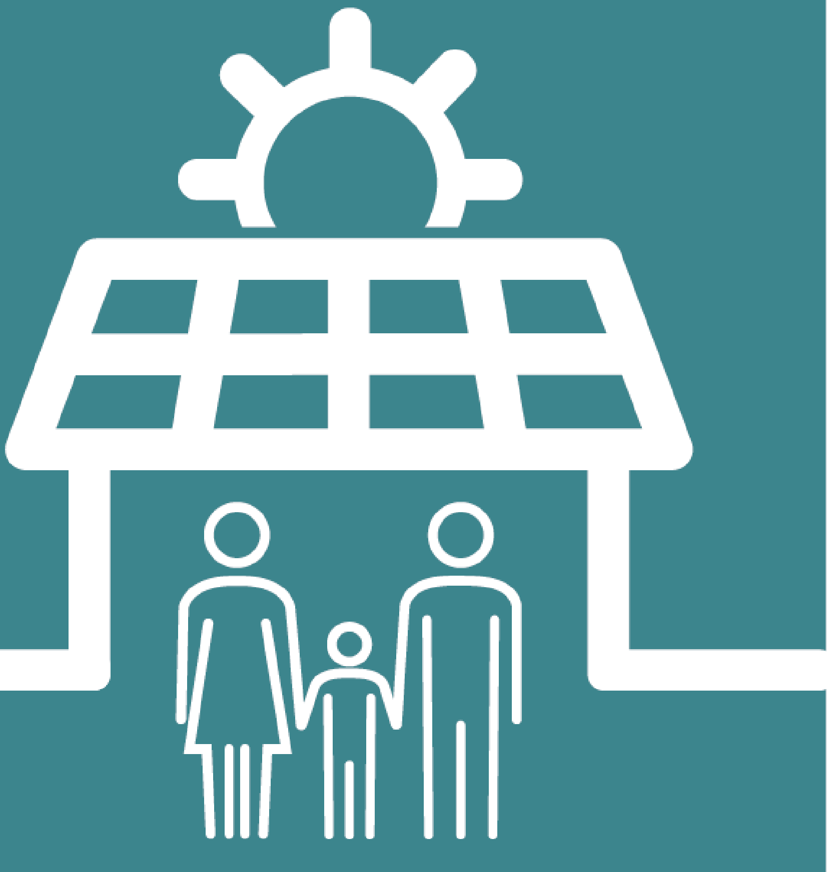
NEA

Action for Warm Homes



Increasing self-consumption of solar PV

Increasing self-consumption of solar PV

Monitors and solar immersion controllers

Paul Rogers and Michael Hamer

February 2023

Background

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

This project was carried out by the Innovation and Technical Evaluation team at NEA.

February 2023
National Energy Action
Level 6 (Elswick)
West One
Forth Banks
Newcastle upon Tyne
NE1 3PA
www.nea.org.uk

Acknowledgements

Funding for this project was provided by the Energy Industry Voluntary Redress Scheme

We would also like to thank our project partners:

Gentoo, London Borough of Camden, London Borough of Waltham Forest, Wakefield Council, WDH, Northampton Partnership Homes, North Devon Homes, Stockport Homes, Cannock Chase Council, Chase Community Solar (CCS), Energise Barnsley, Magna Housing

Action for Warm Homes

Table of contents

1. Overview

1.1. Increasing Self-Consumption of Solar PV project

'Increasing Self-Consumption of Solar PV' was a project funded by the Energy Industry Voluntary Redress scheme. The project had several different aspects to it:

- Development and distribution of advice materials
  - Over 7,000 copies of a new solar PV advice leaflet distributed to households with solar PV living in social housing
  - Production of a video explaining how solar PV systems work
  - Advice materials about solar PV on the NEA website
- Providing advice about solar PV
  - Telephone and email advice for households
  - Home advice visits
  - Advice clinics, presentations and webinars
  - An eLearning course on solar PV provided to front-line workers
- Installation of small measures to help households make better use of PV generation
  - Solar PV monitors
  - Smart plugs
  - Monitors with disaggregation of electricity consumption
  - Solar immersion controllers
- Assessment of the long-term performance of about 100 solar PV systems and investigating causes of faults
  - The long-term performance of 75 solar PV systems installed in socially rented homes is covered in a separate report

1.2. Installation of monitors and solar immersion controllers

The project aimed to install a series of small measures that could complement solar PV systems. These included solar PV monitors, solar immersion controllers and smart plugs.

As part of the research for the project, it was intended to assess the benefits of these technologies through questionnaires while also analysing data on the solar PV generation and household electricity consumption.

There were a number of issues which delayed this part of the project and made it more challenging. These included:

- The Covid pandemic – it was not possible for the project team or electricians to visit properties during the first half of 2021. Visits were also a challenge after the end of the lockdown and it was not possible to get any measures fitted in over the summer of 2021
- Some social landlords had their own in-house electricians, and they were too busy after the lockdown to facilitate these installations. They were also affected through staff being sick or having to self-isolate
- Some social landlords have planned maintenance contractors. There were some challenges working with this arrangement (landlord and contractor). The costs for the planned maintenance electricians in London were found to be far higher than for an electrician outside of the capital.

- Multiple staff changes at one landlord affected plans severely
- One landlord felt it would be necessary to engage a Principal Designer for installation of a small number of solar PV monitors at a cost of about £1,500 per installation, which made the installations uneconomic
- While some partners were easy to work with, others it took many weeks to negotiate data sharing agreements or agreements over installation works, and who would be responsible for a device after installation
- There were limited properties with both solar PV and an accompanying hot water cylinder, restricting the opportunities for installing a solar immersion controller
- During the course of the project a couple of solar PV monitors were withdrawn from production
- Many solar PV monitors use CT clamps on cables from the electricity meter and from the solar PV system to the consumer unit. Neat solar PV installations may not have accessible solar PV cables. Also, some installations employed twin and earth cabling to the generation meter, so electricians were needed to install the monitors
- Some landlords had concerns about some of the small measures. There were concerns that smart plugs turning on and off appliances might be a fire risk. These were not offered to social landlords who had concerns while only the metering aspect was promoted to residents of other social landlords. There were also concerns from a social landlord about offering slow cookers to residents for fire safety reasons
- There were delays with partners installing measures after they received devices. In one case there were issues with delays to installation of solar PV systems - waiting for a grid connection agreement. Also, there were delays due to a shortage of electronic components. In some cases, these delays amounted to over 6 months
- A partner placed an order for solar immersion controllers, and it took several months before they were delivered due to supply chain issues

1.3. Monitors and solar immersion controllers report

The current report reviews a range of different monitoring technologies, discussing the advantages, disadvantages and how effective and useful they are to residents. It also discusses 2 models of solar immersion controller and their associated monitors.

Data from a number of systems was also analysed, to assess the accuracy of the monitors and the performance of some solar PV systems and solar immersion controllers. This is discussed in the second half on the report.

The solar PV monitors can be divided into different types:

- With or without an in-home display
- Operate with or without an internet connection
- Monitor associated with the inverter or a different data logger
- Using current clamps, a pulse logger or another system for measurement

2. Review of solar PV monitors

2.1. GEO Solo PV II

The device came with the following components:

- Solo PV II display
- Power supply unit for the display
- LED sensor and adhesive Velcro ring
- Wireless transmitter and batteries

The Velcro ring is attached to the generation meter for the solar PV system, fitting around the flashing LED on the meter. The LED sensor is then fitted onto the Velcro so that it measures the flashes of the LED.

The battery powered transmitter unit is fitted near the generation meter and a cable from the LED sensor is plugged into the transmitter. It is a simple process to set up the display and pair it with the transmitter.

The device only measures PV generation and not household electricity consumption.

Figure 2.1 GEO Solo PV II display

The GEO Solo PV II has a speedometer on the display which shows the current rate of energy generation from the solar PV system. When the display is configured in "settings", the size of the PV system can be entered as 2, 4, 6, 8 or 20kW and this scales the speedometer. The display also shows the current power output from the PV system (in kW) and the amount of electricity that has been generated that day (in kWh). There is a green icon with a hand pressing a button and this is to indicate when it is a good time to turn on higher power appliances to maximise savings from the solar PV. The ‘switch on’ icon is lit once the PV system generates 750W or more.

It is possible to see details of previous generation from the PV system with the display. By pressing the left-hand button, you can cycle between the generation from today, yesterday, the day before yesterday, this week, last week, this month and last month (previous calendar month).

The device was simple and did not need the internet to operate and so was suited to a wide range of people. This monitor may not be suitable to use if the generation meter was installed in the loft as changing batteries may be an issue for householders.

Figure 2.2 shows an example of a GEO Solo PV II installation, with the LED Sensor fitted over the pulse output of the generation meter and the cable from this plugging into the transmitter. In this case the display was fitted on the wall close by, but it could be put in a suitable location near a mains supply in another room.

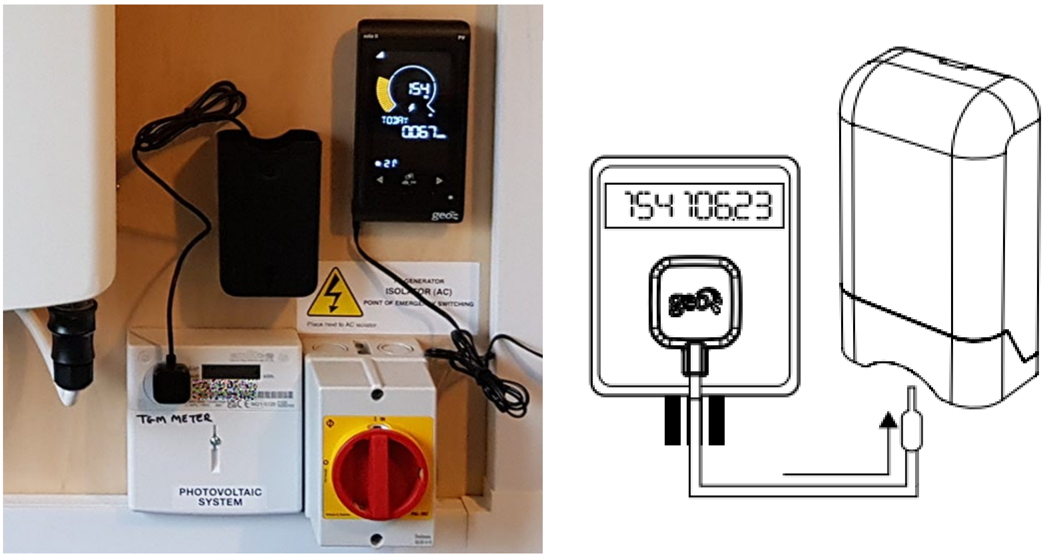


Figure 2.2 (a) GEO Solo PV II installation (b) Schematic showing LED sensor and transmitter

An issue users experienced was the LED sensor becoming detached over time. Using additional tape to attach the sensor to the meter normally addressed this issue.

As part of this project, GEO Solo PV II monitors were fitted for over 10 households. One of these in Devon had the generation meter in the garage. As a result, it was not easy to check on the generation from the solar panels. The residents did not have a smart phone and so wanted a monitoring system with a display. A GEO Solo PV II was installed for the household and the display located in the living room where it could easily be seen.

The residents found the display very clear and simple and liked the speedometer. They used the monitor to provide an indication of when they could use high power appliances more effectively from the solar. For example, if they wanted to use the dishwasher, washing machine or electric shower, they would wait until the GEO monitor showed a significant amount of generation.

The household found the monitor easier to use and more informative than their smart meter in-home display (IHD). The features of the smart meter IHD and how it could be used were explained to the household by NEA staff during the final visit with them.

The LED sensor for the monitor became detached from the generation meter, but the residents reattached it with electrical tape. Another household stopped using the monitor due to the sensor falling off and believing it not to be accurate.

GEO stopped manufacture of the Solo PV II and it was no longer available from distributors from early 2022.

A major feature is its ease of installation, with no requirement for electricians or skilled personnel.

Advantages

- Monitor is easy to install and does not require an electrician
- Display is easy to use and understand
- Does not require the internet or a smart phone

Disadvantages

- GEO has discontinued manufacturing the monitor
- Pulse logger is prone to become detached from the generation meter
- If the generation meter is located in the loft, there would be difficulties for residents changing the batteries for the transmitter
- Does not monitor household electricity consumption
- No internet or phone app monitoring

2.2. Eco Eye Smart PV

Figure 2.3 Eco Eye Smart PV monitor kit

The Eco Eye SmartPV comes with:

- Transmitter unit where current transformer (CT) sensors plug in (battery powered)
- 2 x CT clamps – PV sensor and grid sensor
- Voltage sensor –foil sensor that wraps around the live meter tail
- Smart in-home display (battery powered)
- Optional memory card

Like the GEO Solo II PV, the Eco Eye Smart PV comes with a display and does not require the internet to operate. The monitor can display solar PV generation, household consumption and net import/export.

Installation involves fitting a CT sensor around one of the meter tails (neutral cable) for the main supply meter and a CT sensor for the solar PV on the neutral cable coming from the inverter to the consumer unit. A foil voltage sensor is also wrapped around an insulated “live” cable, normally one from the main meter to the consumer unit.

Some installations can be more complicated and might need an electrician. For example, with neat solar PV installations, cables from the inverter to the consumer unit might be in plastic conduit and not exposed. In some installations, electricians used ‘twin and earth’ cable to go between the generation meter and the consumer unit. Fitting a CT sensor over this will not monitor the solar PV. It would be necessary to either expose a section of the neutral cable before the consumer unit or fit the CT sensor inside the consumer unit.

Once the sensors have been fitted, they are plugged into the battery powered transmitter unit. This is paired with the display. If there are multiple Eco Eye monitors in a local area, the transmitter can be set to use a different radio channel so there is no interference between them.

Pressing the red button on the display can switch between the screen showing generated power, used power and the difference between generated and used power. For some installations, the red button could be rather stiff and difficult to switch between modes.

There are red, amber and green traffic light indicators on the top left-hand corner of the display which show whether it is a good time to turn on further appliances. The green LED flashes if you are generating at least 100W more than you are using. The amber LED will flash if you are using a similar amount of power to what you are generating while the red LED flashes when you are using more than you are generating.

Most users preferred the setting on the display which showed the difference between generated and used power – which shows whether the property is exporting, importing or "balanced" with generated power. Coupled with the traffic light, it is an easy to use real time indication for power use.

An MMC memory card can be fitted into the display. This can record generation and consumption data at 4 second intervals. The memory card provided by Eco Eye has been specially formatted to allow several years of data to be stored on the card while using little battery power from the display.

Eco Eye provides a programme called 'Trax', which can download data either via a USB cable or by reading the memory card. Although the Trax software feels slightly dated, it is flexible and can display a wide range of data. It can show energy used and generation over a day, week, month and year. In the hour detail setting (figure 2.4), data is shown at intervals of 10 minutes. With the minute detail graph, generation and energy used is shown in 4 second intervals. This could be of particular use in better understanding household consumption. To change the resolution on the y-axis, the plus or minus magnifying glasses on the bottom left-hand corner can be clicked. To change the period analysed, the left or right buttons on the bottom right can be clicked.

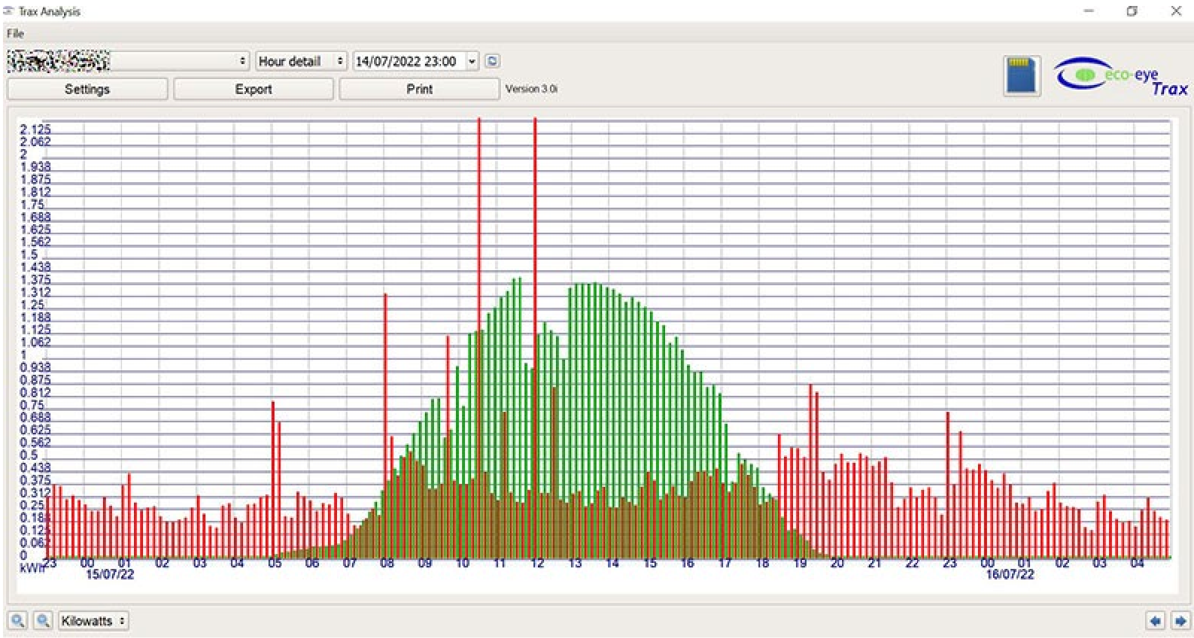


Figure 2.4 Image from Trax software for the Eco Eye Smart PV, showing an hour detail graph

While trialling the monitor, NEA staff found there could be issues with the reliability of the memory card system. Eco Eye had supply issues in 2022. This included difficulties obtaining MMC cards as they are no longer routinely available. The accuracy of the monitor using CT-sensors is expected to be within ±10% with potentially higher accuracy if the grid voltage for the property is input via the display or Trax software.

Eco Eye plans to release an updated monitor in 2023. This will have a colour display, Wi-Fi connectivity, so data can be uploaded to the internet and a rechargeable battery. Data will continue to be stored at 4 second intervals, but a more readily available SD memory card will be used. There will also be an update to the Trax software for the device.

Advantages

- Easy to understand in-home display which shows PV generation, household consumption and net import or export
- Does not require the internet or a smart phone
- Records readings every 4 seconds on the memory card

Disadvantages

- The current model provides no internet or phone app monitoring
- It might require an electrician to access the cable for the PV sensor
- At the time of writing the current monitor was not available and the new version had not been released

2.3. Monitoring with inverters and battery systems

Solar PV inverters normally record the electricity generated by the system. This is typically shown on a display on the inverter but is often not easily accessible if the inverter has been fitted in a garage or the loft.

Many inverter manufacturers now offer system owners the ability to monitor the performance of systems online via a web-portal or phone app. This is often achieved by having a Wi-Fi dongle attached to the communications port of the inverter and the dongle connected to the home Wi-Fi signal. Dongles are typically relatively inexpensive at under £50 and are becoming more common. Modern SMA inverters already have built in communications, which means once the inverter is connected to the household Wi-Fi, monitoring is possible via the Sunny web portal.

Hybrid inverters and battery systems can typically monitor both the solar PV generation and household electricity consumption. Again, these systems are normally online and may require a wired connection of Wi-Fi dongle.

2.3.1. Solis Inverter Wi-Fi dongle

Figure 2.5 (a) Solis Wi-Fi dongle (b) Solis Wi-Fi dongle fitted to Solis inverter

The Solis Wi-Fi dongle connects to the 4-pin COM port of the inverter. A Wi-Fi antenna is screwed onto the bottom of the dongle to ensure good communications, with the antenna pointing towards the broadband router.

There were 6 households that received Solis Wi-Fi dongle installations during the project. The last of the installations received an updated version of the dongle with a differing installation and setup method. The dongle does not need an electrician to install. It is possible for residents to set the system up, but more suited to a technically competent energy advisor.

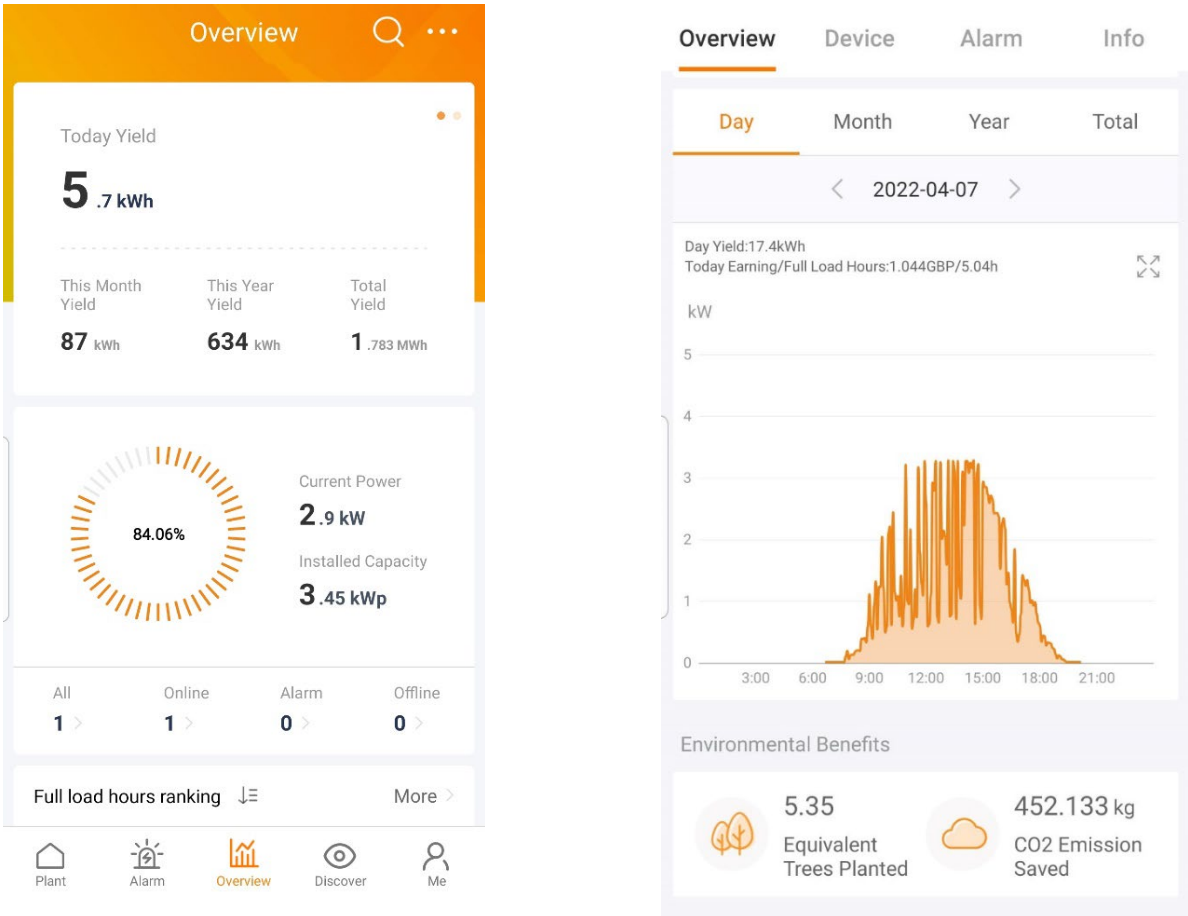


Figure 2.6 (a) Solis Cloud app 'Overview' (b) Solis Cloud app 'Plant' with graphs

Monitoring is available via the Solis Cloud app or Solis Cloud web portal. The systems record the solar PV output every 5 minutes and can plot graphs showing generation. However, finding information on the versions of the app or portal at the time of writing was not always intuitive.

When loading the Solis Cloud app, it automatically goes into the 'Overview' section (figure 2.6 (a)). This displays some basic statistics, such as the current power output and the generation or yield today, the yield this month, this year and in total since installation.

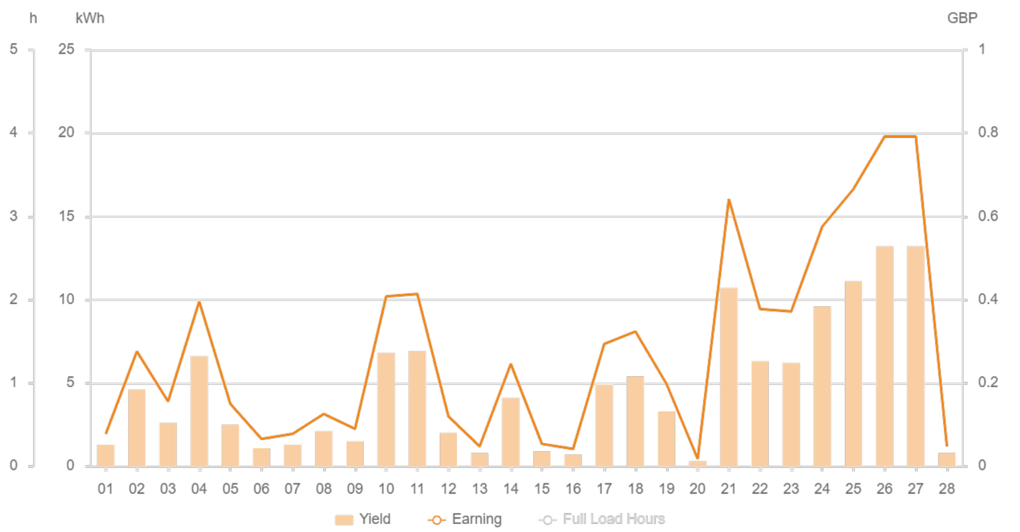
It is possible to plot graphs of the performance of the system by clicking on the plant icon in the bottom left corner. That takes you to a screen with your installations (normally just one with a domestic installation). After clicking on this, there is more information about that particular inverter or plant. This includes an overview where you can plot a graph showing the daily generation for different days. Alternatively, you can also plot a bar chart showing the daily generation over a month or the monthly generation over a year.

While the phone app is more convenient for quickly checking the level of generation for households, the web portal allows greater data analysis. The initial login screen shows the current power output, daily, monthly and total yield from the system. In order to plot graphs, you have to click on the installation name. It is then possible to plot graphs for a particular day, month, year or since installation (multiple years). There is also an export button which allows the graph to be downloaded as a spreadsheet, along with the data used to produce the graph. Figure 2.7 shows an example of information on a monthly spreadsheet with yield, earnings and hours of full load. The earnings are based on a figure entered during the setup for the value of the electricity generated. This for example could be the generation tariff from the feed-in tariff.

Plant_2022-02Chart

Installed Capacity:3.450kWp

Monthly Yield(kWh):130.000kWh This Month Earning:7.800GBP Month Full Load Hours(h):3



Number	Time	Today Yield(kWh)	Today Earning(GBP	day Full Load Hours(h)
1	2022-02-01	1.300	0.078	0.380
2	2022-02-02	4.600	0.276	1.330
3	2022-02-03	2.600	0.156	0.750
4	2022-02-04	6.600	0.396	1.910
5	2022-02-05	2.500	0.150	0.720
6	2022-02-06	1.100	0.066	0.320
7	2022-02-07	1.300	0.078	0.380
8	2022-02-08	2.100	0.126	0.610
9	2022-02-09	1.500	0.090	0.430
10	2022-02-10	6.800	0.408	1.970
11	2022-02-11	6.900	0.414	2.000
12	2022-02-12	2.000	0.120	0.580
13	2022-02-13	0.800	0.048	0.230
14	2022-02-14	4.100	0.246	1.190
15	2022-02-15	0.900	0.054	0.260
16	2022-02-16	0.700	0.042	0.200
17	2022-02-17	4.900	0.294	1.420
18	2022-02-18	5.400	0.324	1.570
19	2022-02-19	3.300	0.198	0.960
20	2022-02-20	0.300	0.018	0.090
21	2022-02-21	10.700	0.642	3.100
22	2022-02-22	6.300	0.378	1.830
23	2022-02-23	6.200	0.372	1.800
24	2022-02-24	9.600	0.576	2.780
25	2022-02-25	11.100	0.666	3.220
26	2022-02-26	13.200	0.792	3.830
27	2022-02-27	13.200	0.792	3.830
28	2022-02-28	0.800	0.048	0.230

Figure 2.7 Graph and data table from a download from the Solis Cloud web-portal

The Wi-Fi dongle needs to be connected to the Wi-Fi router for the system to record data. If the household changes broadband supplier, the connection is lost to the Wi-Fi dongle. In order for further data to be recorded on Solis Cloud, it is necessary to reconnect the dongle to the internet so that the system uses the new Wi-Fi password. This may be a challenge for some households who might need support.

There were 7 Solis Wi-Fi dongles which were either installed or setup by NEA staff for households during the project. By January 2023, 3 of the loggers were still online and 2 had gone offline due to changing broadband supplier. Another had gone offline due to major refurbishment work in the house with the PV system being turned off. Connection was lost to the portal for the last household connection due to a password change. Installations took place in between January and May 2022 and the systems which went offline lost connection in June and July 2022. Given that households regularly change broadband supplier, it is important that the method of connecting the dongle to the internet is straightforward.

An interview was carried out with a household 8 months after they had a Solis Wi-Fi datalogger. The household strongly agreed that they understood how to use the solar PV monitor, that it was easy to use and they were interested to see the amount of electricity generated by the solar PV. Soon after the installation, the resident was looking at the monitor on a daily basis, but at the time of the interview it was closer to weekly. She liked to see the level of generation as well as the daily and monthly graphs. The resident strongly agreed that she changed when she used electricity due to seeing when the solar panels generate electricity and that the solar PV monitor helped her make better use of the electricity from the solar panels.

The resident did her washing during the day when the sun was out. She also tried to cook during the day as well. She aimed to use one appliance at a time, staggering the use of high-power appliances, to maximise what was powered by the solar PV.

Advantages

- Low-cost upgrade to offer monitoring of solar PV
- Installation does not require an electrician
- It is possible to plot graphs with the app and download data with the web portal

Disadvantages

- Not all households have broadband and smart phone
- The inverter may be in the loft, making access for the installation harder
- Connecting the dongle to the WIFI system may be a challenge with some systems if there is a poor signal
- If the household switches broadband provider, the dongle needs to be reconnected to the new broadband router

2.3.2. SMA Sunny portal

SMA includes a Wi-Fi output with most of its recent domestic solar PV inverters. System owners can connect their inverter to the SMA Sunny Portal by connecting the inverter to their household Wi-Fi. The Sunny Portal system has been operating for a number of years and in the second quarter of 2023, SMA intends to shift Sunny Portal and associated applications to a more modern data centre.

Figure 2.8 shows the Sunny Portal at the time of writing. The PV system overview includes some key details and performance information about the system, including the current PV output and the electricity generated today. It is possible to plot a graph showing generation for that day, month (with daily yield as in the figure) and year (with bar chart with monthly generation). The drop-down menu below the graph is used to select the period covered by the graph. It is possible to download a spreadsheet (CSV file) with data from the graph by clicking on the system symbol on the bottom right-hand corner. A download of a daily graph includes data every 15 minutes.

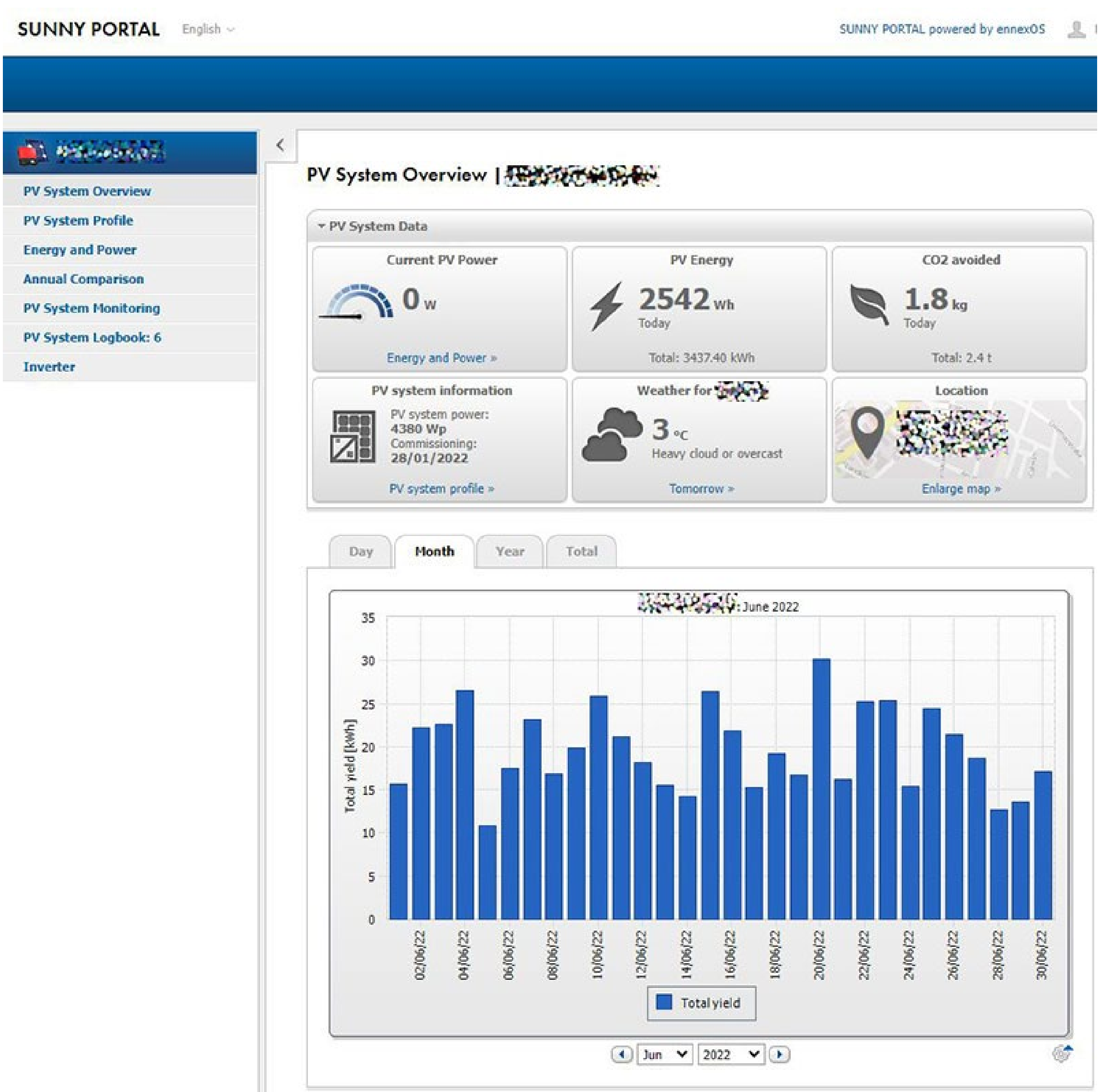


Figure 2.8 Screenshot from the SMA Sunny Portal

The Annual comparison link on the left side menu allows the monthly and annual performance of the PV system to be compared in different years.

Monitoring and analysis of the performance of PV systems is important for system owners to avoid extended periods when the system is not operating or has a partial fault. Modern SMA inverters benefit from the SMA Smart Connected service when connected to the internet. SMA is able to detect operational anomalies and proactively inform the system owner and installer by email when a fault is detected. This reduces the system downtime when an inverter fault occurs, saving the owner money.

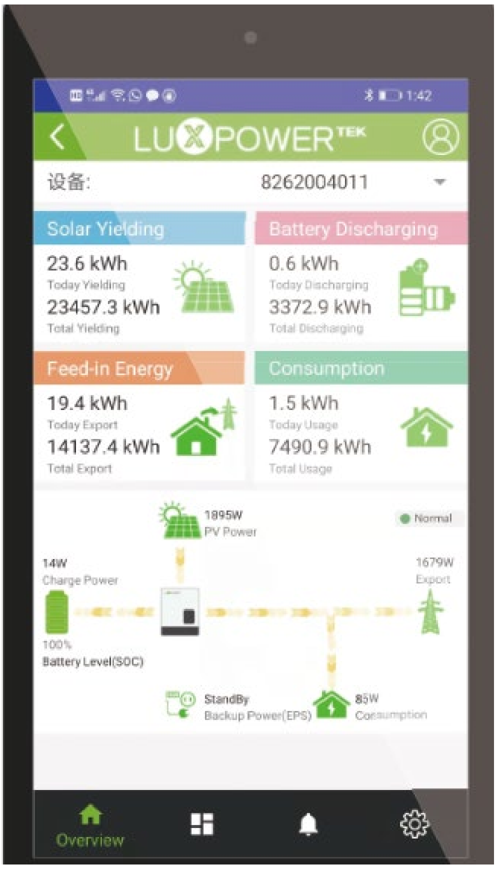
Advantages

- Free monitoring system available with SMA inverters
- SMA Smart Connected service where SMA monitors online for inverter faults
- Setting up the portal does not require an electrician
- It is possible to plot graphs and download data with the web portal
- Comparisons can be made with previous years

Disadvantages

- Not all households have broadband and smart phone
- If the household switches broadband provider, the inverter needs to be reconnected to the new broadband router
- Sunny Portal at the time of writing was a bit dated and downloads not provided in a convenient format

2.3.3. Lux Power Hybrid inverter



A hybrid inverter is designed to be able to work with a solar PV system and a battery. It is able to simultaneously manage PV power generation along with battery charge and discharge. A hybrid inverter is several hundred pounds more than a standard inverter and a battery can be added at the time of installation or at a later date.

A Wi-Fi dongle is normally fitted to the hybrid inverter to allow communication with the internet.
The hybrid inverter measures the grid import/export via a CT sensor or electricity meter. The monitoring system is able to display household consumption (or grid import/export) as well as solar PV generation. If a battery system is installed, it can also show the battery charge and discharge.

Figure 2.9 shows a screenshot from the Luxpower View monitoring app for a Luxpower inverter system. The app shows values from today and since installation for the solar yield (generation), battery discharge, export (feed-in) and household consumption.

Figure 2.9 Screenshot from the Luxpower app

The app also includes a schematic with live information on the current power output from the solar panels, the electricity being used in the home and the export to the grid. If a battery is installed, it will include the charge/discharge for the battery and the percentage charge level. The app can also plot daily or monthly performance graphs (under that data section) and show any alerts or alarms under the monitor section.

There is also a web portal for the Luxpower inverter system. The main monitor screen includes the same information as the Overview on the app. There are the values for Solar Yield, Battery Discharge, Feed-in Energy and Consumption. Also, the system information graphic showing the current levels of power flow. In addition to this is an Input & Output Power graph and an Energy Overview chart (figures 2.10 and 2.11).

The Input & Output Power graphs can show the solar PV generation, battery charge/discharge, grid consumption and household consumption for any selected day. The Energy Overview chart plots values of solar production, battery discharge, export to grid and household consumption for different days in a month (figure 2.11), months in a year and years since installation.

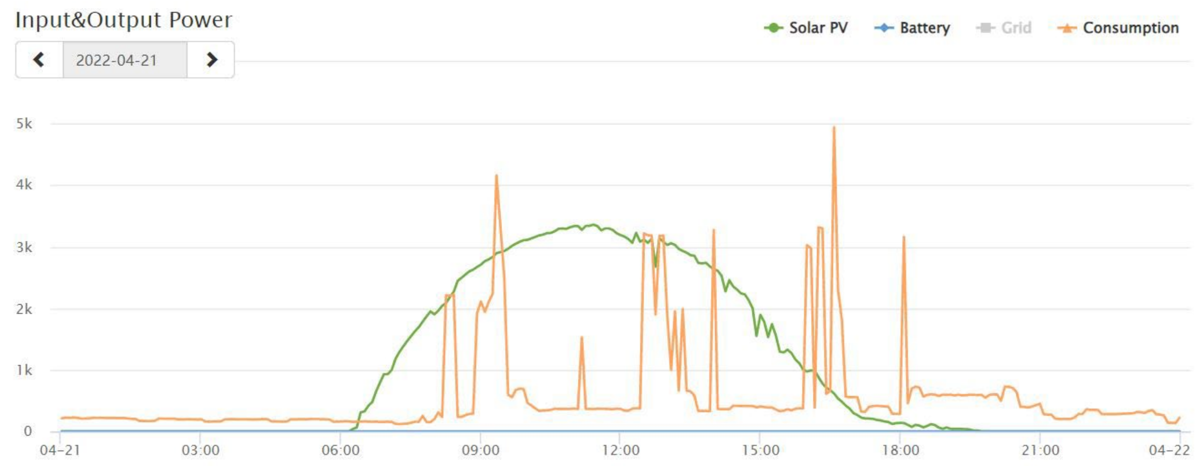


Figure 2.10 Input & Output Power graph from the Luxpower web portal showing PV generation and household consumption for a property on 21 Apr 22

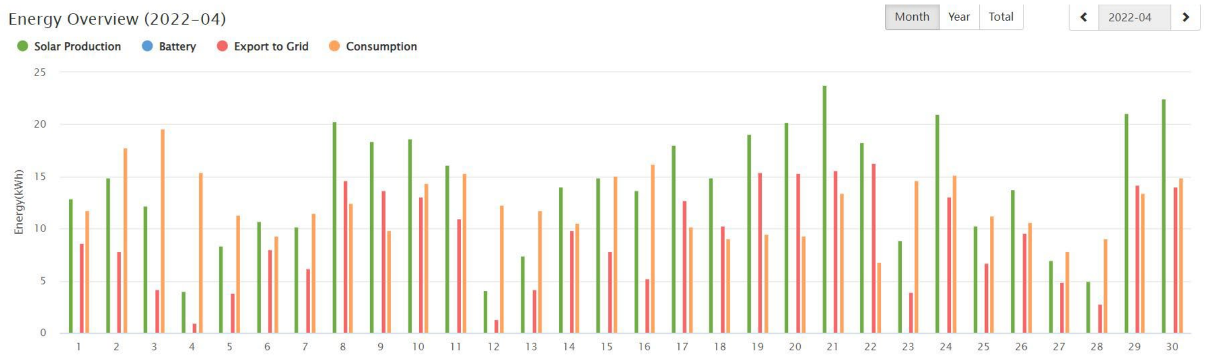


Figure 2.11 Energy Overview chart from the Luxpower web portal daily solar production, export to grid and household consumption for a property during April 2022

The portal is also able to show the voltage and power output from each string of the inverter. This data along with additional data associated with a battery if present is available at 5-minute intervals in a History Data section. This is primarily for installers and the manufacturer to be able to assess performance and whether there are any faults. Data from this section can be downloaded. Although it is possible to download data such as the daily, monthly and annual PV generation, export and household consumption with many other systems, this is not currently possible with the Luxpower portal.

Advantages

- Monitoring system with phone app and web portal
- Includes household consumption and export to grid as well as PV generation
- Can also monitor battery system if included

Disadvantages

- Requires internet connection and reconnecting if broadband provider is switched
- A hybrid inverter is more expensive than a standard inverter
- Not suitable for households without a smart phone or broadband
- Data downloads are of limited use for the system owner

2.4. Smart meter in-home displays

Figure 2.12 Chameleon IHD

Figure 2.13 GEO Trio II IHD

Households are normally provided with an In-Home Display (IHD) when they have a smart meter installed. The smart meter and IHD communicate through a Home Area Network (HAN) using a Zigbee wireless signal[1].

The IHD screen is updated about every 10 seconds for electricity and every 30 minutes for gas. There are a number of models of IHD provided by suppliers, coming from manufacturers like Chameleon and GEO Together. They show the current cost of energy use in pounds and pence as well as the amount of electricity or gas that has been used in kWh. It is also possible to access historical energy consumption data for a period of up to 13 months[2].

The screen of an IHD can be switched to show the energy use now, with the amount of electricity being imported from the grid. This is very useful for monitoring the consumption in the home by different appliances. It can also help households maximise the benefit from a solar PV system.

When a solar PV system is exporting to the grid, a smart meter IHD will either show there is 0W consumption or the level of export to the grid. The photo in figure 2.14 shows a Chameleon IHD7 in a home with a solar PV system. The IHD shows there was export to the grid with an arrow pointing to a pylon symbol. At the time of the photo, there was 1.33kW of export. Households could use higher power appliances for free when the PV export reaches a certain level, such as 2,000W for a washing machine.

Figure 2.14 Chameleon IHD7 showing export of electricity to the grid

[1] The Smart Meter Home Area Network, https://www.smartme.co.uk/home-area-network.html (Accessed 27 Jan 23)
[2] FAQs – The in-home display, Smart Energy GB, https://www.smartenergygb.org/faqs/the-in-home-display (Accessed 27 Jan 23)

Not all smart meter IHDs show the level of export to the grid. It appears for example that the older Chameleon IHD6 only shows the grid import is 0W when export occurs rather than the level of export.

During interviews with households that received other monitors, residents were asked about their use of smart meter in-home displays. Most regularly used the IHD, but it was primarily to check the cost of the energy they had consumed. A household used it as an encouragement to turn off appliances. None with solar PV used the IHD as a method to know when to use appliances for free.

Some households may have lost or broken their IHD. Others may find their particular IHD dated and difficult to use. It is not possible to buy another standard IHD and set it up yourself as this requires an engineer working for the supplier to pair the IHD with the communications hub of the meter.

Figure 2.15 ivie Bud IHD from Chameleon[4]

An alternative is to fit an ivie Bud IHD which can be installed and activated by households and does not require an engineer to set it up[3]. It can be used with most smart meters and compatibility can be checked on the ivie website. Set up involves connecting the Bud to the Wi-Fi and scanning the QR code on the ivie Bud screen and following the instructions. Activating the ivie Bud can take a few minutes but might take up to a few hours. In order to verify the customer lives at the correct address, identification is required.

The ivie Bud display has similarities to the Chameleon IHD7. Households can also use the ivie app which will display live energy data when connected to an ivie Bud. The app uses smart energy data from your account to provide reports and personalised energy saving tips. The app attempts to disaggregate the electricity consumption and show how much electricity has been used by different types of appliances.

Figure 2.16 shows the estimated breakdown or disaggregation of the electricity consumption of one household. Disaggregation software compares the patterns in household electricity consumption with those of particular appliances. It can be a challenge to make accurate estimates on consumption of different appliances using these methods. In this case, the software estimated that 89kWh of the monthly consumption was due to refrigeration. A smart plug was fitted to the fridge and recorded about 25 to 30kWh per month. It is possible that the calculation for consumption due to refrigeration was affected by other appliances which regularly cut in and out such as a fresh water pump at this site.

[3] Chameleon, Smart Meter Data, https://www.smartme.co.uk/meter-data.html#ivie (Accessed 27 Jan 23)
[4] Ivie, https://ivie.co.uk/product/ivie-bud/ (Accessed 31 Jan 23)

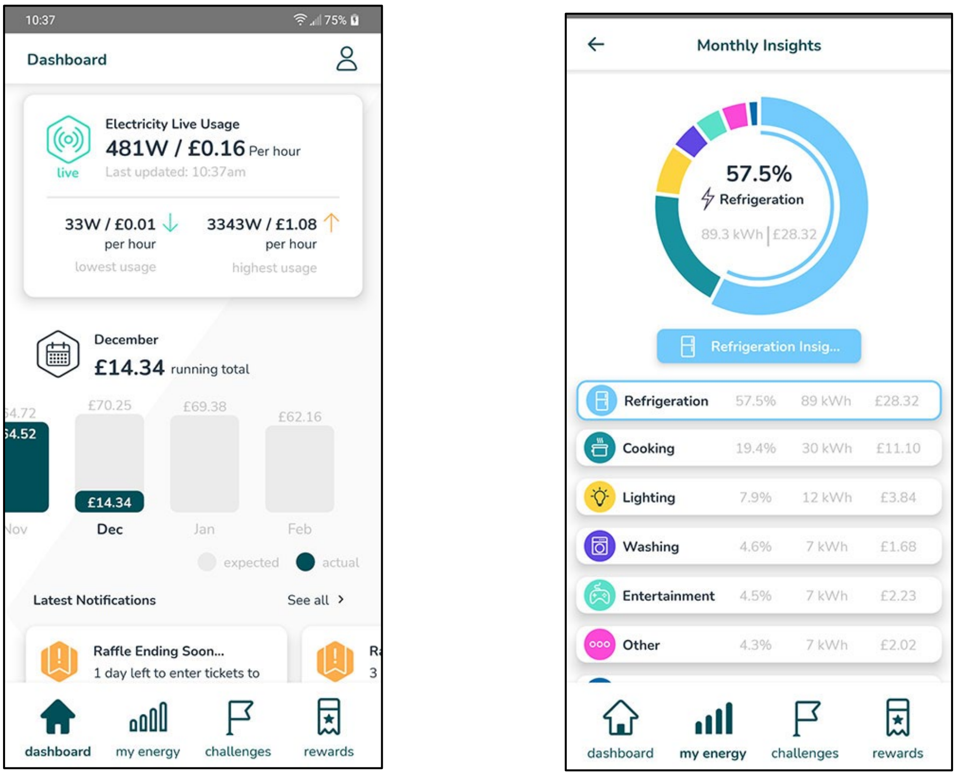


Figure 2.16 Images from the ivie app

As part of the project, 2 households were provided with an ivie Bud monitor and completed questionnaires after using it for several months. Both households strongly agreed that the monitor was easy to use and they understood how to use it. They also strongly agreed that they were interested to see the amount of electricity generated by the solar and changed when they consumed electricity due to seeing when the solar panels were generating electricity.

Both households found setting up the monitor a challenge and one needed extensive support from the manufacturer. The other household noted it took several weeks for the monitor to collect any data from the smart meter and continued to have intermittent problems.

One of the households found it useful to check when the pylon symbol was showing and the level of export to the grid. It was particularly helpful to be able to see when the panels were generating (exporting to the grid) using the monitor as the inverter and generation meter were in the garage. The other household was unable to see the pylon symbol indicating export. This might have been due to the version of the ivie Bud using older firmware, but the manufacturer's support staff refused to discuss the issue with the household. In this case it was only possible tell when there was zero consumption from the grid to help residents make an informed chouce of appliances.

One of the households was with Bulb and the prices on their smart meter IHD had not been updated for over 18 months. It was possible to use a more appropriate tariff rate with the ivie app, but this was still not exact as the household used Economy 7 and the app at the time did not accommodate entering a dual rate time of use tariff. This is a common issue with smart meter IHDs.

Advantages

- Smart meter in-home displays are normally provided for free with a smart meter
- They do not require a smart phone or broadband to work in a home
- Some IHDs can show the level of solar PV export to grid
- Residents can choose good times to use appliances based on the level of consumption or export shown on the display
- The ivie Bud is able to replace lost or old IHDs and includes an app with additional information

Disadvantages

- Not all IHDs show the level of export to the grid
- Many households with solar PV are unaware they can use their IHD to monitor the export to the grid
- An engineer is required to fit a standard IHD
- While households can set up an ivie Bud, this was not always straightforward
- Functionality differs between devices (such as displaying the pylon in a power export situation)
- ivie Bud loses connection frequently even when located close to the meter.

2.5. Wibeee Box

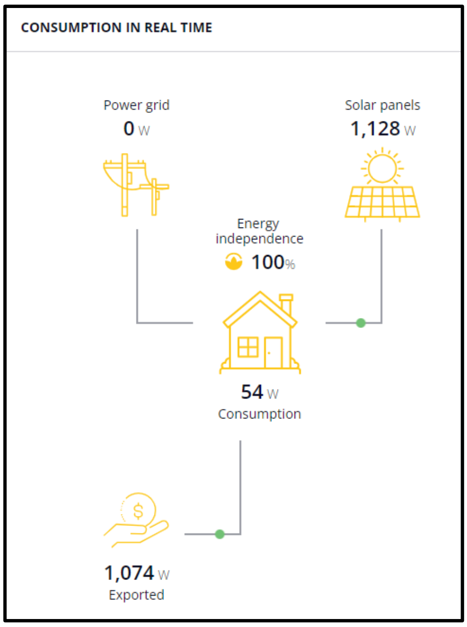


Figure 2.17 (a) Wibeee Box MONO data logger (b) PV view from Wibeee Nest portal

The Wibeee Box is manufactured by Smilics Technologies in Spain and distributed in the UK by NetControl. It is available in two versions: single phase (MONO) and 3-phase (TRI). The Wibeee Box MONO comes with a single 60A current transformer (CT) sensor although additional sensors can be ordered. Optional 100A CT sensors were required on some installations which had a higher power cable. The system for single phase installations is able to monitor 3 different electrical circuits if 3 CT sensors are plugged into the Wibeee Box MONO.

An electrician is required to install the logger as the sensors are normally fitted inside and power taken from the household consumer unit. The CT sensors clip around the wires for different electrical circuits. Channel 1 normally measures the main household electricity consumption. In this project, Channel 2 or 3 was used to measure the solar PV generation, with a CT sensor around the AC cable coming from the generation meter to the consumer unit. The third channel was used to monitor another circuit. For this project, monitors recorded either the power consumption from the immersion heater, cooker electrical circuit or a ground source heat pump. The data sheet for the device noted an accuracy of 1% in current and voltage measurement and 2% in power measurement.

The device connects to the household Wi-Fi and consumption and PV generation can be monitored via the Wibeee Nest UK app or web portal. There have been several changes to the monitoring portal over the course of the project. Initially there were separate Wibeee Home and Wibeee Business monitoring portals. In 2022, users were migrated to the new Wibeee Nest platform which was more complicated than Wibeee Home. An update to Wibeee Nest was released in January 2023 and UK customers should use the UK version or tenancy rather than the Global version. Some interesting ways of analysing data on the Nest portal were dropped, but the updated version should be easier to understand for domestic users. There were still some more advanced features which business users could access which allowed graphs to be plotted of the voltage, current, frequency and power factor for example.

Wibeee divided the monitoring information into 4 sections on the Wibeee Nest app and portal. These were 'Consumption', 'Tariff', 'Breakdown' and 'Meters'. There were also other sections with 'Notifications', 'Permissions' and where you could change the settings.

In the 'Consumption' section there was the 'PV view' (figure 2.17 (b)) which shows the 'Consumption in Real Time' with the real time generation from the solar panels, the consumption in the home and the level of import to or export from the grid. This is the key information that most home users would want, allowing them to check on the output of the solar panels and if there is export, so they can turn on appliances and power them for free. A battery could be added on the third channel and this would also then be shown in 'PV view'.

There is the potential to use 'Night Mode' on the app and portal with the graphics having a dark background, which could reduce battery consumption. An issue at the time of writing was that the graphic was not ideally sized, and it was necessary to scroll the graphic up to see the level of export.

There was also a 'Solar Energy' graph in the 'Consumption' section (figure 2.18). Household electricity consumption was shown in blue and solar generation in yellow. There were also summary statistics below the graph with details of the total PV generation, household consumption as well as import and export from and to the grid. The level of energy independence was also shown. In the previous version of Wibeee Nest it was also possible to plot the grid import, grid export and the self-consumed generation. While this was rather complex, it would still be useful to have the level of self-consumption shown along with the energy independence.

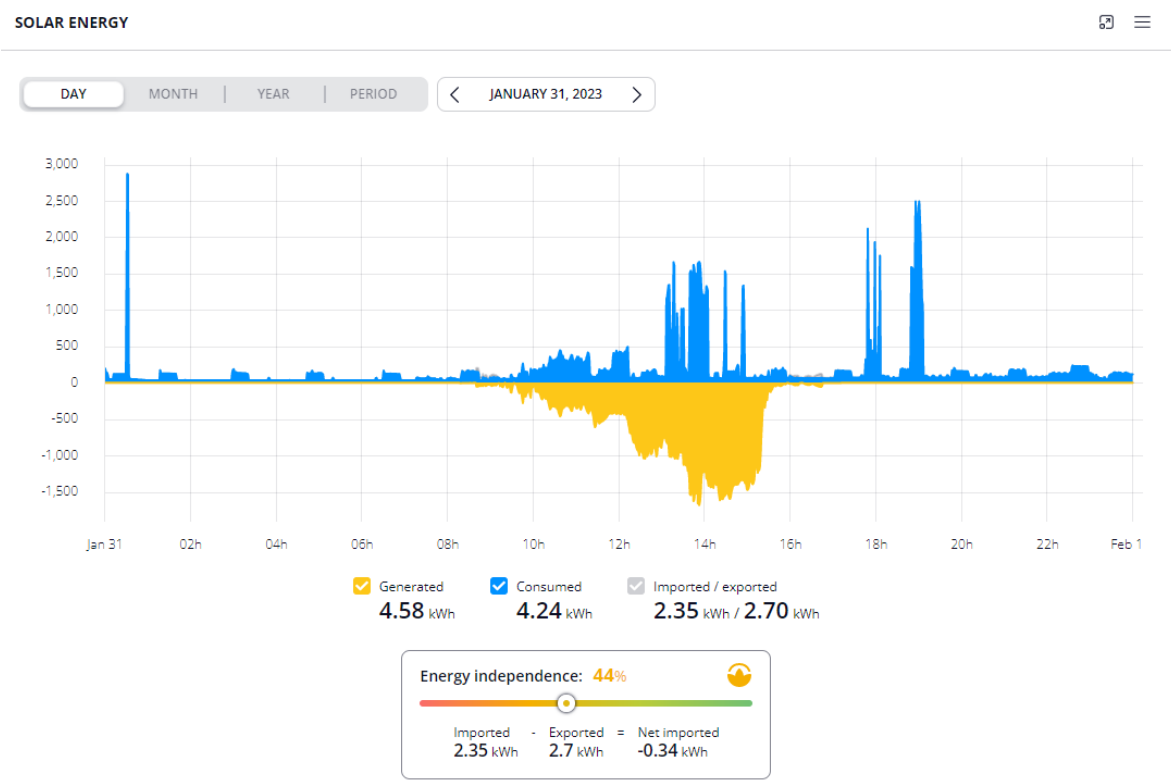


Figure 2.18 Solar Energy graph from the 'Consumption' section of the Wibeee Nest portal

Data could be shown for individual days, months, years or selected periods via a date picker. It was not possible to select to view an individual day or month via a date picker – you needed to move between them sequentially. To view a day several months ago, the easiest solution was to select the period view and use the date picker for a single day.

There were 3 horizontal lines or a 'hamburger' symbol to the top right of the graph. This could be used to download an image of the graph or a spreadsheet of the data which made up the graph. For a daily graph, data was provided every minute for the:

- Bought energy or grid consumption in watts
- Exported energy in watts
- Total consumption in watts
- Generated energy in watts

For a monthly graph, the data provided was the average value for each hour over the month. These were effectively the values of consumption, generation or export in watt hours (Wh) for that hour. For the yearly graph, the data download provided daily totals in (Wh). At the time of writing there was some variation between the totals shown in the data and those displayed below the graph.

The 'Tariff' section for the Global tenancy of Wibeee Nest includes some economic analysis based on Spanish electricity tariffs. The UK tenancy of Wibeee Nest is also likely to eventually do this with UK electricity tariffs. It also shows values of the monthly maximum power consumption over the last year.

The 'Breakdown' section of Wibeee Nest attempts to breakdown or disaggregate the electricity consumption by different electrical appliances in the home. For some like washing machines and fridges, the software attempts to estimate the consumption based on typical patterns of consumption for these appliances. For others like toasters and kettles, the software needs training to learn the consumption by these appliances. Figure 2.19 shows an estimate of the 'Consumption Distribution' for a house on 31 Jan 23. The software estimated that 10% of the consumption was due to the fridge, 6% was due to the kettle and 2% was due to the washing machine (which was not used that day). The majority of the consumption was due to other appliances which could not be identified.

At the time of writing there were still bugs associated with the 'Breakdown' section of the portal which made it difficult to add further appliances for the disaggregation.

Disaggregation of the electricity consumption of appliances after measuring the household electricity consumption is notoriously difficult and many manufacturers have attempted this. Although patterns of consumption of appliances like fridges are known, homes can have other appliances like pumps which can cut in and out during the day which can confuse disaggregation software. Training the software to recognise a toaster or kettle can be effective, but the accuracy could be affected if there are other appliances which might have a similar level of consumption and usage pattern.

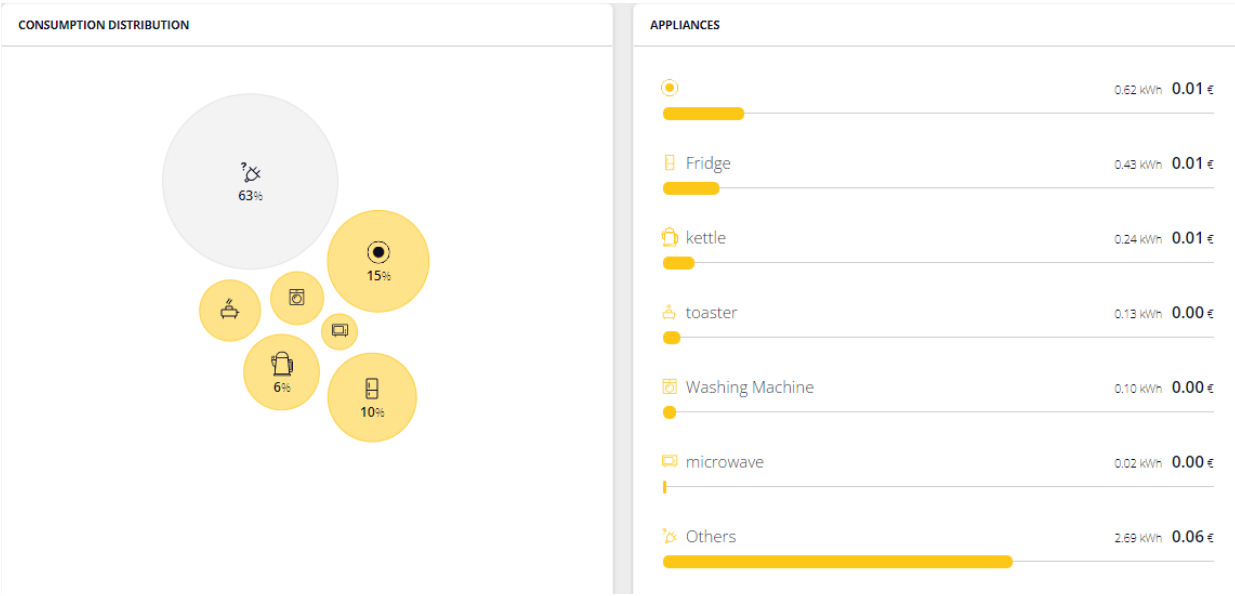


Figure 2.19 'Breakdown' section of Wibeee Nest portal showing disaggregation of the electricity consumption of different electrical appliances on 31 Jan 23

It is more accurate to measure individual electrical circuits or appliances by other means. The 'Meters' section of the Wibeee Nest app and portal allows 3 different circuits to be monitored.

Clicking on the main meter opens a 'Consumption in Real Time' plot (figure 2.20) for each of the 3 circuits and shows the solar generation, household consumption and import/export with the grid. In this case channel 1 is the main household consumption, channel 2 is the cooker electrical circuit and channel 3 the solar PV system.

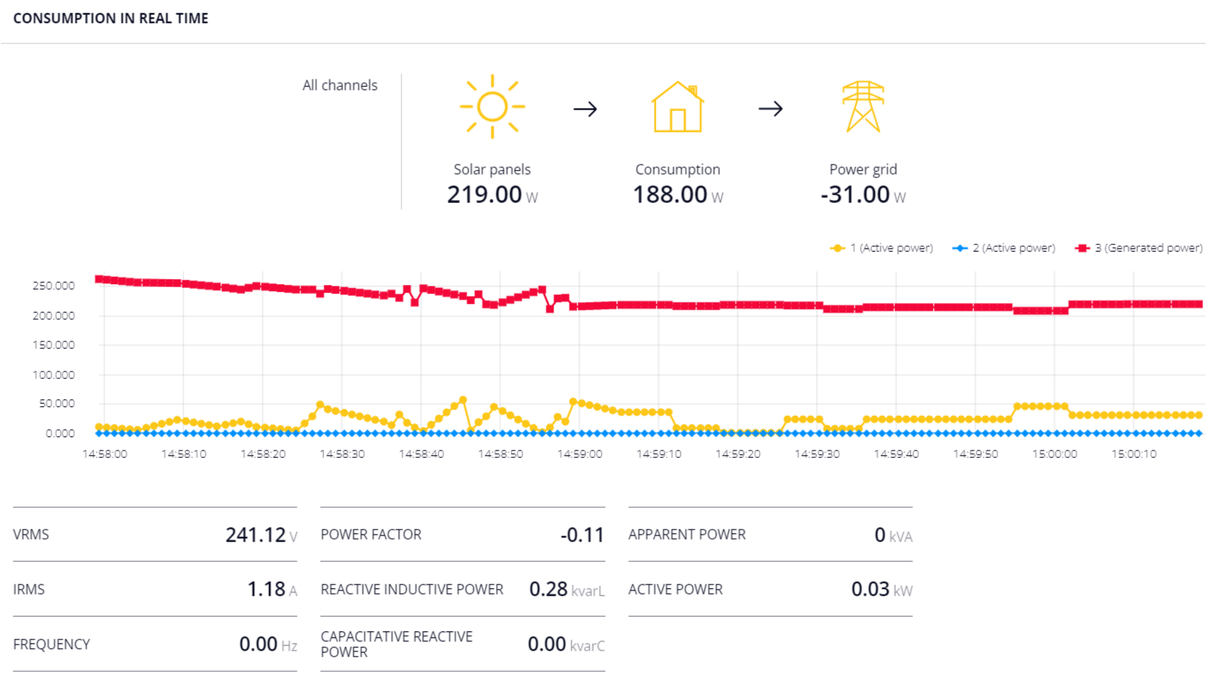


Figure 2.20 Consumption in Real Time' graph from the 'Meters' section of the Wibeee Nest portal

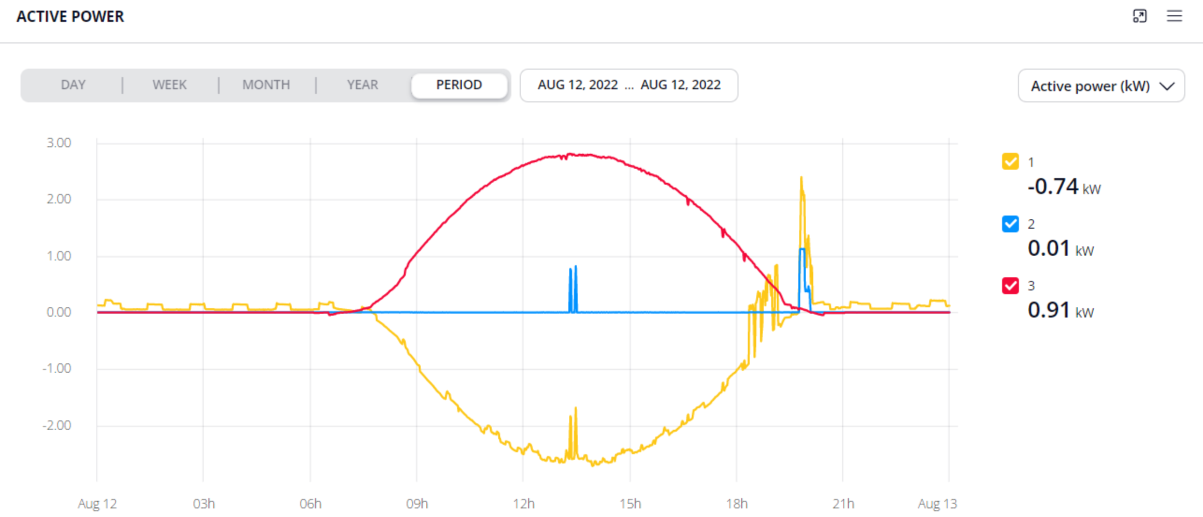


Figure 2.21 Active Power graph from the Meters section of the Wibeee Nest portal from 12 Aug 22

The main graph from the 'Meters' section of the Wibeee Nest portal is the 'Active Power' graph. This plots the electricity recorded from Channels 1 to 3 of the Wibeee Box monitor. Figure 2.21 shows an 'Active Power' graph from 12 Aug 22, with the household consumption on Channel 1, the cooker circuit on Channel 2 and the solar PV system on Channel 3. It was a bright sunny day and there was characteristic bell-shaped curve from the solar generation. Overnight, there was a small level of household consumption due to the fridge turning on and off. By 08:00, the solar generation was greater than the household consumption and the property was exporting electricity to the grid. As a result, the power recorded on Channel 1 was negative from about 08:00 to 18:30. After this time, use of household appliances meant there was some grid import. Channel 2 only recorded consumption at lunchtime and in the evening on the cooker electrical circuit.

As well as displaying Active Power, this graph can also show Voltage, Current and Frequency, with additional useful information available for those with a 3-phase version of the Wibeee Box logger. As with the solar energy graph, it is possible to download an image of a graph or the data which produced it by clicking on the 3 horizontal lines in the top corner of the graph.

Advantages

- Monitoring system with phone app and web portal
- Provides the most information out of all the monitoring systems trialled
- Can monitor 3 different electrical circuits
- Can download data at 1-minute intervals for individual days

Disadvantages

- Requires an electrician to install
- Requires Wi-Fi connection and reconnecting if broadband provider is switched
- Not suitable for households without a smart phone or broadband
- Disaggregation feature is not particularly accurate

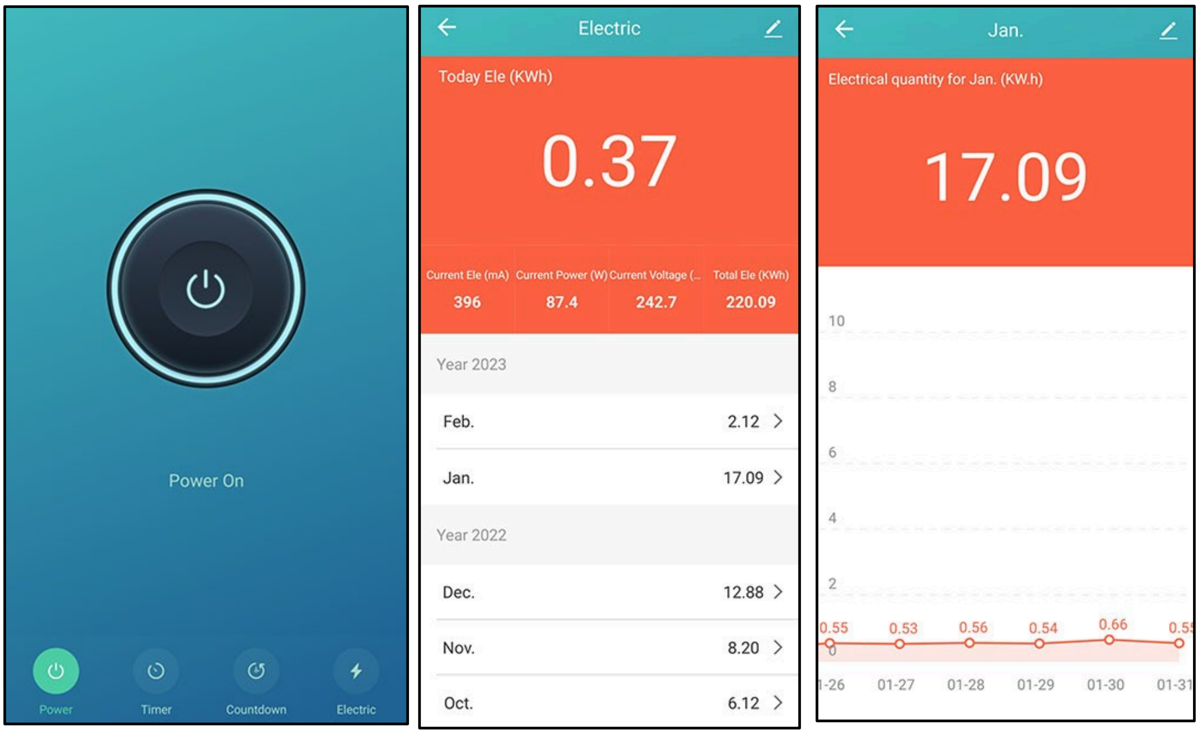
2.6. Smart plugs

Smart plugs are now available from many companies. They typically cost £10 to £20 each. They connect to the home Wi-Fi and allow appliances which are plugged in to be remotely turned on using an app. This may be through manual control of the app or using a schedule or timer.

Some of these smart plugs also can monitor electricity consumption through the plug. This can be viewed through the app and can provide real time data and daily consumption.

Figure 2.22 Smart plug

There is a similar monitoring feature in the smart plug app for smart plugs sold by several different companies. The main screen provides a large power on/off button (figure 2.23 (a)). It is also possible to switch the plug on using a timer or countdown timer via screens accessed using buttons at the bottom of the screen. On the bottom right is the Electric button, which leads to the monitoring feature. The first screen (figure 2.23 (b)) shows the electricity consumption that day as well as the real time current (in mA), power (in Watts), voltage and the total electricity consumption (in kWh) since the plug was set up. It also shows the consumption for different months. By clicking on the consumption for a particular month, it is possible to see the consumption for each day in that month (figure 2.23 (c)).



(a) (b) (c)

Figure 2.23 Images from smart plug app

This project planned to provide households with smart plugs to allow them to monitor and control when appliances were running in order to improve their consumption of solar PV. There was concern from some social landlord partners that households turning on appliances when they were out might pose a fire risk. As a result, few smart plugs were distributed and they were only used for monitoring electricity consumption.

A set of 7 smart plugs were tested with a series of 3 appliances: a kettle, a toaster and a vacuum cleaner. Readings were compared with those recorded using a Wibeee Box logger on a dedicated electrical circuit.

A smart plug from one manufacturer recorded instantaneous consumption figures similar to the Wibeee Box, with a typical error in the reading of about 0.3%. The other smart plugs were from a second manufacturer. Most of these smart plugs showed an error in the reading of less than 5% compared to the Wibeee Box. For one plug, the error was only 0.1%, however, for another, it was over 20%.

Smart plugs offer the opportunity for monitoring long term consumption of appliances, but it is worth checking their performance against a more accurate monitor first.

There are a few issues with the devices. They are prone to loss of connection if they are shielded by furniture and walls and distant from the Wi-Fi router. If the household uses multiple appliances in a single socket, the smart plug may be disconnected or record the consumption of more than one appliance.

Advantages

- Low-cost monitoring device
- Does not require an electrician to install
- Daily electricity consumption through the socket can be recorded on an app
- Can show real-time power consumption and voltage through the socket
- Can turn the socket on and off using the smart phone app

Disadvantages

- Landlords likely to be unhappy with devices turned on and off remotely
- Requires broadband, Wi-Fi and smart phone
- Needs to be reinstalled if broadband supplier switched
- Can lose connection if poor quality Wi-Fi signal near the socket
- Issues with monitoring if household unplugs socket or uses another appliance in socket
- Accuracy of the monitoring of the smart plugs can vary

3. Review of solar immersion controllers and monitors

There are typically high levels of export to the grid in summer from homes with solar PV systems. A way to increase the level of self-consumption of the solar generation is to use a solar diverter. This uses a current transformer (CT) sensor to measure the grid import/export and when there is export to the grid, excess generation is used to power another appliance. This is often an immersion heater for a hot water cylinder, but other solar diverters can be used to charge an electric vehicle.

A solar immersion controller can heat hot water throughout the year, but is most effective between March and October. The device is a lower cost alternative to a solar thermal water heating system for households that already have or are going to fit solar PV. In most cases very little extra water heating is required between Spring and Autumn apart from on particularly dull and rainy days.

Factors which affect the level of savings achieved by a solar immersion controllers include:

- Solar PV generation
- Household electricity consumption
    - Affecting whether there is excess generation to power the immersion heater
- Hot water demand
    - Size of household
    - Number and type of showers (e.g. mixer or electric)
    - Number of baths
- Hot water cylinder
    - How much heating is provided by other sources (e.g., the gas boiler)
    - Time of day of any additional water heating occurs (e.g. boilers)
    - Length of the immersion heater and position in the tank
    - Setting for the immersion heater thermostat
    - Size of the cylinder
    - Level of insulation of the cylinder

This project aimed to install 30 solar immersion controllers and 29 had been installed by the project end date. One of the challenges for the project was finding suitable homes with hot water cylinders.

Most socially rented properties with gas central heating now have combi boilers. Properties with hot water cylinders tend to have older boilers which landlords may be planning to replace with combi boilers. With the drive to decarbonise homes, solar PV is becoming more common and can be combined with electrical and/or heat storage. There may be more heating systems fitted with hot water cylinders in future as a result.

There are many homes which are off the gas grid which use off-peak electric heating with storage heaters. Often these homes have an electric shower and a hot water cylinder with an immersion heater. Such homes are well suited for solar PV and using a solar immersion controller for water heating and fitting a mixer shower would significantly reduce water heating costs.

3.1. Marlec Solar iBoost+ immersion controller and Buddy monitor

Figure 3.1 Marlec Solar iBoost+ solar immersion controller

The Solar iBoost+ consists of the main Solar iBoost+ unit, a battery powered ‘sender’ and a current transformer (CT) sensor.

The Solar iBoost+ main unit is typically fitted near the hot water cylinder and electrically connected between a fused outlet or the MCB (miniature circuit breaker) and the immersion heater[5]. There needs to be a minimum clearance of 100mm around the unit to allow airflow for cooling. It is best if it is not fitted on wooden or stud walls as there is the risk that the sound of the fan might be amplified. The device can power 2 separate 3kW circuits. This could be the immersion heaters in the top and the bottom of the hot water cylinder. Each immersion heater must have a working mechanical thermostat.

The CT sensor fits around the live cable that runs between the main utility meter and the consumer unit. It is important that the CT sensor is fitted in the correct orientation to ensure that it detects excess current and only uses this to power the immersion heater. It is important that the installer fits this correctly and anyone moving the clamp such as a smart meter installer does not replace the sensor incorrectly. Otherwise, it would lead to increased bills rather than savings.

The ‘sender’ is paired with the main Solar iBoost+ unit by holding button B on the main unit until ‘Pairing with sender’ is displayed and then the button on the ‘sender’ is held for up to 10 seconds to pair the devices. When the batteries on the ‘sender’ unit are starting to go flat, a message will be shown on the Solar iBoost+ display saying, ‘Sender Battery LOW’. The batteries should be replaced as soon as possible after seeing this message. The manufacturer recommends several tests as part of the commissioning process for the device. These tests aim to verify that the Solar iBoost+ is only using excess PV generation to power the immersion heater.

[5] Solar iBoost+ Installation Instructions, https://www.marlec.co.uk/wp-content/uploads/2018/10/Solar-iBoost-Installation-Instructions-SM-504A-010818.pdf (Accessed 1 Feb 23)

The solar immersion controller cuts in when the level of generation from the solar panels is about 100W higher than the household consumption. It will only do this until the hot water cylinder achieves its target temperature based on the immersion heater thermostat. The Solar iBoost+ will then display a message 'Water tank HOT'.

The solar immersion controller may cut out before the water is sufficiently hot if the thermostat for the immersion heater has not been set sufficiently high. The other risk is that the water from the system may be too hot if it has been set too high. Following the installation and after running the system on a sunny day, it may be necessary to adjust the immersion heater thermostat up or down.

It is possible to see how much electricity has been diverted to the immersion heater by pressing the left hand 'Display' button on the Solar iBoost+. This can show the amount of energy that has been saved today, yesterday, in the last 7 days, in the past 28 days and since the system was installed.

The Solar iBoost+ can be programmed to power the immersion heater from the grid at set times. There can be different times programmed for the summer and the winter. It is also possible to have a manual boost for periods of 15 minutes or more by pressing the right hand 'Boost' button on the Solar iBoost+ main unit.

It is possible to add the mains powered iBoost+ Buddy monitor to the system. This is useful for monitoring the performance of the Solar iBoost+ diverter and also the solar panels.

Figure 3.2 Marlec iBoost+ Buddy monitor and its features[6]

[6] Solar iBoost Buddy Display, https://www.marlec.co.uk/product/solar-iboost-buddy/ (Accessed 1 Feb 23)

Pairing the Buddy with the iBoost+ is easy. Buttons B and Boost on the top right of the Buddy display are held down for 5 seconds. One of the buttons on the Solar iBoost+ is pressed to wake it up and Button B on the Solar iBoost+ is also held for 5 seconds. The display on the Solar iBoost+ should then show the message 'Pairing Successful'.[7]

The display will show the amount of power currently going to the immersion heater and the historic savings can also be displayed by pressing the left-hand display button.

At the top of the Buddy monitor is a coloured LED. This glows red if more than 300W of electricity is being imported from the grid. It will change to green if there is more than 300W being exported to the grid. This is useful for households as it indicated there is spare electricity which could power appliances in the home. The LED glows amber during the periods of low import or export. This will occur for example when the Solar iBoost is powering the immersion heater and trying to match the solar generation.

As well as the traffic light LED, there is a speedometer or eco-gauge on the LCD screen. The gauge moves clockwise when there is solar generation being exported and anti-clockwise when there is electricity being imported from the grid. The digital energy reading shows the current value of either electricity import or export. The combination of the eco-gauge and digital energy reading provides an easy indicator of whether there is spare generation which could power home appliances.

Advantages

- Solar iBoost+ is suitable for households without the internet or a smart phone
- The Buddy is a simple to use monitor which shows savings and import/export
- Traffic light LED and Eco-gauge is easy to understand
- The device is relatively inexpensive and is an alternative to solar thermal water heating

Disadvantages

- The 'sender' unit is battery powered which might be an issue with rented properties
- There is limited data available on the savings
- It is not possible to check historic savings, consumption and generation online
- Buddy monitor needs mains power which might limit where it can be located

[7] iBoost+ Buddy Operating Instructions, https://www.marlec.co.uk/wp-content/uploads/2018/06/SM-503B-iBoost-Buddy-Manual-290518.pdf (Accessed 1 Feb 23)

3.2. Myenergi eddi solar immersion controller with myenergi app

Figure 3.3 Devices manufactured by myenergi[8]

Myenergi is a UK company which manufactures several green technologies. These include the eddi solar immersion controller, the zappi electric vehicle charger and the libbi modular battery storage system. All these devices can improve the self-consumption of solar PV by diverting excess generation which would otherwise be exported to the grid. The devices can be combined in the same ecosystem with monitoring and control via the myenergi app. There is also a myenergi web portal where graphs of consumption/export and device use can be plotted. At the time of writing, it was not possible to download data from the portal or app.

The myenergi eddi is an advanced solar immersion controller which offers many options and settings. The device can power two heaters sequentially like the Solar iBoost. This could be a second immersion heater or some other form of electric heater. Examples of other types of electric heating include an electric radiator or underfloor heating mat on a dedicated circuit with an isolator switch. There is a manual and programmable boost along with automatic daylight-saving time adjustment for the clock.

An optional relay and sensor board can be easily added to the eddi. Among the things this offers is the ability to integrate with heat pumps and their heating cycle to kill off Legionella bacteria. The heat pump immersion heater relay is connected to the relay and sensor board and responds to a signal from the heat pump, powering the immersion heater.

The system can work well with battery storage. The myenergi libbi battery system integrates directly with the eddi. Other battery systems can also be accommodated. It is possible to increase the threshold of export at which the eddi starts to power the heater from 0W to say 100W, which would allow the battery to charge first. Also, an additional current transformer (CT) sensor can be fitted which could monitor the battery system.

[8] Eddi turns excess solar into heat, https://blog.spiritenergy.co.uk/homeowner/eddi-excess-solar-heat (Accessed 3 Feb 2023)

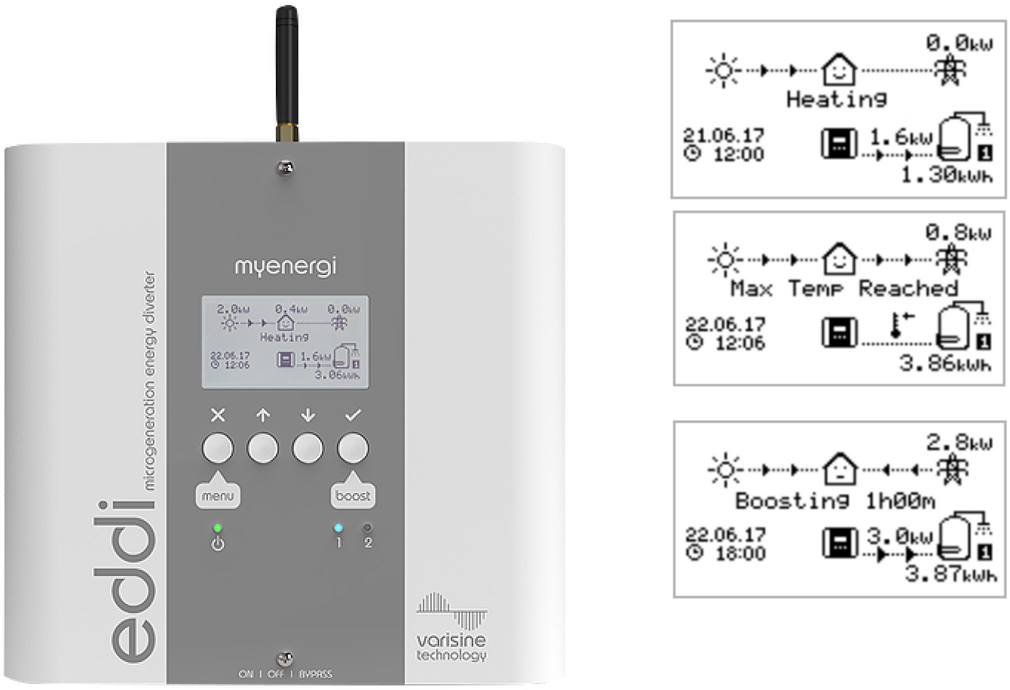


Figure 3.4 Myenergi eddi version 1 solar immersion controller and images from the display

The display on the eddi provides information on the operational state of the eddi, the power being exported or imported, the power to the heater and amount diverted that day. Further information is available with the myenergi app. To connect the version 1 of the eddi to the internet it was necessary to have a myenergi hub communications unit. This device was mains powered, wirelessly paired with the eddi and was connected to the home broadband router via an Ethernet cable. Version 2 of the myenergi eddi was released in August 2022. It has built in Wi-Fi and Ethernet, so a myenergi hub is not required.

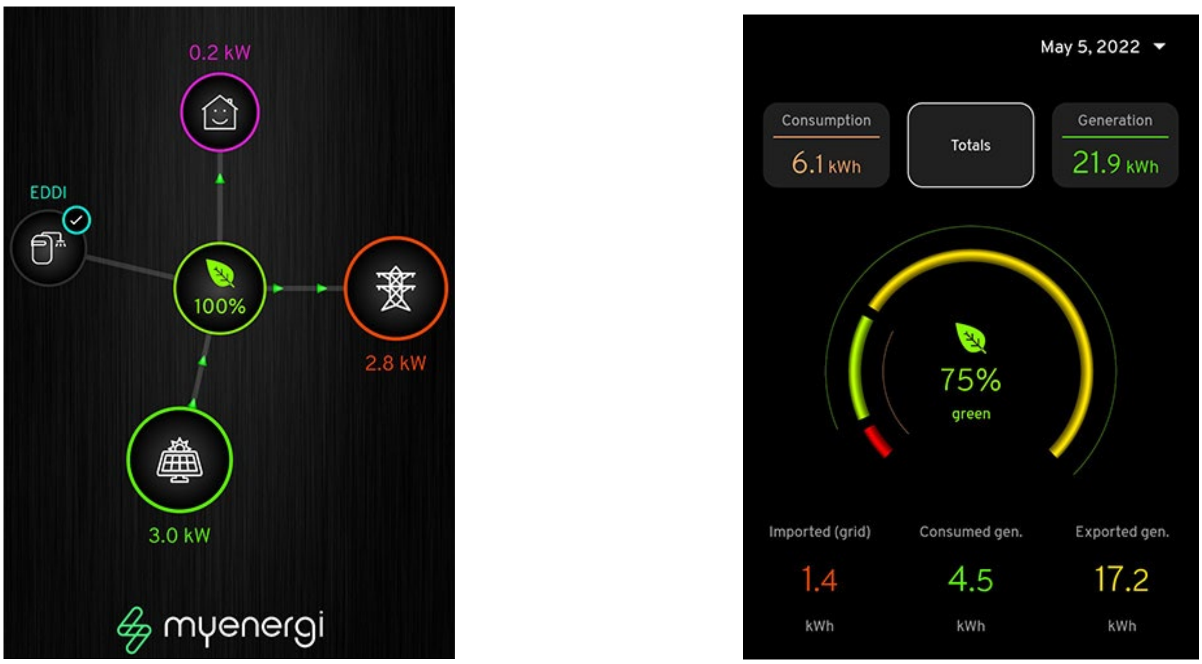


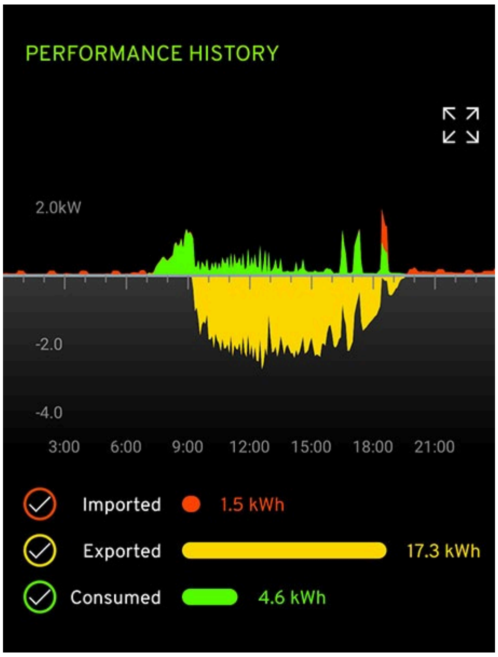
Figure 3.5 (a) Myenergi app home screen (b) Myenergi app totals screen

A grid CT sensor is fitted between the electricity meter and the consumer unit to measure when there is export to the grid. There is the option to fit a second CT sensor to monitor the PV generation. This allows the main screen to show the generated power and the total power consumption of all the other appliances in the property. Additional CTs can also be fitted for battery systems or general loads such as a heat pump.

Figure 3.5 (a) shows the home screen of the myenergi app. This particular installation showed generation from the solar panels, consumption by the eddi (in figure 3.5 (a) it had reached temperature and so displayed a tick), consumption by the home and export to the grid. If the household had a zappi electric vehicle charger or a libbi battery, there would also be a circle for these.

By clicking on any of the circles, showing the solar panel, grid, or home, you can plot graphs of the generation, export or consumption. By clicking on the leaf in the middle you can plot graphs and see totals covering all the other circles. Figure 3.5 (b) is the first screen that is shown with the totals for consumption, generation, import, consumed generation and exported generation. This data and the graphs associated with the this can be obtained for today, yesterday, this week, last week, this month, last month and a custom date.

Scrolling the screen up, there is a Performance History graph, with the electricity import shown in red, the exported generation in yellow and the consumed generation in green (figure 3.6 (a)). Scrolling further to the bottom, there is a graph (figure 3.6 (b)) which shows the electricity diverted by the eddi (in cyan) and the electricity consumed by the home (in magenta).



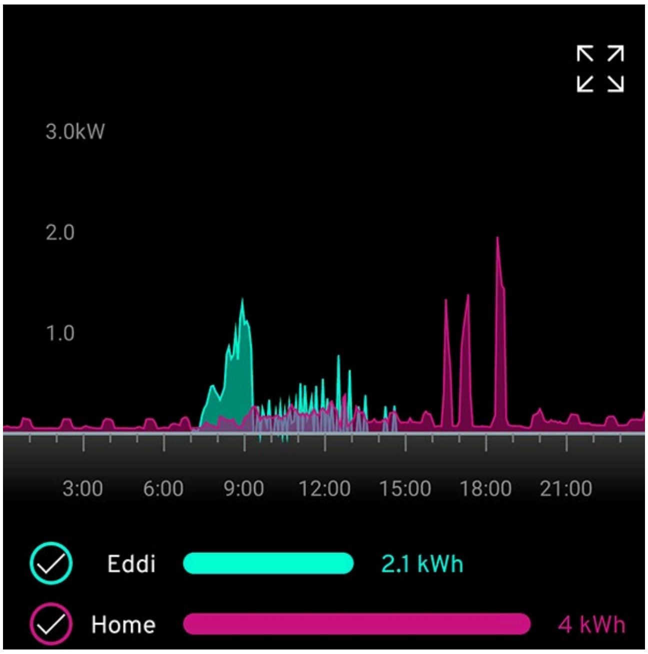
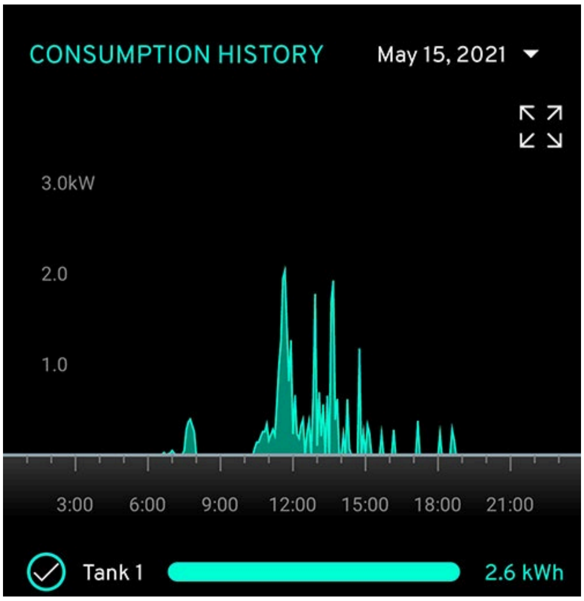


Figure 3.6 (a) Performance History (b) eddi and household consumption

By clicking on the circle for the eddi, it is possible to look at the consumption history specifically for the eddi (figure 3.7 (a)). This can be for any date and for both tank 1 and tank 2. By clicking on the tab for a specific tank, it is possible to set a manual boost (figure 3.7 (b)) or schedule a timed boost.



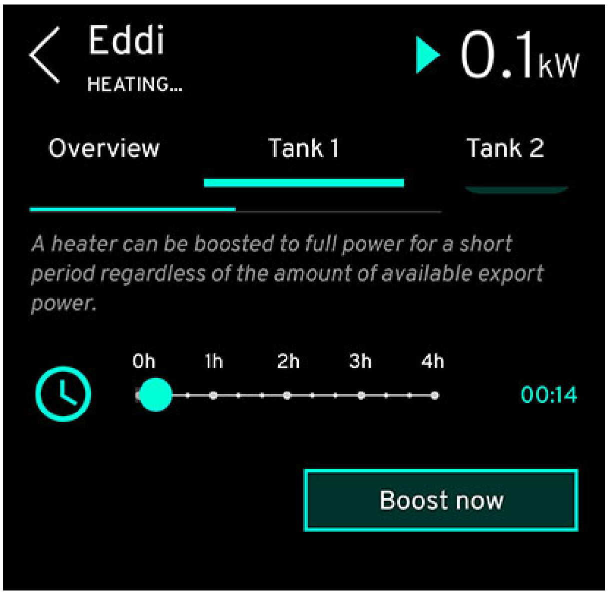


Figure 3.7 (a) eddi consumption history (b) Manual boost for eddi in myenergi app

Advantages

- Myenergi integrate their eddi solar diverter, zappi EV charger and libbi battery
- The eddi is a highly flexible solar immersion controller
- It can work with heat pumps and respond to Legionella heating cycles
- The latest version includes built in Wi-Fi and Ethernet communication
- The myenergi app can provide data and graphs for any date

Disadvantages

- The monitoring system requires the internet and ideally a tablet or smart phone
- It is more expensive than rival solar immersion controllers
- Accuracy of the data recorded is not as high as for some other monitors

4. Case studies with PV monitors and solar immersion controllers

Among the aims of the project was to install solar PV monitors and solar immersion controllers and assess how they performed. Delays due to the COVID-19 pandemic and issues with partners meant that many of the monitors and solar immersion controllers were installed later than had been planned and there were limited sites where data was available for analysis.

There were 2 sites with solar immersion controllers where longer-term performance data was available. These sites also trialled solar monitors such as the Wibeee Box and Eco Eye and it was possible to compare the performance of the different systems at these sites.

Shorter case studies were also produced for households that received Solis Wi-Fi dongles, Eco Eye Smart PV monitors and the GEO Solo PV II monitor.

4.1. Case Study 1 – Household with a GEO Solo PV II monitor and a solar PV system with a Solis inverter

Household G-01 lived in a bungalow which was off the gas grid. Space and water heating was provided by an oil boiler, although there was an electric shower. The residents were retired and at home most of the day.

They had a solar PV system funded by the Green Homes Grant Local Authority Delivery (LAD) scheme. The system was rated at 2.76kW and faced approximately southwest, with an estimated annual generation of 2,642kWh and was commissioned on 20 Aug 21.

Over nearly a year, from 25 Nov 21 until 21 Nov 22, the PV generation was 2,913kWh, which was above the estimated generation.

On 21 Nov 22 the generation meter reading was 3,499 kWh and a value of export obtained from the smart meter was 2,551 kWh. This indicated from the installation date on 20 Aug 21 until 21 Nov 22, the electricity used from the solar PV was 948kWh and the percentage self-consumption was 27.1%.

The generation reading on the Solis inverter on 21 Nov 22 was 3,476kWh, a difference of 23kWh compared to the generation meter and an error of 0.66%.

4.2. Case Study 2 – Household with a Solis inverter and Wi-Fi dongle

Household S-01 had a 2.07kW solar PV system fitted in Devon under the Green Homes Grant LAD scheme. The system was commissioned on 23 Aug 21 and the annual generation was estimated to be 2,252kWh. The system faced approximately south and there was limited shading.

An estimate of the annual generation was made using PVGIS and this was slightly lower than the value estimated by the installer at 2,102kWh. Generation meter readings and inverter meter readings were taken during visits in March and November 2022.

Table 4.1 shows monthly estimates of generation from PVGIS[9] along with monthly values of generation recorded by the Solis inverter system during the monitoring period. Also included are values of household electricity consumption obtained from the smart meter in-home display during visits.

Month	PVGIS Estimated Generation (kWh)	Solis Inverter Wi-Fi dongle (kWh)	Household Consumption (kWh)
Feb 22	114		206
Mar 22	185.6	205	174
Apr 22	242.1	241	153
May 22	257.8	246	160
Jun 22	251.4	259	149
Jul 22	254.2	266	139
Aug 22	230.3	261	118
Sep 22	195.8	168	123
Oct 22	134	144	153
Nov 22	92.3	77	
Dec 22	65.7	52	
Jan 23	79	76	
Total	**2,102**		

Table 4.1 Estimate PV generation, actual generation and household consumption for household S-01

For the period March 2022 to January 2023, PVGIS estimated the generation to be 1,988kWh and the actual generation recorded by the Solis inverter was 1,995kWh. This was very close to the estimated generation and suggests the system was performing as might be expected over this period.

The generation meter reading on 21 Nov 22 was 2,405kWh and the reading from the Solis inverter was 2,363kWh. The Solis inverter reading was therefore 1.75% lower than the generation meter reading.

On 21 Nov 22, the level of export recorded by the smart meter since installation on 23 Aug 21 was 1,827kWh. Therefore, the level of self-consumption was 24.0%.

The annual generation is estimated to be about 2,102kWh and the annual household consumption from November 2021 to October 2022 was 2,153kWh. The resident was working full-time on shifts, but could be in part of the day. Estimates of the percentage annual self-

[9] Photovoltaic Geographical Information System (PVGIS), EU Science Hub, https://re.jrc.ec.europa.eu/pvg_tools/en/ (Accessed 10 Feb 23)

consumption of solar PV can be made using the MCS Guidance Document MGD 003[10]. For a household with the above values of annual generation and consumption who is out all day, the percentage self-consumption is 19%, while for a household in half the day it is 24%.

Note that for the period 23 Aug 21 to 21 Nov 22, there is an additional Autumn period with lower generation and this is likely to increase the overall percentage self-consumption. However, the actual and estimated values were quite close.

4.3. Case Study 3 – Household with a myenergi eddi solar immersion controller, Wibeee Box and Eco Eye monitors

Household W-01 had gas central heating and a mixer shower. The property was normally occupied by a single resident who was often away at the weekend during the monitoring for this project. A 4kW solar PV system was installed in July 2012. The system was made up of 20 x 200W panels in a split array with 8 panels on the left of the roof and 12 panels on the right (figure 4.2). Lower down in the middle part of the roof were 2 old flat plate solar thermal collectors which were fitted in about 1980.

There was originally no monitoring with the system apart a standard generation meter. The roof faced about 15˚ west of south and was inclined at 20˚. On the MCS certificate, the estimated annual generation was 3,219kWh. An estimate using PVGIS and assuming no shading suggested an annual generation of 3,966kWh.

Figure 4.2 Household W-01 with solar PV arrays on the left and right and 2 flat-pate solar thermal collectors in the middle of the roof

[10] MCS Guidance Document:MGD 003, Determining the Electrical Self-Consumption of Domestic Solar Photovoltaic (PV) Installations with and without Electrical Energy Storage, https://mcscertified.com/wp-content/uploads/2022/04/MGD-003-Solar-PV-Self-Consumption-Issue-2.0-Final.pdf (Accessed 26 Jan 23)

There was some shading of the split PV array due to a nearby large tree. Figure 4.2 was taken on 21 Jan 23 at 11:00 and there was significant shading of the left-hand solar PV array. This shading moved to the right-hand array later in the day. Shading was greater when the sun was lower in the sky, particularly in the morning and outside the summer months.

A Wibeee Box monitor was fitted at the site in October 2020 and was able to record the household consumption, electricity consumption on the cooker circuit and the solar PV generation. There was a loss of 4 days data in April 2022 as the monitoring portal shifted from Wibeee Home to Wibeee Nest. The system also only recorded grid import and export after the Wibeee Nest portal was set up for solar PV in mid-July 2022.

Figure 4.3 shows an Excel graph of solar PV generation on 29 Aug 22 using 1-minute data from the Wibeee Box monitor. It was a bright sunny day and the plot was a characteristic bell shaped curve. There may have been some clouds overhead at lunchtime which may have caused the dip in generation. The system never generated more than a maximum of 3.3kW despite having used a 4kW inverter. This might be due to the shading, although the Distribution Network Operator (DNO) requested the system be restricted due to the inverter being rated at more than 3.68kW.

A plot of monthly solar PV generation is shown in figure 4.4 for 3 years for household W-01. The data from 2013 was based on meter readings taken from the generation meter for the system. Values from 2021 and 2022 were based on data from the Wibeee Box logger.

In 2013, soon after installation, the annual generation was 3,609kWh while the value recorded in 2021 using data from the Wibeee was 3,527kWh. The generation recorded by the Wibeee logger in 2022 excluding the 4 full days of missing data in April was 3,591kWh. The annual generation for this system was typically in the range 3,500 to 3,650kWh.

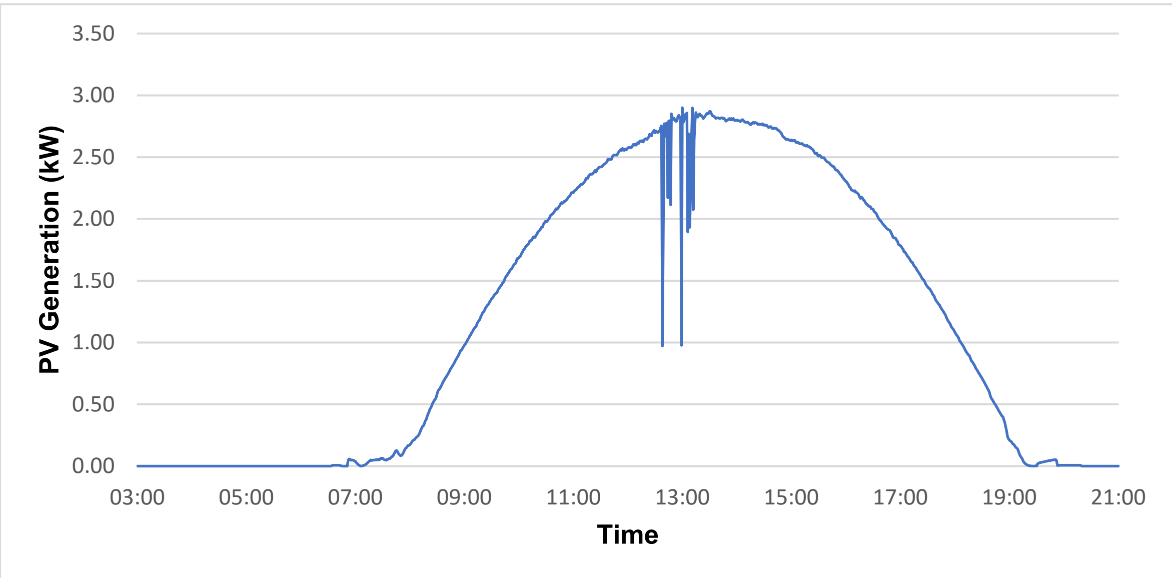


Figure 4.3 Plot of solar PV generation on 29 Aug 22 for household W-01 using 1-minute data from the Wibeee Box monitor

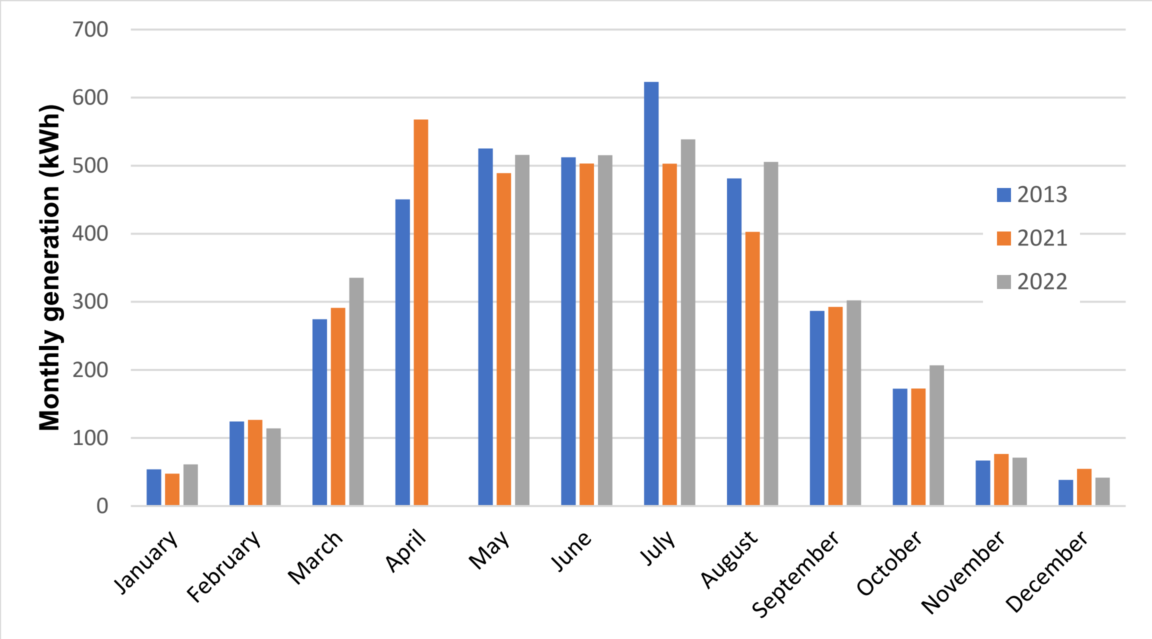


Figure 4.4 Plot of monthly solar PV generation for household W-01 based on data from the generation meter (2013) and the Wibeee Box monitor (2021 and 2022)

There was a solar thermal flat plate collector at the property, but this only provided significant benefit in the middle of summer. Performance had also deteriorated after a new wet central heating system and a larger 172 litre hot water cylinder was fitted in 2019. A myenergi eddi solar immersion controller was fitted at this site in mid-January 2021. This included a myenergi hub to allow online monitoring. A second CT sensor was fitted later that year to improve the monitoring of the solar generation.

A Solar Energy graph for household W-01 from the Wibeee Nest portal for the bright sunny day of 29 Aug 22 is shown in figure 4.5. This is the same day as the data in the Excel graph in figure 4.3. The solar generation in yellow is negative on the graph while the consumption in blue is positive. The shaded yellow areas show export of the solar generation.

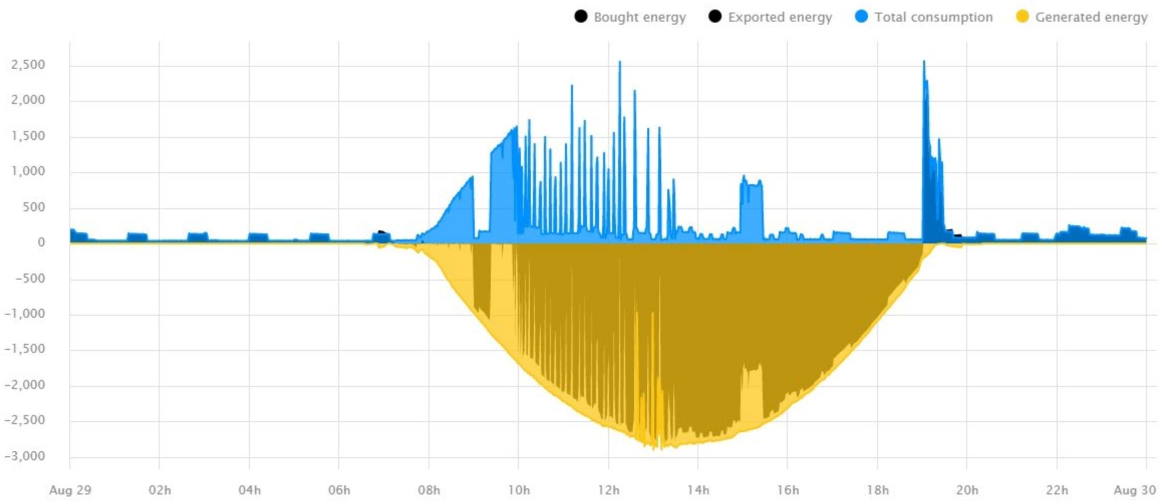


Figure 4.5 Plot of solar PV generation and electricity consumption on 29 Aug 22 for household W-01 from the Wibeee Nest portal

Figure 4.6 shows data from the myenergi app on the same day. In figure 4.6 (a), electricity imported from the grid is shown in red. There was a ripple of consumption overnight and this was due to the baseload of appliances including the fridge turning on and off. There was a peak in grid import in the early evening at 19:00 due to cooking. The myenergi monitoring system estimated that on 29 Aug 22 the generation by the solar PV system was 21.6kWh. Out of this, 17.8kWh was exported to the grid (shown in yellow in figure 4.6 (a)) and 3.8kWh of that generation was consumed in the home (shown in green). Out of the 3.8kWh of solar generation used in the home, 2kWh of this was diverted to power the immersion heater by the myenergi eddi. Figure 4.6 (b) shows a couple of peaks in consumption (in cyan) due to the eddi at about 08:00 to 09:00 and 09:00 to 10:00, with further lower power spikes in consumption until just after 13:00. The spikes in consumption due to the immersion heater coming on for short periods between 10:00 and 13:30 are also clear in figure 4.5, with the Wibeee Nest plot on the same day. The peaks were higher with the 1-minute resolution data.

On 29 Aug 22, using data from the myenergi app, the level of self-consumption of the solar generation was 17.6%. Without the myenergi eddi, it would have been only 8.3%.

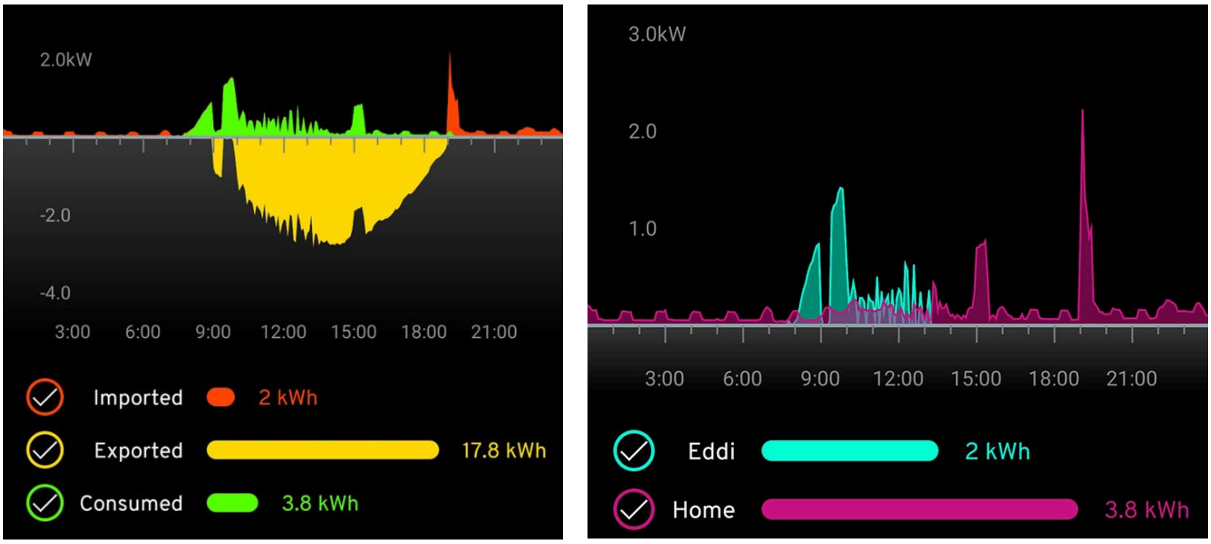


Figure 4.6 (a) (b)

Plot of the solar generation, household consumption and Eddi consumption from the Myenergi app for household W-01 on 29 Aug 22

A smart meter was fitted for household W-01 in May 2022. Table 4.7 and figure 4.8 show the monthly grid consumption recorded by the smart meter, myenergi app and Wibeee monitor.

The grid consumption recorded by the smart meter ranged from 34.4 kWh (1.15kWh/day) in June 2022 to 75.9kWh (2.45kWh/day) in January 2023. The household was a low electricity consumer. There was rarely any supplementary electric heating used. Clothes were washed about once a week, normally when it was sunny, and there was no tumble drier. A halogen oven or microwave was used instead of a conventional oven. The resident was also often away at weekends, which reduced the average consumption.

Grid consumption data was available from the myenergi app for the whole of 2022. However due issues associated with the switch to Wibeee Nest, grid consumption readings were only available for the Wibeee monitor from mid-July 2022.

The difference between the Wibeee monitor and the smart meter readings for grid consumption was small. This ranged from the grid consumption recorded by the Wibeee being 1.8% lower in November 2022 to 4.6% lower in January 2023. In August and November 2022, the difference in readings was only 1kWh.

The difference between the grid consumption recorded by the myenergi app and the smart meter was considerably higher. This ranged from the values recorded by the myenergi app being 16.6% to 33.6% higher than the smart meter. The accuracy of the grid consumption readings on the myenergi app was greater when the grid consumption was higher and the PV generation was lower. Myenergi advised that this issue may have been due to the eddi using old firmware and an update to the firmware was subsequently downloaded.

Month	Smart Meter (kWh)	Wibeee (kWh)	Myenergi eddi (kWh)	Wibeee offset to Smart Meter (%)	Eddi offset to Smart Meter (%)
Jan-22			72.5		
Feb-22			60.3		
Mar-22			58.8		
Apr-22			56.6		
May-22			45.8		
Jun-22	34.4		46.0		33.6%
Jul-22	37.8		49.0		29.6%
Aug-22	43.3	42.3	53.6	-2.4%	23.7%
Sep-22	45.4	43.9	55.3	-3.2%	21.9%
Oct-22	49.1	47.8	60.1	-2.6%	22.5%
Nov-22	60.0	59.0	71.9	-1.8%	19.8%
Dec-22	70.0	68.2	82.7	-2.6%	18.1%
2022 total			**712.6**		
Jan-23	75.9	72.4	88.5	-4.6%	16.6%

Table 4.7 Grid consumption or import for household W-01 as recorded by a smart meter, the myenergi eddi app and the Wibeee monitor

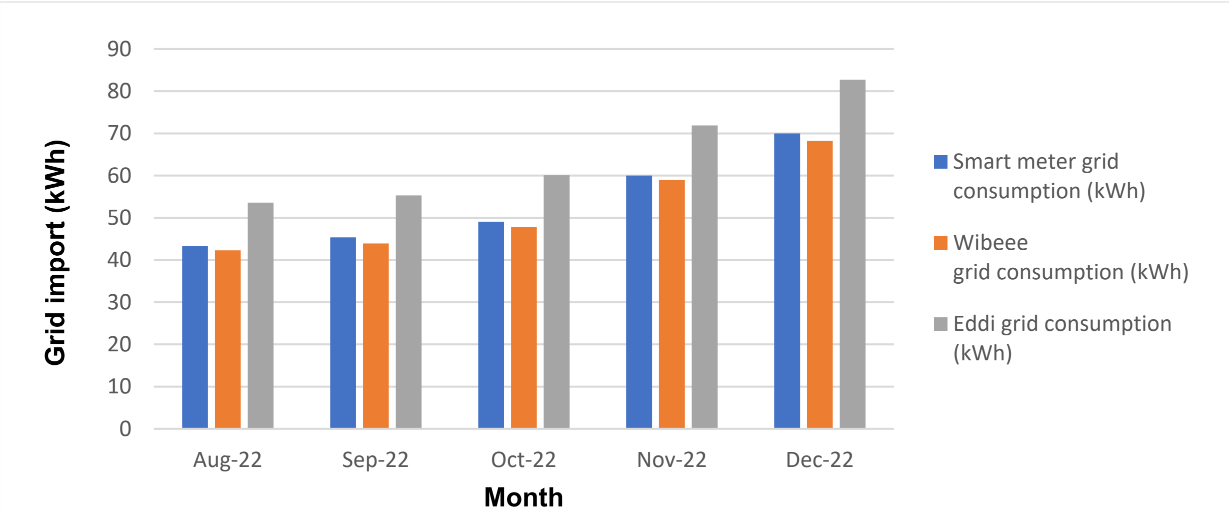


Figure 4.8 Plot of grid consumption recorded by a smart meter, Wibeee Nest and myenergi eddi

The solar PV generation measured by the Wibeee monitor and myenergi eddi is shown in table 4.9. The data for the Wibeee from January 2021 up until the end of March 2022 came from the Wibeee Home portal. Over the whole of 2021, the Wibeee monitor measured the solar PV generation as 3,527kWh.

PV generation data was available from the myenergi app from May 2021, and this was normally between 2 and 3% higher than the reading from the Wibeee Home portal. In December 2021, the reading was 37% lower than with the Wibeee. This was likely to have been due to broadband connectivity issues.

The household switched between the Wibeee Home and Wibeee Nest portals in April 2022. As a result of this switch, 4 full days of data were lost and part of 2 further days. This meant a full year of generation data was not available in 2022 for the Wibeee monitor. Ignoring the missing days of data, the generation recorded was 3,591kWh compared to 3,746kWh recorded by the myenergi app. The offset between the solar generation measured by the Wibeee and eddi appeared to be lower after switching to the Wibeee Nest portal, with a difference of about 1 to 2%. In November 2022, manual readings of the generation meter recorded the generation to be 70.3kWh compared to 71.1 with the Wibeee and 71.7 with the eddi.

Month	PV generation measured by Wibeee 2021 (kWh)	PV generation measured by Eddi 2021 (kWh)	PV generation measured by Wibeee 2022 (kWh)	PV generation measured by Eddi 2022 (kWh)	Eddi offset to Wibeee 2021 (%)	Eddi offset to Wibeee 2022 (%)
January	47.6		61.3	63.7		3.8%
February	126.6		114.2	117.5		2.8%
March	291.0		335.3	344.0		2.5%
April	567.8			478.6		
May	489.1	499.6	516.0	523.3	2.2%	1.4%
June	503.3	522.5	515.5	523.7	3.8%	1.6%
July	503.0	513.4	538.7	547.6	2.1%	1.6%
August	402.7	407.5	505.5	515.3	1.2%	1.9%
September	292.4	299	302.1	308.0	2.2%	1.9%
October	172.7	176.8	206.7	209.9	2.4%	1.5%
November	76.4	78.7	71.1	71.7	3.0%	0.8%
December	54.7	34.3	41.7	42.3	-37.3%	1.3%
Total	**3527.3**			**3745.6**		

Table 4.9 Solar PV generation for household W-01 as recorded by the myenergi eddi app and the Wibeee monitor

Table 4.10 shows several sets of data recorded by the myenergi app and values of self-consumption of the solar PV based on that data. The second column shows the solar PV generation recorded by the myenergi app while the third column is the amount of this generation that was consumed in the home. The fourth column is the amount of excess solar generation that was diverted to power the immersion heater by the eddi. The remaining electricity that was exported to the grid each month is shown in column 5.

Month	Generation (kWh)	Total consumed generation (kWh)	Diversion by Eddi (kWh)	Export to the grid (kWh)	Self-consumption of solar generation with eddi (%)	Self-consumption of solar generation without eddi (%)
May-21	499.6	101.3	45.1	398.3	20.3%	11.2%
Jun-21	522.5	79.6	24.1	442.9	15.2%	10.6%
Jul-21	513.4	69.8	15.7	443.6	13.6%	10.5%
Aug-21	407.5	81	33.9	326.5	19.9%	11.6%
Sep-21	299	73.3	36.5	225.7	24.5%	12.3%
Oct-21	176.8	66.3	38.4	110.5	37.5%	15.8%
Nov-21	78.7	49.4	29.8	29.3	62.8%	24.9%
Dec-21	34.3	28.5	15.3	5.8	83.1%	38.5%
Jan-22	63.7	33.8	17.6	29.9	53.1%	25.4%
Feb-22	117.5	46.5	26	71	39.6%	17.4%
Mar-22	344	69.6	31.9	273.8	20.2%	11.0%
Apr-22	478.6	98.2	48.2	380.4	20.5%	10.4%
May-22	523.3	80.6	30.5	442.7	15.4%	9.6%
Jun-22	523.7	92.5	37.4	431.2	17.7%	10.5%
Jul-22	547.6	70.7	16.5	476.9	12.9%	9.9%
Aug-22	515.3	72.9	22.8	442.4	14.1%	9.7%
Sep-22	308	87	49.3	221	28.2%	12.2%
Oct-22	209.9	81.3	50.6	128.6	38.7%	14.6%
Nov-22	71.7	51.2	32.2	20.5	71.4%	26.5%
Dec-22	42.3	36.6	22.1	5.7	86.5%	34.3%
2022	**3745.6**	**820.9**	**385.1**	**2924.1**	**21.9%**	**11.6%**

Table 4.10 Generation and consumption data from the myenergi app along with levels of self-consumption of solar PV for household W-01

Between May and July, the monthly generation was typically over 500kWh. This dropped considerably between November and January with generation typically between 30 and 80kWh per month. Out of this generation, only 5 to 6kWh was exported to the grid in December, but the PV export increased to over 400kW a month during the summer.

Figure 4.11 shows that the generated electricity that was consumed in the home ranged from 28.5kWh in December 2021 to 101.3kWh in May 2021. The total consumed generation was low in winter due to low levels of PV generation. The consumed generation was at its highest for this household in Spring and Autumn. This was when the greatest amount of PV generation was diverted by the eddi. The amount of solar generation diverted by the eddi to power the immersion heater ranged from 15.3kWh in December 2021 (a month with some likely data loss) to 50.6kWh in October 2022. The electricity diverted by the eddi over the whole of 2022 was 385.1 kWh or 1.06kWh/day.

There was limited diversion in winter due to lower PV generation. There was also reduced diversion by the eddi in the middle of summer (e.g. 15.7kWh in July 2021) as this was when the old solar thermal flat-plate collector was able to supply much of the water heating demand. In June 2021 and July 2022, the eddi solar immersion controller was responsible for about 23% of the consumed PV generation. However, between September 2021 and April 2022, the eddi was responsible for 45 to 63% of the monthly consumption of PV generation.

Figure 4.12 and columns 6 and 7 of table 4.10 show the percentage self-consumption of the solar generation with the myenergi eddi solar immersion controller and also what it would have been had the eddi not been fitted. Without the eddi, the self-consumption would have ranged from 9.6% in May 2022 to 38.5% in December 2021. In 2022, the self-consumption of the solar generation without the eddi would have been 11.6%.

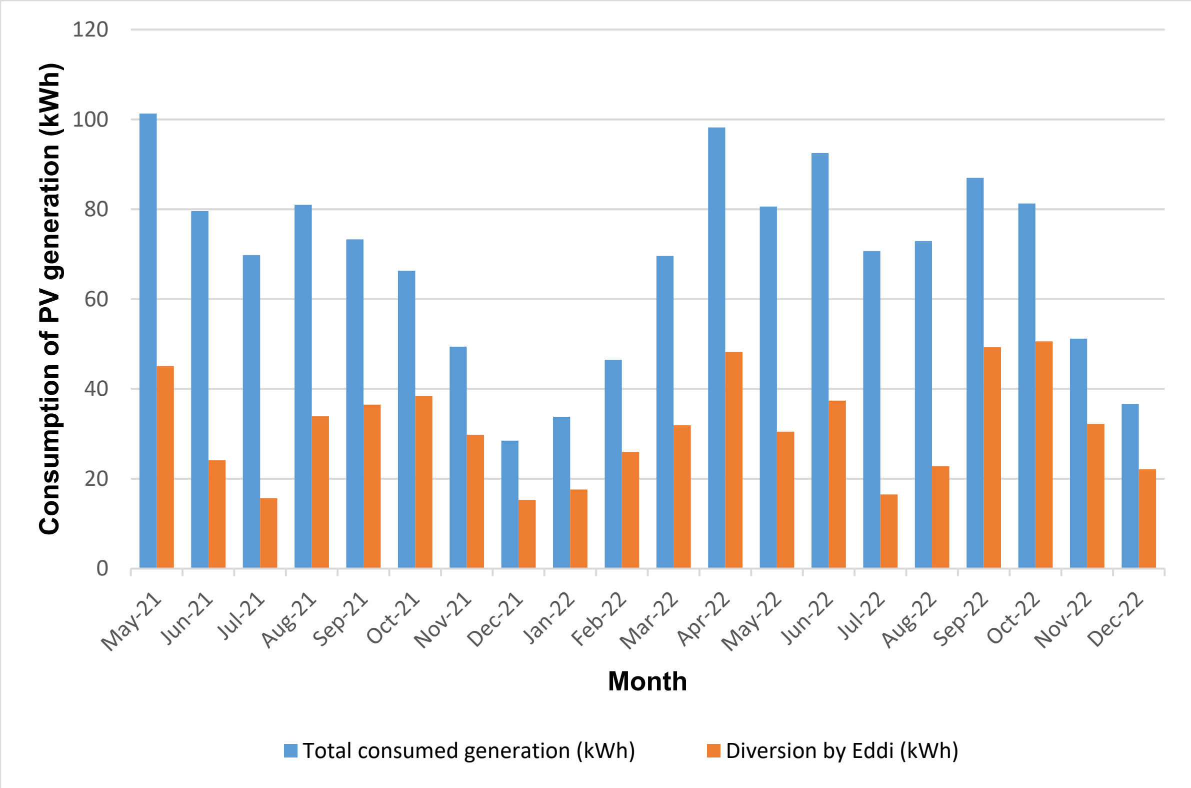


Figure 4.11 Graph showing the monthly solar PV generation consumed by household W-01 and the amount of this that was diverted by the eddi solar immersion controller

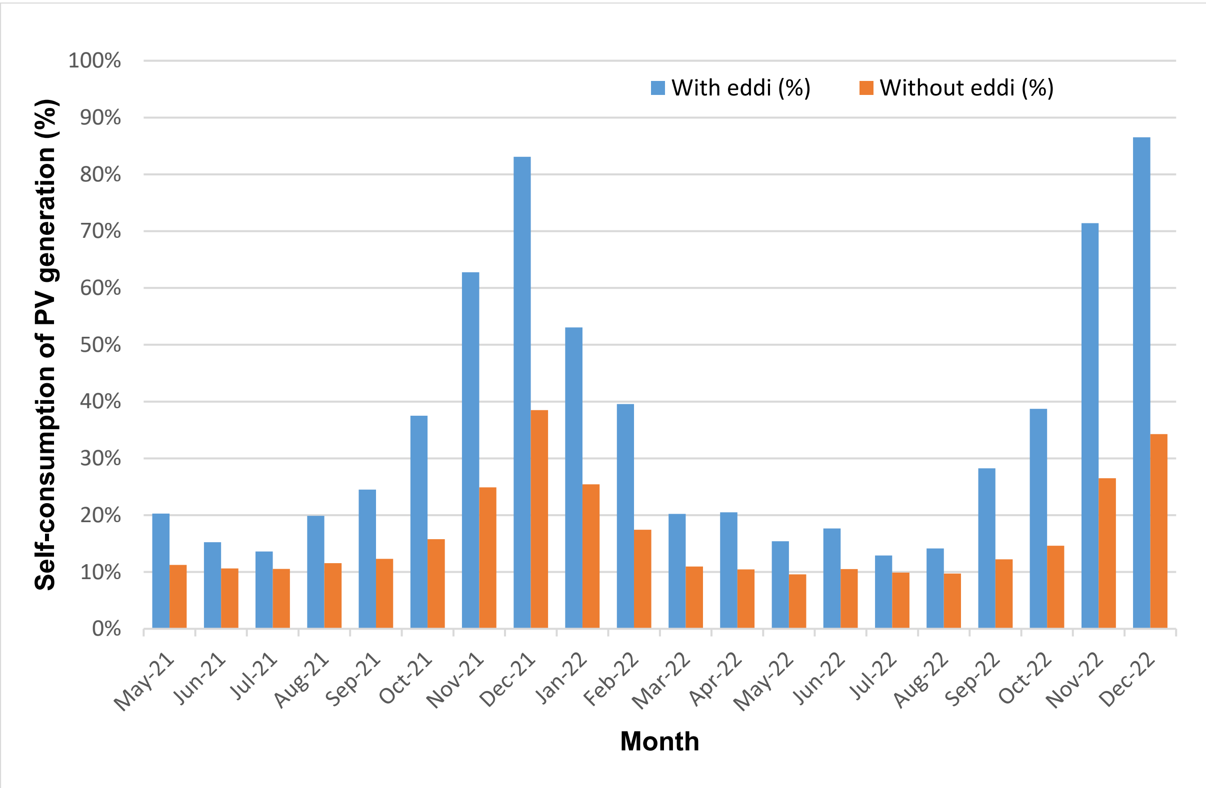


Figure 4.12 Graph showing the percentage self-consumption of the solar PV generation for household W-01 with and without the eddi solar immersion controller

With the myenergi eddi running, the self-consumption of the solar generation in 2022 for household W-01 was 21.9%. During 2022, the eddi was responsible for 46.9% of the self-consumption of solar PV. There was 16.5kWh diverted by the eddi in July 2022 and this increased the self-consumption from 9.9% to 12.9%. In the middle of summer there were some days when there was no water heating by the eddi despite there being hot water consumption in the home. The low level of diversion by the eddi in the middle of summer was due to significant water heating by the solar thermal panel system on sunny, hot days.

The hot water cylinder was an RM Stelflow 180 unvented indirect twin coil (figure 4.13). This was suitable for a home with a gas boiler and solar thermal panels. The cylinder had a capacity of 172 litres. The solar thermal system was connected to the lower of the two coils and the specification noted there was a dedicated solar volume of 60 litres. The immersion heater was a short horizontal unit which was fitted just over half way up the hot water cylinder. The standing heat loss of the cylinder was 1.4kWh/day

Figure 4.13 Hot water cylinder for household W-01

In October 2022 there was 50.6kWh diverted by the eddi, more than 3 times the amount in July 2022. In this case, the percentage self-consumption of solar PV increased from 14.6% to 38.7% due to the eddi solar immersion controller. There was still a significant amount of PV generation in October (210kWh), but the solar thermal system was less effective and as a result, the majority of the water heating was from the eddi solar immersion controller.

There were days in the middle of summer with hot water consumption but no eddi diversion due to heating from the solar thermal panels. In Spring and Autumn there were days with no hot water consumption, but with water heating due to the eddi.

Figure 4.14 shows screen shots from the myenergi app for 18 Mar 22. The resident was not at home that day or the day before. The only consumption peaks were due to the baseload consumption, fridge turning on and off and from the eddi solar immersion controller. There was no consumption of hot water that day and so the water heating was just to maintain the water in the cylinder at temperature. The eddi solar immersion controller diverted 0.9kWh of the excess PV generation for water heating. This was likely to be due to compensating for heat loss from the cylinder during the day. As noted earlier, the standing heat loss for the cylinder was 1.4kWh/day.

Further screen shots from the myenergi app for 5 Feb 23 are shown in figure 4.15 for household W-01. This was also a sunny day, but the water was quite cold after the previous cloudy day. There was water heating by the eddi from about 09:00 bringing the cylinder up to temperature. The resident had a shower at about 10:00 and after this there was reheating of the water in the cylinder. The washing machine was used at 11:00 and this caused the 2kW peak in electricity consumption, which was only partially powered by the solar PV. There was additional water heating by the eddi after lunch due to hot water consumption while washing dishes. The myenergi app indicated that there was 7.2kWh of PV generation and 5kWh of this was used in the home (self-consumption of 69.4%). The amount diverted by the eddi was 3.5kWh or 70% of the solar PV that was consumed in the home.

Figure 4.14 Images from the myenergi app on 18 Mar 22, a sunny day with the resident not at home

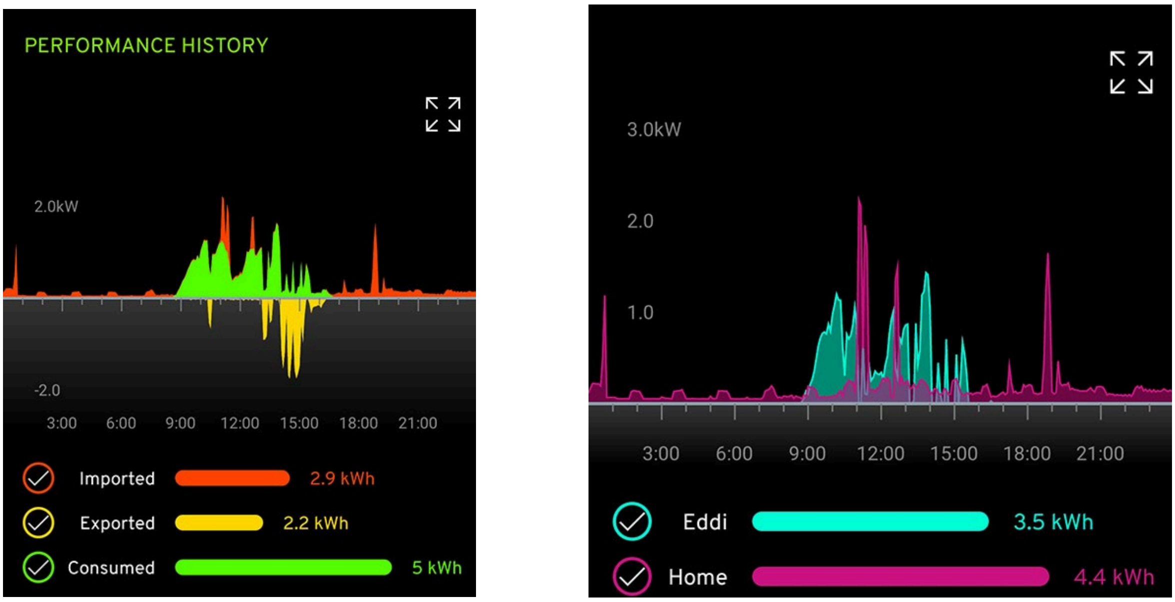


Figure 4.15 Images from the myenergi app on 5 Feb 23, a sunny day with the resident at home

Figure 4.16 shows a graph from the Wibeee Nest portal for the same day. At the end of the project, the CT-sensor for channel 2 was switched from monitoring the cooker electrical circuit to monitoring the immersion heater circuit. This meant it was possible to compare the eddi consumption in both the myenergi and Wibeee monitoring systems. The electricity diverted to power the immersion heater is shown in blue in figure 4.16 and the solar PV generation in red. Using 1-minute interval data from the Wibeee monitor, the consumption by the immersion heater was calculated to be 3.45kWh and the PV generation was 7.08kWh.

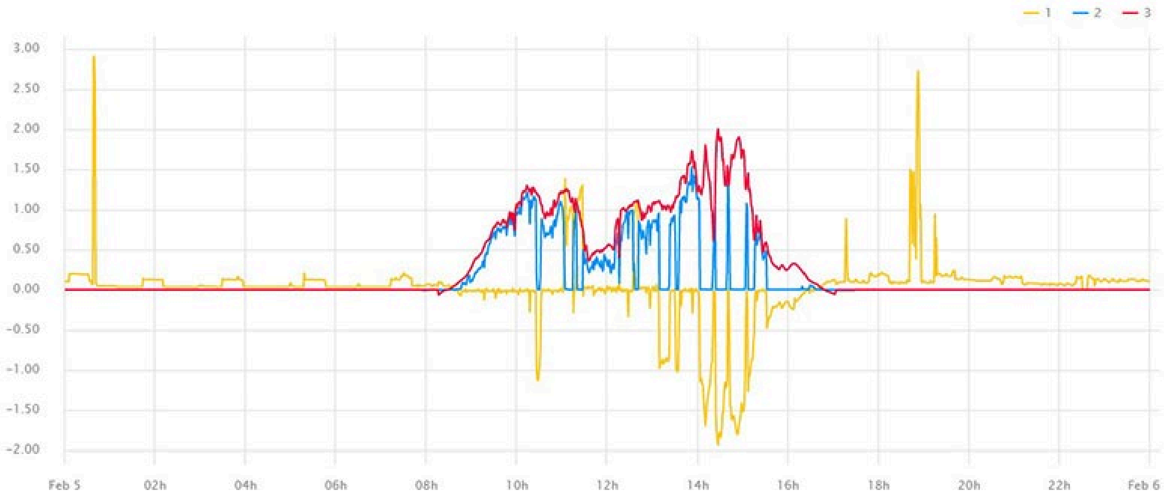


Figure 4.16 Graph from the Wibeee Nest portal showing grid import/export (in yellow), electricity consumption by the immersion heater (in blue) and PV generation (in red) for 5 Feb 23

4.4. Case Study 4 – Household with a Solar iBoost+ immersion controller and several monitoring devices

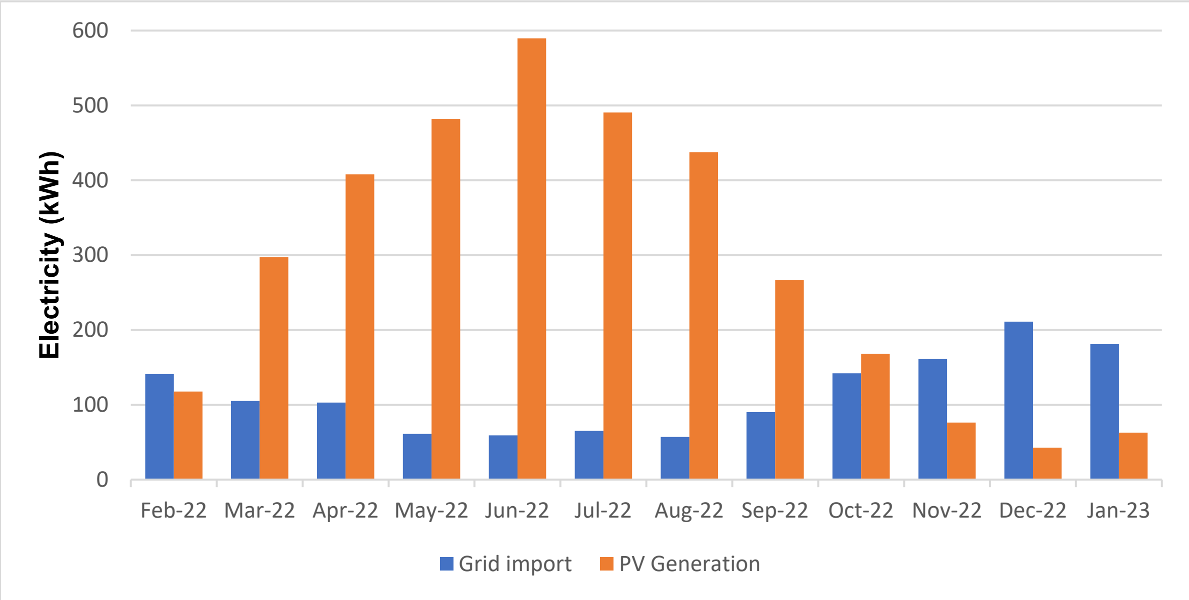


Figure 4.17 Graph showing electricity import recorded by the utility app for a smart meter and solar PV generation recorded by the SMA Sunny Portal for household W-02

Household W-02 was located in the North East of England. The rural property had an oil-fired condensing boiler with a 145-litre hot water cylinder. A 4.38kW solar PV system was installed in late January 2022 on an approximately east-west roof. The system included an SMA inverter. This had a Wi-Fi output and when connected to the internet, it was possible to monitor the PV generation using the SMA Sunny Portal. A GEO Solo PV II monitor was also fitted on the generation meter measuring the flashes from the pulse LED output. The display showed the current level of power generation and the historic PV generation.

The household had a smart meter and data was obtained the suppliers app and the meter. Figure 4.17 shows the household grid import and solar PV generation over the first year of operation of the PV system. Over this first year, the solar PV system generated 3,439kWh while the grid import was 1,376kWh. For comparison, the estimated annual generation from the MCS certificate was 3,714 kWh.

As for household W-01, there was a Wibeee Box monitor fitted for household W-02. There were similar issues over limited data due to the switch from the Wibeee Home to the Wibeee Nest monitoring portal. Full data was available including solar PV, import and export from the middle of June 2022.

Figure 4.18 shows a plot of PV generation on 16 Jul 22 for households W-02 and W-01. The data from the Wibeee monitor was at 1-minute intervals. Also plotted was data from the SMA Sunny Portal at 15-minute intervals. There was a lag in the SMA data compared to the Wibeee, with the SMA data being lower in the morning and higher in the afternoon.

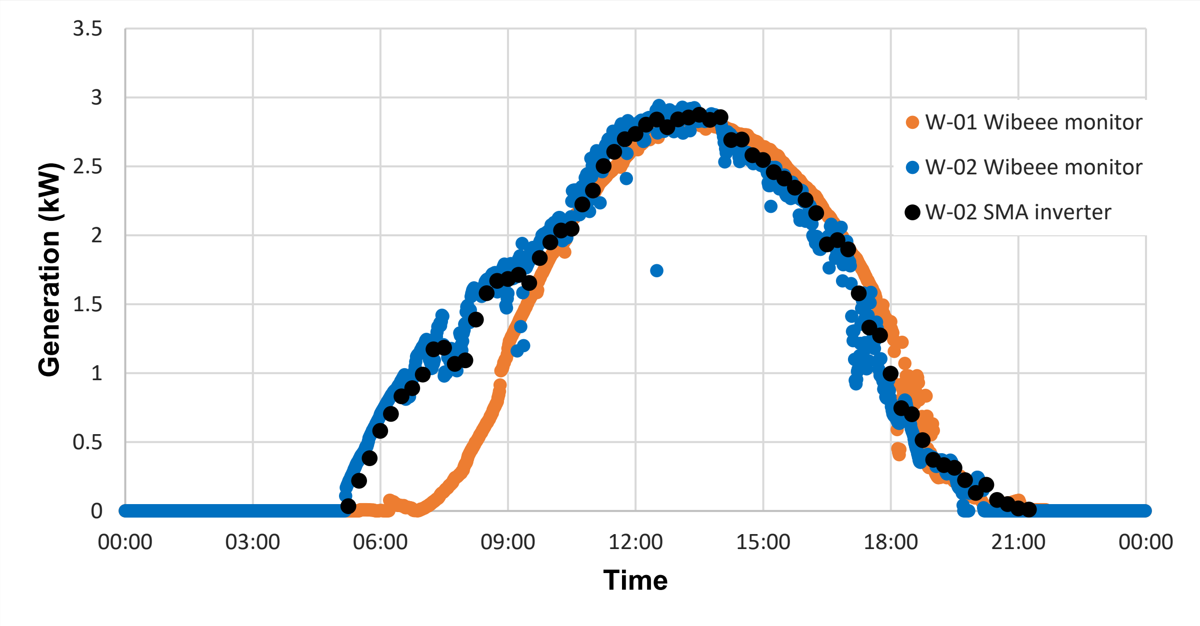


Figure 4.18 Graph showing PV generation on 16 Jul 22 for household W-02 recorded by a Wibeee monitor and SMA Sunny Portal and for household W-01 with a Wibeee monitor

The PV generation for household W-02 was higher in the morning than for W-01 due to its east facing roof receiving greater direct sunlight in the morning. There may be some shading towards the end of the day caused by a tree about 20 metres to west of the property. This or differences in weather between the sites on the day may have caused lower generation for household W-02 in the afternoon.

A Solar iBoost+ solar immersion controller was fitted at the same time as the solar PV system. The performance of the solar iBoost+ system was monitored using an iBoost Buddy display. The electricity consumed by the immersion heater was also recorded by one of the CT-sensors for the Wibeee Box monitor.

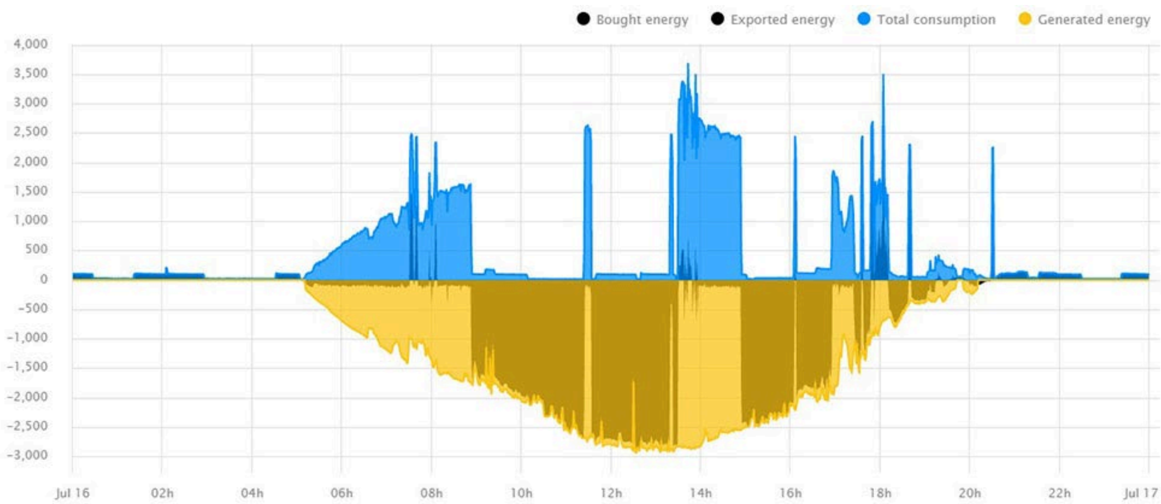


Figure 4.19 Plot of solar PV generation (in yellow) and electricity consumption (in blue) from the Wibeee Nest portal for household W-02 on 16 Jul 22

Figure 4.19 shows the solar PV generation and electricity consumption for household W-02 on 16 Jul 22. The PV generation is shown in yellow and is shaded darker when it was exported to the grid. The electricity consumption is shown in blue and is darker when imported from the grid. Figure 4.20 shows a further plot from the Wibeee Nest portal with the solar PV generation on circuit 2 in blue and the immersion heater on circuit 3 in red.

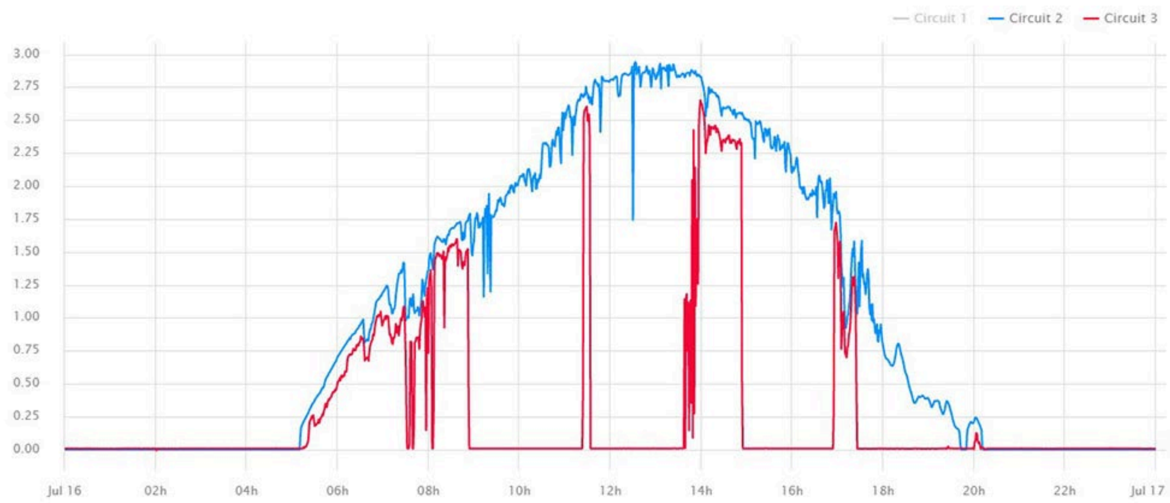


Figure 4.20 Plot of solar PV generation (in blue) and electricity consumption by the immersion heater (in red) from the Wibeee Nest portal for household W-02 on 16 Jul 22

It was a sunny summer day on 16 Jul 22. The solar PV array on the east facing roof meant the solar PV system began generating electricity shortly after 05:00. The PV system was generating more than 250W by 05:20 and the immersion heater was starting to receive power. Most of the PV generation until 09:00 was used to power the immersion heater, with a slight dip around 08:00 when a kettle or toaster was used. There was further power diverted to the immersion heater at 11:25, 13:40 and 16:55 after there was consumption of hot water. The water temperature in the cylinder decreased which led the thermostat to turn on the immersion heater again.

Readings from the generation meter that day indicated the amount of solar PV generation was 25.32kWh while data from the Wibeee Nest portal indicated the PV generation was 25.39kWh. The Solar iBoost+ Buddy monitor recorded 6.49kWh of the PV generation had been diverted to the immersion heater. The Wibeee monitor measured 6.71kWh of consumption by the immersion heater circuit. This could be an overestimate as the data suggested a consistent consumption of about 0.007kW throughout the day.

A similar plot from the Wibeee Nest portal is shown in figure 4.21 for 6 Feb 23 which this time includes the grid import/export in yellow on circuit 1. It was a sunny winter day and the PV system started generating from just after 08:00. Excess solar PV generation was diverted to power the immersion heater through much of the day. This was because there was insufficient excess PV generation to provide power for the immersion heater to bring the hot water cylinder up to temperature. The maximum PV generation during the day was 1.1kW and the Solar iBoost+ diverted up to 750W. The remaining electricity powered household appliances (135 – 220W baseload) and there was some consistent export to the grid (about 100W). This explains the offset between the lines for circuit 2 (PV generation) and circuit 3 (immersion heater).

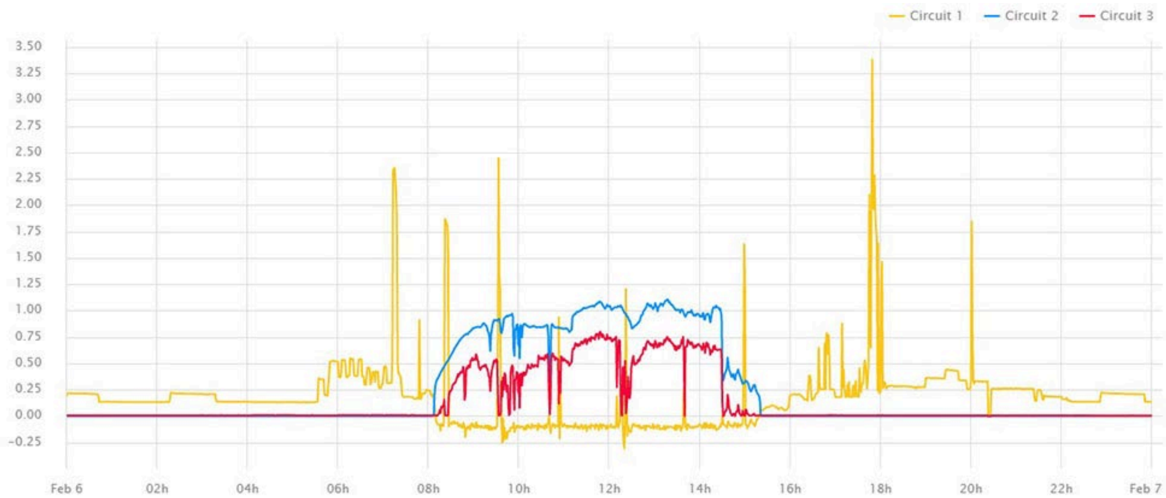


Figure 4.21 Plot of grid import/export (yellow) PV generation (blue) and consumption by the immersion heater (red) from the Wibeee Nest portal for household W-02 on 6 Feb 23

Data from the Wibeee monitor indicated that the solar PV generation on 6 Feb 23 was 5.96kWh. Out of this 5.29kWh was used in the home with 3.40kWh diverted to power the immersion heater. The grid import measured by the Wibeee was 4.81kWh, with a total household electricity consumption of 10.10kWh. The percentage self-consumption of solar PV was 88.8%. For comparison, the app provided by the utility showed the grid import to be 4.98kWh.

Month	Generation Meter (kWh)	Wibeee Nest (kWh)	SMA Sunny Portal (kWh)	GEO Solo PV II (kWh)
Jul-22	496.5	493.0	490.6	
Aug-22	440.1	440.6	437.5	
Sep-22	269.3	268.5	267.1	
Oct-22	170.5	168.3	168.1	168.0
Nov-22	77.0	75.5	76.3	79.1
Dec-22		40.5	42.6	
Jan-23		60.5	62.8	

Table 4.22 Solar PV generation measured by manual readings from the generation meter and from data from the Wibeee Nest and SMA Sunny Portals and GEO Solo PV II monitor

The solar PV generation for household W-02 measured by different methods is shown in table 4.22. Manual meter readings were taken at the end of each day along with daily generation values from a GEO Solo PV II monitor. Data was also downloaded from the Wibeee Nest portal and SMA Sunny Portal. There was little variation in the PV generation recorded between the different methods, with the difference typically within 2 to 3kWh.

Table 4.23 shows the grid import, measured by manual readings from the smart meter and from the app provided by the utility. There are also values of grid import derived from the Wibeee Nest portal.

Month	Manual reading of Smart Meter (kWh)	Wibeee Nest (kWh)	Utility Smart Meter App (kWh)	Wibeee Offset to Smart Meter (%)	Smart meter app offset to manual reading (%)
Jul-22	64.35		65.0		1.0%
Aug-22	59.17	48.73	57.00	-17.6%	-3.7%
Sep-22	87.53	74.77	90.00	-14.6%	2.8%
Oct-22	142.05	130.56	142.00	-8.1%	0.0%
Nov-22	162.12	150.51	161.00	-7.2%	-0.7%
Dec-22		202.59	211.00		
Jan-23		185.41	181.00		

Table 4.23 Grid import for household W-02 measured by manual readings of the smart meter, the utility smart meter app and from the Wibeee Nest portal

Over the Autumn and Winter, as the solar generation decreased, the monthly grid import increased. There was a larger difference between the grid import recorded by the smart meter and the Wibeee Nest for household W-02 than for household W-01. The offset between the Wibeee and smart meter readings was between 7.2 and 17.6% for household W-02 compared to 1.8 to 4.6% for household W-01.

Table 4.24 shows the monthly variation in PV generation, grid import, household electricity consumption and export to the grid for household W-02 determined from the Wibeee Nest portal. In August 2022, 440.6kWh was generated by the solar PV system and 292.7kWh exported to the grid. As the PV generation decreased, the amount of excess generation exported to the grid also decreased, with the export under 10kWh/month during November, December and January.

Month	PV generation (kWh)	Grid import (kWh)	Household consumption (kWh)	Export to the grid (kWh)
Aug-22	440.6	48.7	196.9	292.7
Sep-22	268.5	74.8	221.9	121.5
Oct-22	168.3	130.6	265.6	33.3
Nov-22	75.5	150.5	217.7	8.3
Dec-22	40.5	202.6	239.6	3.5
Jan-23	60.5	185.4	239.7	6.3

Table 4.24 PV generation, grid import, household consumption and export to the grid for household W-02, determined from the Wibeee Nest portal

The solar PV generation that was consumed by household W-02 as determined using data from the Wibeee Nest portal is shown in table 4.25. Also shown is the amount of PV generation that was diverted by the Solar iBoost+ to power the immersion heater. The diversion to the immersion heater in July 2022 was 134.7kWh. This was the highest value during the monitoring period with the Wibeee Nest portal. However, data from the iBoost+ Buddy monitor indicated that 130kWh was diverted in March 2022 and 142.5kWh in June 2022. There was a low value of only 90.7kWh in August 2022 as the household was away for between 2 and 3 weeks and the hot water demand was lower than usual as a result.

Month	Consumed PV generation (kWh)	Diversion to Immersion heater (kWh)	Self-consumption with iBoost (%)	Self-consumption without iBoost (%)
Jul-22		134.7		
Aug-22	148.2	90.7	33.6%	13.1%
Sep-22	147.1	99.0	54.8%	17.9%
Oct-22	135.0	78.1	80.2%	33.8%
Nov-22	67.2	30.1	89.0%	49.2%
Dec-22	37.0	11.4	91.3%	63.2%
Jan-23	54.3	21.9	89.7%	53.4%

Table 4.25 Consumed PV generation, diversion to the immersion heater and calculated percentage self-consumption of solar PV for household W-02 from Wibeee data

The diversion to the immersion heater was higher in September than August despite the PV generation being lower. The greater water heating by the immersion heater was due to the residents being at home and there being greater hot water demand.

The percentage self-consumption of solar PV is the proportion of the solar PV generation that is consumed in the home. It is also possible to calculate what the self-consumption would have been without the Solar iBoost+ by subtracting the diversion to the immersion heater from the consumed PV generation.

In August 2022, the self-consumption of the PV generation was 33.6%, but it would have been as low as 13.1% without the Solar iBoost+. In the winter months, with less PV generation, there is normally greater self-consumption of the solar PV. Without the solar immersion controller, the self-consumption would have been between 49.2 and 63.2% for the months November 2022 to January 2023. With the solar immersion controller, the self-consumption was between 89 and 91.3% for these months. There was a particularly large increase in self-consumption due to the solar immersion controller in October 2022. For this month it would have been 33.8% without the Solar iBoost+ and rose to 80.2% with the device.

During its first year of operation, the Solar iBoost+ recorded that 1,020.4kWh of solar generation was diverted to power the immersion heater. This was an average of 2.8kWh/day. Over the first year 29.7% of the electricity generated by the solar panels was used to power the immersion heater. For comparison, there was 385.1kWh of generation diverted in 2022 for household W-01 or an average of 1.06kWh/day.

Figure 4.26 shows a photo of the Solar iBoost+ installation for household W-02 along with the hot water cylinder and immersion heater (silver cap on the top of the cylinder with a white cable coming out on the right). The immersion heater for the cylinder is vertical. It was originally 27” long (68.6cm), but was replaced by the resident in October 2022 with a longer immersion heater that was 36” long (91.4 cm).

Figure 4.26 Solar iBoost+ solar immersion controller for household W-02 with the hot water cylinder and immersion heater

There are a number of reasons why there was greater diversion to the immersion heater for household W-02 than W-01:

- Household W-01 had an old solar thermal flat plate collector which provided much of the hot water demand in the middle of summer (June to August)
- There was a long vertical immersion heater for household W-02 which was effective at heating the whole cylinder. For household W-01, there was a short horizontal immersion heater that was fitted more than halfway up the cylinder and was only particularly effective at heating the top half of the cylinder
- Household W-02 had more residents and a greater hot water demand
- The resident at household W-01 was frequently away from home with no hot water demand beyond maintaining the cylinder at temperature
- The cylinder for household W-01 was more modern and had a lower standing heat loss

4.5. Case Study 5 – Household an Eco Eye Smart PV monitor

Household E-01 had a solar PV system installed around the time the property was built in 2013. It was a 1.75kW system which faced approximately east. The annual PV generation was estimated to be 1,522kWh using PVGIS[11].

The household had 2 residents and had a high electricity consumption for the property, using 6,073kWh in 2021. The monthly consumption ranged from about 325 to 650kWh. There was an electric shower which was typically used 4 times a day and the washing machine and tumble drier was used daily. The residents were working and in part of the day.

An Eco Eye SmartPV monitor was fitted on 3 Mar 22. The memory card from the monitor was collected for analysis with the Eco Eye Trax software on 9 Nov 22.

Figure 4.27 Property with 1.75kW solar PV system

Eco Eye Energy used (kWh)	Eco Eye PV generation (kWh)	Eco Eye Grid import (kWh)	Eco Eye Grid export (kWh)	Smart meter Grid import (kWh)	Generation meter PV generation (kWh)
5152.2	1591.2	4083.7	522.6	3729.4	1398.4

Table 4.28 Data from the Eco Eye monitor compared to meter readings for household E-01 between 3 Mar 22 and 9 Nov 22

Data from the Eco Eye monitor memory card at 4-second intervals was used to derive values for the household electricity consumption (or energy used) and PV generation between 3 Mar 22 and 9 Nov 22. This data was used to calculate the grid import and export. The grid import calculated from the data from the Eco Eye monitor was 4,083.7kWh. This compared to 3729.4 from smart meter data. The calculated grid import from the Eco Eye data was 9.5% higher than the grid import from the smart meter data.

The PV generation between 3 Mar 22 and 9 Nov 22 was 1398.4kWh based on readings from the generation meter taken on the household visits. The generation recorded by the Eco Eye between 3 Mar 22 and 9 Nov 22 was 1591.2kWh, which was 13.8% higher than the value from the generation meter.

Eco Eye noted that the difference between meter readings and data obtained using CT-sensors can be ±10%. Greater accuracy may be achieved if an accurate value for the household supply voltage is used with the Trax software or Eco Eye display. This was not possible with these installations. Another issue was that with the CT-sensors and cables

[11] EU Science Hub Photovoltaic Geographical Information System, https://re.jrc.ec.europa.eu/pvg_tools/en/ (Accessed 9 Feb 23)

being fitted in the consumer unit, there may have been some electrical interference affecting readings.

The PV generation that was consumed in the home was 1068.5kW, which equates to a percentage self-consumption of 67.16%. A plot of PV generation (in green) and household electricity consumption (in red) is shown in figure 4.29 for 22 Jun 22, a bright sunny day. There was PV generation recorded from about 05:00. There was a strong increase in generation shortly before 06:00 and by that time it had reached 750W. The maximum value of PV generation was 1.5kW which occurred at 10:00. Being an approximately east facing roof, the peak in PV generation occurred earlier in the day. By late afternoon, the PV generation was at low levels despite it being close to the longest day of the year.

At that time, the property had a high baseload electricity consumption of 800 to 1000W. It is unclear at the time of writing the cause of this, but it was a major factor in the high electricity consumption of the household. There was use of the electric shower at about 16:00 where the consumption rose to about 10kW. In the evening there was likely to be cooking from about 19:15 until 20:40 with the consumption reaching a maximum of about 3kW at times.

Using data from the Eco Eye monitor, the PV generation that day was about 11.66kWh with a household consumption of 28kWh and a grid import of 19.4kWh. For comparison, smart meter data showed the grid import was 18.14kWh. The level of self-consumption of the PV generation was about 73.8%.

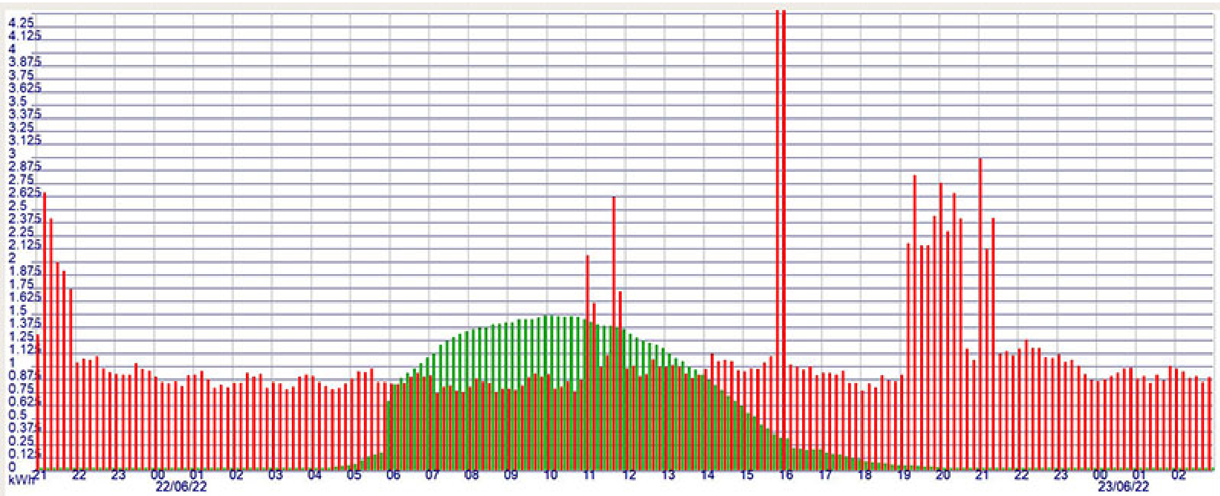


Figure 4.29 Eco Eye Trax software plot for household E-01 on 22 Jun 22

Another plot from the Eco Eye Trax software is shown in figure 4.30 from 26 Oct 22. The baseload electricity consumption had dropped from the summer to about 300 to 400W. Maximum PV generation was 0.98kW at about 10:00 and generation decreased significantly in the afternoon. There was a consumption peak of about 2.5kW from 11:00 to 11:20 and for 7 minutes after 11:30. The electric shower was used at 14:15 for about 15 minutes. There was a period of higher electricity use for an hour from 15:15 with regular cycles of high consumption which might have been due to use of an oven. There was a further peak in consumption from 19:30 to 20:30 which again had regular cycles with higher consumption. This was again likely to be due to cooking which included use of the oven.

Data from the Eco Eye monitor indicated the household consumption was 14.67kWh while 3.82kWh was generated by the solar panels. The grid import derived from the Eco Eye data was 12.75kWh compared to 11.27 from the smart meter. The export to the grid was 1.9kWh. The estimated self-consumption of the solar PV was 50.3%. Unusually this was lower than on 22 Jun 22. A major factor in the unusually high consumption on the summers day was the high baseload consumption at that time.

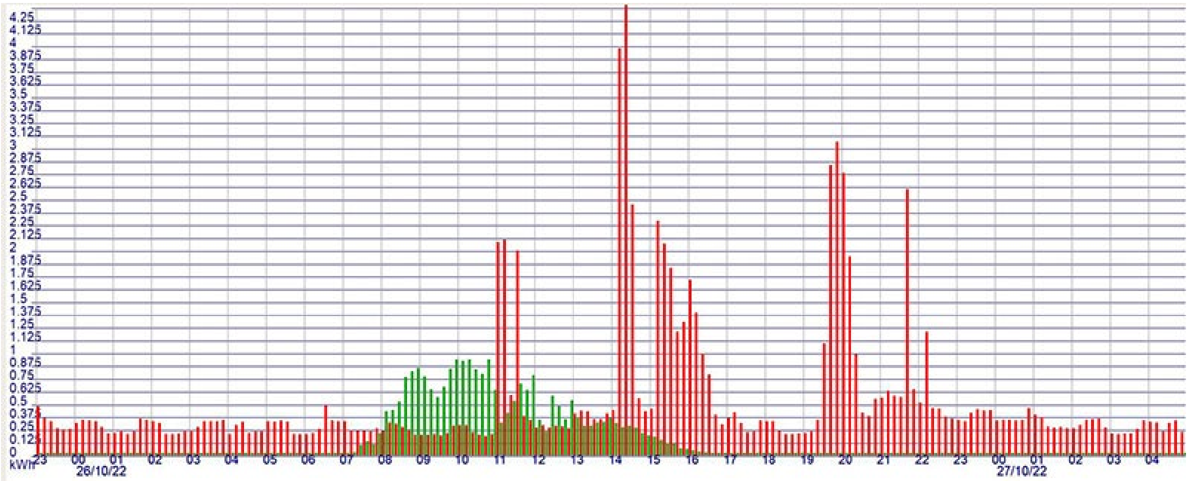


Figure 4.30 Eco Eye Trax software plot for household E-01 on 26 Oct 22

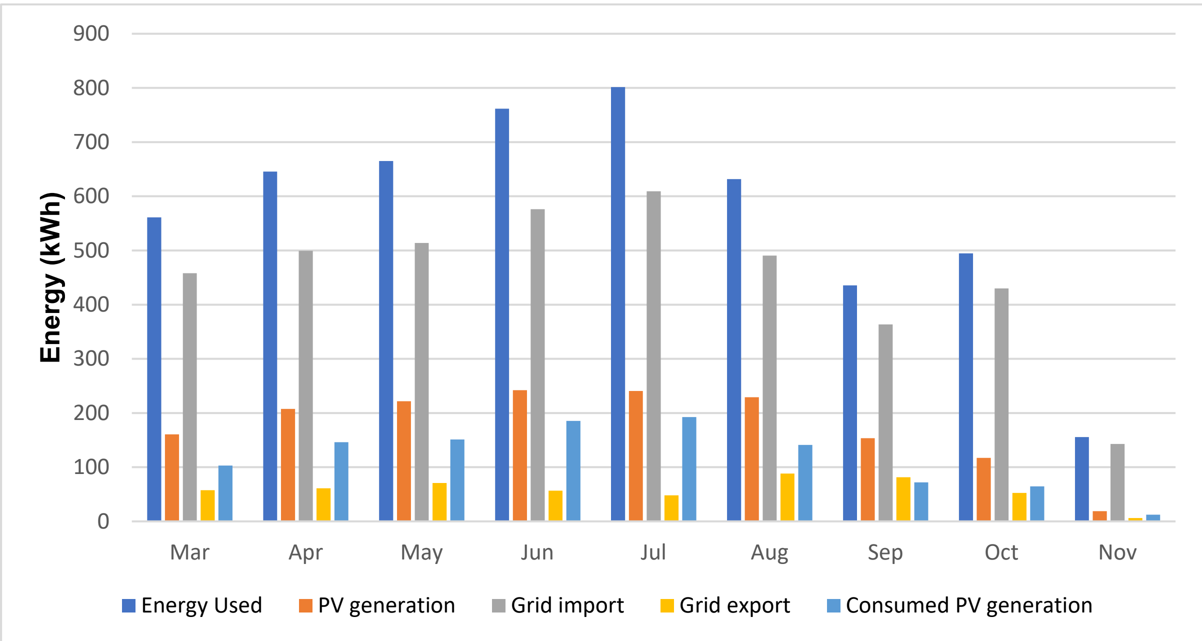


Figure 4.31 Energy data derived from the Eco Eye monitor for household E-01

Figure 4.31 is a graph which shows energy data derived from the Eco Eye monitor for the period 3 Mar 22 to 9 Nov 22. The household consumption or energy used increased from March up to July where it reached 802kWh. The grid consumption followed a similar pattern, with a maximum value of 609.3kWh. This compares to 563kWh recorded on the smart meter. There was a significant decrease in energy used and grid import in August and

September. This was due to the household baseload consumption dropping from 800 to 1,000W to about 300W on 17 Aug 22.

The monthly PV generation was between 207 and 242kWh for the months of April to August and was greatest in June. The consumed PV generation was between 141 and 192kWh for the months April to August and fell to 72kWh in September. The decrease in September was due to a combination of a 31% drop in household consumption and lower PV generation.

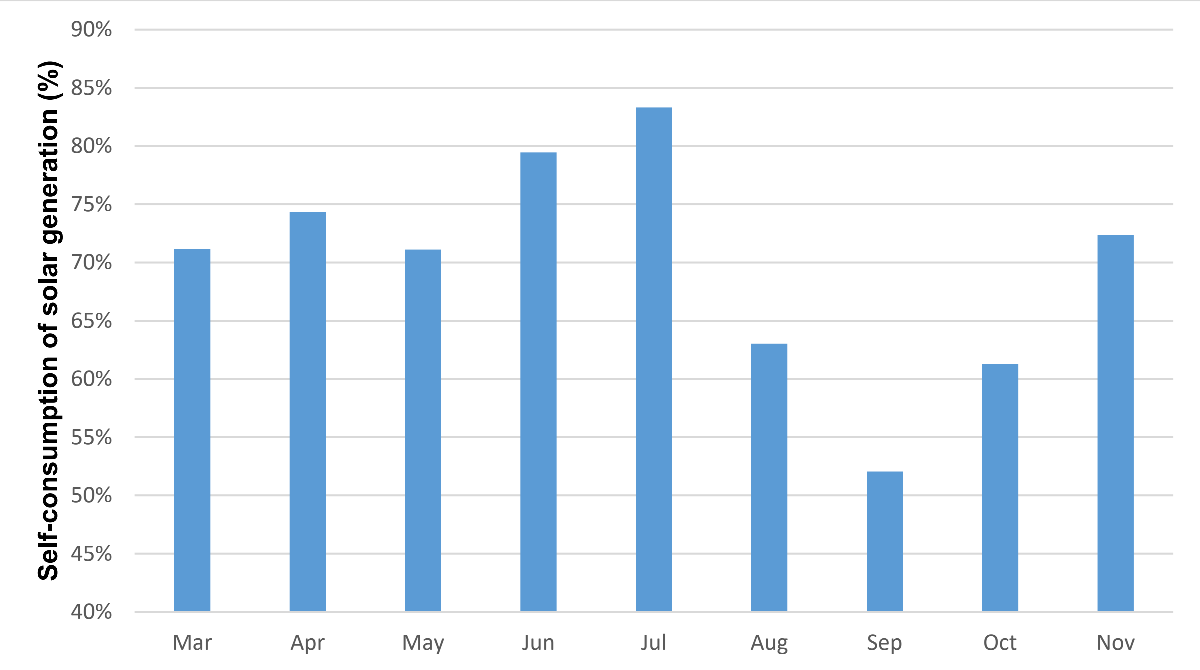


Figure 4.32 Variation in the percentage self-consumption of solar generation for household E-01

A plot of the variation in self-consumption of solar generation for household E-01 is shown in figure 4.32. This was based on data derived and calculated from the Eco Eye monitor. The self-consumption of the solar generation was between 71 and 83% for the months March to July. This was so high because the household was a high electricity consumer and during this period had a baseload consumption which was about 60% of the maximum PV generation. The percentage self-consumption fell to 63% in August after there was a decrease in baseload consumption on 17 Aug 22. The lower baseload consumption and lower PV generation led the self-consumption to fall to 52% in September.

The PV system for household E-01 was relatively small at 1.75kW. Since it faced east, there was little or no generation in the late afternoon/evening when there was most consumption by the household. In October and November, the PV generation decreased further and times when the PV generation was greater than the baseload consumption were more limited. As a result, the percentage self-consumption increased again.

4.6. Case Study 6 – Household an Eco Eye Smart PV monitor

Household E-02 lived in a property built at the same time as E-01. Heating was provided by a gas combi boiler and there was an electric shower. There were 5 residents. The property had a 7-panel solar PV system with a capacity of 1.75kW. In this case it was close to south facing rather than nearly east facing, with the solar panels orientated at about 20˚ west of south. The estimated annual generation using PVGIS was 1,750kWh[12].

An Eco Eye smart PV monitor was installed on 3 Mar 22. An electrician was required as the generation meter and cabling associated with the solar PV were inside the consumer unit. A final interview was completed with the resident and the memory card from the monitor was collected on 11 Nov 22.

Eco Eye Energy used (kWh)	Eco Eye PV generation (kWh)	Eco Eye Grid import (kWh)	Eco Eye Grid export (kWh)	Smart meter Grid import (kWh)	Generation meter PV generation (kWh)
2995.7	1533.8	2225.3	763.4	2318	1553.6

Table 4.33 Data from the Eco Eye monitor compared to meter readings for household E-02 between 3 Mar 22 and 11 Nov 22

Table 4.33 shows energy data for household E-02. The energy used and PV generation data were derived from 4 second data from the Eco Eye memory card and values of grid import and export were calculated using this data. Meter readings from the smart meter and generation meter were taken at the time of installation of the monitor and when the memory card was collected.

The grid import calculated from the Eco Eye data was 4% lower than the readings from the smart meter. For comparison it was 9.5% higher than the smart meter readings for household E-01. The grid consumption by household E-02 was lower than for E-01 with a grid import of 2,318kWh compared to 3,729kWh over the monitoring period.

For household E-02, the solar PV generation calculated from the Eco Eye data was 1.3% lower than the values derived from PV generation meter readings. For household E-01, the PV generation calculated from the Eco Eye data was 13.8% higher than from the meter readings. The Eco Eye data suggested that the PV system from household E-01 generated more than for household E-02. Meter reading data showed that it was in fact the PV system for household E-02 which generated more over the monitoring period with 1553.6kWh compared to 1398.4kWh for household E-01.

It is apparent there can be some variation in the accuracy of the monitors. Factors which might affect this could be how well the CT-sensors have been fitted and whether there might be some interference from other electromagnetic fields nearby. In this case there was more of a risk with interference for the CT-sensors and cables inside the consumer unit.

[12] EU Science Hub, Photovoltaic Geographical Information System, https://re.jrc.ec.europa.eu/pvg_tools/en/ (Accessed 10 Feb 23)

Figure 4.34 shows a graph with monthly values of PV generation for household E-02 measured by the Eco Eye monitor and compared to the values estimated using PVGIS. Typically, the generation recorded by the Eco Eye was close to the values estimated by PVGIS. In March, the Eco Eye measured a higher level of generation despite the monitoring only beginning on 3 Mar 22. In July and August, the measured generation was greater while in September there was a drop in generation compared to the PVGIS estimate. There is normally some variation between estimates and measured generation due to differences in levels of solar irradiation between years. PVGIS estimated the year-to-year variability in the annual generation to be about 70kWh.

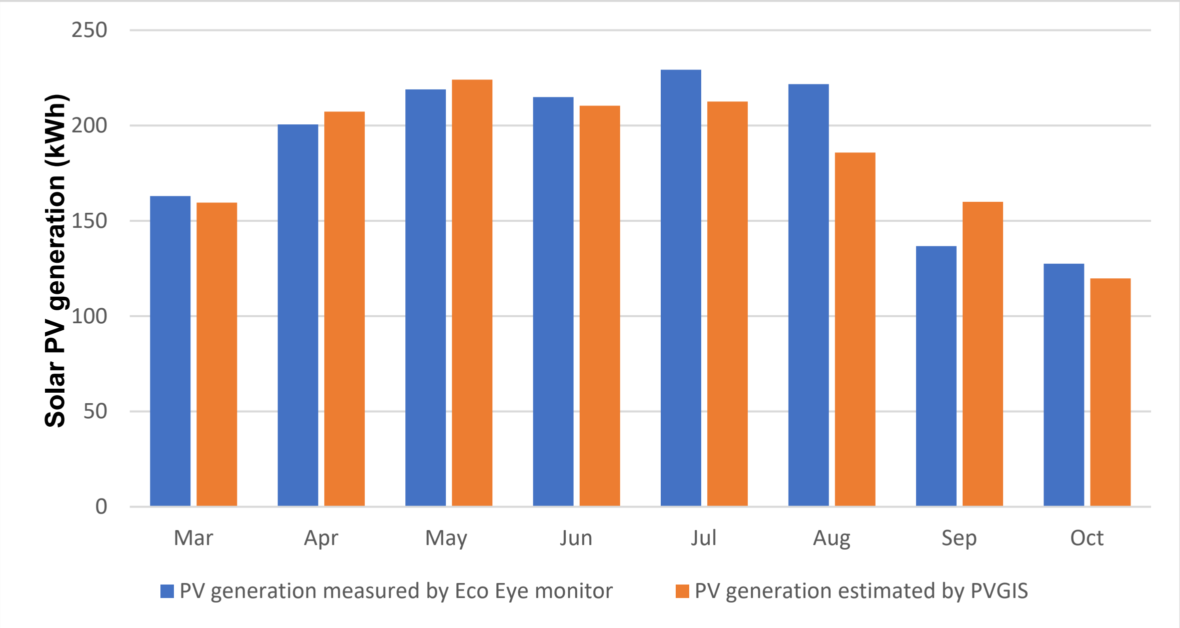


Figure 4.34 Monthly PV generation for household E-02 measured by the Eco Eye monitor and estimated using PVGIS

Figure 4.35 shows a plot from the Eco Eye Trax software for household E-02 on 22 Jun 22. This can be compared to figure 4.29 for household E-01 on the same day. There was a baseload of 150 to 250W overnight, less than a third of the value for E-01. Use of appliances by the household began from 05:00 when it was likely that a kettle was boiled. There was further consumption from just before 06:00 for a period of 20-minutes where the consumption was typically 2.3kW, but briefly reach 5kW. This might be due to washing of clothes on a short cycle. The consumption rose to about 8.9kW at 10.35 due to use of the electric shower. This lasted for 7.5 minutes, about the average length for a shower. At 11:10, there was a consumption of 2kW for about 15-minutes, which was likely to have been due to an appliance producing heat such the hob or oven on a cooker. An appliance was used at lunchtime which consumed about 4.5kW for 3 minutes.

The electric shower was used again for 4-minutes at 16:10, for 3-minutes at 17:05 and 7-minutes at 18:20. There was no evidence of longer periods of high electricity consumption due to cooking in the evening. Food might have been warmed up in a microwave for a couple minutes and there was use of a kettle. The baseload consumption of the household was quite low, but the main consumption on 22 Jun 22 was due to use of the electric shower on 4 occasions.

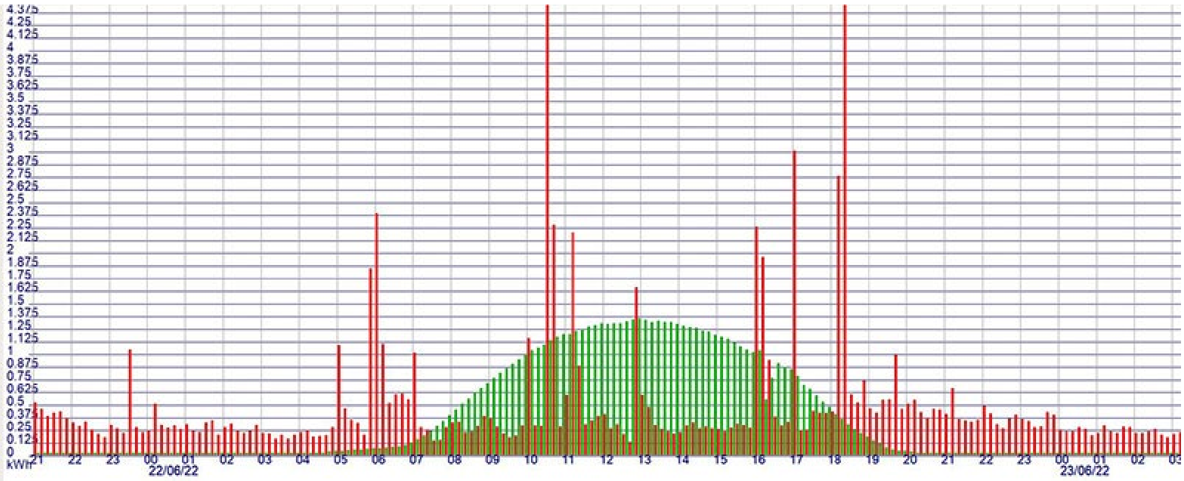


Figure 4.35 Eco Eye Trax software plot for household E-02 on 22 Jun 22

It was a sunny day on 22 Jun 22 and the solar PV generation had a bell-shaped curve that is common on sunny days with no cloud cover. The solar generation powered the baseload generation for the home between about 07:00 and 18:00. There was grid import at times during the day when higher power appliances like the electric shower or other heating appliances were used.

Figure 4.36 plots the solar PV generation for households E-01 and E-02 using 4 second data from the Eco Eye monitors. There was a rapid rise in PV generation from 06:00 for household E-01 due to the roof facing approximately east. Maximum generation was at 10:00. For household E-02, the rise in PV generation was more gradual and the maximum generation was 1.36kW at about 13:00. The peak in generation for household E-01 shown in figure 4.36 was 1.5kW and higher than for household E-02. However, PV generation recorded by the Eco Eye was 13.8% higher than those from the generation meter. Compensating for this error reduces the maximum generation to about 1.32kW, lower than for household E-02.

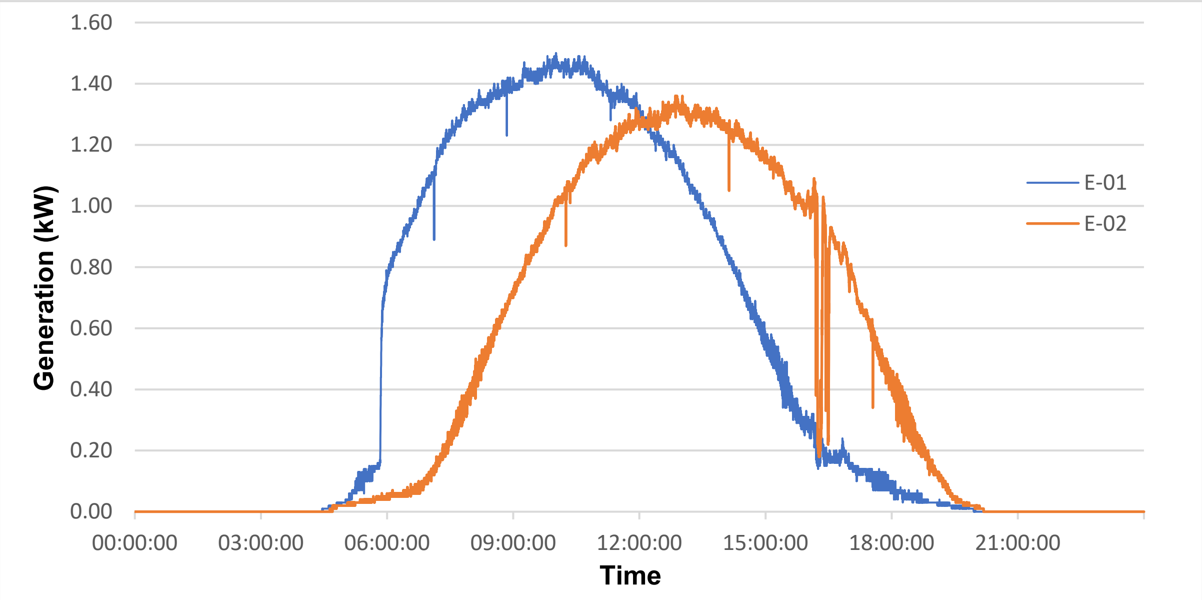


Figure 4.36 Plot of solar PV generation on 22 Jun 22 for households E-01 and E-02

While the PV generation for household E-01 was higher than for E-02 in the morning, this reversed shortly after 12:00. The PV generation for household E-02 was higher in the afternoon due to the roof facing 20 west of south and catching more direct sunlight than E-01 in the afternoon. The system for E-02 was still producing 400W at 18:00, while only 7W was recorded by the Eco Eye for household E-01.

Over the day, data from the Eco Eye monitor indicated that 10.7kWh of electricity was generated by the solar panels. There was 12.68kWh used in the home (household consumption). Calculations using the 4 second Eco Eye data indicated that the grid import was 8.75kWh and 6.77kWh was exported to the grid. The electricity from the solar panels that was used in the home that day was 3.93kWh, making the self-consumption of solar generated electricity 36.7%.

The self-consumption for household E-01 was higher on 22 Jun 22 at 50.3%. This was due to a different electricity consumption profile with a high baseload of electricity consumption (about 900W). For household E-02 the baseload consumption was much lower at 150-250W. There were also occasional peaks of high consumption due to appliances like the electric shower where the solar PV could only provide a small proportion of the power for the appliance.

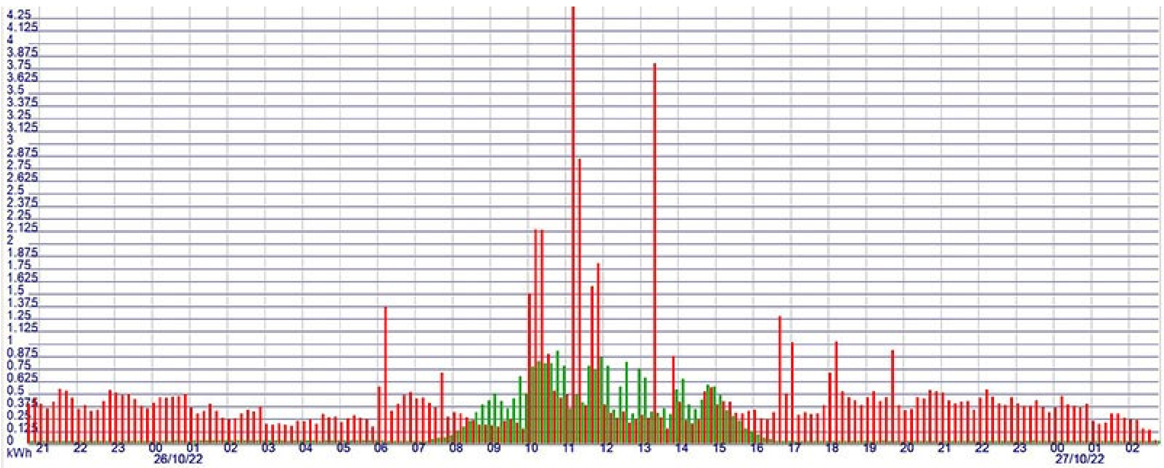


Figure 4.37 Eco Eye Trax software plot for household E-02 on 26 Oct 22

A plot of the electricity use and solar generation for household E-02 on 26 Oct 22 is shown in figure 4.37. There were some similar consumption patterns to the graph on 22 Jun 22 due to similar household behaviour. Overnight, the baseload electricity consumption was around 150W to 300W.

Members of the household were awake by 06:00 and an appliance used about 5kW for about 3 minutes at 06:10. It is likely the kettle was used for a couple minutes at 07:45. At 10:00, there was consumption of 3kW for a couple minutes, followed by a decrease to baseload for a couple minutes and then a consistent consumption of about 2kW for about 25 minutes. This might have been due to cooking with the hob or oven. At 11:15, there was use of the electric shower for 8-minutes. There was another period of consistent consumption of 2kW at 11:45 for 15 minutes, which might have been due to use of the cooker hob.

At 13:25 there was another shower which lasted for 4-minutes. There was consumption of about 3kW at 13:50 most likely due to use of the kettle. There was a further shower at 16:45 which lasted just a minute and after that the kettle was boiled at 17:00. There was consumption of 1.7kW at 18:15 for 5 minutes, most likely due to use to a device like a microwave. The kettle was boiled once more at 19:45. Over the evening, the baseload consumption of the household increased to 300 to 500W. This was most likely due to use of televisions and games consoles and extra lighting in the evening. Again, the consumption for this household was characterised by a fairly low baseload consumption and short periods of high consumption in the middle of the day due to use of kettles and showers.

There was less consistent sunshine on 26 Oct 22, as a result there were frequent dips in the PV generation due to clouds blocking the sun. The PV generation was normally able to power much of the baseload electricity consumption from about 08:30 to about 15:30, although there were periods with lower generation. The maximum PV generation was 1.36kW at 11:40, but the generation could drop from about 1.3kW to 250W within a couple minutes as a cloud covered the sun.

The solar generation on 26 Oct 22 was measured to be 3.88kWh using the Eco Eye monitor. The energy used in the home (household consumption was 11.69kWh). It was estimated that use of the electric shower accounted for 1.9kWh of the household consumption.

Calculations using the 4 second data from the Eco Eye indicated the grid import was 9.27kWh. For comparison, the grid import from smart meter data was 8.89kWh. The electricity from the solar panels used in the home was 2.41kWh and the grid export was 1.47kWh. The level of self-consumption of the solar generation was 62.2%.

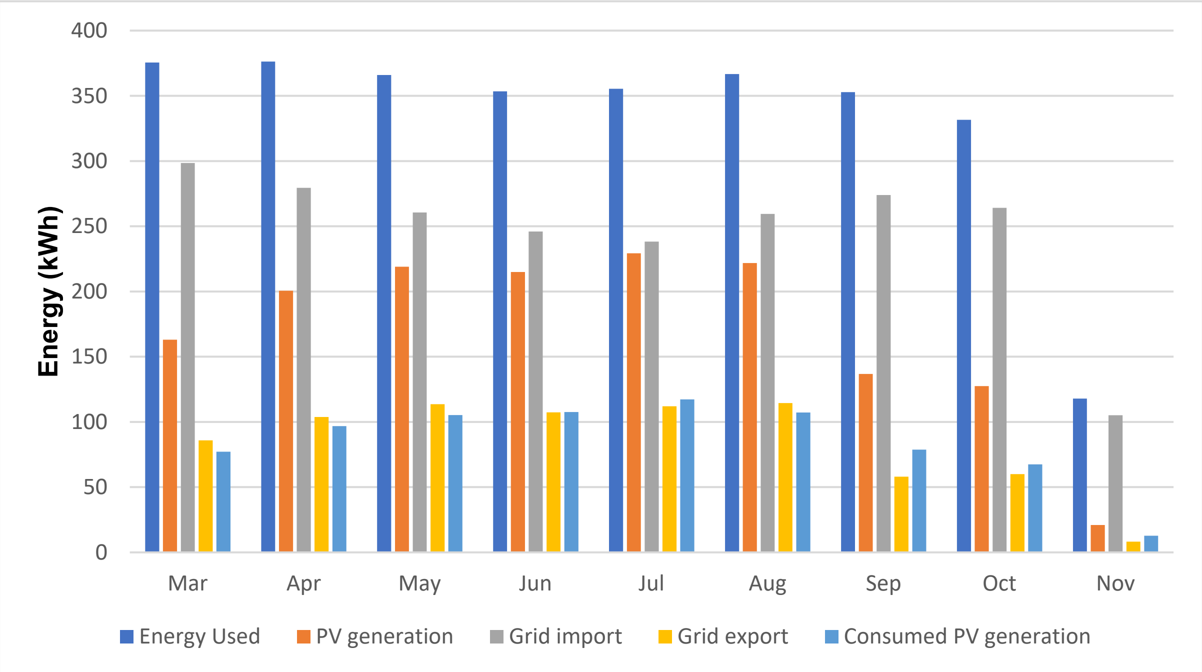


Figure 4.38 Energy data derived from the Eco Eye monitor for household E-02

Figure 4.38 shows a plot with energy data for household E-02 between 3 Mar 22 to 11 Nov 22. This was derived from 4 second data from the memory card for the Eco Eye monitor. For most months, the household consumption (energy used) was approximately in the range 350 to 375kWh. There was a small decrease to 331.6kWh in October. The large decrease to 117.8kWh in November was due to recorded less than 11 days of full data.

The monthly PV generation was between 200 and 230kWh for the months April through to August. The PV generation was 163kWh in March, but this was not a full month with the monitor fitted on 3 Mar 22. There was a surprisingly high decrease in PV generation from 221.8kWh in August to 136.8kWh in September with a smaller decrease to 127.5kWh in October.

The grid import was about 300kWh in March but fell during the summer to a minimum monthly value of 238.2kWh in July. The lower import during the summer months was likely to primarily be due to greater PV generation. The export of electricity from the solar panels was between 103 and 115kWh/month for the months April through to August. It decreased below 60kWh in September and October, primarily due to lower PV generation in those months. The electricity from the solar panels that was consumed in the home was between 105 and 118kWh/month for the months May to August. Analysis of the Eco Eye data indicated at 770.35kWh of electricity from the solar panels was used in the home for the monitoring period between 3 Mar 22 and 11 Nov 22. Using a single rate electricity tariff of 34p/kWh for the Energy Price Guarantee from 1 Oct 22 to 31 Mar 23, this would equate to a saving of about £262 over the monitoring period.

Figure 4.39 is a plot showing how the percentage self-consumption of the solar generation varied by month. It was in the range 52 to 57% for the sunnier months of March to August. The self-consumption increased as the PV generation fell, rising to 72.4% for the first 11 days in November. Over the full monitoring period, the percentage self-consumption was 57.4%.

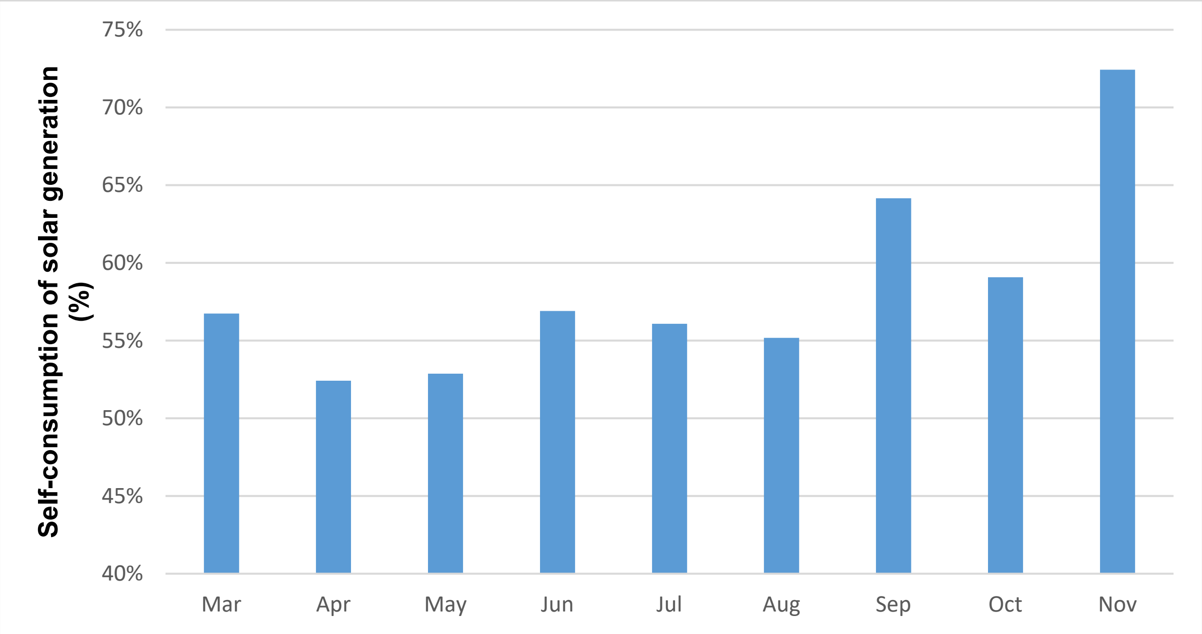


Figure 4.39 Variation in the percentage self-consumption of solar generation for household E-02

5. Summary

5.1. Solar PV monitors

Monitoring of solar PV systems is important as it provides the opportunity for households to maximise the benefit of the solar panels by aiming to use electrical appliances at times of greater PV generation. It also enables an assessment of the long-term performance of the PV system and early detection of any faults that might develop.

A number of solar PV monitoring systems were assessed during this project. Some had been on the market for several years. The GEO Solo PV II was an easy to install monitor with a standalone mains-powered display. An LED sensor was fitted on the generation meter and the PV generation was determined by measuring the flashes of the LED on the generation meter. Households found the display easy to interpret, but the LED sensor was prone to become detached from the generation meter. It was ideal for households who did not have the internet or a smart phone. Unfortunately, GEO has stopped manufacturing the product.

The Eco Eye Smart PV was another standalone display which did not require the internet or a smart phone. It was able to measure the solar generation and household consumption. This was determined using current transformer (CT) sensors fitted around cables from the utility meter and the solar PV. In some situations, it could be fitted by an advisor, but with some installations an electrician was needed. The device had a memory card and so performance data at 4 second intervals could be assessed using software on a computer. A new version of the monitor is expected to be released in 2023 which includes internet connectivity and uses more easily available SD memory cards.

A factor in the drop in popularity of standalone monitors has been the greater availability of monitoring through the solar PV inverter. SMA inverters have a built-in output and online monitoring can be achieved by connecting the inverter to the household Wi-Fi. Other inverter manufacturers like Growatt, SolaX or Solis can supply a Wi-Fi dongle which can provide communications for the inverter. Monitoring can be done through a smart phone app or web-portal. Setting up the Wi-Fi dongle does not require an electrician, but a technically competent advisor might be needed. These devices are not suitable for households without smart phones or the internet. If the household switches broadband supplier, the Wi-Fi dongle will need setting up again with the new Wi-Fi password. This may be an issue with less technically competent households or for systems in rented accommodation.

A standard inverter will only provide details of the solar PV generation. A hybrid inverter is one that can be interfaced directly with a battery. If one of these has been fitted, it is possible to monitor the household consumption and grid import/export as well as the PV generation. These inverters cost several hundred pounds more than a standard inverter, but could be fitted with a battery or be battery ready.

Smart meter in-home displays (IHDs) can be a useful aid to improve the self-consumption from solar PV systems. These are normally provided for free if you have a smart meter. Some newer models will show the level of electricity consumption and also PV export to the grid when the correct screen is selected. Export is normally shown with a pylon symbol on the IHD and the display often shows the amount of PV export. Older IHDs may only show that there is no consumption and the cost of the energy use is £0.00 per hour. When households can see there is a higher level of PV export to the grid, they know this could be a good time to use a higher power appliance such as a washing machine.

The smart meter IHD is set up by the engineer at the time of the smart meter installation and it is not straightforward to replace the IHD with another model. There are however other devices available such as the ivie Bud which can interface with the smart meter and show similar data. Many households with solar PV have smart meter IHDs, but are unaware of how they can use them to see the times when there is export of electricity from their solar panels. This could be a way that households without smart phones or the internet can check when the solar panels are generating more electricity than is being used in the home.

There are other more advanced monitors such as the Wibeee Box. This can measure the electricity used or generated for up to 3 different household circuits. These could include the overall household consumption, the solar panels and a further circuit such as a heat pump or immersion heater. Like some other monitors, the Wibeee uses current transformer (CT) sensors. These are often fitted in the household consumer unit, so an electrician may be needed for the installation. The device connects to the household Wi-Fi and will lose connection if the broadband supplier is switched. Monitoring for the Wibeee is through the Wibeee Nest UK phone app or web-portal. The latest version of the Wibeee Nest UK app has an easy-to-understand graphic showing the consumption in real time with solar PV generation, household consumption and export to the grid. More detailed analysis of the performance of systems is possible with the Wibeee Nest UK portal with data available at 1-minute intervals. The Wibeee Box is a useful monitoring device, but it was the most expensive of those tested. It was also only suitable for households with broadband and a smart phone and reconnecting the system after the household switched broadband supplier was not easy. It's ideal for householders heavily engaged with their systems and actively managing their generation / energy demand.

Other devices associated with solar PV systems can provide monitoring of the solar panels. These include solar diverters and battery systems. The Buddy monitor with the Solar iBoost+ solar immersion controller was a standalone display. It did not require the household to have either the internet or a smart phone. As well as showing the electricity diverter to power the immersion heater it also showed the level of electricity import or export. This was shown with a speedometer or eco-gauge, a traffic light LED which shone green for export and red for import as well as a digital energy reading showing the level of export or import.

Myenergi manufacture several green technology devices which have an integrated monitoring system. There is the eddi solar immersion controller, zappi electric vehicle charger and libbi electrical energy storage system. All of these use the myenergi app and can display graphs and data for solar PV generation, household consumption, grid import and export. The monitoring system requires the household to connect the device to the internet. While there is an online portal for the myenergi system, most people will access the data via the myenergy app on a smart phone or tablet. Lots of useful data is provided by the myenergi app and the graphs produced can help households better understand their household consumption and when the PV system is generating most.

5.2. Solar immersion controllers

Solar immersion controllers divert excess solar generation to power the immersion heater of a hot water cylinder. The device determines when electricity is being exported to the grid with a CT sensor and then uses the excess electricity to power the immersion heater. These devices are a low-cost add-on to a solar PV system which can provide similar benefits to a solar thermal water heating system.

A solar immersion controller can heat hot water throughout the year but is most effective between March and October. They are typically used in homes with system boilers or where there is electric space and water heating. In order to provide the water heating, there must be more PV generation than household electricity consumption for periods of the day. Factors which affect the level of savings achieved by a solar immersion controllers include:

- Solar PV generation
- Household electricity consumption
- Hot water demand
    - Size of household
    - Whether there is a mixer shower or electric shower
    - Whether a bath is used
- Hot water cylinder
    - Amount of heating provided by other sources (e.g., the gas boiler)
    - Time of day of any additional water heating (e.g. boiler)
    - Length of the immersion heater and position in the tank
    - Setting for the immersion heater thermostat
    - Size of the cylinder
    - Level of insulation of the cylinder

The Solar iBoost+ is a lower cost solar immersion controller which is straightforward to install for an electrician. It is suitable for households who do not have the internet or a smart phone, but would still like a monitoring system. The main Solar iBoost+ unit will show the electricity diverted to power the immersion heater. If a Buddy monitor is added, this will show the solar diversion and also the level of import or export to the grid. The device can power up to 2 immersion heaters sequentially. This could first power the upper immersion heater in an Economy 7 hot water cylinder followed by the lower immersion heater once the upper has reached the temperature set by the immersion heater thermostat.

The myenergi eddi solar immersion heater has a more advanced range of settings. If the optional relay and sensor board is fitted, it can be used with a heat pump and integrate with the heat pump's Legionella cycle. There is detailed monitoring and control available with the myenergi app and this can integrate with other myenergi devices. Like the Solar iBoost+, the eddi could power up to 2 immersion heaters sequentially. The manual also advises on powering other devices such as an electric radiator on a dedicated circuit.

Solar immersion controllers can divert between about 1 and 6kWh in a day depending on the solar generation, hot water consumption and characteristics of the heating system. Some systems can provide the majority of the water heating for about 6 months a year.

5.3. Evaluation of installations with monitors and solar diverters

Performance of Wi-Fi dongle monitors

There were 7 households where Solis Wi-Fi dongles were either installed or setup on this project. By January 2023, 3 of the loggers were still online and 2 had gone offline due to changing broadband supplier. Another had gone offline due to major refurbishment work at the house while the last system was no longer accessible due to a password change.

2 households with Solis inverters were visited in November 2022. The solar PV systems had been fitted in August 2021 and after about 15 months of operation, the readings recorded by the Solis inverter and Wi-Fi dongle were 0.66% and 1.75% lower than the generation meter.

Household G-01 had a 2.76kW PV installation and was typically in all day. After 15 months, the percentage of the solar generation which had been consumed in the home was 27.1%. Household S-01 had a 2.07kW solar PV installation. The resident worked full time in shifts and so was sometimes at home during the day. The level of self-consumption of the solar generation between August and November was 24%.

Household with myenergi eddi solar immersion controller and Wibeee monitor

Household W-01 had a 4kW solar PV system along with 2 old solar thermal panels which only provided significant water heating in the middle of summer. The eddi solar immersion controller was able to divert 385.1kWh to power the immersion heater in 2022 or an average of 1.06kWh/day.

There was limited diversion in winter due to lower PV generation. There was also reduced diversion by the eddi in the middle of summer as this was when the old solar thermal flat-plate collector was able to supply much of the water heating demand. The minimum monthly diversion in 2022 was 16.5kWh in July when the solar thermal panels were making a greater contribution. The highest diversion was 50.6kWh in October when there was still fairly high PV generation but the solar thermal system had more limited impact.

The Eddi solar immersion controller increased the self-consumption of the solar generation from 11.6% to 21.9% in 2022. In July there was a small increase from 9.9% to 12.9% due to the solar thermal system providing much of the water heating. However, in October the percentage self-consumption increased from 14.6% to 38.7% and in December from 34.3% to 86.5%.

For periods with no hot water consumption (e.g. resident away) outside the summer, the solar immersion controller still heated the water (about 0.9kWh/day) due to the standing heat loss from the cylinder.

The accuracy of the monitoring of the grid consumption with the Wibeee and eddi was compared against a smart meter. Monthly readings of grid consumption from the Wibeee were 1.8 to 4.6% lower than the smart meter. There was lower accuracy with the eddi with the grid consumption 16.6 to 33.6% higher than for the smart meter. Myenergi advised this issue might be due to the eddi using old firmware and with the assistance of their technical support team an update to the firmware was downloaded. Readings of PV generation from the eddi were 0.8 to 1.9% higher than the values from the Wibeee Nest monitoring portal. One of the CT-sensors for the Wibeee was moved to record the power consumed by the immersion heater. On a particular day, the eddi indicated that 3.5kWh was diverted while the Wibeee recorded 3.45kWh consumption on the immersion heater circuit.

Household with Solar iBoost+ immersion controller and various PV monitors

Household W-02 had a 4.38kW solar PV system installed in January 2022. The PV system was split between approximately east and west facing roofs. The annual generation estimated by the installers was 3,714kWh, but during the first year of operation, 3,439kWh was generated. The PV system generated greater electricity early in the morning than the system for household W-01 due to there being solar panels on an east facing roof.

A Solar iBoost+ solar immersion controller and Buddy monitor was fitted at the time of the PV installation and there was monitoring from a Wibeee Box, the SMA inverter and a GEO Solo PV II. The difference between the PV generation recorded by manual meter readings and the different monitors was low and typically between 2 and 3kWh. There was a 0.5% difference between readings from the Wibeee Nest and SMA portals in July, but it was 5.2% in December.

There was a greater difference between the grid import from the smart meter and the Wibeee Nest for household W-02 than for W-01. The offset between the Wibeee and smart meter readings was between 7.2 and 17.6% for household W-02 compared to 1.8 to 4.6% for household W-01.

During its first year of operation, the Solar iBoost+ recorded that 1,020.4kWh of solar generation was diverted to power the immersion heater. This was an average of 2.8kWh/day. Over the year, 29.7% of the electricity from the solar panels was used to power the immersion heater. There was 142.5kWh diverted in June 2022. This decreased to 90.7kWh in August 2022 when the household was away for 2 to 3 weeks. With the lower generation in winter, there was only 11.4kWh diverted in December.

In August 2022, the self-consumption of the PV generation was 33.6%, but it would have been as low as 13.1% without the Solar iBoost+. Without the solar immersion controller, the self-consumption would have been between 49.2 and 63.2% for the months November 2022 to January 2023. With the solar immersion controller, the self-consumption was between 89 and 91.3% for these months. There was a particularly large increase in self-consumption due to the solar immersion controller in October 2022. For this month it would have been 33.8% without the Solar iBoost+ and rose it to 80.2% with the device.

Over a 12 month period, the solar immersion controller for household W-02 diverted 1020.4kWh compared to 385.1kWh for household W-01. There were several reasons for the greater diversion by household W-02. These included:

- Household W-01 also had water heating from an old solar thermal system in summer
- Household W-02 had a long vertical immersion heater which heated the whole cylinder while W-01 had a short horizonal immersion heater which was fitted half way up the cylinder and only effectively heated the top half of the cylinder
- Household W-02 had more residents and a greater hot water demand

- There were more regular periods of away from home for household W-01
- The hot water cylinder for household W-01 was newer and likely to have a lower standing heat loss

Household with Eco Eye smart PV monitors

The project installed Eco Eye smart PV monitors for a number of households in socially rented homes. Case studies were written for 2 of these households which had 1.75kW solar PV systems. The PV system for household E-01 faced east while for household E-02 it faced 20˚ west of south. The monitors were installed in March 2022 and memory cards from the monitors were collected in November 2022. Data from the memory cards was analysed using the Eco Eye Trax software for the device.

The Eco Eye memory card provided readings of energy used (household consumption) and PV generation at an interval of 4 seconds. Summary data (daily, hourly or half hourly) or the detailed 4 second data could be download from the software for analysis. Using the 4 second data, it was possible to calculate the grid consumption and PV export. Data from the 2 households was compared to smart meter readings and generation meter readings.

For household E-01, the PV generation obtained from the Eco Eye data was 13.8% higher than the value from the generation meter. In contrast, for household E-02 the PV generation was 1.3% lower with the Eco Eye data. The calculated grid import for household E-01 was 9.5% higher using the Eco Eye data than the value determined from smart meter data. For household E-02, the grid import calculated from the Eco Eye data was 4% lower than from the smart meter. An error of up to ±10% is typical when using CT-sensors rather than meters. Greater accuracy is possible with the Eco Eye if the household voltage is input using the software or display. It was not possible to correct for this in this study. Another possible issue was due to the CT-sensors and cables being installed in the consumer unit. There may have been errors due to the clamp not being fully closed or stray electromagnetic fields.

On a sunny day in June, the PV generation for household E-01 with solar panels facing approximately east had reached 50% of the maximum generation by 0600. The peak in generation of 1.5kW occurred at 10:00. The generation decreased significantly in the afternoon, even in summer due to less direct sunlight on the solar panels.

For household E-02, the peak in generation was at about 13:00 and the generation was higher in the afternoon that for E-01. A plot showing PV generation from households E-01 and E-02 on the same day suggested that the peak in generation for E-01 (1.5kW) was higher than for E-02 (1.36kW). This difference was likely to be due to the measuring error in the solar generation between the 2 monitors.

Over the monitoring period, the Eco Eye data suggested that the PV system for household E-01 generated 1591kWh and 1068.5kWh of the solar PV generation was consumed in the home. This would equate to a percentage self-consumption of 67.16%. The monthly percentage self-consumption ranged from 52% to 83%. This was particularly high for household E-01 as there was a high baseload electricity consumption of 800 to 1000W until mid-August. After that the baseload consumption fell to 300 to 400W. This meant the percentage self-consumption fell from 83% in July to 52% in September.

The Eco Eye data suggested that household E-02 generated 1533.8kWh over the monitoring period between March and November. Out of this, 770.3kWh of the solar generation was used in the home. Using a single rate tariff of 34p/kWh (the value for the Energy Price Guarantee from 1 Oct 22 to 31 Mar 23), the saving over the period due to the solar panels was £262. The percentage self-consumption over the full monitoring period was 57.4%. The monthly self-consumption was 52 to 53% in April and May, but increased above 59% in September to November.

Household E-02 had a lower baseload electricity consumption of 150 to 300W. There were periods during the day with high electricity consumption due to electric showers, use of the kettle and other appliances likely to be associated with cooking. A lower daytime baseload consumption than for household E-01 and only occasional periods with high consumption accounted for the lower level of self-consumption compared to household E-01.

Other households in the study had lower levels of self-consumption. These included household W-01 with 21.9%, G-01 with 27.1% and S-01 with 24%. These lower values of self-consumption were due to a combination of larger PV systems and lower household consumption.