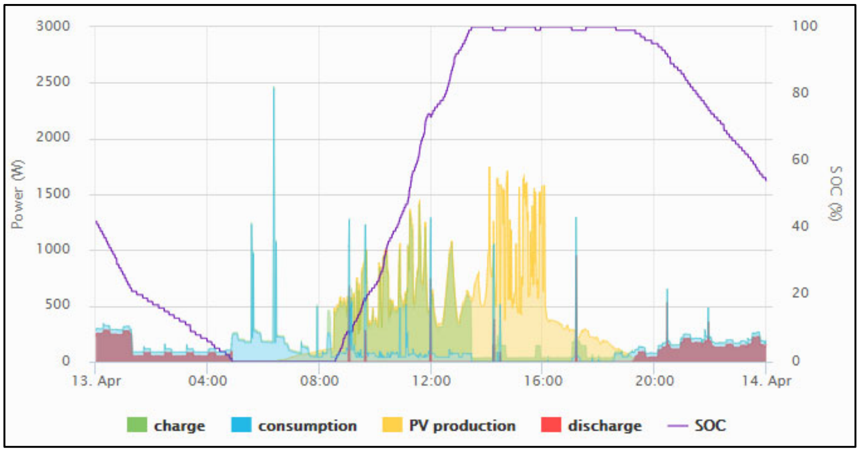

Figure 3.61 Battery history plot for Household T-23 on 13 April 2017

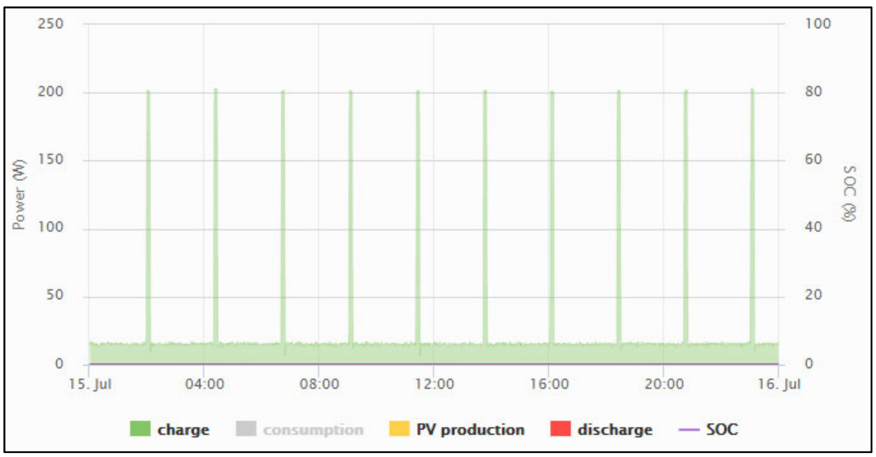

Figure 3.62 Plot showing the battery charge for T-23 in July 2017 during a period when the PV system had tripped

The battery system continued to record data over the period the PV system had tripped. This made it possible to assess the power consumption of the battery during periods when there was no solar charging. Figure 3.62 shows a plot from 15 July 2017 where only the power charging the battery from the grid is shown. It can be seen that there is a baseload consumption of about 15W to maintain operation of the battery system. During the 24-hour period there were 10 short bursts where the battery received about 200W for just over 7 minutes. These were to maintain an adequate level of charge in the battery. During summer days, there would be little need for grid battery charging. However, in winter, when solar generation often may not exceed household consumption, grid charging of the battery to maintain the charge level will be necessary.

Table 3.63 shows data from the sonnen web-portal which provides details of the performance of the battery solar system at household T-23. Also included is data from the smart generation meter for the PV system. It should be noted that this was within about 1kWh of the value derived from the battery current clamps apart from in March 2017. During that month the battery system had 2 days when it was offline and not recording data due to a system refresh.

During the periods the PV system for household T-23 was operating, there was lower PV production compared to the system for household T-22. For comparable months in the winter, there was about 80 to 90% of the generation.

Date	Battery discharge (kWh)	Battery Charge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	Feed-in to grid (kWh)	From Grid (kWh)	PV Generation meter (kWh)
1 Jan 17 to 31 Jan 17	5.12	26.43	28.81	225.01	2.4	219.91	29.47
1 Feb 17 to 28 Feb 17	14.54	38.85	47.62	152.55	3.75	133.01	47.52
1 Mar 17 to 31 Mar 17	35.87	72.16	124.01	128.43	32.78	73.5	130.65
1 Apr 17 to 20 Apr 17	29.41	55.99	135.78	77.55	62.19	30.53	135.08
1 Sept 17 to 9 Sept 17	10.88	22.46	46.52	21.62	18.17	4.85	45.9
13 Oct 17 to 31 Oct 17	13.66	28.41	42.91	79.85	3.11	54.79	41.9
1 Nov 17 to 20 Nov 17	8.77	21.02	31.22	103.9	2.73	87.65	30.3
1 Jan 18 to 31 Jan 18	6.37	20.85	29.52	172.88	2.95	160.8	28.4
1 Feb 18 to 28 Feb 18	19.07	39.8	57.05	134.82	5.14	103.64	55.8
1 Mar 18 to 24 Mar 18	20.02	40.52	69.98	92.38	17.16	60.07	68.9
24 Mar 18 to 31 Mar 18	0.55	1.8	0	46.88	0	48.13	0

Table 3.63 Monthly performance of the battery solar system (in kWh) for T-23 during periods with the solar PV online

Date	Battery discharge (kWh/day)	Battery Charge (kWh/day)	Solar PV Production (kWh/day)	Household Consumption (kWh/day)	Feed-in to grid (kWh/day))	From Grid (kWh/day)	Battery round trip efficiency
1 Jan 17 to 31 Jan 17	0.18	0.91	1.00	7.78	0.08	7.60	19.4%
1 Feb 17 to 28 Feb 17	0.54	1.44	1.77	5.66	0.14	4.94	37.4%
1 Mar 17 to 31 Mar 17	1.24	2.50	4.30	4.45	1.14	2.55	49.7%
1 Apr 17 to 20 Apr 17	1.47	2.81	6.80	3.89	3.12	1.53	52.5%
1 Sept 17 to 9 Sept 17	1.21	2.50	5.17	2.40	2.02	0.54	48.5%
13 Oct 17 to 31 Oct 17	0.72	1.49	2.26	4.20	0.16	2.88	48.1%
1 Nov 17 to 20 Nov 17	0.44	1.05	1.56	5.20	0.14	4.39	41.7%
1 Jan 18 to 31 Jan 18	0.21	0.67	0.95	5.59	0.10	5.20	30.6%
1 Feb 18 to 28 Feb 18	0.68	1.42	2.04	4.82	0.18	3.71	47.9%
1 Mar 18 to 24 Mar 18	0.87	1.76	3.05	4.02	0.75	2.61	49.4%
24 Mar 18 to 31 Mar 18	0.07	0.23	0.00	5.93	0.00	6.09	30.7%
1 Jul 17 to 15 Jul 17	0.00	0.59	0.00	5.80	0.00	6.39	

Table 3.64 Monthly performance of the battery solar system (in kWh/day) for household T-23

The household electricity consumption for T-23 was lower than for T-22 and less than half of that for household T-21. The number of household members and times they were at home were not recorded for household T-23 as they were not interviewed.

Table 3.64 shows that the battery round trip efficiency for the system at T-23 was in between those for households T-21 and T-22. Data was analysed between 1 July and 15 July 2017 when the solar PV system was not operating due to the RCD tripping. It can be seen that the battery was consuming 0.59kWh per day while operating and maintaining an adequate level of battery charge. Apart from the lost benefit from PV production there were increased costs due to running the battery with no solar system available to charge it. It can be seen that the grid consumption per day in the first half of July 2017 was higher than for any month with data apart from January 2017. Normally in the UK where there is little need for air conditioning, you would expect lower electricity consumption in the summer than for winter months where there is greater use of lighting and sometimes use of supplementary electric heating.

The RCD protection tripped out again on 24 March 2018. The grid consumption between 24 and 31 March was 6.09kWh/day compared to 2.61kWh/day for the rest of the month. This large increase was due to loss of PV generation and some grid consumption being required to maintain the battery charge.

Household T-24 with a sonnen 2kWh battery

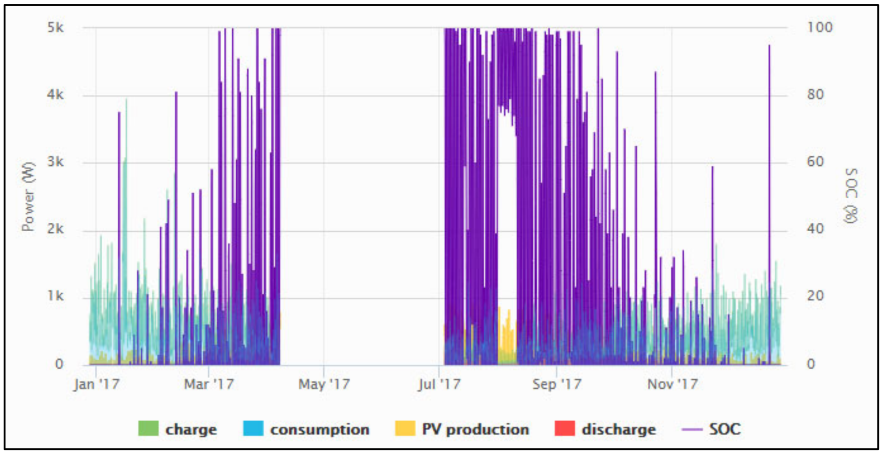

Figure 3.65 Battery history plot from the sonnen web-portal for T-24 in 2017 including state of charge (SOC)

Household T-24 is located near T-22 and T-23 and the property also has a London Valley roof. While the orientations of the roofs were the same for each property (a south west/north east split), the PV system fitted at T-24 was 2.16kW compared to 3.24kW for T-22 and T-23. Based on the serial number provided, the inverter fitted with the PV system was a SolaX mini1000, which might be undersized for the array size. The maximum power output from the PV array recorded by the sonnen web-portal was typically in the range 1000 to 1300W.

Although the solar PV system was operating throughout 2017, the battery system went offline between early April and early July 2017. This may have been due to a fault with the TP links connecting the battery to the WiFi. The smart generation meter for the solar PV system showed the total generation in 2017 was 1119.7kWh.

Date	Battery discharge (kWh)	Battery Charge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	Feed-in to grid (kWh)	From Grid (kWh)	PV Generation meter (kWh)
1 Jan 17 to 31 Jan 17	2.60	23.15	23.90	519.07	0.72	516.45	19.18
1 Feb 17 to 28 Feb 17	8.36	30.15	35.38	359.42	1.19	347.02	30.29
1 Mar 17 to 31 Mar 17	28.87	60.90	93.31	293.08	5.97	237.76	86.35
4 Jul 17 to 31 Jul 17	38.65	76.47	162.35	166.48	54.15	96.09	154.2
1 Aug 17 to 31 Aug 17	30.26	66.82	148.16	141.94	58.06	88.40	139.7
1 Sep 17 to 30 Sep 17	30.59	62.21	99.87	217.69	6.79	156.23	92.7
1 Oct 17 to 31 Oct 17	12.25	30.02	58.88	289.70	1.81	250.40	52.6
1 Nov 17 to 30 Nov 17	5.04	17.85	32.41	309.82	1.63	291.85	27.1
1 Dec 17 to 31 Dec 17	1.88	11.20	17.14	389.06	0.67	381.91	12.4
1 Jan 18 to 31 Jan 18	3.20	14.61	22.44	351.63	1.25	341.85	17.4
1 Feb 18 to 28 Feb 18	8.57	22.79	42.88	295.76	2.23	269.33	37.3
1 Mar 18 to 31 Mar 18	19.67	38.70	67.17	328.30	5.05	285.21	60.4
1 Apr 18 to 30 Apr 18	27.02	48.60	109.15	261.40	24.51	198.34	101.5
1 May 18 to 31 May 18	44.82	75.79	198.08	194.77	83.20	110.87	189.7

Table 3.66 Monthly performance (in kWh) for T-24 during periods when the system was online

Table 3.66 shows the performance of the battery solar system for household T-24. Smart generation meter data is shown in the right hand column for comparison with the data derived from the sonnen battery system. Additional data was included to the end of May 2018. This was not possible for other sonnen sites as these batteries or PV systems had gone off line. It should be noted that the diffence in values for the solar PV generation between the generation meter and those derived from the sonnen battery CT clamps range from 4.7 to 8.5kWh. This cannot be explained by battery system refreshes as that would cause the 'solar PV production' figure from the battery system to be lower. Here they are higher than for the generation meter. Normally an error of ±5% might be expected from the CT clamps, with up to 10% at low currents. In winter the difference in readings could be over 20%, but in summer it fell to about 5%. This error may affect other readings derived from the current clamps.

Household T-24 had a smaller PV array than T-21, T-22 or T-23. As a result of this and the inverter used, this system had the lowest figures for monthly solar PV production among the systems that were fitted with sonnen batteries (table 3.66). The household was also one of the highest electricity consumers.

The system had low values for battery round trip efficiency in winter (figure 3.67). This was due to the PV system having the lowest generation and the household consumption being high. There were few periods when the solar PV could charge the battery and as a result more grid charging to avoid the battery losing too much charge. The battery consistently had the lowest values of battery discharge of all the sonnen installations throughout the year. This combination of low solar generation and high consumption was likely to be the cause.

Figure 3.68 shows a plot of the battery-solar performance during July/August 2017. The household consumption dropped significantly during the first 10 days in August, most likely due to the residents being away. Although there were sunny days which charged the battery, it supplied only the baseload consumption which meant the battery only partially discharged each day. While grid consumption was very low, the battery round trip efficiency was only 16.75% a figure typical of winter. The battery discharge per day was also much lower than typically expected in summer.

Date	Battery discharge (kWh/day)	Battery Charge (kWh/day)	Solar PV Production (kWh/day)	Household Consumption (kWh/day)	Feed-in to grid (kWh/day))	From Grid (kWh/day)	Battery round trip efficiency
1 Jan 17 to 31 Jan 17	0.09	0.76	0.78	16.97	0.02	16.89	11.2%
1 Feb 17 to 28 Feb 17	0.30	1.08	1.27	12.93	0.04	12.48	27.72%
1 Mar 17 to 31 Mar 17	0.94	1.97	3.02	9.50	0.19	7.70	47.41%
4 Jul 17 to 31 Jul 17	1.38	2.74	5.81	5.95	1.94	3.44	50.55%
1 Aug 17 to 31 Aug 17	0.98	2.16	4.79	4.59	1.88	2.86	45.29%
1 Sep 17 to 30 Sep 17	1.02	2.08	3.33	7.27	0.23	5.22	49.18%
1 Oct 17 to 31 Oct 17	0.39	0.97	1.90	9.34	0.06	8.07	40.80%
1 Nov 17 to 30 Nov 17	0.17	0.60	1.08	10.34	0.05	9.74	28.23%
1 Dec 17 to 31 Dec 17	0.06	0.36	0.55	12.56	0.02	12.33	16.81%
1 Jan 18 to 31 Jan 18	0.10	0.47	0.73	11.36	0.04	11.05	21.89%
1 Feb 18 to 28 Feb 18	0.31	0.81	1.53	10.58	0.08	9.63	37.59%
1 Mar 18 to 31 Mar 18	0.64	1.25	2.17	10.63	0.16	9.23	50.82%
1 Apr 18 to 30 Apr 18	0.90	1.62	3.64	8.72	0.82	6.62	55.60%
1 May 18 ot 31 May 18	1.45	2.45	6.41	6.30	2.69	3.59	59.13%
1 Aug 17 to 10 Aug 17	0.21	1.26	4.63	0.59	3.30	0.32	16.75%

Table 3.67 Monthly performance of the battery solar system (in kWh/day) for household T-24

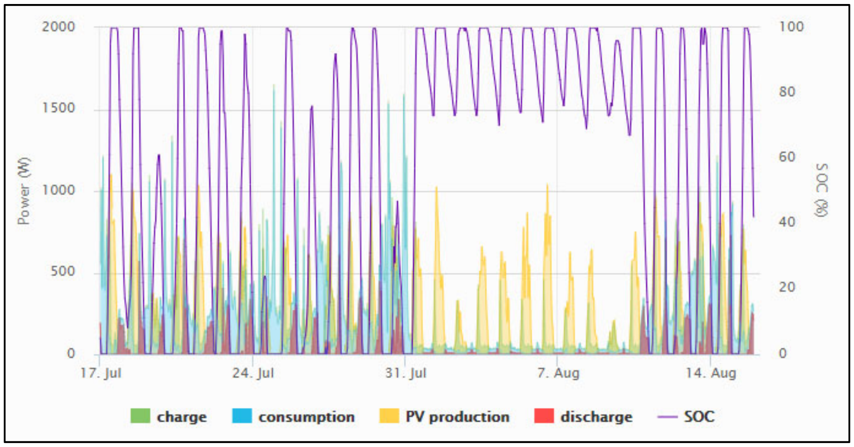

Figure 3.68 Battery history plot for Household T-24 during July/August 2017

Household T-25 with a sonnen 2kWh battery

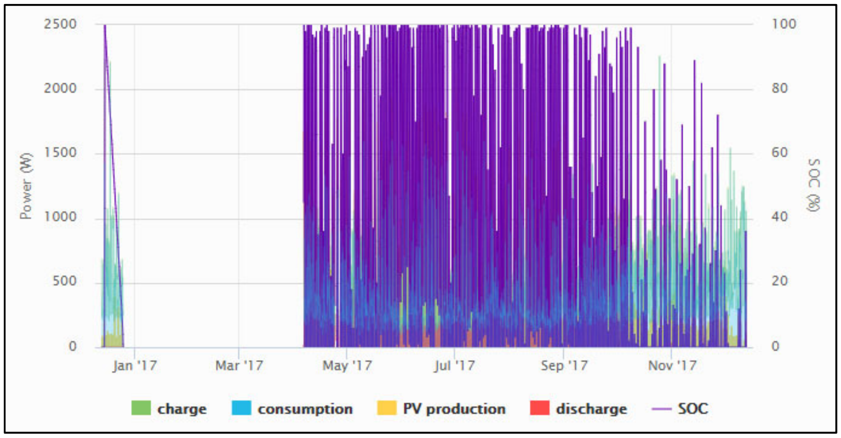

Figure 3.69 Battery history plot from the sonnen web-portal for T-25 in 2017 including state of charge (SOC)

All the properties which had sonnen battery installations had solar PV systems fitted on London Valley roofs apart from the system for household T-25. Here a 2.7kW PV system was fitted on a pitched roof that faced approximately east. The PV generation in 2017 was 2057kWh, which was the highest among the installations with sonnen batteries. This was 100kWh higher than the value derived from the sonnen portal data for household T-21 which had a 3.24kW system fitted with panels facing south east and north west on a London Valley roof.

Date	Battery discharge (kWh)	Battery Charge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	Feed-in to grid (kWh)	From Grid (kWh)	PV Generation meter (kWh)
7 Apr 17 to 30 Apr 17	38.05	68.26	199.17	234.05	29.51	94.59	211.80
1 May 17 to 31 May 17	49.53	92.40	277.42	303.10	38.74	107.30	275.10
1 Jun 17 to 30 Jun 17	48.94	91.21	329.11	302.06	54.64	69.86	327.50
1 Jul 17 to 31 Jul 17	51.23	93.52	294.95	280.01	44.62	71.96	293.20
1 Aug 17 to 31 Aug 17	48.63	84.17	260.32	273.82	43.53	92.58	258.40
1 Sep 17 to 30 Sep 17	46.87	77.87	181.88	288.35	20.52	157.99	179.50
1 Oct 17 to 31 Oct 17	27.06	48.05	107.65	380.31	7.10	300.75	105.40
1 Nov 17 to 30 Nov 17	18.10	34.64	65.43	357.95	2.56	311.62	63.60
1 Dec 17 to 31 Dec 17	7.15	18.61	33.87	425.42	1.00	404.02	32.20

Table 3.70 Monthly performance (in kWh) for T-25 during periods when the system was online

Table 3.70 shows that for every month apart from April, the PV generation meter data was within 1 to 2 kWh of the values obtained from the sonnen portal data. During April 2017 there was a battery system refresh which took the battery offline for 2 days when the PV generation was not recorded.

The solar PV system generated consistently from the time it was installed in September 2016. There were problems getting the sonnen battery system online during the first few months after the installation. The system was connected for a few weeks in December 2016, but the connection failed at the end of that month. It was not until the beginning of April that the online connection for the battery system was restored. The battery produced consistent data until the middle of January 2018. NEA staff noted during the final interview in mid-February 2018 that the light on the battery was on, which suggested it was working. The earlier and more recent problems were likely to be due to issues with the TP Links providing the connection to the WiFi router.

Household T-25 showed less of a reduction in household electricity consumption between winter and summer than the other households with sonnen batteries. This was despite the solar PV system generating the most electricity. The property had 6 residents, with 2 who were elderly and at home, cared for by another household member. An oil-filled electric radiator was regularly used to keep the room warmer for the older resident. The washing machine was used during the day 5 times a week. These are likely have contributed to a relatively high electricity consumption througout the year. This was also frequently maintained during the day as shown by figure 3.72.

The feed-in to the grid each month was low, with less than 2kWh per day. The battery round trip efficiency was above 50% between April and November. The battery discharge per day was the highest for the sonnen batteries between September and December 2017. However for household T-21, the battery discharge per day was higher in the summer months between April and August 2017.

Date	Battery discharge (kWh/day)	Battery Charge (kWh/day)	Solar PV Production (kWh/day)	Household Consumption (kWh/day)	Feed-in to grid (kWh/day))	From Grid (kWh/day)	Battery round trip efficiency
7 Apr 17 to 30 Apr 17	1.73	3.11	9.06	10.65	1.34	4.30	55.7%
1 May 17 to 31 May 17	1.60	2.98	8.96	9.79	1.25	3.47	53.6%
1 Jun 17 to 30 Jun 17	1.63	3.04	10.98	10.08	1.82	2.33	53.7%
1 Jul 17 to 31 Jul 17	1.66	3.02	9.53	9.05	1.44	2.33	54.8%
1 Aug 17 to 31 Aug 17	1.57	2.72	8.40	8.84	1.41	2.99	57.8%
1 Sep 17 to 30 Sep 17	1.56	2.60	6.07	9.62	0.69	5.27	60.2%
1 Oct 17 to 31 Oct 17	0.87	1.55	3.47	12.27	0.23	9.71	56.3%
1 Nov 17 to 30 Nov 17	0.60	1.16	2.18	11.94	0.09	10.40	52.2%
1 Dec 17 to 31 Dec 17	0.23	0.60	1.09	13.73	0.03	13.04	38.4%

Table 3.71 Monthly performance of the battery solar system (in kWh/day) for household T-25

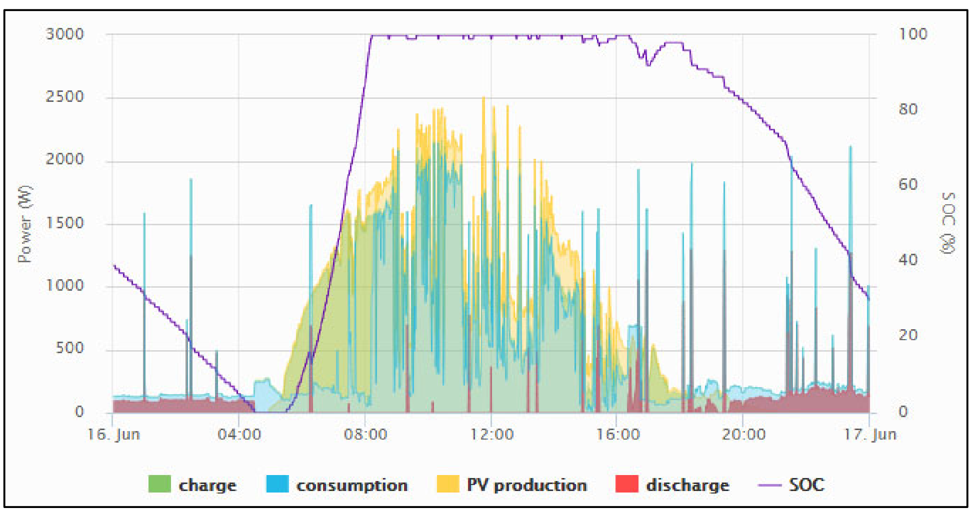

Figure 3.72 Battery history plot for Household T-25 on 16 June 2017

Household T-26 with a sonnen 2kWh battery

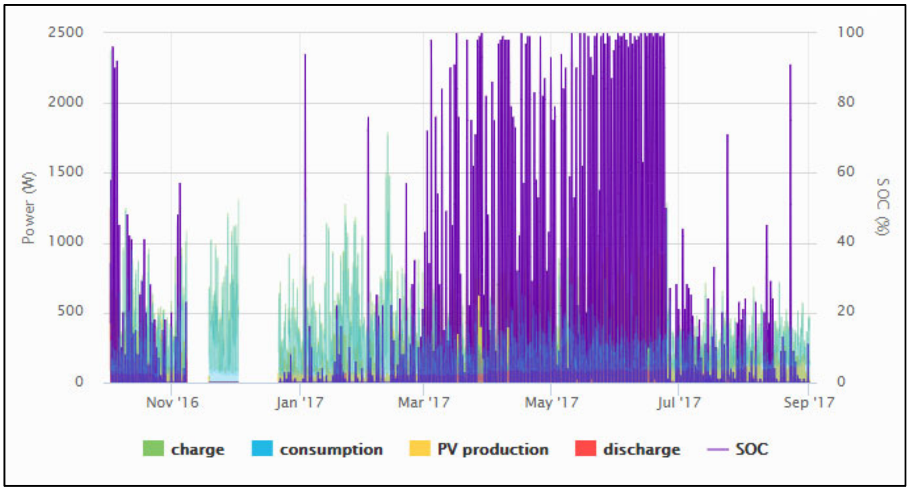

Figure 3.73 Battery history plot from the sonnen web-portal for household T-26 in 2017 including state of charge (SOC)

The solar PV system fitted at this site was the joint smallest of those having sonnen batteries. Both household T-24 and T-26 had 2.16kW PV arrays. They were fitted on London Valley roofs which had the panels split between roofs facing south-west and north-east. This installation appears to have had an oversized inverter for the PV array as the serial number indicated a SolaX SL-TL3300T inverter was used. In contrast, for household T-24 a SolaX MINI1000 inverter seems to have been used, which may be undersized.

The solar PV and battery system was installed in mid-September 2016, with the battery online until 7th November 2016 when the connection was lost. The system was back online in mid-November until early December 2016 but was only recording the household electricity consumption. The PV system was operating continuously throughout this period and so the problems may have included issues with TP Links and/or the CT clamps for the battery. From late December 2016, the battery system was again recording battery charge/discharge, solar generation and household consumption.

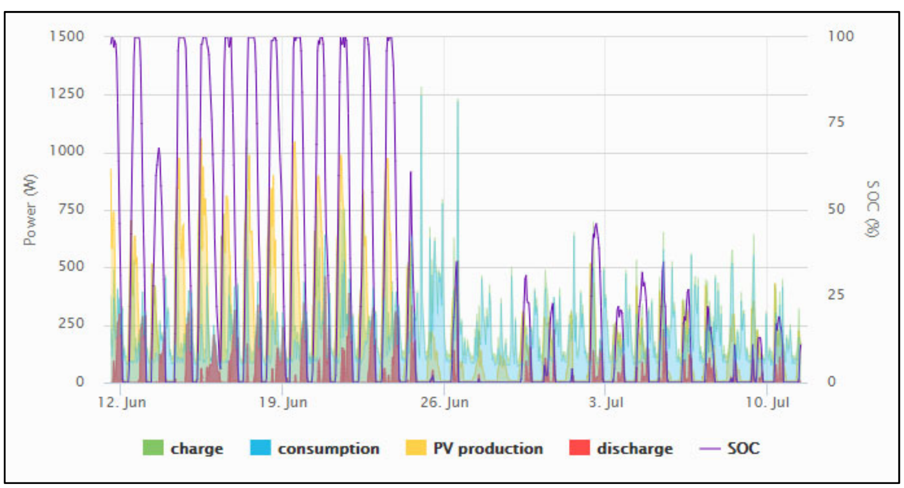

Figure 3.74 Battery history plot from June/July 2017, showing a drop in PV generation, suggesting a likely PV fault.

It can be seen from figure 3.73 that the state of charge (SOC) for the battery regularly reached around 100% from March 2017. However, this no longer occurred from the end of June 2017, despite being in the middle of summer. Figure 3.74 shows there was a significant decrease in the solar PV generation from 24th June. This suggests that a PV fault had developed at this time. As a result, most of the remaining solar generation was consumed in the home and there was less excess available to charge the battery. From the beginning of September 2017, the battery system was no longer online, most likely due to issues with the TP Links. Daily meter readings from the smart generation meter showed the solar PV system continued to operate beyond September, but there was less electricity generation. During 2017, the solar PV array for household T-26 produced 768kWh of electricity.

NEA staff advised the council of the problem with the PV system in August 2017. There were however other issues associated with this and other sites. At the time of the installations, Camden Council was not informed by the contractors that the solar panels on the London Valley roofs were going to cover hatches which provided roof access from the loft. The council maintenance team were keen to restore access to the roof and there were ongoing discussions with the contractors over whether to remove the solar panels which blocked the roof hatch. As a result of this, there was reluctance to set up scaffolding and address a PV fault if it was necessary to return at a later date to remove panels from the PV system.

Table 3.75 shows the monthly performance of the solar PV and battery system for household T-26. There was again daily smart generation meter data available (right hand column) for comparison with the Solar PV Production readings derived from measurements of the current clamps of the sonnen battery system. For the sonnen installations at households T-22, T-23 and T-25, the values of the monthly Solar PV Production were typically within 1-2kWh of the values from the smart generation meter. However, for this installation, the difference ranged from 4 to 11kWh. For most months, this represented an error of between 5 and 10%, however in January and February where there was lower generation, the error was about 20 to 25%. Normally the error from these current clamps would be expected to be in the range ±5%, rising to 10% with low current.

Date	Battery discharge (kWh)	Battery Charge (kWh)	Solar PV Production (kWh)	Household Consumption (kWh)	Feed-in to grid (kWh)	From Grid (kWh)	PV Generation meter (kWh)
15 Sep 16 to 30 Sep 16	16.35	33.62	49.13	61.88	1.15	31.17	45.12
1 Oct 16 to 30 Oct 16	21.63	50.08	71.28	178.79	1.25	137.21	63.99
1 Jan 17 to 31 Jan 17	6.03	28.08	31.02	220.01	0.07	211.10	23.00
1 Feb 17 to 28 Feb 17	11.05	33.10	40.70	176.72	0.18	158.25	32.83
1 Mar 17 to 31 Mar 17	35.13	69.32	102.36	123.92	5.38	61.13	92.75
1 Apr 17 to 30 Apr 17	48.30	86.99	149.13	155.41	10.73	55.70	139.37
1 May 17 to 31 May 17	49.10	89.00	169.69	165.83	24.13	60.17	158.70
1 Jun 17 to 23 Jun 17	36.53	67.65	158.29	101.68	50.91	25.42	150.10
1 Jul 17 to 31 Jul 17	10.54	34.02	65.28	142.10	1.04	101.34	56.40
1 Aug 17 to 31 Aug 17	5.20	19.54	52.63	161.95	1.81	125.47	44.00

Table 3.75 Monthly performance of the battery solar system (in kWh) for household T-26 during periods when the system was online

Date	Battery discharge (kWh/day)	Battery Charge (kWh/day)	Solar PV Production (kWh/day)	Household Consumption (kWh/day)	Feed-in to grid (kWh/day))	From Grid (kWh/day)	Battery round trip efficiency
15 Sep 16 to 30 Sep 16	1.02	2.10	3.07	3.87	0.07	1.95	48.6%
1 Oct 16 to 30 Oct 16	0.70	1.61	2.30	5.76	0.04	4.42	43.2%
1 Jan 17 to 31 Jan 17	0.20	0.91	1.00	7.11	0.00	6.82	21.5%
1 Feb 17 to 28 Feb 17	0.40	1.18	1.46	6.32	0.01	5.66	33.4%
1 Mar 17 to 31 Mar 17	1.14	2.24	3.31	4.01	0.17	1.98	50.7%
1 Apr 17 to 30 Apr 17	1.61	2.90	4.98	5.19	0.36	1.86	55.5%
1 May 17 to 31 May 17	1.59	2.87	5.48	5.35	0.78	1.94	55.2%
1 Jun 17 to 23 Jun 17	1.59	2.94	6.89	4.43	2.22	1.11	54.0%
1 Jul 17 to 31 Jul 17	0.34	1.10	2.11	4.59	0.03	3.27	31.0%
1 Aug 17 to 31 Aug 17	0.17	0.63	1.70	5.23	0.06	4.05	26.6%

Table 3.76 Monthly performance of the battery solar system (in kWh/day) for household T-26

The PV arrays for households T-26 and T-24 were both 2.16kW, but T-26 generated more between January and March 2017. In July 2017, the PV generation was only 56.4kWh compared to 150kWh between 1 June and 23 June 2017. This drop was the result of developing the PV fault.

The electricity consumption for household T-26, along with household T-23 was the lowest among those that received solar PV systems with sonnen batteries. Table 3.76 shows that the household consumption was 7.11kWh/day in January compared to 19.16kWh/day for household T-21.

The values of battery discharge/charge and round-trip efficiency were comparable between households T-26 and T-21 in February 2017. For T-21, the battery discharge was 0.40 kWh/day, charge was 1.16kWh/day and efficiency was 34.3%. These values will be affected by the balance between solar PV production and household consumption and the pattern of use.

As well as the solar PV generation dropping after the PV fault, the data from July and August 2017 shows that the battery charge and discharge also dropped. The values of battery round trip efficiency at 31% and 26.6% were more typical of winter months like January and February.

Financial benefit for households from the sonnen battery solar systems

Technical Reference Number	Period	Household consumption (kWh)	PV generation (kWh)	PV generation used excluding battery (kWh)	Financial benefit from solar PV excluding battery storage (£)	Battery discharge (kWh)	Financial benefit from Battery Discharge (£)
T-21	1 Jan 17 to 31 Dec 17	5964.3	1957.5	1177.2	£188.35	406.6	£65.05
T-22	1 Jan17 to 14 Apr 17	796.4	351.4	162.0	£25.92	79.4	£12.71
T-23	1 Jan 17 to 20 Apr 17	583.5	336.2	150.2	£24.03	84.9	£13.59
T-24	1 Jan 17 to 31 Mar 17	1171.6	152.6	104.9	£16.78	39.8	£6.37
T-24	4 Jul 17 to 31 Dec 17	1514.7	518.8	277.0	£44.32	118.7	£18.99
T-25	7 Apr 17 to 31 Dec 17	2845.1	1749.8	1172.0	£187.53	335.6	£53.69
T-26	1 Jan 17 to 23 Jun 17	943.6	651.2	373.7	£59.78	186.1	£29.78

Table 3.77 Household financial benefits from sonnen battery-solar installations using a cost of 16p/kWh for electricity

Table 3.77 shows an assessment of the financial benefit for the sonnen batteries and their associated solar PV systems. The figures for household consumption, PV generation and battery discharge were all determined from data from the sonnen battery system. The same methodology as for the Moixa batteries was used to calculate the ‘PV generation used excluding the battery’ to allow direct comparion. Here the battery discharge (and grid export) was subtracted from the PV generation, although the battery charge would be a more appropriate figure to use.

Out of the 6 sonnen batteries that were installed in Camden, only a single battery, T-21, was online for the whole of 2017 and recording data. The only other battery which was online for most of the year was T-25. Both these systems are highlighted in the table. Battery T-21 discharged 406.6kWh during 2017, with a financial benefit of £65 using a unit rate of 16p/kWh. For household T-25, the battery discharged 335.6kWh between 7 Apr 17 and 31 Dec 17 with a benefit of £53.69.

For T-21, the household consumed 1177kWh of the solar PV generated excluding the battery in 2017. This had a financial benefit of £188.35. When using the battery charge instead of the battery discharge for this calculation, the PV generation used excluding the battery was 857.9kWh with a financial benefit of £137.27. For household T-25. between 7 Apr 17 and 31 Dec 17, the solar PV generation used excluding the battery was 1172kWh with a value of £187.53. When the battery charge was is used to calculate the PV generation used excluding the battery, this decreased to 898.9kWh, with a financial of £143.82.

It was not possible to directly compare the performance of the sonnen and Moixa batteries over the whole of 2017 as had been hoped. However a good comparison can be made between a number of the better performings systems which were online for extended periods. Table 3.78 shows the performance of 6 Moixa batteries and 2 sonnen batteries between April and December 2017. Only household T-25 did not include data from the whole of April due to coming back online on 7 April.

The battery discharge for household T-03 with a Moixa battery was 273.1kWh between April and December 2017. Household T-21, with a sonnenBatterie eco 8.2 discharged 361.9kWh, which was 32.5% higher than for household T-03, the best performing Moixa system. The financial benefit from the battery to the household was £57.90 for the sonnen compared to £43.70 for the Moixa. The other sonnen system at T-25 discharged 62.5kWh more than household T-03 over a period that was 1 week shorter.

Technical Reference Number	Battery model	Period	Household consumption (kWh)	PV generation (kWh)	PV generation used excluding battery (kWh)	Financial benefit from solar PV excluding battery storage (£)	Battery discharge (kWh)	Financial benefit from Battery Discharge (£)
T-03	Moixa	1 Apr 17 to 31 Dec 17	1500.0	1346.5	350.5	£56.07	273.1	£43.70
T-12	Moixa	1 Apr 17 to 31 Dec 17	2373.4	1631.3	642.1	£102.73	230.8	£36.93
T-14	Moixa	1 Apr 17 to 31 Dec 17	3725.4	1699.5	620.2	£99.23	253.5	£40.56
T-16	Moixa	1 Apr 17 to 31 Dec 17	3354.7	1895.1	822.4	£131.58	258.8	£41.40
T-29	Moixa	1 Apr 17 to 31 Dec 17	2919.4	1212.7	766.0	£122.55	153.0	£24.49
T-39	Moixa	1 Apr 17 to 31 Dec 17	3535.9	1549.4	537.7	£86.03	257.3	£41.16
	Moixa	Maximum	3725.4	1895.1	822.4	£131.58	273.1	£43.70
	Moixa	Minimum	1500.0	1212.7	350.5	£56.07	153.0	£24.49
	Moixa	Average	2901.4	1555.8	623.1	£99.70	237.8	£38.04
T-21	sonnen	1 Apr 17 to 31 Dec 17	4422.1	1725.3	1000.0	£159.99	361.9	£57.90
T-25	sonnen	7 Apr 17 to 31 Dec 17	2845.1	1749.8	1172.0	£187.53	335.6	£53.69

Table 3.78 Comparison of the financial benefits from sonnen and Moixa battery-solar installations using a cost of 16p/kWh for electricity

3.6 Growatt SP2000 controller and GBLI 5001 battery

Installation and operational issues

Technical Reference Number	Growatt controller	Growatt battery	Solar PV array	Inverter model
T-27	SP2000	GBLI 5001	1.62kW	SolaX MINI1500
T-28	SP2000	GBLI 5001	3.24kW	SolaX SL-TL3300T
U-01	SP2000	GBLI 5001	1.075kW	Mastervolt XS2000

Table 3.79 Growatt battery – solar installations

The Growatt battery system is DC coupled and is fitted between the solar panels and the inverter (figure 3.1). This contrasts to the Moixa and sonnen battery systems which are both AC coupled. The SP2000 controller can provide a discharge power of up to 2000W. The GBLI battery is rated at 4.875kWh, but in practice the usable output is 3.67kWh once the maximum 80% depth of discharge and conversion efficiency of the SP2000 unit are taken into account.

The Growatt batteries on this project were installed in September 2016 (tables 2.15 and 3.79). A WiFi dongle was fitted in October 2017 on the SP2000 units to allow monitoring of the system performance of systems T-27 and T-28.

The data points every 5 minutes included charge power (W), discharge power (W), solar PV output (W) and total charge and discharge on the day and since installation (kWh) , There were a number of installation and operational issues with the systems. They are summarised below:

Household T-27

- The contractor fitted the DC input to the SP2000 controller with reversed polarity during installation.
- Once the monitoring was fitted on 12 Oct 2017, it was discovered that the battery had not been discharging.
- Growatt carried out a service visit on 15 Nov 2017 and determined that the inverter was undersized for the output of the SP2000 battery controller on discharge. It was necessary to reduce the output of the controller to enable the inverter to work on discharge. This was done by changing the settings to effectively turn the SP2000 controller into a SP1000 controller, which has a maximum output of 1000W.
- The battery was operational from 15 Nov 17 through to May 2018 with the only a major gap being a few days in February 2018.

Household T-28

- The battery was initially installed in the hallway on the ground floor near the utility meter. The SP2000 controller was installed in the loft next to the inverter for the PV system. There was no communication cable between the battery and the controller. The DC cables were undersized for the cable run that went from the ground floor to the attic of a 3-storey house. The battery was later reinstalled in the loft with the SP2000 controller.
- The WiFi dongle was fitted on 12 Oct 2017 and monitoring data was available from that date.
- The battery was offline between 11 Dec 2017 and 31 Jan 2018. This was due to electrical works being carried out at the property and the supply being turned off. When the AC supply to a property is lost due to power outage or extended electrical works the SP2000 controller is off. The battery and the SP2000 controller are normally constantly communicating. If this connection is lost for more than 15 minutes, the battery assumes there is an issue and shuts down. When the the power resumed, the battery did not automatically come back on and it was necessary to press a 'wake-up' button on the side of the battery for the system to start up again.[41] The residents were unaware this was an issue and the problem was addressed on a service visit from Growatt.
- There were other periods where the monitoring was offline:
  - 27-30 Oct 17, 3-22 Nov 17, 3- Feb 18 and 24-28 Apr 18
- There was no data recorded at 5-minute intervals during these shorter periods offline, however it appeared the battery system may have been operating. In most cases there was an increase in the total charge, discharge and PV generation between the gaps in the data.

Household U-01

- Originally there were 3 Growatt battery systems installed and a total of 41 batteries on the project. This battery system never worked and had to be removed.
- Household U-01 was recruited as a potential household for an installation. The contractors were supposed to initally carry out surveys to determine whether the site was suitable and recommend a location for the battery prior to installations. Rather than conducting an in-depth survey and system design, a battery was installed on the first visit.
- The site had a pre-existing 1.075kW solar PV system and after the installation neither the battery or the solar PV system worked. The installers returned to bypass the battery to get the solar PV system working again. The resident later requested that the battery was removed.

Assessment of performance of the Growatt battery systems

There were 2 operating Growatt battery systems and these only had a short period of monitoring between October 2017 and May 2018. This covered the winter period with little solar generation and there were also gaps in the data. Due to this only limited analysis of the system performance was possible. The Growatt battery system recorded values for accumulated battery charge and discharge as well as solar PV generation. These values were used in the following analysis along with those calculated directly from the data recorded at 5-minute intervals. This data was also compared with daily smart meter data from solar PV generation meters and an electricity meter.

[41] Personal communication from Neil Clayton, Technical Services, Growatt New Energy Technology Ltd, UK (9 March 2017)

Household T-27

The WiFi dongle to enable monitoring was fitted to the Growatt system on 12 Oct 17 and this revealed that the battery was unable to discharge. A service visit by Growatt on 15 Nov 17 de-rated the SP2000 controller in order to effectively become a SP1000 controller. The maximum charge and discharge of the unit was therefore reduced to 1000W. Data showing the battery system in operation was available from 16 Nov 17 through to 31 May 18.

The solar PV system was a 1.62kW array on a pitched roof facing 30° west of south. On 16 Nov 17, the Growatt battery system had recorded at total of 1483.1kWh of solar PV generation since the system was installed in September 2016, compared to 1369.9kWh with the smart generation meter. Due to the incompatibility of the SP2000 controller with the SolaX mini inverter, the Growatt system recorded that the battery had only charged 95.1kWh and discharged 3.7kWh.

Following the alterations to the SP2000 controller, the total battery charge recorded by the Growatt system had increased to 274.1kWh on 31 May 18 and the battery discharge had increased to 111.8kWh. This represents a battery discharge of 108.1kWh and battery charge of 179kWh in the period between 16 Nov 17 and 31 May 18. The battery round trip efficiency was 60.4% over this period. The Growatt system showed the accumulated solar PV generation as 2133kWh on 31 May 18 compared to 1884.2kWh recorded by the smart generation meter. The difference between the solar PV generation recorded by the Growatt system and the smart generation meter may be due to errors resulting from the current clamp on the cable to the generation meter. It is possible that there are also similar errors in the readings for battery charge and discharge.

Table 3.80 shows monthly figures determined from the Growatt data and the smart generation meter. The months are incomplete in November since the system was only operating correctly from 15 Nov 17 and in February where there was a gap of several days in the 5-minute interval data at the end of the month. The performance in kWh/day is shown in table 3.81, which allows direct comparison between other months and other systems.

For household T-27, the values of battery discharge, charge and solar PV production calculated directly from the 5-minute interval data were comparable to those recorded by the Growatt battery system. There were however significant differences between the solar PV generation recorded by the Growatt system and the smart generation meter as discussed earlier.

	Calculations using 5 minute interval data				Recorded by Growatt battery system			
Period	Battery discharge (kWh)	Battery charge (kWh)	Solar PV production (kWh)	Grid import (kWh)	Battery discharge (kWh)	Battery charge (kWh)	Solar PV production (kWh)	Smart PV generation meter (kWh)
16 Nov 17 to 30 Nov 17	8.72	11.47	35.51	139.26	8.7	11.3	34.3	26
1 Dec 17 to 31 Dec 17	8.25	14.05	48.64	314.36	8.2	13.8	45.5	32.5
1 Jan 18 to 31 Jan 18	9.33	15.98	51.94	276.8	9.2	15.8	49	35.3
1 Feb 18 to 25 Feb 18	20.61	32.87	83.71	183.89	20.9	32.7	81.1	62.9
1 Mar 18 to 31 Mar 18	17.56	29.42	92.9	206.09	17.4	29.3	90.1	67.9
1 Apr 18 to 30 Apr 18	19.21	31.81	130.22	173.57	19.1	31.2	127.4	99.7
1 May 18 to 31 May 18	22.89	42.14	217.57	129.22	22.9	42.4	214.2	181.1

Table 3.80 Performance (kWh) recorded by the Growatt battery – solar system at Household T-27

Period	Calculations using 5 minute interval data				Recorded by Growatt battery system			Smart PV generation meter (kWh/day)
	Battery discharge (kWh/day)	Battery charge (kWh/day)	Solar PV production (kWh/day)	Grid import (kWh/day)	Battery discharge (kWh/day)	Battery charge (kWh/day)	Solar PV production (kWh/day)	
16 Nov 17 to 30 Nov 17	0.58	0.76	2.37	9.28	0.58	0.75	2.29	1.73
1 Dec 17 to 31 Dec 17	0.27	0.45	1.57	10.14	0.26	0.45	1.47	1.05
1 Jan 18 to 31 Jan 18	0.30	0.52	1.68	8.93	0.30	0.51	1.58	1.14
1 Feb 18 to 25 Feb 18	0.82	1.31	3.35	7.36	0.84	1.31	3.24	2.52
1 Mar 18 to 31 Mar 18	0.57	0.95	3.00	6.65	0.56	0.95	2.91	2.19
1 Apr 18 to 30 Apr 18	0.64	1.06	4.34	5.79	0.64	1.04	4.25	3.32
1 May 18 to 31 May 18	0.74	1.36	7.02	4.17	0.74	1.37	6.91	5.84

Table 3.81 Performance (kWh/day) recorded by the Growatt battery – solar system at Household T-27

Normally the solar PV generation is higher in March than in February, however for household T-27, this was not the case in 2018. It can be seen that both the Growatt system and the smart generation meter recorded lower PV generation per day in March than in February. PV generation was higher in April than March and February. Suprisingly, the battery discharge per day was higher in February than in March, April or May.

The battery discharge for household T-27 appeared to be higher in Dec 2017, Jan 2018 and Feb 2018 than for the Moixa and sonnen batteries. However, with the solar PV production recorded by the Growatt battery system being 18 to 40% higher than the values recorded by the smart generation meter, it is possible that the amount of the battery charge and discharge recorded by the system may also have been larger than the actual amounts.

Figure 3.82 shows a plot of discharge power during 27 Apr 2018. Although the de-rated SP2000 controller could charge and discharge at up to 1000W, it frequently discharged at a lower rate which was dependent on the household electricity demand. In this case there was a peak in demand from about 19:15 and the battery began discharging about about 400W, reaching a peak of 535W at 19:39. Raw data from the Growatt portal for the period of the peak is shown in table 3.83, with the discharge power shown as pDischarge1(W) and the grid import as pacToUser(W). It can be seen that some power from the battery is exported to the grid during this period (pacToGrid(W)).

Figure 3.82 Plot of battery discharge against time on 27 Apr 2018 for household T-27

Time	Status	pCharge1(W)	pDischarge1(W)	Ppv1(W)	pacToUser(W)	pacToGrid(W)
2018-04-27 19:14:13	Discharge	0	0	12	409.2	0
2018-04-27 19:19:12	Discharge	0	411.3	12.6	11.1	0
2018-04-27 19:24:12	Discharge	0	408.9	12.5	0	6
2018-04-27 19:29:13	Discharge	0	408.1	14.3	0	23.7
2018-04-27 19:34:14	Discharge	0	425.6	11.8	0	3.9
2018-04-27 19:39:14	Discharge	0	534.9	9.3	187	0
2018-04-27 19:44:14	Discharge	0	403	6.2	6	0
2018-04-27 19:49:14	Discharge	0	433.6	4.8	0	9.7
2018-04-27 19:54:14	Discharge	0	432	2.9	34.8	0
2018-04-27 19:59:15	Discharge	0	483.2	2	8.3	0
2018-04-27 20:04:16	Discharge	0	484.2	1.5	0	14.6
2018-04-27 20:09:16	Discharge	0	553.5	1.3	10.7	0
2018-04-27 20:14:16	Discharge	0	406.8	1.3	6	0
2018-04-27 20:19:16	Discharge	0	453	1.2	0	14.2
2018-04-27 20:24:16	Discharge	0	389.4	1.2	0	6.6
2018-04-27 20:29:16	Discharge	0	356.8	1.2	0	9.1
2018-04-27 20:34:17	Discharge	0	356.6	1.2	14.7	0
2018-04-27 20:39:17	Discharge	0	355.9	1.2	0	0.5
2018-04-27 20:44:18	Discharge	0	355.8	1.3	22.6	0
2018-04-27 20:49:17	Discharge	0	406.5	1.2	0	64
2018-04-27 20:54:17	Discharge	0	494.7	1.2	0	0.9
2018-04-27 20:59:17	Discharge	0	300.2	1.3	24.6	0
2018-04-27 21:04:18	Operating	0	0	1.1	108.3	0

Table 3.83 Sample of raw data from the Growatt portal for household T-27 on the evening of 27 Apr 2018

Table 3.84 shows further raw data relating to the period in the early morning in figure 3.83, when the Growatt battery system was discharging about 200W. It is apparent that as the grid import reached about 100W, it encouraged the battery to start discharging. The preferred output was about 200W and so with a demand just above 100W, almost 100W was also exported to the grid from the battery. This indicates that not all the battery discharge recorded was used in the home.

Time	Status	pCharge1(W)	pDischarge1(W)	Ppv1(W)	pacToUser(W)	pacToGrid(W)
2018-04-26 23:52:40	Operating	0	0	0.6	90.9	0
2018-04-26 23:57:41	Discharge	0	197.5	0.7	0	101.2
2018-04-27 00:02:41	Discharge	0	196.3	0.7	0	97.9
2018-04-27 00:07:41	Discharge	0	162.2	0.6	0	80.8
2018-04-27 00:12:41	Discharge	0	1.7	0.9	134.6	0
2018-04-27 00:17:42	Discharge	0	193.3	0.8	0	82.8
2018-04-27 00:22:42	Discharge	0	197.2	0.7	0	102.1
2018-04-27 00:27:42	Discharge	0	195.7	0.7	0	102.5
2018-04-27 00:32:42	Discharge	0	193	0.7	0	98.3
2018-04-27 00:37:43	Discharge	0	196.1	0.7	0	92.8
2018-04-27 00:42:43	Operating	0	0	0.6	89.4	0
2018-04-27 00:47:43	Operating	0	0	0.5	89.9	0
2018-04-27 00:52:44	Operating	0	0	0.6	89.7	0
2018-04-27 00:57:44	Discharge	0	1.8	0.8	92.9	0
2018-04-27 01:02:46	Discharge	0	195.2	0.6	0	72.7
2018-04-27 01:07:46	Discharge	0	197.4	0.6	0	72.7
2018-04-27 01:12:45	Discharge	0	195.3	0.6	0	71
2018-04-27 01:17:46	Discharge	0	197	0.5	0	72
2018-04-27 01:22:46	Discharge	0	197.8	0.5	0	71.7
2018-04-27 01:27:46	Discharge	0	197.4	0.5	0	70.6
2018-04-27 01:32:48	Discharge	0	196	0.6	0	55.6

Table 3.84 Sample of raw data from the Growatt portal for household T-27 on the early morning of 27 Apr 2018

Household T-28

The PV system for household T-28 had a 3.24kW array on a London Valley roof. Half of the array faced 30° west of south, while the other half faced 30° east of north (and generated less as a result). At the start of monitoring on 12 Oct 17, the Growatt battery system had recorded a cumulative total of 1439.3kWh of solar PV generation and 304.1kWh of battery charge and 280.8kWh of battery discharge since installation in September 2016. The smart generation meter reading for the PV system was 1991kWh on the same date. There is clearly a significant difference between the 2 values recorded for the solar PV generation. This may at least partly be explained by periods when the battery system was not operational. The battery had to be moved from the hallway into the loft to get the system working for example. Although battery system at household T-27 only started discharging following an alteration to the controller on 15 Nov 17, the battery for T-28 had recorded a significant discharge during the previous year. For comparison the battery discharge for household T-21 with a sonnen battery was 407kWh over a 12 month period. With household T-28, it is unclear though how much of the previous year the system was operational.

After the start of online monitoring for the Growatt system for household T-28 there were long periods when the battery system was offline. At least some of these were a result of electrical work at the house and the AC supply being turned off for a sufficiently long period to put the battery into hibernation. There were long periods offline in October, November and December through to the end of January. There were also smaller data gaps in February and April which meant a full month of data was not recorded. As a result data on the performance for the Growatt battery at household T-28 was limited, with analysis possible from early February to late May 2018. Results from this are shown in table 3.85.

Period	Calculations using 5 minute interval data				Recorded by Growatt battery system				
	Battery discharge (kWh)	Battery charge (kWh)	Solar PV production (kWh)	Grid import (kWh)	Battery discharge (kWh)	Battery charge (kWh)	Solar PV production (kWh)	Smart PV generation meter (kWh)	Smart electricity meter (kWh)
7 Feb 18 to 28 Feb 18	9.84	15.06	47.90	196.80	11.00	12.40	45.60	50	222.7
1 Mar 18 to 31 Mar 18	18.32	26.35	76.17	268.57	20.50	22.30	73.50	98.1	297.6
1 Apr 18 to 23 Apr 18	22.38	33.27	102.40	114.73	25.20	29.50	100.40	141.9	131.8
1 May 18 to 31 May 18	41.22	58.00	221.86	102.57	46.70	51.80	219.30	341.1	

Table 3.85 Performance (kWh) recorded by the Growatt battery – solar system at Household T-28

Period	Calculations using 5 minute interval data				Recorded by Growatt battery system				
	Battery discharge (kWh/day)	Battery charge (kWh/day)	Solar PV production (kWh/day)	Grid import (kWh/day)	Battery discharge (kWh/day)	Battery charge (kWh/day)	Solar PV production (kWh/day)	Smart PV generation meter (kWh/day)	Smart electricity meter (kWh/day)
7 Feb 18 to 28 Feb 18	0.45	0.68	2.18	8.95	0.50	0.56	2.07	2.27	10.12
1 Mar 18 to 31 Mar 18	0.59	0.85	2.46	8.66	0.66	0.72	2.37	3.16	9.6
1 Apr 18 to 23 Apr 18	0.97	1.45	4.45	4.99	1.10	1.28	4.37	6.17	5.73
1 May 18 to 31 May 18	1.33	1.87	7.16	3.31	1.51	1.67	7.07	11.00	

Table 3.86 Performance (kWh/day) recorded by the Growatt battery – solar system at Household T-28

It can be seen that the values for solar PV generation calculated from the raw data were comparable to that recorded by the Growatt battery system. However, there were much larger differences between the battery discharge and charge recorded by the 2 methods for household T-28. For comparison, there was little difference in the values of battery discharge and charge for household T-27 calculated from the raw data and provided from the Growatt system.

The battery round-trip efficiency values using the 5 minute-interval data ranged from 65.3% to 71.1% between February and May 2018 for T-28. The round-trip efficiencies using the data recorded from the Growatt system were higher, ranging from 85.4% to 91.9%. For the same months for household T-27, the round trip efficiencies were 54.3.7% to 62.7% using the 5-minute interval data and 54.0% to 63.9% using the values recorded by the Growatt system. This suggests that the charge and discharge recorded by the Growatt system for household T-28 was likely to be inaccurate.

Table 3.86 shows the battery system performance data in kWh/day for household T-28. Comparing the 5-minute interval data with that for household T-27, it can be seen that T-27 performed better in February with a discharge of 0.82kWh/day, although it should be noted that the periods in the month that were monitored were different and so the difference in performance could at least partly be attributed to weather variation. During March, the battery discharge for T-27 was comparible with 0.57kWh/day, while in April and May it performed less well with a battery discharges of 0.64kWh/day and 0.74kWh/day. Solar PV production at household T-27 was higher in February, but lower in March, April and May. The poorer performance of the PV array for T-28 in February was probably due to the orientation and shading on the array at that time of year.

Comparing with another battery system, household T-21 with a sonnen battery discharged 0.49kWh/day in February, 0.46kWh/day in March and 1.04kWh/day in April 2018. If the values determined from the 5-minute interval data are more accurate, this suggests the Growatt battery for household T-28 performed better in March 2018, but not February and April.

There was again a significant difference between the solar PV production measured by the Growatt system and the smart generation meter. This was particularly pronounced in May, where the smart generation meter reading was 53.7% higher than the PV generation calculated from the Growatt system data. Smart electricity meter data was available for household T-28. The values of grid import calculated from the 5-minute interval data ranged from 87% to 90.2% of the value of the smart electricity meter data for the periods studied. The values calculated were closer between the data from the Growatt system and the smart utility meter than for the smart generation meter.

Figure 3.87 shows a plot of battery discharge for the Growatt systems at households T-27 and T-28. During periods of high household consumption (table 3.88), household T-28 was able to discharge up to 2000W. On some days there was greater discharge from battery T-27 and on others more from T-28, as in figure 3.87. The discharge for T-27 tended to be over a longer period when the output was lower.

The raw 5-minute data from the Growatt data portal can be seen for household T-28 on the evening of 21 Mar 2018. The battery discharge in watts is pDischarge1(W), the grid import is pacToUser(W) and the grid export is pacToGrid(W). The period shown in the table included the period with a high battery power output.

In the final interview the resident noted that they normally cook with the oven every evening from 18:30 and they use the washing machine and tumble dryer on a daily basis in the evening. This is likely to explain the high household consumption in the evening. At 21:01, the battery was discharging 1981W and there was also a grid import of 2566W.

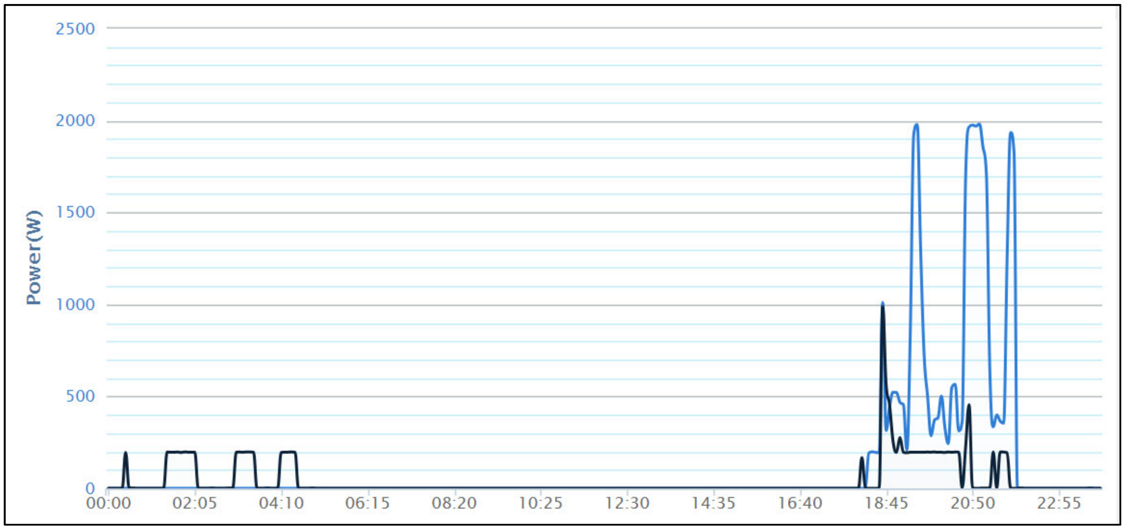

Figure 3.87 Plot of battery discharge against time on 21 Mar 2018 for households T-27 (black) and T-28 (blue)

Time	Status	pCharge1(W)	pDischarge1(W)	Ppv1(W)	pacToUser(W)	pacToGrid(W)
2018-03-21 19:31:02	Discharge	0	1978.1	0.1	331.9	0
2018-03-21 19:36:02	Discharge	0	1290.7	0	0	905.5
2018-03-21 19:41:04	Discharge	0	724.9	0	1647.9	0
2018-03-21 19:46:02	Discharge	0	502.8	0	0	181.8
2018-03-21 19:51:02	Discharge	0	285.7	0	0	0
2018-03-21 19:56:05	Discharge	0	371.4	0	0	63
2018-03-21 20:01:04	Discharge	0	383.1	0	68.1	0
2018-03-21 20:06:04	Discharge	0	501.5	0	0	126
2018-03-21 20:11:06	Discharge	0	331.7	0	75.3	0
2018-03-21 20:16:05	Discharge	0	242.8	0	0	0
2018-03-21 20:21:04	Discharge	0	548.1	0	52.1	0
2018-03-21 20:26:07	Discharge	0	566.4	0	0	227.4
2018-03-21 20:31:06	Discharge	0	312.4	0	0	0
2018-03-21 20:36:06	Discharge	0	362.6	0	2110	0
2018-03-21 20:41:07	Discharge	0	1692.3	0	839.2	0
2018-03-21 20:46:06	Discharge	0	1964.7	0	2379.8	0
2018-03-21 20:51:06	Discharge	0	1975.3	0	2369.4	0
2018-03-21 20:56:09	Discharge	0	1969.9	0	2667.6	0
2018-03-21 21:01:08	Discharge	0	1980.9	0	2565.7	0
2018-03-21 21:06:08	Discharge	0	1859.5	0	663.3	0
2018-03-21 21:11:09	Discharge	0	1712.8	0	0	1123.6
2018-03-21 21:16:08	Discharge	0	645.4	0.1	0	0
2018-03-21 21:21:08	Discharge	0	333.9	0.1	0	83
2018-03-21 21:26:10	Discharge	0	399.8	0.1	57.1	0
2018-03-21 21:31:09	Discharge	0	365.8	0.1	0	127.5
2018-03-21 21:36:09	Discharge	0	353.4	0.1	60.6	0
2018-03-21 21:41:11	Discharge	0	1248.2	0.1	1342.8	0
2018-03-21 21:46:09	Discharge	0	1935.1	0.1	0	1373.5

Table 3.88 Sample of raw data from the Growatt portal for household T-28 on the evening of 21 Mar 2018

The household demand while remaining high, still varied over the evening. This led to decreases/increases in the battery discharge and grid import. However, when these changes occurred, there was a lag in the response of the battery system and some power was exported to the grid. This can be seen in the period shortly after 21:00. At 21:06, the battery discharge was still at 1859.5W, but the grid import had decreased to 663.3W. 5 minutes later at 21:11, the grid import had decreased to 0, but the battery discharge was still at 1712.8W and this led to 1123.6W being exported to the grid. By 21:16, the battery system had responded to the decrease in demand and the discharge had decreased to 645.4W, with a grid import of 0 and a grid export of 0. This illustrates that battery power can be exported to the grid while responding to changes in household demand. The example for household T-27 showed that there can also be grid exports when household demand is steady and less than 200W.

Summary

Overall there was limited performance data for the Growatt battery systems due to monitoring being available only from October 2017 and additional issues reducing the period for monitoring further. This meant there was only monitoring over the winter period. No data was available to compare with the summer performance of the Moixa and sonnen batteries.

The significant differences between the solar PV generation recorded by the Growatt battery system and the smart PV generation meters was also a concern. It was not possible to confidently compare the performance of the Growatt system with the Moixa and sonnen and whether the DC coupled system performed better than the AC coupled systems. The limited data available suggested that Growatt systems may have performed at least as well if not better than the Moixa and sonnen systems in winter, but further work would be needed to verify this.

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 40 batteries in households with solar PV in the London Boroughs of Camden, Islington and Waltham Forest and:

- Assess the performance of the 3 different battery technologies used:
    - Moixa Maslow V3, sonnenBatterie eco 8.2 and Growatt SP2000 controller with GBLI 5000 battery
- Assess levels of resident satisfaction with the battery and solar technologies
- Determine the battery performance over a year 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

Resident satisfaction

- Out of the 10 households interviewed, all agreed or strongly agreed that the battery-solar system did not need any active input to work and the majority (80%) found it easy to use.
- However, 5 households interviewed felt they did not know enough about how the system worked. 7 of the households did not know how to maximise their savings from the solar

panels and none of the 10 households felt they knew how to maximise savings from the battery – this highlights the importance of advice provision, follow-up support and appropriate information materials.

- The perception of savings from the battery solar systems was not clear due to rising prices and some households paying by direct debit. 4 out of 9 households felt there had been a reduction in their energy bills while 6 of the 9 believed they had been saving energy in the home.

Installation and Reliability Issues

- Reliability of the battery solar systems was a problem with 6 of the 10 households interviewed saying they had experienced reliability issues or breakdowns.
- Although solar PV is sometimes regarded as a 'fit and forget technology', there were a number of problems with these PV installations. Several solar PV systems had issues which led to loss of FIT income for the council and electricity savings for the household.
- The maximum PV generation for the installations on London Valley roofs was 2143kWh in 2017. An installation which had multiple RCD trips, however generated only 500.3kWh in comparison. Another installation developed a fault with the inverter or solar PV array which led to reduced generation with a figure of only 768kWh in 2017. A further installation with a large PV array on a London Valley roof which was not studied in-depth generated 908kWh in 2017.
- The battery systems require an internet connection for monitoring, system updates and to maintain effective operation. Many manufacturers like Moixa and sonnen require a consistent internet connection to maintain the warranty on the battery.
- The Moixa and sonnen batteries were typically connected to the household WiFi router using power-line adapters/TP links while the Growatt batteries used a WiFi dongle. There were issues with the reliability of the internet connection to a number of the batteries which affected the monitoring.
- Among the 32 Moixa battery installations, 8 were connected to the internet for less than 150 days between September 2016 and December 2017. Among these were households that did not have the internet and the 3G communication in the battery proved ineffective, while another household refused to allow the battery to have access to their WiFi. Tripping of the RCD protection for the solar PV systems also led to some of the Moixa batteries going offline.
- 5 out of the 6 installations with sonnen batteries had extended periods offline due to problems with the PV systems or TP Links. This limited the data that was available for analysis.
- There were installation problems with the Growatt battery systems. The SP2000 controller was selected for 2 installations where the inverters were too small for the system to operate correctly. Out of these, 1 system never worked and was removed. The other had the SP2000 controller de-rated to a SP1000 controller to allow the battery to discharge. On another installation, the controller was fitted in the loft and the battery on the ground floor with no communication cable and undersized DC cables. The battery was later reinstalled with the controller and inverter in the loft.

Moixa Maslow V3 batteries

- Out of the 32 Moixa Maslow batteries that were installed, 15 were online for a sufficient period to allow an assessment of the performance between March and December 2017.
- The battery discharge was typically in the range 120kWh to 280kWh. Some systems performed less well. This included household T-30 which had a smaller 1.36kW PV system and a high annual household electricity consumption of 8359kWh. This meant there was little excess solar generation to charge the battery and the discharge over the period was only 31kWh.
- Only 3 of the Moixa Maslow batteries were the larger 3kWh model. Out of these, just a single battery had an extended period online which allowed a long-term assessment of the performance. Here the battery discharge was just 36kWh between March and December. The reason for the poorer performance was not clear. Another household with a 3kWh battery noted their electricity bill had become significantly in credit following the battery-solar installation. However, this battery was not online during the summer months and so it was not possible to assess the performance.
- The best performing battery was household T-03 where the discharge between March and December was 290kWh. Here the PV system generated 1786kWh in 2017 while the grid consumption was only 980kWh between 31 Mar 17 and 23 Dec 17. The relatively low day time consumption and the larger PV array meant there was frequently excess solar generation which allowed the battery to regularly charge. The battery was then able to supply a significant proportion of the demand in the evening.
- The Maslow battery has a normal start-up threshold for the battery inverter of 250W. In most cases when residents are at home using appliances, this is exceeded and the battery discharges in the evening. When residents are away, such as on holiday, only base-load appliances like fridges are normally left on and the evening household demand may be consistently below 150W. In this case, the appliances would be powered by the solar PV array during the day, but the consumption is too low for the Maslow battery to start discharging during the evening.
- 8 of the better performing Moixa Maslow battery solar systems were assessed to calculate the financial benefit of the solar PV and the battery systems to the households. For the period 9 Mar 2017 to 31 Dec 2017, the households saved up to £141.60 from the solar PV systems. The batteries saved between £18.56 and £46.39 during the same period.

sonnenBatterie eco 8.2

- There were 6 sonnenBatterie eco 8.2 systems installed in Camden.
- The battery in household T-21 was the only one which was online throughout 2017 and discharged 406.6kWh over the year. The annual grid consumption for the household was 4700.2kWh and the generation from the solar PV system was 1957.5kWh.
- 5 of the 6 sonnen systems were online during March 2017. The battery discharge ranged from 28.87kWh to 37.0kWh over the month. For household T-21, the battery discharge in March 2017 was 31.3kWh.
- The battery inverter on the sonnen system can operate with an input as low as 30W. This means that the battery can charge and discharge at lower powers than the Moixa battery. This is likely to increase the overall level of battery discharge. However, the inverter is less efficient when it operates at low power and this affects the battery round trip efficiency.
- In January 2017 when there was limited solar generation, the battery round trip efficiency

(ratio of battery discharge to battery charge) was only 13.4% for household T-21, but it rose to 64.9% in August 2017.

- Household T-23 had no solar PV generation for extended periods due to trips of the RCD protection. However, the battery was online during this period which provided the opportunity to study the power requirements of the battery for an extended period without solar generation. There was typically a baseload consumption of 15W by the battery and over a 24-hour period there were 10 short bursts of about 200W for just over 7 minutes each. This indicated that the battery consumed about 0.59kWh per day to power the battery and maintain its charge level during extended periods without charging from the solar PV. This is likely to have contributed to the low round trip efficiency in winter.
- During the period when the solar PV system had tripped, the household was no longer saving money from the free daytime electricity from the solar and the battery system was costing them money to run without the solar PV.
- For household T-21 which was online throughout 2017, the financial benefit over the year from the sonnen battery system was £65.06. The electricity savings from the solar PV system excluding the discharge from the battery and the export to the grid was £188.35
- Between April and December 2017, the sonnen battery at household T-21 discharged 361.9kWh with a financial benefit of £57.90. The best performing Moixa battery discharged 274.1kWh, saving £43.70 over the same period.

Growatt SP2000 and GBLI 5001

- All the Growatt battery systems had installation problems. It is likely the contractors had little installation experience with the Growatt battery system which is DC instead of AC coupled and has a battery and separate controller instead of just a single unit.
- WiFi dongles were fitted to the SP2000 controllers in mid-October 2017 to allow monitoring of the systems. This revealed that 1 of the battery systems had not been discharging since installation.
- The period for monitoring was limited due to the WiFi dongles being fitted late in the project, resolving the battery discharge problem and household electrical work causing a battery to go offline.
- The battery discharge recorded for household T-27 ranged from 0.27kWh/day in December 2017 to 0.82kWh/day in February 2018, which was higher than for the Moixa and sonnen batteries.
- There was a significant difference between the amount of solar PV generation recorded by the Growatt battery system and the smart generation meters. Also, for household T-28, there was a difference in the values of battery charge and discharge calculated from the raw data and recorded by the system. It is therefore possible that the accuracy of the data recorded by the Growatt system may not be high.
- When the battery was discharging, some of this was exported to the grid during periods when the household consumption changed. Power was also discharged to the grid during periods when the household consumption was 100-200W. This indicates that not all the battery discharge was used by the household.

4.2 Recommendations for potential future installations

Solar PV is a very effective technology for reducing the electricity bills of residents and it also increases SAP ratings. Social landlords considering a significant number of installations should carefully consider how to successfully deliver such a project. Choosing an installer primarily based on price with less consideration for quality can lead to greater long-term costs. Problems can occur when choosing large companies who subcontract the project at least once. Liaison between partners becomes more complex and costs are taken out by each partner, which may lead to poorer quality components being used and less time available for surveys, design and installation. This might lead to maintenance problems in the future. It should be noted that some installers still drill through slate roofs despite it being against MCS guidelines.

When selecting a contractor, it would be sensible to consider experienced local renewable energy installers who have a good track record on larger contracts. As part of the tendering, they should show detailed examples of the quality of their work. Installers have less experience with battery storage and potential contractors should provide evidence of their experience with the technology. The installations should be neat with trunking and no hanging wires. Batteries should be fitted with separation distances required by the manufacturer to ensure adequate ventilation.

Complex roofs such as those with the London Valley design can suffer from shading. PV systems using optimisers rather than string inverters can overcome shading issues and provide better performance as well as data to confirm correct operation. These however require an internet connection.

When considering installing domestic batteries, it is important to assess whether there would be enough solar PV generation to charge the battery. Batteries at sites with small PV arrays and high household electricity consumption provide little benefit to the residents and are a waste of money.

New smart technologies including battery storage frequently require a continuous internet connection. They are required to ensure optimal performance of the battery, maintain the warranty and also provide information on the performance of the battery and the solar system. In some cases, they can provide alerts when a fault has developed.

Connections such as 3G mobile or WiFi are usually inadequate. TP Links/ powerline adapters are more successful, but still can have problems. The most reliable connection is a hard-wired connection, and this should be used wherever possible. However, tenants may be unwilling to have wiring fitted between the battery location and their WiFi router due to an unsightly cable run.

In some cases, households do not have broadband. In others, they may be unwilling to allow the battery to use their internet connection. Social landlords must check whether there is broadband, and the residents would be willing to have a battery connected to it before considering each installation. They should not just assume they can fit solar PV and batteries to every house in a street.

The battery typically has a current (CT) clamp fitted on the household meter tail and a second clamp measuring the generation of the solar PV. These should be calibrated by taking meter readings at installation and again after a couple weeks. It is possible to do this without disturbing the tenant if the manufacturer is provided with smart PV generation meter data. The data measured by the battery will be more accurate still if small meters are used instead of current clamps. As well as improved accuracy, this can avoid problems from tenants or maintenance staff moving the current clamps at a later date. Battery manufacturers should design their systems so that performance data is stored in memory for at least a month, which can if necessary be uploaded to the internet following a period offline.

As social landlords roll out technologies like solar PV and battery storage, it is important that they have an energy manager able to regularly check performance of the systems to ensure that faults have not developed. When faults do develop, it is important to be able to react quickly and avoid loss of feed-in tariff income and savings for residents. Since the number of systems is likely to be large, monitoring battery portals or use of wireless generation meters with performance alerts are likely to save time.

Camden Council are exploring ongoing monitoring and maintenance options for both the panels and the battery storage to be delivered by a specialist contractor. This aims to address any issues with connectivity with the equipment to minimise downtime and maximise the benefit of renewable energy to residents. They are also investigating whether alternative communication routes may be viable for the battery technology

4.3 Impact on fuel poverty

A solar PV array can significantly reduce daytime electricity consumption between March and October. However, significant amounts of PV generation can be exported to the grid during the summer months and provides no benefit to the household. A battery can charge using electricity which would otherwise be exported for use later in the evening, reducing electricity purchased from the supplier, and providing direct benefit to the household. This is particularly beneficial for households who are out during the day where the PV generation would otherwise mainly power baseload appliances such as fridges, and with some systems, that base load may not be high enough to trigger a discharge from the battery.

Savings from the solar PV systems in the study were typically in the range £100 to £190 per year. The batteries installed in the study had a more limited impact with a sonnen battery saving a household £65 in 2017. The best performing Moixa battery saved the resident £46 between March and December 2017. Savings from the batteries can be improved in future by use of batteries with a larger capacity and higher power outputs. However, a battery is of little benefit to residents if there is insufficient excess PV generation to charge it.

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 Moixa battery solar systems on this project.

The site with Moixa battery in 2017 which received the highest percentage of the household consumption from the battery-solar system was T-35 with 39.5%. However, no data was recorded for January 2017. The next best was T-03 with 37.7%, but here the resident turned the WiFi router off at night, missing some consumption. Household T-12 received just over 33% of their household consumption from the battery solar system. Although values for the solar PV used was recorded over the full year, those for battery discharge were only recorded after 9 March. Over the period April to December 2017, the battery contributed 26.4% (£36.93) and the solar on its own, 73.6% (£103) to the overall savings.

Moixa have written an article about the benefits of a battery-solar systems and noted savings on energy bills up to £350 per year[42].

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
Moixa Maslow V3 2kWh	£2,000		£2,000	£48	41.7	•Cost of £2000+VAT includes installation •Battery discharge of 300kWh used based on maximum value of 290kWh recorded between March and December •No savings included from the Moixa Gridshare scheme •Electricity price of 16p/kWh which remains static
Moixa Maslow V3 2kWh with Gridshare	£2,000		£2,000	£98	20.4	•Cost of £2000+VAT includes installation •Battery discharge of 300kWh used based on maximum value of 290kWh recorded between March and December •Saving of £50 per year from Moixa Gridshare •Electricity price of 16p/kWh which remains static
sonnenBatterie eco 8.2 2kWh	£3,000	£300	£3,300	£65	50.7	•Battery discharge of 406.57kWh •No benefit from sonnenCommunity or other scheme •Electricity price of 16p/kWh which remains static

Table 4.1 Business case for 2016 generation Moixa and sonnen batteries systems installed in this study

The business case for installation of Moixa Maslow V3 and sonnenBatterie eco 8.2 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. Both manufacturers were planning to release new battery models at the time of writing.

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 with the technology installed in the study and current prices, the payback time is in excess of 40 years. The battery has a predicted lifespan of 20 years with an extendable 10-year guarantee. Based on the savings in the current study, there is no payback within the battery lifespan.

Moixa has developed Gridshare, which is an aggregation platform where battery owners can

[42] 'Will future homes come with a solar battery already installed?', Moixa, 14 May 2018 (Accessed 21 May 2018)

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. Battery owners can receive £50 per year and the system is used for only a few minutes a day with a likely low impact on savings from the system. If the financial benefit from Gridshare is included, the payback time reduces to 20.4 years, which is close to the battery lifespan.

The sonnenBatterie system has a larger battery capacity than the Moixa (2kWh compared to 1.6kWh usable capacity). A sonnenBatterie system discharged 407kWh in 2017 and this would lead to a payback time of about 50 years, which again is beyond the battery lifespan. sonnen has a peer-to-peer energy saving network called sonnenCommunity which can provide owners with additional income. Although this operates in Germany, it has not been launched in the UK. Were this available, it would reduce the system payback time in a similar manner to Moixa Gridshare.

The batteries studied in this trial are early models and the technology is rapidly developing. A major focus is looking at how to reduce payback times to make systems economic. 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 supplying 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 supply 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.
- Non-financial 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.

Appendix 1: Glossary of Terms

AC	*Alternating Current*
DC	*Direct Current*
DOD	*Depth of Discharge*
EPC	*Energy Performance Certificate*
HIP	*Health and innovation Programme*
LED	*Light Emitting Diode*
MCS	*Microgeneration Certification Scheme*
NEA	*National Energy Action – the National Fuel Poverty Charity*
PV	*Photovoltaic*
RCD	*Residual Current Device*
RECC	*Renewable Energy Consumer Code*
SAP	*Standard Assessment Procedure (for assessing home energy efficiency)*
SOC	*State of Charge*
TIF	*Technological Innovation Fund*
TP Link	*A brand of powerline network device which uses household electrical wiring to act as a wired data network*

Appendix 2: 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

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Action for Warm Homes