Evaluating solar PV with Electric Heating with North Devon Homes: Main Report

Paul Rogers and Michael Hamer

February 2025

Background - Who we are

National Energy Action (NEA), the fuel poverty charity, campaigns so everyone can afford to live in a warm, safe and healthy home. This is something denied to millions because of poor housing, low incomes, and high bills.

Working across England, Wales and Northern Ireland, everything we do aims to improve the lives of people in fuel poverty. We directly support people with energy and income maximisation advice and we advocate on issues including improving the energy efficiency of our homes.

We do not work alone. Partnerships and collaboration have been at our heart for over 40 years, helping us drive better health and well-being outcomes for people struggling to heat their homes.

This evaluation was carried out by the Innovation and Technical Evaluation team at NEA:

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Executive Summary

Project Overview

There is a drive to shift to greater electric heating for off-gas grid homes and new build homes. Solar PV is a complementary technology to electric heating. It can help reduce space heating costs, particularly in the Spring and Autumn when there is greater solar generation at a time when residents may be heating their homes. The 'Evaluating solar PV with Electric Heating' project examined the energy savings from adding solar PV systems to homes with different types of electric heating. Some of these homes also had battery storage. In addition, some households had Mixergy smart hot water cylinders installed with a solar diverter.

The project was led by North Devon Homes with support from National Energy Action (NEA). There were 18 households that received solar PV systems and 11 of these had Mixergy cylinders installed. Among these households, seven had air-source heat pumps (ASHPs) and Alpha ESS batteries installed on an earlier project while three households had Tesla Powerwall 2 batteries installed in a previous innovation project.

The project started in September 2022 with solar PV installations taking place between June 2023 and March 2024. Final household interviews were conducted in November/December 2024 and the evaluation report was completed before the end of February 2025. Additional project reports focus on the Wondrwall installations with infrared heating, the Mixergy cylinders and the savings with different electricity tariffs.

Details of the installations

The installations took place in North Devon Homes (NDH) properties in Witheridge, North Molton, Bratton Fleming and East Buckland. Details of the installations are shown in table ES1. The solar PV systems ranged in size from 3.89kW to 5.81kW with half of the installations using large 5.81kW arrays. Some of the installations faced south while others were split over east/west roofs.

Households B-01 to B-07 had existing Vaillant aroTHERM plus high temperature ASHPs with Alpha ESS batteries. These installations also already had SunAmp heat batteries which provided heat storage supplying hot water.

The solar PV systems were installed, connecting to the existing Alpha ESS hybrid inverter. Six of these PV systems had a large 5.81kW array. Household B-03 had a 5.67kW system instead. The roof needed replacing and an in-roof solar PV system was installed with different sized solar panels.

The households that did not have the Vaillant aroTHERM plus ASHPs with SunAmp heat batteries all had Mixergy cylinders installed with solar diverters.

Households T-06, T-03 and T-09 all had existing Tesla Powerwall 2 batteries and traditional storage heaters. An ASHP was installed for T-06 at the same time as the solar PV system was fitted. The roof was replaced for T-09 prior to the installation of an on-roof solar PV system. The traditional storage heaters were replaced with Dimplex Quantum high heat retention storage heaters soon after the PV system was installed. These additional works were fully funded by NDH.

Code	Space heating	Hot water storage	Usable battery capacity	Solar PV system size	Orientation	Solar PV install date
B-01	ASHP	SunAmp	9.1 kWh	5.81 kW	South	22 Aug 23
B-02	ASHP	SunAmp	9.1 kWh	5.81 kW	South	22 Aug 23
B-03	ASHP	SunAmp	11 kWh	5.67 kW	East/West	26 Sep 23
B-04	ASHP	SunAmp	9.1 kWh	5.81 kW	East/West	11 Aug 23
B-05	ASHP	SunAmp	11 kWh	5.81 kW	East/West	20 Sep 23
B-06	ASHP	SunAmp	11 kWh	5.81 kW	South	20 Sep 23
B-07	ASHP	SunAmp	11 kWh	5.81 kW	East/West	23 Oct 23
T-06	ASHP	Mixergy	13.5 kWh	4.57 kW	South	5 Sep 23
T-03	NSH	Mixergy	13.5 kWh	4.74 kW	East/West	14 Jun 23
T-09	NSH	Mixergy	13.5 kWh	4.15 kW	South	25 Sep 23
SH-01	NSH	Mixergy	-	3.89 kW	South	12 Mar 24
SH-02	NSH	Mixergy	-	4.98 kW	East/West	31 Jan 24
SH-03	NSH	Mixergy	-	5.53 kW	East/West	24 Nov 23
AC-03	ASHP	Mixergy	-	4.74 kW	East/West	8 Jun 23
AC-04	ASHP	Mixergy	-	4.15 kW	South	9 Oct 23
IC-01	IR panel	Mixergy	-	5.81 kW	South	27 Sep 23
W-01	IR panel	Mixergy	6 kWh	5.81 kW	South	26 Oct 23
W-02	IR panel	Mixergy	6 kWh	5.81 kW	South	27 Oct 23

Table ES1 Details of the properties which received solar PV installations

Households SH-01 and SH-02 did not have an electrical battery and heated the home with storage heaters and panel heaters. Households AC-03 and AC-04 had ASHPs with no electrical battery.

W-01 and W-02 had Wondrwall installations where infrared heating panels replaced storage heaters. There was also an electrical battery with 6kWh usable capacity installed along with a smart hot water cylinder. Household IC-01 bought their own infrared heating panels as they disliked the storage heaters that had been fitted. This household also had a 5.81kWh south facing PV system installed along with a Mixergy cylinder but no battery system.

Households W-01 and W-02 had existing external wall insulation (EWI). Households AC-04 and IC-01 had improvements made to the insulation under the Social Housing Decarbonisation Fund (SHDF) during the project. Existing fibre cavity wall insulation (CWI) was removed, and the cavity wall allowed to dry out. Thermal bead CWI was then installed and later EWI. Household T-06 had the old fibre CWI removed, the cavity was allowed to dry and thermal bead CWI was later installed.

Code	Space heating	Hot water storage	Property type	Solar PV size (kW)	EPC score without solar PV	EPC score with solar PV	EPC score with Mixergy cylinder
B-01	ASHP	SunAmp	Bungalow	5.81 kW	D67	A104	N/A
B-02	ASHP	SunAmp	Bungalow	5.81 kW	D63	A101	N/A
B-03	ASHP	SunAmp	House	5.67 kW	D68	A92	N/A
B-04	ASHP	SunAmp	Bungalow	5.81 kW	D66	A104	N/A
B-05	ASHP	SunAmp	Bungalow	5.81 kW	D66	A104	N/A
B-06	ASHP	SunAmp	Bungalow	5.81 kW	D66	A104	N/A
B-07	ASHP	SunAmp	House	5.81 kW	D67	A93	N/A
T-06	ASHP	Mixergy	House	4.57 kW	C75	A98	A103
T-03	NSH	Mixergy	House	4.74 kW	D58	C79	B82
T-09	NSH	Mixergy	House	4.15 kW	D68	A93	A96
SH-01	NSH	Mixergy	House	3.89 kW	D68	B86	B88
SH-02	NSH	Mixergy	House	4.98 kW	D67	B90	A92
SH-03	NSH	Mixergy	House	5.53 kW	D62	B84	B86
AC-03	ASHP	Mixergy	Bungalow	4.74 kW	C70	A100	A105
AC-04	ASHP	Mixergy	Bungalow	4.15 kW	C74	A105	A109
IC-01	IR panel	Mixergy	Bungalow	5.81 kW	E47	B85	A92
W-01	IR panel	Mixergy	Bungalow	5.81 kW	E48	B91	A94
W-02	IR panel	Mixergy	Bungalow	5.81 kW	E48	B91	A94

Table ES2 Details of the installations and impact on the EPC score

The properties receiving installations were a mix of houses and bungalows. Surveys of the properties were carried out by a domestic energy assessor. The energy score for the Energy Performance Certificate (EPC) was determined under RdSAP 2012 with and without the solar PV installation. The uplift in energy score for the Mixergy cylinder was also determined with an Appendix Q calculation. RdSAP 10.2 is expected to be introduced during 2025, and battery storage will be included as a measure for the first time which will lead to improvements in the energy score.

The increase in energy score ranged from 18 to 43 points after installing solar PV at the properties. The uplift from installing the Mixergy cylinder was between two and seven points. Infrared heating panels lowered the energy score compared to storage heaters.

Social evaluation

Households were asked how satisfied they were with different aspects of their home heating and insulation. All nine of the households interviewed with ASHPs were very satisfied with the amount of control they had over the heating system. Eight of the households were very satisfied and one satisfied with the cost of running the heating system and how warm their home gets when it is cold outside.

There were four households with storage heaters interviewed. Three of the households were very dissatisfied and one dissatisfied with the cost of running the heating system. Three of the households were dissatisfied with how warm the home gets when cold outside while one was neither satisfied nor dissatisfied. Residents were more favourable about ease of use of the storage heaters with one very satisfied, two satisfied and one dissatisfied.

Household were also asked whether they agreed or disagreed with statements on the benefits of the solar PV system. Eight of the ASHP households strongly agreed and one agreed that their electricity costs had decreased since the solar PV system had been installed. Six of the households strongly agreed and two agreed that their electricity cost was lower on a sunny day, and it was cheaper to heat their home on a sunny day. The remaining household did not have a smart meter and didn’t know as a result. Out of the eight households who had storage heaters replaced by an ASHP and battery system, all eight strongly agreed that their current heating system was better than their old one.

Among the four households with storage heaters interviewed, all agreed that their electricity costs had decreased since the solar PV system was installed. While three strongly agreed and one agreed that their electricity cost was lower on a sunny day, all disagreed that it was cheaper to heat their home on a sunny day. This might be expected as solar PV would not reduce consumption of storage heaters overnight.

There was positive feedback on the solar PV systems, particularly with the combined PV, ASHP and battery systems. One household noted that:

“I have never had such a warm house. If I ever moved, I would have to have the same heating system and solar PV. The rest of the village are extremely jealous. My son has not had any asthma issues since moving in. This is the best heating system I have ever had for my disability.”

Technical monitoring

Room temperatures

Temperature and humidity loggers were placed in the living area and the bedroom for each of the households in a pre- and post-installation period. The temperature was analysed over the heating season from 1 November to 1 May.

For the ASHP households, the average living area room temperature ranged from 16.4°C to 22.1°C during the post-installation heating season from 1 Nov 2023 to 1 May 2024.

The most significant change in room temperature between the pre- and post-installation heating seasons was for household T-06. During the pre-installation heating season, space heating was provided by an open fire in the living room and storage heaters elsewhere. The household were rationing energy due to high prices and the old cavity wall insulation was removed, the cavity left to dry out and then replaced by thermal bead CWI. The average temperature in the dining room rose from 16.0°C to 20.2°C during the post-installation period when space heating was now provided just by an ASHP.

Household AC-03 controlled the ASHP more like a gas boiler, turning it off when going out. This led to a low average room temperature of 16.4°C. Others such as Households B-05 and B-07 had the thermostat set to a constant temperature throughout the day with an average temperature of about 22°C

For the storage heater households, the post-installation average temperature over the heating season was between 17.1 and 21.6°C. For household T-03, the post-installation temperature of the dining room could rise and fall by 2.5°C to 3°C due to the daily charge and discharge of the storage heaters. Maximum temperature was typically at 07:00 after the storage heater was fully charged and fell to a minimum by about 17:00. As well as the daily rise and fall there was a longer-term rise and fall most likely due to longer term changes in external temperature.

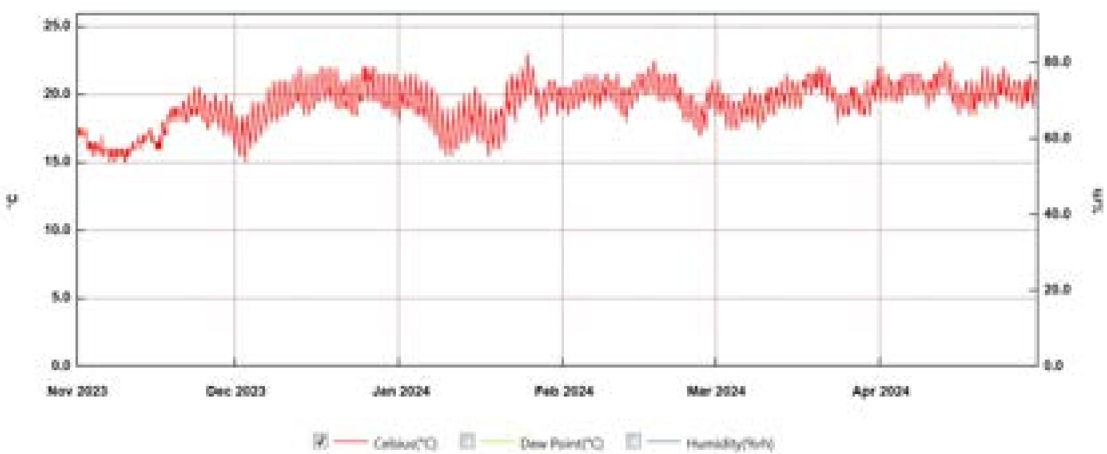

Figure ES3 Dining room temperature for household T-03 during the post-installation heating season with a traditional storage heater

Storage heaters like this are likely to be unpopular due to a combination of factors. These include a lack of control over when heat is emitted, the heater not responding to external temperature and the type of heat provided.

Solar PV generation

Table ES4 shows the solar PV generation for the households. For most of the households this covers the period 1 Jan 2024 to 31 Dec 2024. Different dates were used for three households due to late installations and monitoring issues. The PV generation ranged from 3,282kWh to 5,652kWh. Household SH-01 had the smallest solar PV array, and it was commissioned during March 2024. There was lower generation than expected due to not having a full year of monitoring and the RCD for the PV system tripping for two periods during the year.

Code	Space heating	Battery usable capacity (kWh)	Start date	End date	Solar PV size (kW)	PV Gen (kWh)	% Use in home
B-01	ASHP	9.1	1 Jan 24	31 Dec 24	5.81	5,212	55.9%
B-02	ASHP	9.1	1 Jan 24	31 Dec 24	5.81	5,489	50.2%
B-03	ASHP	11	1 Jan 24	31 Dec 24	5.67	4,778	70.9%
B-04	ASHP	9.1	1 Nov 23	31 Oct 24	5.81	4,755	54.0%
B-05	ASHP	11	1 Jan 24	31 Dec 24	5.81	4,642	61.6%
B-06	ASHP	11	1 Jan 24	31 Dec 24	5.81	5,652	55.7%
B-07	ASHP	11	1 Jan 24	31 Dec 24	5.81	4,159	74.3%
T-06	ASHP	13.5	1 Jan 24	31 Dec 24	4.57	4,416	80.5%
T-03	NSH	13.5	1 Jan 24	31 Dec 24	4.74	3,759	82.8%
T-09	NSH	13.5	1 Jan 24	31 Dec 24	4.15	3,873	65.6%
SH-01	NSH	-	1 Mar 24	31 Jan 25	3.89	3,282	-
SH-02	NSH	-	1 Feb 24	31 Jan 25	4.98	4,125	-
AC-03	ASHP	-	1 Jan 24	31 Dec 24	4.74	3,842	42.4%
AC-04	ASHP	-	1 Jan 24	31 Dec 24	4.15	3,736	33.5%
IC-01	IR panel	-	1 Jan 24	31 Dec 24	5.81	5,116	38.1%
W-01	IR panel	6	1 Jan 24	31 Dec 24	5.81	5,531	35.6%
W-02	IR panel	6	1 Jan 24	31 Dec 24	5.81	5,224	18%

Table ES4 Solar PV generation and solar self-consumption for households

There was reduced generation for household B-07 with two weeks with the inverter not running in January 2024 and a further two weeks in March/April after a loss of internet connection following a change of broadband router.

There was higher PV generation for the households with larger PV arrays and for those facing south rather than east/west.

The solar PV systems generated less than was predicted on the MCS certificates. This was likely to be due to lower-than-average levels of sunshine in 2024.

Table ES4 also shows the percentage self-consumption of the solar generation for each of the households apart from SH-01 and SH-02 where no or limited data was available. The self-consumption of households B-01 to B-07 with Alpha ESS batteries was between 50.2% and 74.3%. These high levels were achieved despite high levels of PV generation. Households T-06, T-03 and T-09 with Tesla Powerwall 2 batteries had a self-consumption level of between 65.6% and 82.8%. These households may have achieved a better level of self-consumption due to a combination of lower PV generation and the Tesla battery having a feature where the system predicts the PV generation for the day and alters the overnight grid charging to maximise self-consumption of the solar PV. In contrast, NEA staff had to manually alter the percentage battery charge overnight for the Alpha ESS battery and adjusted this on a seasonal basis. It was not possible to regularly change the overnight charge to allow greater grid charging on a cloudy day compared to a sunny day.

There were fairly high levels of self-consumption of solar PV of 33.4% and 42.4% over the year for households AC-03 and AC-04. There was daytime electricity consumption by the heat pump, but of greater significance was the consumption by the solar diverter for the Mixergy cylinders.

Household IC-01 was similar to AC-03 and AC-04 with no battery, daytime heating and a Mixergy cylinder. Here the self-consumption was 38.1%

The Wondrwall households had the lowest self-consumption recorded among the installations. This was partly due to a high level of PV generation. W-02 was a very low electricity user, did not use the Mixergy cylinder and consumed only 18% of the solar generation. Household W-01 which used a normal level of electricity consumed 35.6% of the solar generation. In this case, the solar diverter for the Mixergy cylinder was not operational until mid-July 2024.

There was limited data on self-consumption of the solar PV for the households with just storage heaters due to monitoring issues. The percentage self-consumption of the solar PV for household SH-02 was 41.2% over six months.

Solar PV and batteries

It was possible to assess savings from the solar PV using monitoring from the battery storage portals. There were losses from grid charging of the battery. Over a year, these losses were 495 to 589kWh for the Tesla Powerwall 2 batteries. Losses recorded on the Alpha ESS portal as the difference between battery charge and battery discharge were up to 232kWh however it is unclear if the portal recorded the full losses.

Energy savings from the solar PV and battery systems during 2024 were also assessed. These were defined as the difference between household load and grid import. These ranged from 2,699kWh to 3,029kWh for the four Alpha ESS batteries analysed and were between 2,447kWh and 2,808kWh for the Tesla batteries. The savings were likely to be larger with the Alpha ESS systems due to higher generation from the large PV systems.

Electricity consumption

The electricity consumption before and after the solar PV installations was determined from electricity meter readings. There was some variation in the date and length of the pre-installation periods, but the post-installation period covered the whole of 2024.

All households saw a reduction in grid import between the pre- and post-installation periods. This reduction varied from 216kWh to 4,569kWh. Other factors affected the change in consumption apart from the installation of the solar PV. These included behaviour change or change of occupancy of the households as well as other measures being installed.

Household T-06 saw the lowest reduction in grid consumption (216kWh) between the pre- and post-installation periods. Here the household had storage heaters replaced by an ASHP at the time the solar PV system was installed. The household load rose from 7,172kWh to 9,992kWh. This was due to increased thermal comfort. There was an increase in average temperature in the dining room from 16.0°C to 20.2°C over the winter heating season. After the ASHP was installed, the living room was heated by two radiators instead of an open fire.

The grid consumption between pre and post installation periods for B-04 fell by 4,569kWh. This was partly due to a change in occupancy and a reduction in thermal comfort. The electricity consumed by the heat pump fell by about 1,000kWh while the savings from the solar PV were about 2,500kWh.

Figure ES5 plots the monthly grid import of B-05 between October 2020 and the end of 2024. The ASHP was commissioned in late January 2022, replacing traditional storage heaters. The Alpha ESS battery with 11kWh usable capacity was operational from July 2022. The solar PV system was commissioned in late September 2023.

It is apparent there was a reduction of almost 50% in the electricity consumed in January between 2021/22 with the storage heaters and 2023/24 with the ASHP and later the ASHP and solar PV. A similar large decrease in consumption is seen in February between 2021 and 2023/24.

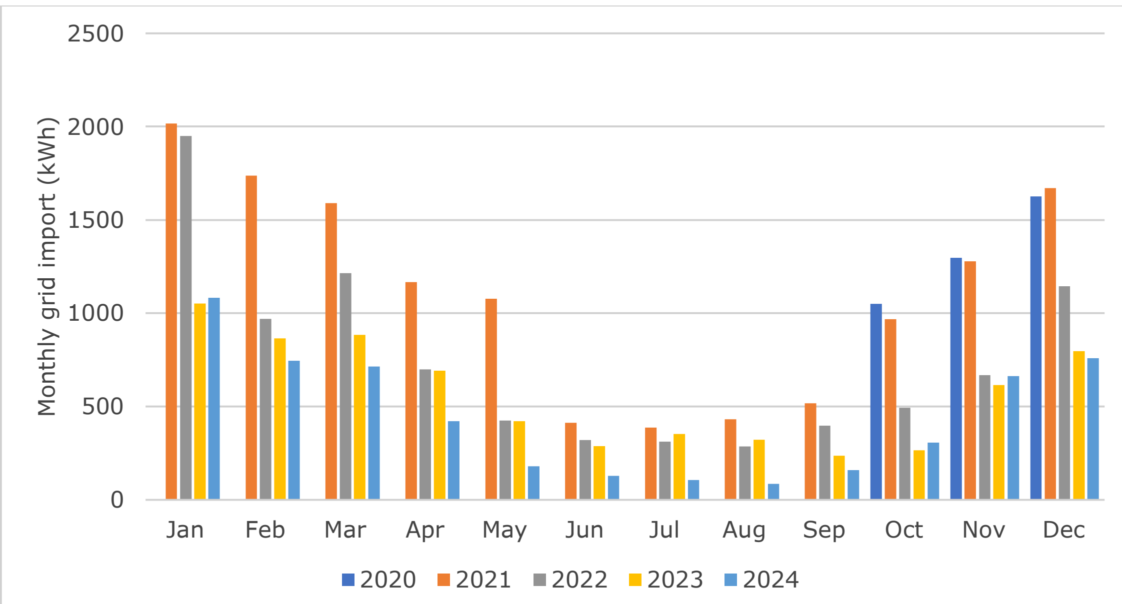

Figure ES5 Monthly grid import from smart meter data for household B-05 from October 2020 to December 2024

While significant electricity savings were achieved by replacing the storage heaters with the ASHP, the graph also shows savings from the solar and battery. In April there was a large decrease in consumption from 2021 to 2022/23 after the ASHP was installed. There was a further reduction in April 2024 due to the solar PV. Similar behaviour is apparent in October, with higher consumption in

2020/21 with the storage heaters, a reduction in 2022 from the ASHP and further savings in 2023/24 due to the solar PV.

March/April and October are months with higher PV generation and significant electricity use from heating. Large savings were also apparent from May to September due to the PV.

From 1 Oct 2020 to 30 Sep 2021 when household B-05 had storage heaters, the electricity consumption was 13,307kWh. This fell to 7,545kWh from 1 Aug 2022 to 31 Jul 2023 with the ASHP and battery while also improving thermal comfort. The addition of solar PV reduced the grid consumption in 2024 to 5,353kWh.

Electricity consumption of heat pumps

Code	Space heating consumption (kWh)	Space heating output (kWh)	Water heating consumption (kWh)	Water heating output (kWh)	Total heating consumption (kWh)	Overall COP
B-01	2,042	8,337	360	939	2,402	3.86
B-02	2,159	7,412	588	1276	2,747	3.16
B-03	2,480	8,226	1,186	2,577	3,666	2.95
B-04	2,394	8,950	290	665	3,059	3.58
B-05	4,495	17,193	715	1,601	5,210	3.61
B-06	4,336	13,062	575	1,079	4,911	2.88
B-07	4,460	17,879	706	1,950	5,166	3.84

Table ES6 Electricity consumption and heat outputs in 2024 based on data from the My Vaillant app for the Vaillant aroTHERM plus ASHPs

Electricity consumption of the ASHP was also obtained from the My Vaillant app for the households with Vaillant aroTHERM plus ASHPs. Data for household B-04 was less accurate as it was offline during December and the first 11 days of January 2025, so consumption data was averaged over that period.

The MCS certificate for the ASHPs with a flow temperature of 55°C indicated a seasonal coefficient of performance of 3.39. This suggests that for each unit of electricity consumed by the heat pump, 3.39 units of heat would be produced. Four of the seven installations performed better than this over 2024.

The total consumption by the ASHPs ranged from 2,402kWh to 5,210kWh. Household B-01 had the lowest total consumption and the highest coefficient of performance (COP) of 3.86. This was the first installation to be completed and is likely to have used higher specification insulation for the pipework which may have boosted performance. The thermostat was set relatively low with a living room temperature of between 17.5°C and 20°C.

The ASHP for household B-06 had the lowest COP of 2.88. There had been teething problems with this installation and further issues developed in late 2024 which may explain the poorer performance.

Households B-05 and B-07 were the highest consuming households. Here, the thermostat was set to 21 to 22°C throughout the year. The constant temperature resulted in a high COP, but the higher temperature led to higher consumption. The overall COP for B-05 was 3.61 but the monthly COP ranged from 3.1 in January 2024 to 4.1 in October 2024. The COP for space heating was higher than the COP for water heating.

Figure ES7 plots the monthly household load for B-05 in 2024 showing the consumption by the ASHP due to space heating and water heating.

The household load ranged from 1,194kWh in January 2024 to 324kWh in August 2024. The percentage consumption by the ASHP was 40.7% in August 2024 but increased to 79.8% in January 2024. B-05 was the household with the highest consumption from the heat pump. In January 2024, consumption from the heat pump contributed 60.7% and 62.1% respectively to the household loads for B-01 and B-02.

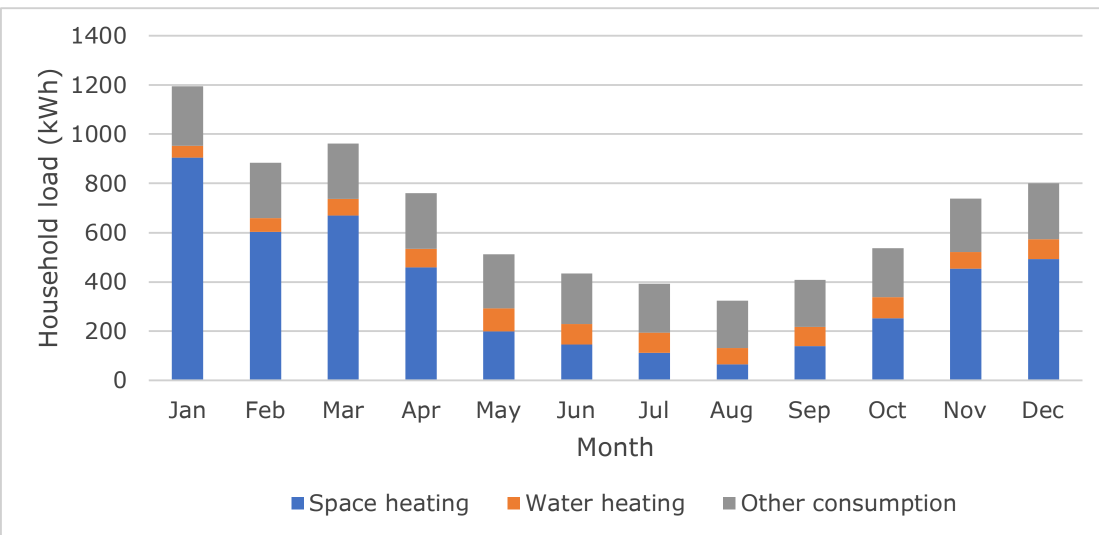

Figure ES7 Household load for B-05 showing the space and water heating load from the ASHP and the load from other appliances in 2024

Figure ES8 shows a plot of the monthly solar PV generation for household B-05. This includes the amounts used in the home and exported to the grid. For the months with lower generation (November to February), more than 98% of the monthly generation was used in the home (78 to 155kWh). There is higher generation in Spring and Autumn (March-May and September/October) while there is also space heating demand. During these months, the amount of the solar generation used was between 254kWh and 364kWh, with the highest self-consumption in April 2024. There continued to be high levels of consumption in the summer months with between 250kWh to 321kWh used in the home.

Over the year, household B-05 used 2,857kWh of the 4,642kWh generated. This represented a percentage self-consumption of 61.6%.

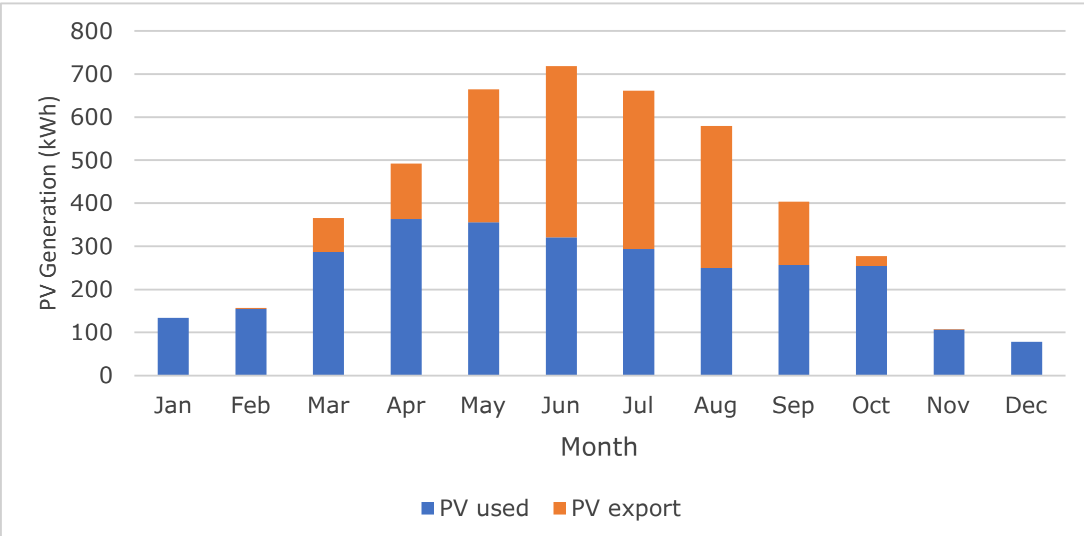

Figure ES8 Solar PV generation in 2024 for household B-05, showing the generation used in the home and the amount exported to the grid

Conclusions and recommendations

- 18 solar PV systems, 11 Mixergy cylinders and two Wondrwall heating systems were installed in North Devon Homes properties
- The solar PV system sizes ranged from 3.89kW to 5.81kW
- The EPC energy score under RdSAP 2012 increased by 18 to 43 points after installing the solar PV and two to seven points due to the Mixergy smart hot water cylinder
- The impact of solar PV and batteries on the EPC energy score should be further investigated once RdSAP 10.2 is introduced
- Households with ASHPs and batteries showed high levels of satisfaction with the amount of control and cost of running the heating system
- Those with storage heaters were dissatisfied with running costs and thermal comfort with the storage heaters
- There were high levels of agreement among ASHP and battery households that electricity costs were lower since the PV system was installed, and it was cheaper to heat their home on a sunny day

- Households with storage heaters agreed that electricity costs had decreased since the solar PV had been installed but disagreed that it was cheaper to heat their home on a sunny day.
- There was positive feedback from the households about the installations, particularly from those with ASHPs, batteries and on smart time-of-use tariffs
- The solar PV generation for the installations in 2024 ranged from 3,282kWh to 5,652kWh which was lower than predicted by the MCS certificate primarily due to lower-than-average sunshine levels in 2024
- Most of the households with battery storage were using between about 50% and 80% of the solar PV generation in the home despite the large PV system sizes
- Households without batteries and with Mixergy cylinders could still use around 30 to 40% of the solar generation in the home
- Data from the Alpha ESS and Tesla portal/app showed that savings from the solar PV for these systems were in the range 2,447kWh to 3,029kWh
- All households had a reduction in grid import between a pre-installation period and post-installation period in 2024
- The reductions were between 216kWh and 4,569kWh but these reductions were also influenced by behaviour change and other measures being installed as well as by the solar PV system
- The Vaillant aroTHERM plus heat pumps consumed between 2,402kWh and 5,210kWh in 2024, with the highest consuming household having a consistent thermostat setting of about 22°C during the year
- For the highest consuming ASHP, the electricity consumption fell from 13,307kWh to 7,545kWh when the ASHP and battery replaced the original storage heaters; the consumption fell to 5,353kWh after the solar PV system was installed
- The solar PV system generated 4,642kWh for this household with 2,857kWh of this (61.6%) used in the home
- This project shows the benefits of installing large solar PV systems for homes with electric heating, leading to high uplifts in the energy score of the EPC and significant energy and cost savings for households
- Further studies should be made investigating the performance of more advanced integrated systems with ASHPs, solar PV and battery storage
- Additional cost savings can be achieved for systems with batteries on smart time-of-use electricity tariffs
- It is important for social landlords to have an energy manager or contractor who regularly checks solar PV and battery systems for performance
- Solar PV with battery systems need to be kept online and more reliable communication systems are required, not relying on tenant's broadband
- Battery manufacturers need to develop solutions to avoid reversed CT clamps which can increase consumption and develop smart charging from the grid taking into account predicted PV generation

1. Project overview

1.1 Introduction

There is a drive to shift to greater electric heating for off-gas grid homes and new build homes. Solar PV is a complementary technology to electric heating. It can help reduce space heating costs, particularly in the Spring and Autumn when there is greater solar generation at a time when residents may be heating their homes. The 'Evaluating solar PV with Electric Heating' project examined the energy savings from adding solar PV systems to homes with different types of electric heating. Some of these homes also had battery storage.

The benefit of lower water heating costs from using a solar diverter was also investigated by installing Mixergy smart hot water cylinders, with significant savings in water heating from Spring to Autumn.

The project was led by North Devon Homes (NDH) and a total of 18 solar PV systems were installed along with 11 Mixergy cylinders. This included two Wondrwall heating systems which combined infrared heating panels with solar PV, battery storage and a smart hot water cylinder. A separate report discusses the Wondrwall installations and compares them to a control property with infrared heating panels, solar PV and a Mixergy cylinder[1]. Another report examines the performance of the Mixergy cylinders[2]. This report will focus on the benefits of solar PV in homes with air-source heat pumps (with and without batteries) and those with storage heaters (with and without batteries).

1.2 Project partners

North Devon Homes (NDH) is a non-profit making housing association and registered charity. The landlord has 3,271 domestic properties that are socially rented. Out of these, 584 properties have storage heaters on an Economy 7 electricity tariff.

Most of the solar PV systems were installed by RES Devon Ltd in Barnstaple. Wondrwall organised the solar PV and battery installations for their two systems. Boxergy connected the solar PV systems to the Alpha ESS hybrid inverters and batteries they fitted on an earlier project. The Innovation and Technical Evaluation team at NEA completed the data analysis and evaluation for this project. They also assisted by providing project coordination, resident engagement and household interviews.

[1] Rogers and Hamer (2025), Evaluating solar PV with electric heating with North Devon Homes: Wondrwall (in press)

[2] Rogers and Hamer (2025), Evaluating solar PV with electric heating with North Devon Homes: Mixergy cylinders (in press)

1.3 Context

In an earlier collaboration between NDH and NEA, Tesla Powerwall 2 batteries were installed in eight homes without solar PV[3]. The homes were heated by electric storage heaters on an Economy 7 tariff. The batteries were able to charge on the off-peak rate and discharge during peak rate. Many of the households had an annual percentage off-peak consumption of 40-60% before the battery installations and this rose to a monthly off-peak consumption of 80-95%.

As a result of shifting consumption from the peak to off-peak rate, households typically saved more than £1 per day. This assumed a price difference of 11p/kWh between the peak and off-peak rates. Three of these households had a solar PV system added to the Tesla battery system in the current project.

A previous Energy Industry Voluntary Redress Innovation project[4] replaced the storage heaters for seven North Devon Homes households with a wet central heating system, air source heat pump (ASHP) and battery storage. When interviewed, all seven households strongly agreed that their new heating system was better than their old one and that they now had whole house heating rather than room heating. Five of the households strongly agreed that their thermal comfort had improved with the new heating system while the other two households agreed with the statement.

Most of the households saw improvements in both average room temperatures and minimum room temperatures. Some average room temperatures increased by 2-4°C over the winter heating season. Bedrooms often saw greater improvements as they had often been heated less.

There was one household (B-02) where there was approximately a full year of monitoring before and after the installation. For the pre-installation period with the storage heaters, the average electricity consumption was 26.2kWh/day. Correcting this for external temperature, the consumption was 4.2kWh/Degree Day. The percentage off-peak consumption was quite high at 69.6% due to overnight charging of the storage heaters and hot water cylinder. For the post-installation monitoring period with the ASHP and battery storage, the average electricity consumption over the year had fallen to 20.8kWh/day or 3.94kWh/Degree Day. The percentage off-peak consumption over the year was still high at 68.5% due to overnight charging of the 10kWh battery and

[3] Rogers and Hamer (2018), Tesla Powerwall 2 batteries charged using off-peak electricity, https://www.nea.org.uk/wp-content/uploads/2020/10/CP1139-TIF-REPORT_FINAL-25-04-19-v2.pdf (Accessed 24 Jan 2025)

[4] Rogers and Hamer (2023), Making Heat Cheaper, Smarter and Greener, https://www.nea.org.uk/wp-content/uploads/2023/06/CP1438-Boxergy-NDH-full-report-16-Jan-22.pdf (Accessed 25 Jan 2025)

discharge during peak rate times. The combination of using battery storage with a time-of-use tariff in both projects led to lower electricity bills

The seven households who received ASHPs and batteries on this earlier project and the four control households all received solar PV installations in the current project.

1.4 Project timeline

The project started in September 2022. 14 of the 18 properties receiving installations had been involved in the two earlier projects discussed in the previous section. This meant there was preinstallation monitoring data available for these households from before the start of the project. The remaining four households were identified by North Devon Homes as suitable for the solar PV project and the households were invited to take part. The solar PV installations took place between June 2023 and March 2024.

Final household visits which included interviews were carried out in late November and early December 2024. The post-installation monitoring took place until 1 Jan 2025 which meant all but two solar PV installations had a year or more of performance data available.

The final reports were written between November 2024 and February 2025. This includes this main report along with additional reports on the Wondrwall installations with infrared heating, the Mixergy smart hot water cylinders and electricity tariffs for electric heating.

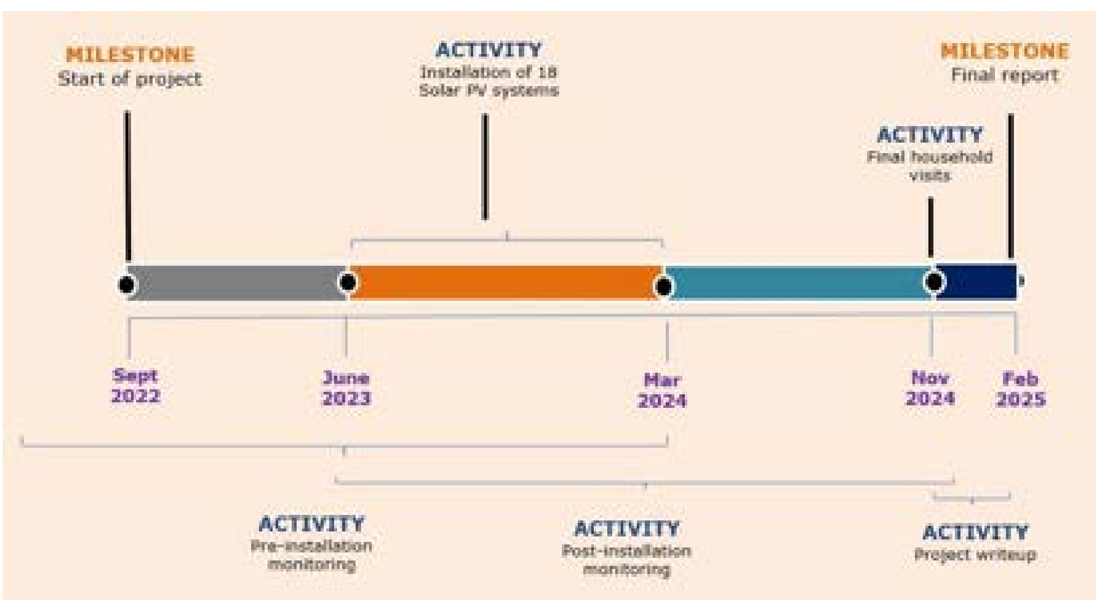

Figure 1.1 Timeline for the Evaluating Solar PV with Electric Heating project

1.5 Factors affecting the project plan

Issue	Description and mitigation
Installation delays	The solar PV installation programme took longer than anticipated. The installer had reduced capacity due to a shortage of experienced electricians. Three of the properties required the roof to be replaced and this and poor weather in Autumn 2023 delayed these installations.
Installation issues	The performance of similar sized and orientated PV systems was compared. One was under-generating due to wiring issues with one string of solar panels and another due to a faulty DC isolator. These issues were resolved soon after the under-generation was noticed.
Failures	Two of the Alpha ESS Smile 5 inverters failed during the project and were replaced under warranty. However, the households were left without the battery system operational for about one and two months respectively.
Export limitation and other settings	Initially the installations with Alpha ESS hybrid inverters and batteries were not maximising their generation. It was necessary to get Alpha ESS to remove export limitation for the inverter and check the installation settings were correct. Subsequently the PV generation increased and there was export to the grid.
Monitoring	The Alpha ESS and Solis inverters were used to monitor the solar PV generation and if the inverter was a hybrid, it also monitored the grid consumption. There was data loss for some households due to issues around using home broadband for internet connectivity.
Change in occupancy	Two of the residents with health conditions passed away during the project and this affected how the heating was used before and after. There was a household who moved out and was replaced by another with different levels of heating and electricity use.
CT clamp issues	There were issues where CT clamps were fitted in the wrong orientation. This affected monitoring for hybrid inverters and performance of Mixergy solar diverters. The CT clamps for two batteries were reversed after electrical work in the home. This caused the batteries to force charge and discharge costing the household more, but this issue was quickly detected and resolved.

2. Installations

2.1 Details of the installations

Figure 2.1 Map showing the location of installations[5]

There were 18 solar PV installations, with 13 in Witheridge, two in North Molton (both Wondrwall installations), two in Bratton Fleming and one in East Buckland.

Out of the 18 solar PV installations, 10 were south facing and eight had the solar panels split between east and west roofs. The south facing installations had a higher maximum daily PV generation and annual generation, but the East/West installations started generating electricity earlier in the morning until later in the evening. There were 9 x 5.81kW installations, the maximum size, while the smallest array was 3.89kW.

The installations with ASHPs and Alpha ESS batteries had a reference code B-01 to B-07 and were discussed in an earlier report[6]. The solar PV system sizes were all 5.81kW apart from B-03 which had a 5.67kW in-roof installation after the slate roof was replaced. The 11.4kWh Alpha ESS battery units (2 x 5.7kWh) had a usable capacity of 11kWh. The 10.1kWh Alpha ESS battery had a usable capacity of 9.1kWh. These installations had the electrical battery and a SunAmp heat battery (which provided hot water) in an external box.

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[5] Map produced with EasyMapMaker, https://www.easymapmaker.com/

[6] Rogers and Hamer (2023), Making Heat Cheaper, Smarter and Greener, https://www.nea.org.uk/wp-content/uploads/2023/06/CP1438-Boxergy-NDH-full-report-16-Jan-22.pdf (Accessed 25 Jan 2025)

Code	Space heating	Hot water storage	Usable battery capacity	Solar PV system size	Orientation	Solar PV install date
B-01	ASHP	SunAmp	9.1 kWh	5.81 kW	South	22 Aug 23
B-02	ASHP	SunAmp	9.1 kWh	5.81 kW	South	22 Aug 23
B-03	ASHP	SunAmp	11 kWh	5.67 kW	East/West	26 Sep 23
B-04	ASHP	SunAmp	9.1 kWh	5.81 kW	East/West	11 Aug 23
B-05	ASHP	SunAmp	11 kWh	5.81 kW	East/West	20 Sep 23
B-06	ASHP	SunAmp	11 kWh	5.81 kW	South	20 Sep 23
B-07	ASHP	SunAmp	11 kWh	5.81 kW	East/West	23 Oct 23
T-06	ASHP	Mixergy	13.5 kWh	4.57 kW	South	5 Sep 23
T-03	NSH	Mixergy	13.5 kWh	4.74 kW	East/West	14 Jun 23
T-09	NSH	Mixergy	13.5 kWh	4.15 kW	South	25 Sep 23
SH-01	NSH	Mixergy	-	3.89 kW	South	12 Mar 24
SH-02	NSH	Mixergy	-	4.98 kW	East/West	31 Jan 24
SH-03	NSH	Mixergy	-	5.53 kW	East/West	24 Nov 23
AC-03	ASHP	Mixergy	-	4.74 kW	East/West	8 Jun 23
AC-04	ASHP	Mixergy	-	4.15 kW	South	9 Oct 23
IC-01	IR panel	Mixergy	-	5.81 kW	South	27 Sep 23
W-01	IR panel	Mixergy	6 kWh	5.81 kW	South	26 Oct 23
W-02	IR panel	Mixergy	6 kWh	5.81 kW	South	27 Oct 23

Table 2.2 Details of the properties which received solar PV installations

Households T-03, T-06 and T-09 all had Tesla Powerwall 2 batteries which were installed in an earlier project. The reference codes are the same for these installations as in the associated report[7].

Household T-06 originally had storage heaters and an open fire. A new heating system was installed in August 2023, with an ASHP and radiators along with a Mixergy smart hot water cylinder and solar diverter. The open fireplaces were blocked up. The combination of ASHP and battery was like B-01 to B-07, although the Tesla Powerwall 2 battery had a higher usable capacity of 13.5kWh.

Household T-03 had three storage heaters which were used during the heating season along with a coal fire in the living room. The household was on an Economy 7 tariff and the battery charged overnight and supplied electricity to the home during the day, reducing peak rate consumption.

There was a similar installation for household T-09, however the traditional storage heaters were replaced by Dimplex Quantum high heat retention storage heaters in October 2023, soon after the solar PV installation. As well as being in the report on Tesla batteries, household T-09 was in the study of heat pumps and batteries as control property C-02[6].

[7] Rogers and Hamer (2018), Tesla Powerwall 2 batteries charged using off-peak electricity, https://www.nea.org.uk/wp-content/uploads/2020/10/CP1139-TIF-REPORT_FINAL-25-04-19-v2.pdf (Accessed 24 Jan 2025)

Households SH-01 and SH-02 did not have an electrical battery. Space heating was provided by storage heaters downstairs and panel heaters in the bedrooms. Both households had families of four or more. Large 250 litre and 210 litre Mixergy hot water cylinders with solar diverters were installed at the time of the solar PV systems. Some households had the Mixergy cylinders installed a few months after the solar PV. Household SH-03 withdrew from the study and so will not be discussed in any detail in the report.

Households AC-03 and AC-04 were also control properties C-03 and C-04 in the earlier heat pump and battery study[6]. These installations had Daikin heat pumps with no battery. Mixergy cylinders with solar diverters were installed after the solar PV. Household AC-04 had external wall insulation installed under the Social Housing Decarbonisation Fund, and this was completed shortly before the solar PV system was operational.

Households W-01 and W-02 had Wondrwall smart heating systems installed. These included infrared heating panels, solar PV, battery storage and smart heating controls and sensors. These installations will not be discussed in any depth in this report and are covered in detail elsewhere[8]. Also discussed in the other report is household IC-01 where the residents fitted their own infrared heating panels. The Wondrwall households had a battery with a 6kWh usable capacity while IC-01 did not have a battery.

Performance of the Mixergy smart hot water cylinders is also discussed in a separate report for this project.[9]

[8] Rogers and Hamer (2025), Evaluating solar PV with electric heating with North Devon Homes: Wondrwall (in press)

[9] Rogers and Hamer (2025), Evaluating solar PV with electric heating with North Devon Homes: Mixergy cylinders (in press)

2.2 Characteristics of the properties

Figure 2.3 Two houses with east-west facing in-roof solar PV installations

Figure 2.4 Two houses with south and east-west facing on-roof solar PV installations

The houses in Witheridge and East Buckland which received installations were built ca 1950 and had cavity walls and a rendered exterior. The two houses in Bratton Fleming were built in the 1980s and had a timber-frame construction.

The bungalows in Witheridge were semi-detached or terraced and were built in the 1970s. Two of these properties had external wall insulation (EWI) fitted during the project resulting in a rendered exterior. The bungalows in North Molton were also semi-detached. They dated from the 1950s and had EWI fitted in about 2015.

Table 2.5 shows details of the installations at the properties. It also shows the impact on the score/band of the Energy Performance Certificate (EPC) of having the solar PV system and Mixergy cylinder (where fitted).

Code	Space heating	Hot water storage	Property type	Solar PV size (kW)	EPC score without solar PV	EPC score with solar PV	EPC score with Mixergy cylinder
B-01	ASHP	SunAmp	Bungalow	5.81 kW	D67	A104	N/A
B-02	ASHP	SunAmp	Bungalow	5.81 kW	D63	A101	N/A
B-03	ASHP	SunAmp	House	5.67 kW	D68	A92	N/A
B-04	ASHP	SunAmp	Bungalow	5.81 kW	D66	A104	N/A
B-05	ASHP	SunAmp	Bungalow	5.81 kW	D66	A104	N/A
B-06	ASHP	SunAmp	Bungalow	5.81 kW	D66	A104	N/A
B-07	ASHP	SunAmp	House	5.81 kW	D67	A93	N/A
T-06	ASHP	Mixergy	House	4.57 kW	C75	A98	A103
T-03	NSH	Mixergy	House	4.74 kW	D58	C79	B82
T-09	NSH	Mixergy	House	4.15 kW	D68	A93	A96
SH-01	NSH	Mixergy	House	3.89 kW	D68	B86	B88
SH-02	NSH	Mixergy	House	4.98 kW	D67	B90	A92
SH-03	NSH	Mixergy	House	5.53 kW	D62	B84	B86
AC-03	ASHP	Mixergy	Bungalow	4.74 kW	C70	A100	A105
AC-04	ASHP	Mixergy	Bungalow	4.15 kW	C74	A105	A109
IC-01	IR panel	Mixergy	Bungalow	5.81 kW	E47	B85	A92
W-01	IR panel	Mixergy	Bungalow	5.81 kW	E48	B91	A94
W-02	IR panel	Mixergy	Bungalow	5.81 kW	E48	B91	A94

Table 2.5 Details of the installations and impact on the EPC score

The analysis of the EPC scores was carried out in 2025 under RdSAP 2012 since RdSAP10.2 had not been released. Under RdSAP10.2, the 12 households with battery storage would also see an improvement to the energy score from that technology. The additional impact of the Mixergy cylinder compared to a standard hot water cylinder was assessed using an Appendix Q calculation under RdSAP 2012. This used version 5 of the Appendix Q spreadsheet which was released on 16 Jan 2025[10].

The increase in energy score ranged from 18 to 43 points after installing solar PV at the properties in table 2.5. The uplift in the score due to installing the Mixergy cylinder was between two and seven points for the households with Mixergy cylinders.

The lowest improvement in the energy score from the solar PV was for household SH-01. Smaller improvements in the score occurred for houses and for smaller solar PV systems such as for SH-01. The houses saw an uplift of between 18 and 26 points in the energy score due to the solar PV. The uplift for the bungalows was between 30 and 43 points. The uplifts for all the solar PV installations in the project were typically higher than would be achieved by other energy saving measures under RdSAP 2012.

[10] SAP/RdSAP 2012, Appendix Q Calculation Tool – Smart Hot Water Tank, SAP Appendix Q database, https://www.ncm-pcdb.org.uk/sap/page.jsp?id=18 (Accessed 28 Jan 2025)

Five of the bungalows with ASHPs saw a large uplift of 37 or 38 points after installation of a 5.81kW solar PV system. This took the final energy score to between 101 and 104 in band A.

Household IC-01 also saw an uplift of 38 points from a 5.81kW solar PV system. The same size PV system was installed for W-01 and W-02 and here the uplift was as high as 43 points. The final energy scores were still in band A, but not as high as for the other bungalows, with values of 92 points for IC-01 and 94 points for W-01 and W-02. The lower total energy scores were likely to be due to these households having infrared heating panels. The EPCs for these three properties suggested that replacing the infrared heating panels with high heat retention storage heaters on a time of use tariff could raise the energy score by between 16 and 22 points. Earlier assessments suggested a decrease in the energy score of about 10 points when the traditional storage heaters at W-01 and W-02 were taken out and replaced by the infrared heating panels.

3. Social evaluation

3.1 Profiles of households

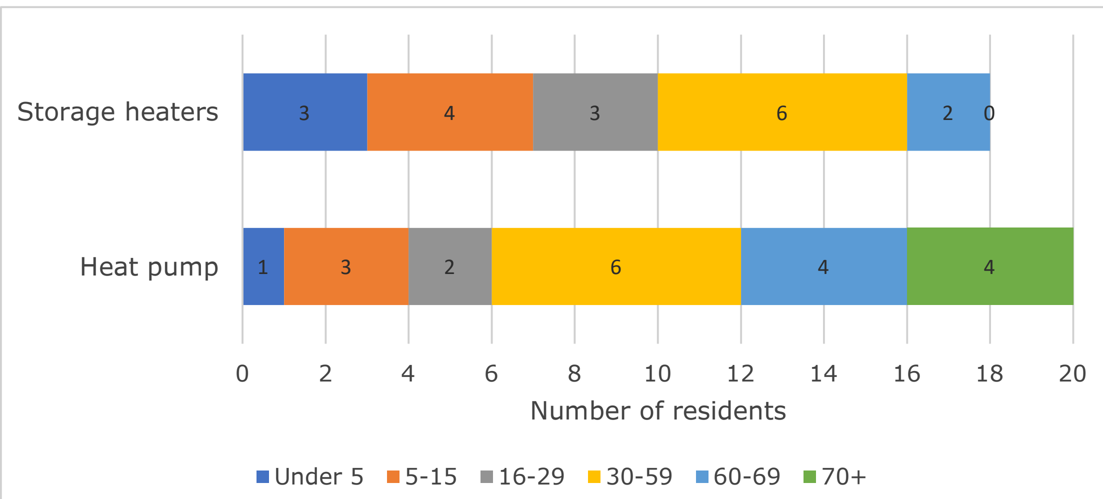

Figure 3.1 Age of residents in homes with storage heater and heat pumps

Four households with storage heaters were interviewed. They all lived in two-storey houses with between two and four bedrooms. Two of these households had Tesla Powerwall 2 battery systems. There was a total of 18 residents, with the number per property ranging from two to eight. More than half of the residents were under 30-years old, with seven aged 15 or under.

All four households had a resident normally at home all day. Three of the residents interviewed were working part-time while the other resident was a full-time carer. All four households had reasons, typically due to health or young children why they needed to maintain rooms at a higher temperature throughout the winter.

The number of households interviewed with air-source heat pumps (ASHPs) was nine. All but one of these also had a battery storage system. Three of the households lived in two-storey houses with either two or three bedrooms. The other properties were bungalows. Five of the bungalows were two-bedroom and the other was a single bedroom.

There were 20 residents in the nine homes with ASHPs. The age profile in the houses was younger than for those in the bungalows. Overall, there were eight of the 20 residents aged 60 years or over and all but one of these lived in bungalows. Eight of the nine households had a resident who was normally in all day. There were four households where the resident interviewed was retired and three where the resident was not working due to health or a disability. Two of the residents interviewed were working, with one full-time and one part-time. All but one of the households had a reason to maintain room temperature at a higher temperature throughout the winter.

3.2 Satisfaction with the heating system

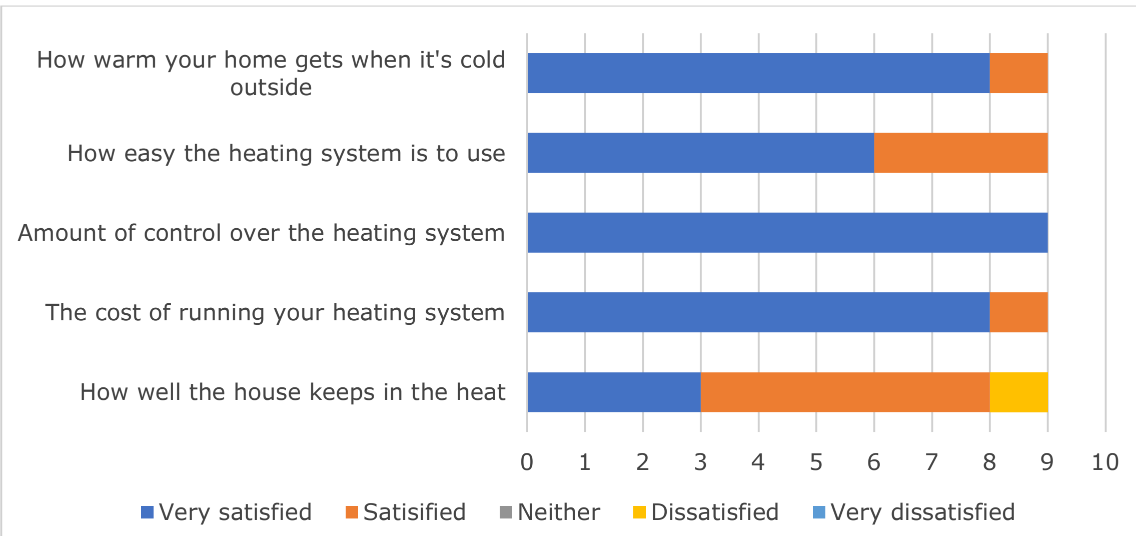

Figure 3.2 Satisfaction with the heating system for households with ASHPs

The households were asked how satisfied they were with different aspects of their home heating and insulation. Figure 3.2 shows the response from the nine households with ASHPs where all but one also had battery storage and were on a time-of-use electricity tariff. These households had very high levels of satisfaction. Eight of the households were very satisfied with the cost of running the heating system and how warm the house gets when it was cold outside, while the remaining household was satisfied. All nine households were very satisfied with the amount of control with the heating system, while six were very satisfied and three satisfied with how easy the heating system was to use. The perception of how well the house keeps in the heat is primarily about insulation and draught-proofing but the speed at which the heating cools can be a factor.

On this question, three of the households were very satisfied with how well the house keeps in the heat and five satisfied. One of the residents in a two-storey house was dissatisfied with the retention of heat.

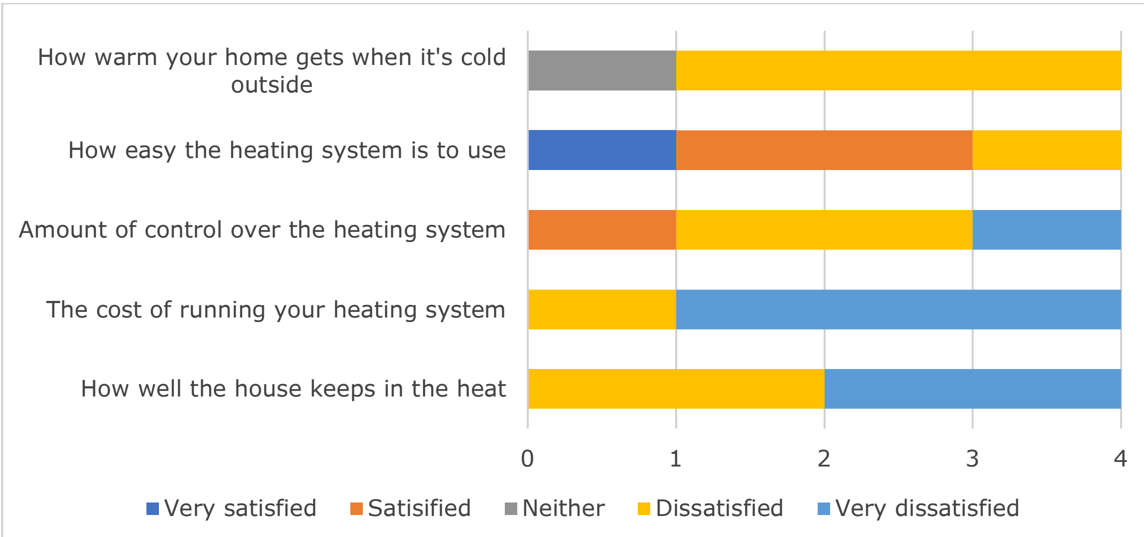

Figure 3.3 Satisfaction with the heating system for households with storage heaters

The four households with storage heaters were asked the same set of questions (figure 3.3) but the level of satisfaction was far lower than for the ASHP households. Three of the four households with storage heaters were very dissatisfied with the cost of running the heating system while the other household was dissatisfied. Two households were very dissatisfied and two dissatisfied with how well the house kept in the heat. Three of the households with storage heaters were dissatisfied with how warm their home gets when it is cold outside while the other household was neither satisfied nor dissatisfied.

Residents were more positive about ease of use of the storage heaters. One household was very satisfied, two satisfied and only one dissatisfied. Finally, one household was satisfied with the amount of control over the heating system. Two of the households were dissatisfied with the level of control and one very dissatisfied.

3.3 Benefits of the new installations

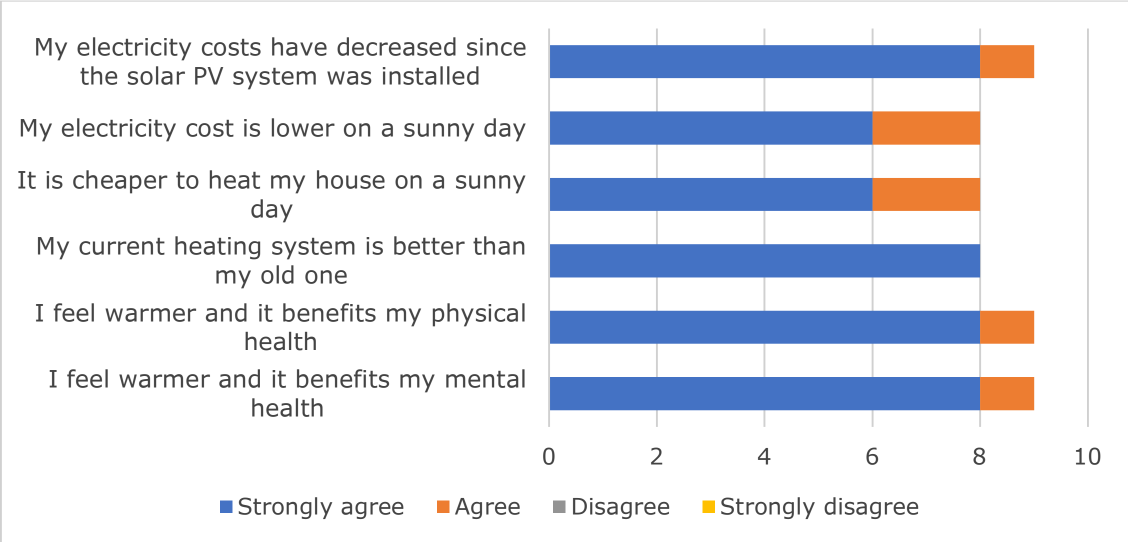

Figure 3.4 Assessing the benefits of the solar PV system for households with ASHPs

Households were also asked about whether they agreed or disagreed with a series of statements about the benefits of the solar PV system. Figure 3.4 plots the responses for the nine households with ASHPs.

Most of the responses to the statements were strongly agree although one or two households agreed with the statements. Household B-06 agreed with four of the six statements. A less positive response might be due to greater teething problems with this ASHP and battery system.

When asked if their electricity costs had decreased since the solar PV system was installed, eight of the ASHP households strongly agreed and one agreed. Six households strongly agreed and two agreed that their electricity cost was lower on a sunny day, and it was cheaper to heat their house on a sunny day. One of the households didn't know as the home did not have a smart meter in-home display or other form of monitoring.

All eight households that had an ASHP (with battery) which replaced the storage heaters strongly agreed that their current heating system was better than their old one. Households felt they were warmer, and it benefitted their physical and mental health with eight households strongly agreeing and one agreeing.

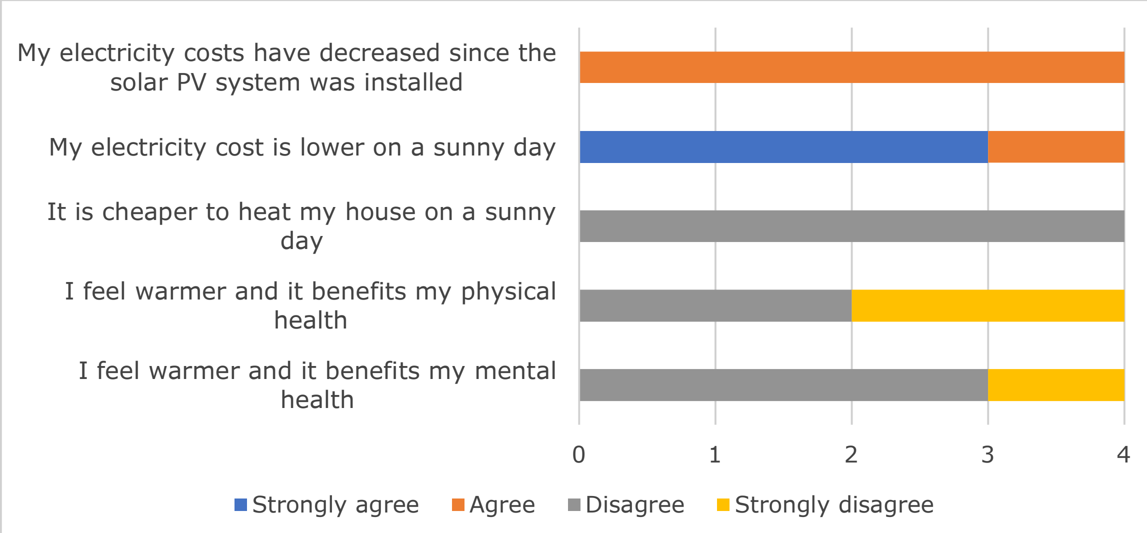

Figure 3.5 Assessing the benefits of the solar PV for households with storage heaters

The households with storage heaters were less positive about the benefits of the solar PV system than those with ASHPs. Figure 3.5 illustrates that all four households with storage heaters agreed that their electricity costs had decreased since the solar PV system had been installed. Three strongly agreed that their electricity cost was lower on a sunny day and the fourth agreed.

All four households with storage heaters disagreed that it was cheaper to heat their home on a sunny day. This is as might be expected since the solar PV would not reduce the consumption of storage heaters overnight. Two households disagreed and two strongly disagreed that they felt warmer, and it benefited their physical health. When asked the similar statement considering mental health, three households disagreed, and one strongly disagreed.

3.4 Benefits of solar PV monitor

The project aimed to provide each household with a solar PV monitor. This was not possible for all households. Boxergy who installed the seven ASHP and battery systems in Witheridge used an Alpha ESS battery. They were unhappy about households being offered access to the Alpha ESS monitoring app as the households could change settings for the system. If residents were provided with access to the app, they were unwilling to continue to provide support for the battery system. As a result, residents were not offered the app. However, many of these households were provided access to the Carbon Coop PowerShaper monitor portal where they could monitor their smart meter consumption.

Most of the monitoring systems used phone apps and some households did not have smart phones or struggled with apps. The Solis hybrid inverter had a display screen on the front of the inverter which showed the energy produced by the solar panels along with the amount used in the home and exported to the grid. This was popular with households who had this inverter installed and residents often viewed the screen if the inverter was accessible.

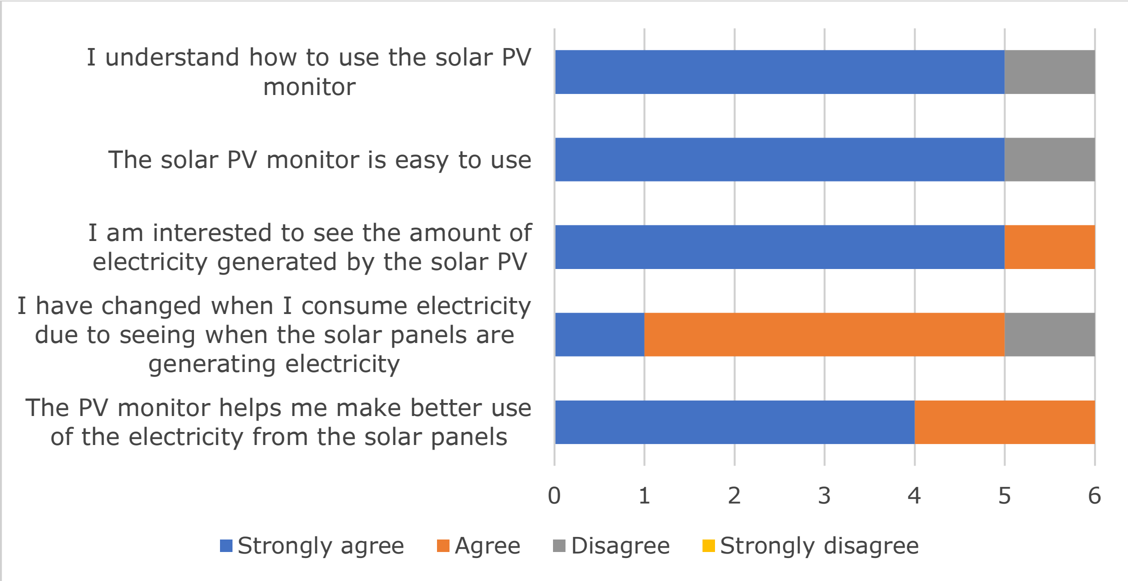

Figure 3.6 Assessing the benefits of the solar PV monitors for households

Six of the households with some form of solar PV monitoring were interviewed and results are shown in figure 3.6. These generally showed a high level of engagement with the monitoring. The apps used included those from Solis, Tesla and Wibeee. Five of the six households strongly agreed that they understood how to use the solar PV monitor, and it was easy to use. One household disagreed and found the Solis app too technical or complex. Five of the households strongly agreed and one agreed that they were interested to see the amount of electricity generated by the solar PV system. There was some behaviour change from households, with one strongly agreeing and four agreeing that they had changed when they consumed electricity due to seeing when the solar panels were generating electricity. One household disagreed and this was one that was otherwise very engaged. Four of the households strongly agreed and two agreed that the PV monitor helped them make better use of the electricity from the solar panels.

The solar PV monitors used included ones for the Solis inverter, Tesla battery and a Wibeee electricity monitor for solar generation and electricity consumption. Many of the households with smart hot water cylinders also had the Mixergy app. The three households with Tesla batteries thought that app for monitoring the solar PV and battery was most useful. Two households with

Wibeee electricity monitors found the Wibeee Nest UK app most useful. Many of the households with Mixergy cylinders found that app easy to use and useful[11].

Two of the households were viewing the monitoring app daily. Three households were using the app on a weekly basis, but all had been viewing it daily when they first had it. The household who struggled with the Solis app used it less frequently, viewing it monthly.

3.5 Resident feedback on installations

The feedback from households about the systems was excellent for the homes with solar PV, battery and heat pumps. Those with solar PV and Mixergy cylinders also provided positive feedback commenting on savings and availability of hot water. Examples of the comments are as follows:

Solar PV, battery and ASHP

I have never had such a warm house. If I ever moved, I would have to have the same heating system and solar PV. The rest of the village are extremely jealous. My son has not had any asthma issues since moving in. This is the best heating system I have ever had for my disability.

It is more efficient. The home is warmer in every room which improves our quality of life. It is more effective with regards to cost, and we spend less and get more heat. We feel good that solar PV is on the house and making a positive contribution. What makes it work is the solar PV, heat pump, battery and Cosy Octopus (electricity) tariff. If one element was missing, the impact would be significant. The connectivity with the apps takes it to another level and we can always check performance.

It is definitely cheaper to run. It is completely different to Economy 7 storage heaters and very economical. With storage heaters, you wanted the heat in the evening at 4.30pm and it wasn’t there. This is 100% better.

Solar PV, Mixergy cylinder and ASHP

Very pleased with the system and much cheaper. Only five months when there are greater costs during the winter.

[11] Rogers and Hamer (2025), Evaluating solar PV with electric heating with North Devon Homes: Mixergy cylinders (in press)

Solar PV, battery storage, Mixergy cylinder and storage heaters

When the sun is out, it is an excellent system. Main concern is if there is an issue with the Tesla battery in the future as that is the lynchpin of the whole system.

Been great during sunny days, being able to heat hot water from the sun has been fantastic. Since installation, there has been seamless interaction between the solar panels and the battery. On a sunny day in summer, the solar and battery can provide most electricity. Some weeks, the solar and battery meant we only used £3-£4 of electricity in a week.

Solar PV, Mixergy cylinder and storage heaters

Definitely found benefit in the summer which makes a massive difference. Have a young child and need to do more washing. The Mixergy cylinder is smaller than the old one, heats up faster and keeps in the heat better than the old one.

Solar PV is lowering the cost and can see when it is generating on the app. The Mixergy cylinder is good and there is always enough hot water.

A full list of the resident comments and notes on installation and maintenance issues can be found in Appendices 1 and 2.

4. Technical monitoring

4.1 Methods of monitoring

The temperature and relative humidity in properties was monitored using a Lascar EL-USB-2 data logger.[12] Properties normally had a logger placed in the living room and one of the bedrooms. If the living room had an open fire of wood burning stove that was used, the logger was placed in the dining room. The recording interval for data was every 30 minutes. Monitoring was typically carried out over the heating season before and after the installations.

Monitoring of the solar PV system was carried out using the monitoring portals or apps for the solar PV inverter or battery system. This included the Alpha Cloud monitoring portal for the seven installations with Alpha ESS hybrid inverters. The Tesla app was used for the three households with Tesla batteries. Where a Solis inverter was installed, the Solis Cloud portal was used for monitoring. If the inverter was a Solis hybrid inverter, the grid consumption, solar PV export and solar PV consumed was measured in addition to the solar generation. Wibeee Box single phase electricity monitors[13] were fitted for six households. These could monitor the electricity consumption/generation for three electrical circuits. For some installations the solar PV was monitored. Other circuits monitored included the ASHP, immersion heater for the Mixergy cylinder and an electric shower.

All the households on the project had smart electricity meters fitted by the end of the project. Meter reading data for some households was provided by the energy supplier with consent of the household. There were 10 out of the 18 households who signed up to use the Carbon Coop PowerShaper monitor portal[14]. This provided graphs showing half hourly electricity consumption and data which could be downloaded for more detailed analysis.

Figure 4.1 Lascar EasyLog EL-USB-2 temperature and humidity data logger

[12] EasyLog – EL-USB-2, Lascar Electronics, https://lascarelectronics.com/data-loggers/temperature-humidity/el-usb-2/ (Accessed 28 Jan 2025)
[13] Wibeee Box: the most effective general circuit consumption meter on the market, Smilics Technologies, https://smilics.com/en/wibeee-products/wibeee-box/ (Accessed 28 Jan 2025)
[14] PowerShaper monitor, Carbon Coop, https://powershaper.io/ (Accessed 28 Jan 2025)

4.2 Room temperatures

Households with air-source heat pumps

01 November 2022 To 01 May 2023							
Tech Ref	Average Temp (°C) 24 hours	Maximum Temp (°C) 24 hours	Minimum Temp (°C) 24 hours	Std Dev Temp (°C) 24 hours	Average Temp (°C) 5pm to 9pm	Maximum Temp (°C) 5pm to 9pm	Minimum Temp (°C) 5pm to 9pm
B-01	17.36	24.50	14.00	1.71	17.55	23.00	14.50
B-02	20.54	25.00	16.50	1.11	21.07	24.00	18.00
B-03	19.10	26.00	12.50	1.90	19.43	24.50	14.50
B-04	20.39	22.00	12.50	0.98	20.42	21.50	15.00
B-05	22.29	24.00	20.00	0.72	22.38	23.50	20.50
B-06	19.13	21.00	16.50	0.62	18.95	20.50	16.50
B-07	18.21	21.50	13.50	1.01	18.09	20.50	15.00
AC-03	16.35	20.50	10.50	1.96	17.36	20.50	12.00
AC-04	19.85	22.00	16.50	1.02	20.35	22.00	19.00
T-06	16.02	20.50	11.00	1.74	15.89	19.50	11.00
Maximum	22.29	26.00	20.00	1.96	22.38	24.50	20.50
Minimum	16.02	20.50	10.50	0.62	15.89	19.50	11.00
Average (Mean)	18.92	22.70	14.35	1.28	19.15	21.95	15.60

Table 4.2 Living room/dining room temperature data for the pre-installation winter heating season for the households which had ASHPs

01 November 2023 To 01 May 2024							
Tech Ref	Average Temp (°C) 24 hours	Maximum Temp (°C) 24 hours	Minimum Temp (°C) 24 hours	Std Dev Temp (°C) 24 hours	Average Temp (°C) 5pm to 9pm	Maximum Temp (°C) 5pm to 9pm	Minimum Temp (°C) 5pm to 9pm
B-01	18.56	22.50	11.00	1.43	18.61	21.00	11.00
B-02	20.11	23.50	16.50	0.77	20.32	23.50	19.00
B-03	17.79	29.50	10.50	1.83	18.09	24.00	12.50
B-04	19.85	25.00	16.00	1.35	19.86	23.50	17.00
B-05	22.07	24.00	19.50	0.51	22.15	23.50	20.50
B-06	19.29	21.00	14.50	0.69	19.10	20.50	15.50
B-07	21.00	23.00	16.00	0.88	20.84	22.50	16.50
AC-03	16.44	20.50	11.00	2.27	16.97	20.50	12.00
AC-04	20.55	22.50	18.00	0.72	21.02	22.50	19.50
T-06	20.18	23.50	17.50	0.89	19.76	22.50	17.50
Maximum	22.07	29.50	19.50	2.27	22.15	24.00	20.50
Minimum	16.44	20.50	10.50	0.51	16.97	20.50	11.00
Average (Mean)	19.58	23.50	15.05	1.13	19.67	22.40	16.10

Table 4.3 Living room/dining room temperature data for the post-installation winter heating season for the households which had ASHPs

Tables 4.2 and 4.3 show temperatures for the pre-installation winter heating season of 1 Nov 2022 to 1 May 2023 and for the post-installation winter heating season from 1 Nov 2023 to 1 May 2024.

As an indication of the external temperature during these periods, Degree Day data from Dunkeswell Airport (Station ID 3840) was assessed[15]. There were 1678.9 Degree Days for the dates of the pre-installation heating season compared to 1546.7 Degree Days over the period of the post-installation heating season. This indicates that the pre-installation winter heating season was on average colder than for the post-installation period.

The most significant change between years 1 and 2 was for household T-06 where there were changes to the heating and insulation as well as adding the solar PV. The old fibre cavity wall insulation (CWI) was extracted in October 2022 and the cavity left to dry. This was replaced by thermal bead CWI in February 2023. In August 2023, a Daikin ASHP was installed with a new wet central heating system. Over the whole winter heating season in year 1, the average dining room temperature for T-06 was 16.02°C. For the period without CWI from 1 Nov 2022 to about 1 Mar 2023, the average temperature was 15.65°C and this increased to 16.71°C for the period 1 Mar 2023 to 1 May 2023 with the new CWI. The average dining room temperature for the post-installation heating season with the ASHP was 20.18°C. This was 4.16°C warmer than for the average over the preinstallation heating season and 3.47°C warmer than the pre-installation period with the thermal bead cavity wall insulation.

The average living room temperature was 17.36°C for household B-01 in the pre-installation heating season. This low average temperature of was due to the thermostat settings used by the resident. The set point temperature was turned down from about 19°C to 17°C at the end of January 2023. During the post-installation heating season, the average temperature was 18.56°C. Over this period, the set-point temperature was typically about 19.5°C with the temperature falling to a minimum of 17.5°C after the heating cycle. The household was away for three periods over the winter and the heating was turned off with the temperature falling to a minimum of 11°C on one occasion.

There was little difference in the living room temperatures for households B-02, B-05 and B-06 between the pre- and post-installation winter heating seasons. The post-installation averages were 20.11°C, 22.07°C and 19.29°C respectively. All three households had the Vaillant sensoCOMFORT controller set to manual. Household B-05 wanted a warmer temperature in the home 24-hours a day and the set point temperature was 22°C. All three households had a quite consistent temperature graph over the heating season. This limited variation in temperature is also indicated by the lower values of standard deviation for temperature.

There was a change in tenancy for B-03 in February 2024. The new residents had the thermostat set lower compared to the previous tenants. This was particularly noticeable in late February/early March 2024 as they got to know the

[15] Bizee Degree Days – Weather Data for Energy Saving, https://www.degreedays.net/ (Accessed 28 Jan 2025)

heating system and control. As a result, the average temperature decreased from 19.1°C to 17.79°C for the pre- and post-installation heating seasons.

There were adjustments to the thermostat temperature for household B-04 mainly due to the health of one of the residents. This led to the average living room temperature decreasing from 20.39°C to 19.29°C between the pre- and post-installation periods.

The number of children for household B-07 increased by the post-installation heating season. The lead resident wanted a warm home due to health reasons and felt better able to afford the electricity bill after a shift to the Cosy Octopus heat pump tariff. The thermostat temperature was turned up in the post-installation heating season and the average living room temperature increased from 18.21°C to 21.0°C.

Households AC-03 and AC-04 lived in single-bedroom bungalows and had ASHPs with no battery. The residents controlled the heating in different ways. The temperature profile for household AC-03 showed the temperature regularly ranging from under 15°C to up to 20°C (figure 4.4). This seemed to be due to the resident regularly turning the heating off when going out or away, in all but the coldest weather. The ASHP sometimes had to raise the living room temperature by about 7°C several times in a week. There may have been savings due to periods with the ASHP not running, but the ASHP would also have consumed more electricity while raising the room temperatures rather than maintaining the room temperatures. This led the average living room temperatures to be only 16.35°C and 16.44°C for the two monitoring periods. This household also had the highest standard deviation for temperature.

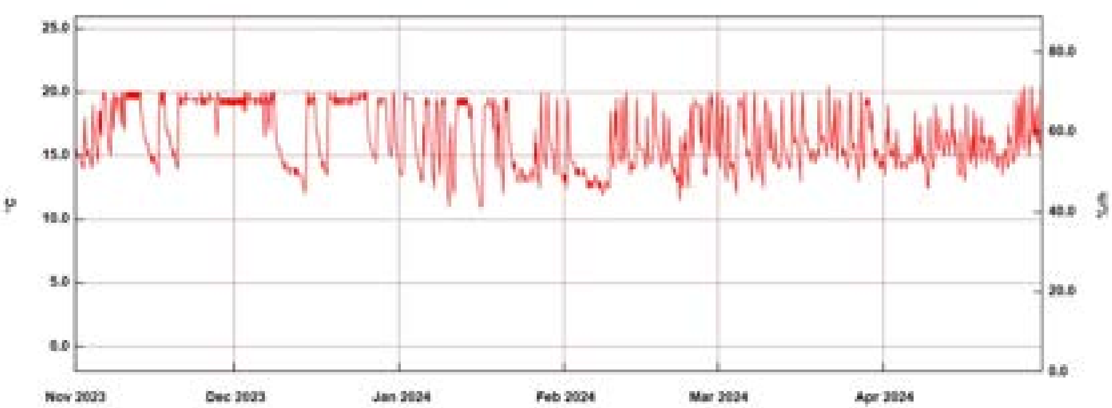

Figure 4.4 Living room temperature for household AC-03 during the post-installation heating season with an ASHP turned off when the resident was out

In contrast, household AC-04 used the programable thermostat for the heating system with a daily heating schedule and small setback temperature overnight. The temperature ranged from 16.5°C to 22.0°C for the pre-installation period and from 18.0℃ to 22.5°C for the post installation heating season. The average living room temperatures for the two heating seasons were 19.85°C and 20.55°C respectively. The programmable thermostat settings may have been altered during the study. However, the smaller range between maximum and minimum temperatures in the post-installation heating season for AC-04 was likely to be due to external wall insulation being installed by October 2023.

The average temperature of the bedrooms for the heat pump households for the pre-installation heating season was 18.87°C compared to 18.92°C for the living rooms. While the average room temperatures across all the properties were similar, there were often significant differences between the living room and bedroom temperatures in individual properties. This could be due to residents preferring the bedrooms to be cooler. Four of the households had lower bedroom temperatures pre-installation and the difference between the living room and bedroom temperature ranged from 0.41°C to 2.76°C. Five of the bedrooms were warmer than the living room pre-installation and this difference was between 0.23°C and 2.55°C. This could be due to different settings on thermostatic radiator valves (TRVs), smaller rooms which were easier to heat or wanting greater heat in a child's bedroom.

For the post-installation heating season, the average bedroom temperature for the heat pump households was 19.18°C while the average living room temperature was 19.58°C. Again, there could be significant differences between the living room and bedroom temperatures in an individual property. Broadly there was the same pattern with the same households having a warmer living room or warmer bedroom. The one difference was household AC-04 which had a warmer bedroom in the pre-installation period and warmer living room post installation.

During the pre-installation period for household T-06, there were panel heaters in the bedroom and there was no cavity wall insulation (CWI) for much of the heating season. The average bedroom temperature was only 13.86°C while it was 16.02°C in the dining room. Following installation of the ASHP system with radiators in the dining room and bedrooms and thermal bead CWI, there was an improvement in bedroom and dining room temperatures. For the post-installation heating season, the average bedroom temperature had risen 3.1°C to 16.96°C while the dining room temperature had increased by 4.16°C to 20.18°C.

Households with electric storage heaters

01 November 2022 To 01 May 2023							
Tech Ref	Average Temp (°C) 24 hours	Maximum Temp (°C) 24 hours	Minimum Temp (°C) 24 hours	Std Dev Temp (°C) 24 hours	Average Temp (°C) 5pm to 9pm	Maximum Temp (°C) 5pm to 9pm	Minimum Temp (°C) 5pm to 9pm
T-03 LR	19.39	23.00	14.50	1.46	19.07	22.50	15.50
T-03 BR	19.54	23.00	15.50	1.32	19.28	22.00	16.00
T-09 LR	21.23	25.50	18.00	1.14	21.68	25.00	19.00
T-09 BR	19.19	22.00	16.00	0.99	19.19	21.50	16.00
SH-01 LR	20.58	25.50	15.00	1.52	20.79	25.00	16.50
SH-01 BR	19.17	22.50	15.00	1.38	19.28	22.50	15.50
Maximum	21.23	25.50	18.00	1.52	21.68	25.00	19.00
Minimum	19.17	22.00	14.50	0.99	19.07	21.50	15.50
Average (Mean)	19.85	23.58	15.67	1.30	19.88	23.08	16.42

Table 4.5 Living room/bedroom temperature data for the pre-installation winter heating season for the households which had electric storage heaters

Living room and bedroom temperatures are shown in tables 4.5 and 4.6 during the pre- and post-installation heating seasons for the electric storage heater households. For the pre-installation heating season, the average room temperatures were between 19.17°C and 21.23°C. Households T-03 and T-09 had traditional storage heaters. There was little difference between the dining room and bedroom temperature for T-03. Household T-09 preferred the bedroom temperature to be cooler and the whole upstairs was warmed by a storage heater on the landing while the bedroom heaters were not used.

Household SH-01 only used the storage heater in the hallway. A 2kW electric fire was used in the mornings in winter. There were panel heaters in the bedrooms, and these were used in the morning and evening. The average temperatures were 20.58°C in the living room and 19.17°C in the bedroom. However, there was a wide temperature range of between 15°C and 25.5°C in the living room.

The average temperature for the post-installation heating season for T-03 was comparable to the pre-installation period and there had been no change in the heaters. Dimplex Quantum storage heaters were installed for T-09 in October 2023. There was little change in the bedroom temperature with heating again coming from the landing storage heater. The average living room temperature for household T-09 decreased from 21.23°C with a traditional storage heater to 20.34°C with the new Dimplex Quantum.

The average living room temperature for SH-01 increased from 20.58°C to 21.02°C for the post-installation heating season. The temperature range of 16°C to 25°C was slightly narrower than for the pre-installation heating season. There was some daily variation in room temperature from heating and cooling along with longer term variations due to changes in the external temperature. This household was dissatisfied with how warm the home gets when it is cold outside and very dissatisfied with the cost of running the heating system. Households with ASHPs in tables 4.2 and 4.3 could have lower average temperatures but were usually very satisfied with home warm their home got when it was cold outside.

01 November 2023 To 01 May 2024							
Tech Ref	Average Temp (°C) 24 hours	Maximum Temp (°C) 24 hours	Minimum Temp (°C) 24 hours	Std Dev Temp (°C) 24 hours	Average Temp (°C) 5pm to 9pm	Maximum Temp (°C) 5pm to 9pm	Minimum Temp (°C) 5pm to 9pm
T-03 LR	19.36	23.00	15.00	1.56	18.98	21.50	15.50
T-03 BR	19.28	22.00	16.00	1.18	19.02	21.00	16.00
T-09 LR	20.34	25.00	16.50	1.13	20.94	25.00	17.50
T-09 BR	19.07	22.50	15.50	1.04	19.17	22.00	16.00
SH-01 LR	21.02	25.00	16.00	1.22	21.10	24.50	16.00
SH-01 BR	19.81	23.00	15.00	1.15	20.06	22.50	16.50
SH-02 LR	21.60	26.50	13.00	2.30	21.17	25.00	13.00
SH-02 BR	17.07	25.50	11.00	1.87	17.03	25.00	11.00
Maximum	21.60	26.50	16.50	2.30	21.17	25.00	17.50
Minimum	17.07	22.00	11.00	1.04	17.03	21.00	11.00
Average (Mean)	19.69	24.06	14.75	1.43	19.69	23.31	15.19

Table 4.6 Living room/bedroom temperature data for the post-installation winter heating season for the households which had electric storage heaters

For SH-02, the average living room temperature was 21.6°C after the solar PV and Mixergy cylinder installation. The room temperature varied on a daily basis between about 20°C and 25°C due to use of the storage heater and an electric fire. The bedroom had panel heaters which could be used on a timer between 4am and 6am. The average bedroom temperature was 17.1°C over the post-installation heating season. The variation in the bedroom temperature over longer periods was due to changes in the external temperature. In the colder weather between early December and mid-March, there were sharp rises in temperature on some days due to use of the panel heaters. Often the temperature rose above 20°C and on one occasion it exceeded 25°C.

Figure 4.7 shows the variation in dining room temperature for household T-03 during the post-installation heating season. There was a daily rise and fall in temperature of about 2.5°C to 3°C due to the traditional storage heater charging and discharging heat daily. Maximum temperature was typically soon after the storage heater had finished charging at 7am and then decreased to the minimum daily temperature by about 5pm. As well as the daily rise and fall of the temperature, there was also a longer-term rise and fall which was likely to be due to changes in the external temperature over a period of weeks.

Storage heaters like this are likely to be unpopular due to a combination of factors. These include a lack of control over when heat is emitted, the heater not responding to external temperature and the type of heat provided.

Figure 4.7 Dining room temperature for household T-03 during the post-installation heating season with a traditional storage heater

A more consistent temperature can be achieved with an ASHP and programable thermostat. Figure 4.8 shows the living room temperature for household B-05 where the thermostat was left constantly at 22°C. The temperature variation was normally only 1-2°C. The longer-term variation in room temperature with external temperature seen in figure 4.7 was not apparent. The room temperature was quite consistent as the external temperature varied and this avoided the resident feeling colder when the outside temperature dropped.

Figure 4.8 Living room temperature for household B-05 during the post-installation heating season with an ASHP and battery

4.3 Solar PV generation

Code	Space heating	Battery usable capacity (kWh)	Start date	End date	Solar PV size (kW)	PV Gen (kWh)	% Use in home
B-01	ASHP	9.1	1 Jan 24	31 Dec 24	5.81	5,212	55.9%
B-02	ASHP	9.1	1 Jan 24	31 Dec 24	5.81	5,489	50.2%
B-03	ASHP	11	1 Jan 24	31 Dec 24	5.67	4,778	70.9%
B-04	ASHP	9.1	1 Nov 23	31 Oct 24	5.81	4,755	54.0%
B-05	ASHP	11	1 Jan 24	31 Dec 24	5.81	4,642	61.6%
B-06	ASHP	11	1 Jan 24	31 Dec 24	5.81	5,652	55.7%
B-07	ASHP	11	1 Jan 24	31 Dec 24	5.81	4,159	74.3%
T-06	ASHP	13.5	1 Jan 24	31 Dec 24	4.57	4,416	80.5%
T-03	NSH	13.5	1 Jan 24	31 Dec 24	4.74	3,759	82.8%
T-09	NSH	13.5	1 Jan 24	31 Dec 24	4.15	3,873	65.6%
SH-01	NSH	-	1 Mar 24	31 Jan 25	3.89	3,282	-
SH-02	NSH	-	1 Feb 24	31 Jan 25	4.98	4,125	-
AC-03	ASHP	-	1 Jan 24	31 Dec 24	4.74	3,842	42.4%
AC-04	ASHP	-	1 Jan 24	31 Dec 24	4.15	3,736	33.5%
IC-01	IR panel	-	1 Jan 24	31 Dec 24	5.81	5,116	38.1%
W-01	IR panel	6	1 Jan 24	31 Dec 24	5.81	5,531	35.6%
W-02	IR panel	6	1 Jan 24	31 Dec 24	5.81	5,224	18%

Table 4.9 Solar PV generation and solar self-consumption for households

The electricity generated from the solar PV systems for 17 of the 18 installations is shown in table 4.9. This includes details of the type of space heating, the usable capacity of the battery if present, the start and end dates for the analysis period and the % self-consumption of the solar generation (% use in home).

It was not possible to use the same start and end dates for all the installations. This was because SH-01 and SH-02 were commissioned in early 2024 and there was a monitoring issue with B-04. There would have been some impact due to different levels of solar generation over the different time periods, however they were not significant. For example, B-05 generated 4,642kWh during 2024 and generated 4,683kWh from 1 Nov 2023 to 31 Oct 2024.

The households with ASHPs that generated the greatest amount were B-01, B-02 and B-06 with 5,212 to 5,652kWh. These were all south facing 5.81kW systems. Soon after installation, a comparison of the daily generation between these three properties showed that B-01 was generating half the amount of each of the other two. This was due to a fault with the wiring of one of the strings of solar panels for B-01 which was later corrected after the issue was identified.

A plot of the daily solar PV generation in November 2023 is shown in figure 4.10 for the 5.81kW PV installations for B-01, B-02 and B-04. The graph shows that the daily PV generation for B-01 was half the level for B-02 despite the same system size, orientation and being close to one another.

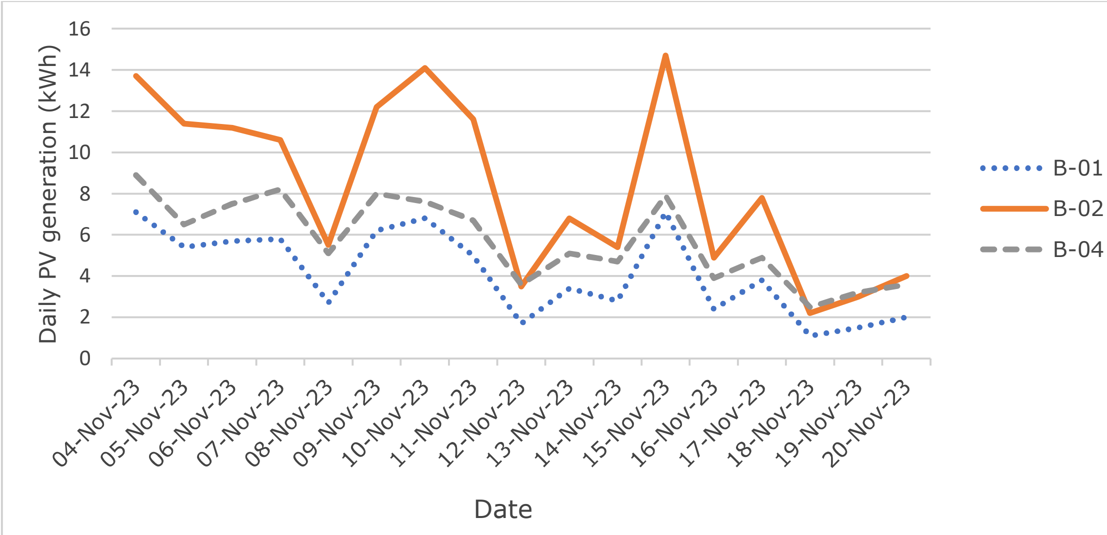

Figure 4.10 Daily solar PV generation for 5.81kW installations in November 2023

The south facing installation for B-02 could generate up to 15kWh on a sunny day in November while the east-west array of B-04 generated up to 9kWh. On a cloudy day, both installations generated less electricity and the south and east-west installations generated similar amounts. Solar PV systems will generate more in direct sunlight with the sun shining directly on the panels. In diffuse sunlight on a cloudy day there is less PV generation, and the level of sunlight will be similar on a south and an east/west installation.

The PV generation from B-06 was 440kWh greater than for B-01. This is higher than might be expected given that these properties were next door to each other, there was no significant shading and the fault for B-01 had been corrected. Household IC-01 was close to the other three installations in Witheridge and had another 5.81kW south facing solar PV system with a Solis inverter rather than an Alpha ESS. This generated 5,116kWh, which was less than B-01, B-02 and B-06.

The predicted annual generation on the MCS certificate was 6,223kWh for B-01, B-06 and IC-01 while it was 6,252kWh for B-02. The measured solar PV generation was between 9.2% and 17.8% lower than the values predicted by the MCS certificate. It is likely this can be explained by 2024 being a year with lower-than-average sunshine. In England SW and South Wales there were 1,333 hours of sunshine compared to 1,542 hours for the same region over a 20-year average between 2000 and 2019[16].

[16] England SW/Wales S Sunshine, UK and regional series, Climate and Climate Change, The Met Office, https://www.metoffice.gov.uk/research/climate/maps-and-data/uk-and-regional-series (Accessed 13 Jan 2025)

The PV system for household B-07 generated 4,159kWh in 2024. This was the lowest for all the 5.81kW systems. The generation was lower than for the south facing systems due to an east/west roof. There was an inverter failure in December 2023/January 2024 which meant reduced generation in January 2024. There were also two weeks of missing data in March/April 2024 due to the resident switching broadband router and not replacing the Ethernet cable for the installation.

Household B-03 had a 5.67kW east/west installation which generated 4,778kWh in 2024. Households B-04 and B-05 had larger 5.81kW arrays which also faced east/west, however these generated less than B-03. The reason for this lower generation was likely to be shading from a tree on the east side of the two bungalows.

Households T-03 and AC-03 had east/west solar PV arrays with a smaller capacity of 4.74kW. These generated 3,759kWh and 3,842kWh in 2024.

Smaller south facing 4.15kW arrays were installed for T-09 and AC-04. The PV generation in 2024 for these systems was 3,873kWh and 3,736kWh which was comparable to the generation by the larger east/west arrays for T-03 and AC-03.

The east/west array for SH-02 was 4.98kW in size. This was operational from the beginning of February 2024 and generated 4,125kWh over a 12-month period. Household SH-01 had a south facing 3.89kW array. The PV system was operational from mid-March 2024. The residual current device (RCD) for the solar PV system tripped for two weeks in March/April and one week in November. This meant a full year of data could not be collected and the 3,282kWh generated between 1 Mar 2024 and 31 Jan 2024 was lower than would otherwise be expected for the operational period.

The south facing 5.81kW solar PV systems for Wondrwall installations W-01 and W-02 generated 5,531kWh and 5,224kWh respectively. This was comparable to the PV generation from the installations at B-01, B-02 and B-06 which had the same system size and orientation but were about 10 miles apart.

Table 4.9 also shows the percentage self-consumption of the solar generation by the households over the year. Most of the bungalows with ASHPs and batteries consumed between 50 and 56% of the solar generation. Household B-05 had the thermostat for the heating set to 22°C throughout the day and most of the year. This led to a higher electricity consumption and self-consumption of the solar PV with a value of 61.6%. Households B-03 and B-07 were houses with a higher heating demand and had east-west facing solar PV systems which generated less than the south facing systems. Household B-07 also turned up the thermostat during the winter of 2024/2025 leading to greater electricity consumption. Overall, the high electricity consumption and lower PV generation led to high levels of self-consumption of the solar PV of 70.9% and 74.3% respectively.

Households T-06 and T-03 with the Tesla Powerwall 2 batteries had the greatest self-consumption of the solar generation with values of 80.5% and 82.8%. The Tesla battery used weather forecasting to predict the daily solar generation. Algorithms could automatically adjust the grid charging of the battery so that on a sunny day there was less overnight battery charging from the grid and greater capacity available for solar charging. Households with the Tesla app had concerns about this behaviour as they thought the battery was not charging overnight as it should until this feature was explained to them.

In contrast, during the project, it was necessary to manually set the level of overnight charge for the Alpha ESS batteries in the settings for the battery. This was adjusted by NEA staff during the project so that the batteries would charge to 100% overnight in winter but may charge to only 50% or less in summer. NEA staff recommended to Alpha ESS that they introduced a feature where the system would automatically decide the level of overnight charge based on the predicted solar generation and household consumption. However, it is unclear when or if this feature will be added to the system.

There were no electrical battery systems installed for households AC-03, AC-04 and IC-01. All had heating systems which ran during the day and Mixergy hot water cylinders with solar diverters. Both space and water heating could be at least part powered by the solar PV and this led to self-consumption levels of between 33.4% and 42.4%.

The Wondrwall households had lower levels of self-consumption of the solar PV. This was in part due to high levels of generation from the south facing 5.81kW PV systems. Wondrwall household W-02 used only 18% of the solar generation. The resident rarely using the heating, did not use the Mixergy cylinder and had an exceptionally low household electricity consumption. This meant there was limited consumption for the PV system to power. Household W-01 had a self-consumption of 35.6% of the solar generation. The household had a more normal level of electricity consumption, but the Mixergy cylinder and solar diverter was only operating as intended from early July 2024. This is likely to have reduced consumption of the solar generation compared to other households.

There was limited data for the percentage self-consumption of the solar generation for households SH-01 and SH-02 due to late installation and monitoring issues. Between September 2024 and December 2024, household SH-01, with the smallest solar PV system had a monthly self-consumption of between 67.4% and 97.2%. This was partly due to consumption by household appliances but also due to charging of the Mixergy cylinder by the solar diverter. The self-consumption would be lower in summer when there is greater generation. For household SH-02, the monthly solar self-consumption ranged from 29.2% in July 2024 to 78.8% in November 2024. Over the six-month period from July to December 2024, the self-consumption was 41.2%.

4.4 Solar PV and battery storage

The project installed solar PV systems in seven homes with existing Alpha ESS batteries and three homes with Tesla Powerwall 2 batteries. Prior to the solar PV installations, these batteries were charging only from the grid on time-of-use electricity tariffs, saving the households money through price arbitrage.

Monitoring of the performance of these batteries and the household consumption was possible before and after the solar PV installations using the Alpha ESS monitoring portal and the Tesla app.

Table 4.11 shows the Alpha ESS battery data for four of the installations in bungalows with ASHPs. This is for the period 1 Aug 2022 to 31 Jul 2023 before any of these households had solar PV systems installed. The Alpha ESS batteries had been installed along with ASHPs in 2021/22[17].

The difference between the household load and the grid import in the table was due to export of electricity from the battery to the grid. In addition to this there are losses during the battery charge/discharge cycle. This may not be accurately reflected in the data in table 4.11, with issues with the data for B-01 and B-02.

Code	PV gen (kWh)	Battery export (kWh)	H/hold load (kWh)	Grid import (kWh)	Battery charge (kWh)	Battery discharge (kWh)	Losses (kWh)
B-01	0	9.6	5,192	5,202	2,785	2,843	
B-02	0	24	6,828	6,852	3,288	3,285	
B-05	0	3.6	7,339	7,343	3,384	3,156	-232
B-06	0	27.6	8,711	8,738	4,144	3,964	-208

Table 4.11 Data from the Alpha ESS portal for households with ASHPs for the period 1 Aug 2022 to 31 Jul 2023, before the installation of the solar PV systems

The difference between the battery charge and discharge for B-05 and B-06 was 228kWh and 180kWh respectively. Once the battery export was also taken into account, there were losses of 232kWh and 208kWh with these batteries charging from the grid over the year. Although there were energy losses with the battery, there were significant cost savings for the household. This was due to the battery charging at off-peak times and discharging during peak rate times (electricity price arbitrage).

[17] Rogers and Hamer (2023), Making Heat Cheaper, Smarter and Greener, https://www.nea.org.uk/wp-content/uploads/2023/06/CP1438-Boxergy-NDH-full-report-16-Jan-22.pdf (Accessed 5 Feb 2025)

Code	PV gen (kWh)	PV export (kWh)	H/hold load (kWh)	Grid import (kWh)	Battery charge (kWh)	Battery discharge (kWh)	Savings (kWh)
B-01	5,212	2,300	6,948	4,130	2,783	2,654	2,818
B-02	5,489	2,716	6,497	3,798	2,781	2,660	2,699
B-05	4,642	1,784	7,947	5,196	2,887	2,748	2,751
B-06	5,652	2,507	8,547	5,518	2,940	2,767	3,029

Table 4.12 Data from the Alpha ESS portal for households with ASHPs for the period 1 Jan 2024 to 31 Dec 2024, after the installation of the solar PV systems

Table 4.12 shows data from the Alpha ESS portal for the households with ASHPs and Alpha ESS batteries in 2024, after the solar PV systems were installed. The number of Heating Degree Days in 2024 was 2,048.1 at the nearby weather station, Dunkeswell Airport[18]. For the 12-month period from 1 Aug 2022 to 31 Jul 2023, the number of heating degree days was 2,053. This suggests the heating requirements over the two 12-month periods were similar.

The household load for B-01 in 2024 was 1,756kWh higher than the earlier 12-month period. This was primarily due to the household getting an electric vehicle which consumed 1,353kWh during the year while charging. The difference in the loads for the other households for the two periods were 160 – 610kWh.

If the savings from the solar PV are defined as the difference between the household load and the grid import, this ranged from 2,699kWh to 3,029kWh for the four installations. The percentage reduction in grid import as a result of the solar PV and battery ranged from 34.6% for B-05 to 41.5% for B-02.

The three Tesla Powerwall 2 batteries were installed in 2018[19]. Table 4.13 shows data from the Tesla app for the period 1 May 2022 to 30 April 2023 before the solar PV systems were installed. During this analysis period, there were 2085.3 degree days, slightly higher than the number in the other analysis periods.

All three households had traditional storage heaters at this time. The batteries saved the households money by charging from the grid at off-peak electricity rates and discharging during peak rates. There were losses in the battery with the charge/discharge cycle. The losses were likely to be more accurately reflected in the Tesla app than in the data from the Alpha ESS portal. The round-

[18] Bizee Degree Days – Weather Data for Energy Saving, https://www.degreedays.net/ (Accessed 5 Feb 2025)

[19] Rogers and Hamer (2018), Tesla Powerwall 2 batteries charged using off-peak electricity, https://www.nea.org.uk/wp-content/uploads/2020/10/CP1139-TIF-REPORT_FINAL-25-04-19-v2.pdf (Accessed 24 Jan 2025)

trip efficiency of the battery charge/discharge cycle was between 85.3% and 87.7% for the three batteries over the 12-month period. This was similar to the performance soon after they were installed[19]. As a result, there were energy losses of between 495 and 589kWh from the battery system over the year but savings overall on electricity cost due to price arbitrage.

The annual grid import for T-03 and T-09 was similar to values noted in the previous study[19]. The grid import for T-06 in previous years was often 10,000kWh or more. Over the analysis period in table 4.13, the household made more limited use of the storage heaters while reducing costs during the energy crisis. The average dining room temperature was only 16.0°C during the winter heating season of that year (see table 4.2).

Code	PV gen (kWh)	Battery export (kWh)	H/hold load (kWh)	Grid import (kWh)	Battery charge (kWh)	Battery discharge (kWh)	Losses (kWh)
T-06	0	0.2	7,172	7,761	4,003	3,415	-589
T-03	0	0.2	12,473	13,046	4,323	3,751	-573
T-09	0	0.2	9,451	9,946	4,003	3,509	-495

Table 4.13 Data from the Tesla app for households with storage heaters for the period 1 May 2022 to 30 Apr 2023, before the installation of the solar PV systems

Table 4.14 shows data from the Tesla app for the three installations after the solar PV system was installed. For household T-06, the storage heaters were replaced in Aug/Sept 2023 by a Daikin ASHP, wet central heating system and Mixergy smart hot water cylinder.

T-03 had a standard hot water cylinder replaced by a Mixergy cylinder at the end of February 2024. It was not possible to get the solar diverter to operate correctly due to interactions with the Tesla battery. A mixer shower was installed a few months later, replacing an electric shower.

Code	PV gen (kWh)	PV export (kWh)	H/hold load (kWh)	Grid import (kWh)	Battery charge (kWh)	Battery discharge (kWh)	Savings (kWh)
T-06	4,416	862	9,992	7,184	4,887	4,264	2,808
T-03	3,759	645	9,894	7,447	4,776	4,224	2,447
T-09	3,873	1,333	9,009	6,319			2,690

Table 4.14 Data from the Tesla app for households with storage heaters for the period 1 Jan 2024 to 31 Dec 2024, after the installation of the solar PV systems

Household T-09 had the traditional storage heater replaced by Dimplex Quantum high heat retention storage heaters in October 2023, close to the time of the solar PV installation. A Mixergy cylinder was fitted in May 2024 and a mixer shower replaced the electric shower a few weeks later. As for T-03, there were interactions for T-09 between the Tesla battery and the Mixergy solar diverter which meant the diverter rarely used excess solar generation and could use power from the battery to heat water.

There was an increase in household load in 2024 for T-06. It might be expected that the ASHP would reduce the household consumption after replacing the storage heaters. In fact, the household load increased from 7,172kWh to 9,992kWh. This was likely to be due to greater heating being provided by the ASHP. The average dining room temperature over the heating season rose from 16.0°C to 20.2°C. The living room was heated by an open fire before the ASHP was installed. The resident estimated they were spending £120 to £150 per month on coal and wood for the open fire during the heating season. After the new installations, the open fire was blocked and heating in the living room was provided by two radiators supplied by the ASHP.

While there was a small reduction in the household load for T-09 between the two monitoring periods, it was more significant for T-03. The load recorded fell from 12,473kWh to 9,894kWh and the grid import fell in 2024 fell to 7,447kWh. The grid import recorded by a smart meter in 2024 was 11,978kWh (see next section). The reason for the discrepancy between the two readings was that after the Tesla battery was commissioned for the solar PV, the battery was no longer recording electricity consumption from the storage heaters on the heating circuit. This was due to moving a CT clamp and led to lower values of household load and grid import being recorded by the Tesla battery

If the electricity savings from the solar PV are again defined as the difference between the household load and the grid import, the savings for the three Tesla households ranged from 2,447kWh to 2,808kWh.

While the Alpha ESS batteries being discussed were all in bungalows, the Tesla Powerwall 2 batteries were all in houses with a higher household load. Despite the PV systems being smaller and generating less, the savings for T-06 and T-09 were comparable to B-01 and B-02. The combination of the higher household loads for the Tesla households and the predictive grid charging feature with the Tesla Powerwall 2 battery may have improved savings.

The percentage reduction in grid import due to the solar PV and battery was 28.1% for T-06 and 29.9% for T-09. These reductions were lower for than for the households analysed with Alpha ESS batteries. This was because the houses with Tesla batteries had higher household loads than the bungalows with Alpha ESS batteries.

4.5 Electricity consumption

		Pre-installation dates		Pre-install	Post-install 2024
Code	Technology	Start date	End date	Grid consumption (kWh)	Grid consumption (kWh)
B-01	ASHP+ battery	1 Aug 22	31 Jul 23	5,317	4,227
B-02	ASHP+ battery	22 Feb 22	23 Feb 23	6,943	3,939
B-04	ASHP+ battery	1 Aug 22	31 Jul 23	8,311	3,742
B-05	ASHP+ battery	1 Aug 22	31 Jul 23	7,545	5,353
B-06	ASHP+ battery	1 Aug 22	31 Jul 23	9,015	5,690
B-07	ASHP+ battery	1 Aug 22	31 Jul 23	9,510	8,683
T-06	NSH/ASHP + battery	1 Aug 22	31 Jul 23	7,508	7,292
T-03	NSH + battery	5 Apr 22	23 Apr 23	14,243	11,978
T-09	NSH + battery	1 Aug 22	31 Jul 23	10,025	6,550
SH-01	NSH	1 Jan 23	31 Dec 23	9,465	8,852
AC-03	ASHP	9 Mar 22	8 Mar 23	3,757	2,314
AC-04	ASHP (+EWI)	1 Aug 22	31 Jul 23	5,855	2,452
IC-01	IR panel (+EWI)	1 Aug 22	31 Jul 23	7,145	5,136

Table 4.15 Electricity consumption before and after the solar PV installations

The electricity consumption of the households before and after the solar PV installations is shown in table 4.15. This is based mainly on data from smart electricity meters. There was some variation in the date and length of the pre-installation periods. This was due to the date of the solar PV installation or what dates meter readings were available. The post-installation period covered the whole of 2024 for all the households.

All households saw a reduction in grid import between the pre- and post-installation periods. This reduction varied from 216kWh to 4,569kWh. Other factors affected the reduction in consumption apart from the installation of the solar PV. These included behaviour change or change of occupancy of the households as well as other measures being installed.

Household B-01 saw the grid consumption decrease by 1,090kWh to 4,227kWh after installation of the solar PV. This was a relatively small drop in grid consumption compared to others with ASHPs and batteries. In 2024 the household started using an electric car which was charged from the household electricity supply. During 2024, the consumption of the electric vehicle was 1,353kWh. Data from the monitoring for the Alpha ESS battery indicated savings from the solar PV and battery of 2,818kWh.

Household B-02 maintained similar levels of thermal comfort between the two periods and the grid consumption decreased by 3,004kWh between the pre- and post-installation periods. Data from the Alpha ESS battery portal indicated there was a reduction in consumption of 2,699kWh from the solar PV system.

The largest change in grid consumption between the pre- and post-installation periods was for household B-04. During the pre-installation period the consumption of 8,311kWh was the second highest of the bungalows with ASHPs and batteries. In 2024, after installation of the solar PV system, the grid consumption had decreased by 4,569kWh (a 55% reduction) to 3742kWh and became the lowest consuming household with an ASHP and battery. This was partly due to a change in occupancy after a resident passed away in December 2023 and the thermostat temperature subsequently being turned down.

The electricity consumed by the heat pump (recorded by the My Vaillant app) decreased from 3,667kWh in the pre-install period to about 2,685kWh in 2024. There were periods with the battery and heat pump system offline in 2024 for this household which makes an assessment of the annual PV generation and savings in 2024 less accurate. Between 1 Nov 2023 and 31 Oct 2024, the PV generation recorded by the Alpha ESS portal was 4,755kWh. The saving from the solar PV system was about 2,508kWh.

The thermal comfort for household B-05 was high, with the thermostat normally set to a constant 22°C. The grid consumption fell from 7,545kWh to 5,353kWh following the PV installation. This reduction of 2,189kWh compares to a saving from the solar PV of 2,751kWh based on data from the Alpha ESS battery portal.

The grid consumption of household B-06 at 9,015kWh in the pre-installation period was the highest of the bungalows with ASHPs and batteries. The ASHP consumption in the pre-installation period was 4,684kWh. This installation was being investigated at the time of writing as the high consumption did not appear to be due to high thermal comfort. The grid import decreased by 3,325kWh to 5,690kWh in 2024. Data from the Alpha ESS battery monitoring portal indicated a saving from the solar PV of 3,029kWh which is comparable to the reduction in grid import from the meter.

The electricity consumption was typically higher for household B-07 as the property was a house rather than a bungalow. The pre-installation grid consumption was 9,501kWh and this decreased by 827kWh to 8,683kWh in 2024 after the solar PV system was fitted. The lower reduction in grid consumption between the two periods was primarily due to increased thermal comfort in 2024, with the consumption from the ASHP rising from 3,863kWh to 5,166kWh. The solar PV system was not running in January 2024 due to an inverter failure and there were two weeks of missing data in March/April 2024 due to the household switching broadband router. For the period with available data on the Alpha ESS portal, the savings from the solar PV system were 2,962kWh.

Household T-06 saw the lowest reduction in grid consumption (216kWh) between the pre- and post-installation periods. Here the household had storage heaters in the pre-installation period and an ASHP fitted at the time the solar PV system was installed. Data from the Tesla battery app showed that the household load rose from 7,172kWh to 9,992kWh. This was due to increased thermal comfort. There was an increase in average temperature in the dining room from 16.0°C to 20.2°C over the winter heating season. After the ASHP was installed, the living room was heated by two radiators instead of an open fire. The grid consumption recorded by the Tesla app for 2024 was 7,184kWh which was only 1.5% lower than the reading of 7,292kWh from the smart meter.

Household T-03 also had a Tesla Powerwall 2 battery but had traditional storage heaters for both the pre- and post-installation monitoring periods. The grid consumption fell from 14,238kWh to 11,978kWh. The pre-installation period was inflated in comparison to the post-installation period partly as it was 383 days compared to 365 days. The Tesla app suggested the grid import was 7,447kWh in 2024 but this was lower than it should have been as the battery was no longer also recording the electricity consumed by the storage heaters. The difference between the value from the Tesla app and the smart meter readings suggests the electricity consumed by the storage heaters was about 4,531kWh. The Tesla app also indicated that out of the 3,759kWh generated by the solar panels, 1,016kWh was used by the Tesla battery and 2,097kWh was used in the home.

Household T-09 initially had traditional storage heaters, but these were replaced by Dimplex Quantum storage heaters soon after the solar PV system was installed. The grid consumption decreased from 10,025kWh to 6,550kWh between the pre- and post-installation periods, with a reduction of 3,475kWh. The Tesla battery was not correctly commissioned for the solar PV system and after commissioning the app no longer recorded the battery charge and discharge. The solar PV system generated 3,872kWh according to the Tesla app, with 2,689kWh used in the home. There may have been further consumption through charging of the battery which was not recorded by the app due to the commissioning issue.

Household SH-01 heated the home by a storage heater and electric fire downstairs and panel heaters upstairs. The 3.89kW solar PV system was the smallest installed. The PV system was the last commissioned and generated 3,282kWh between 1 Mar 2024 and 31 Dec 2024. There were also behavioural and technical issues which meant the solar diverter on the Mixergy cylinder was not providing benefit until late June 2024. As a result of these different factors there were lower savings from the solar PV system with a reduction in grid consumption of 613kWh from 9,465kWh to 8,852kWh.

Household AC-03 had an ASHP and a Mixergy cylinder was installed in February 2024. The solar diverter was operational from the beginning of March 2024, but there were about three weeks in the year when the CT clamp was reversed and the diverter not working correctly. There was a 1,443kWh reduction in grid consumption from the analysis periods before and after the solar PV installation. Data from the Solis hybrid inverter indicated that in 2024, the solar PV generation was 3,842kWh with 1,628kWh (42.4%) used in the home.

The grid consumption for household AC-04 decreased by 58% (3,403kWh) from 5,855kWh to 2,452kWh between the pre- and post-installation periods for the solar PV. As for AC-03, there was an ASHP with no battery and a Mixergy cylinder was installed. Fibre insulation had been removed from the cavity wall and the cavity allowed to dry out during the winter of 2022/23. Thermal bead cavity wall insulation was installed in the Spring of 2023 and external wall insulation (EWI) had been completed by October 2023. This led to a change in the level of wall insulation between the two monitoring periods. Also, there was a reduction in occupancy from the summer of 2023 and lower electricity consumption as a result.

The Solis hybrid inverter indicated that the solar PV generation in 2024 was 3,736kWh. Out of this, 1,252kWh of the solar generation was used in the home. This meant that about 2,151kWh of the reduction in electricity consumption was due to reduced occupancy/use of appliances and reduced heating demand due to the better insulation.

Household IC-01 heated the home with infrared heating panels. A larger 5.81kW solar PV system was installed in September 2023 and this generated 5,116kWh in 2024. A Mixergy smart hot water cylinder was also installed, and this was operating correctly with the solar diverter from late March 2024. Data from the Solis hybrid inverter indicated that the electricity consumed in the home was 1,948kWh.

IC-01 had a similar change in insulation to AC-04, with fibre CWI removed, thermal bead CWI installed and EWI installed. The pre-installation period included a winter partly without CWI while for the post-installation period, the household had both CWI and EWI. The grid consumption between the pre- and post-installation periods decreased by 2,009kWh from 7,145kWh to 5,136kWh.

Most of the savings in grid consumption are likely to have come from the solar PV. The improved insulation primarily led to warmer room temperatures in 2024.

Monthly electricity consumption data was available for household B-05 from October 2020 to the end of 2024 and is plotted in figure 4.16. The ASHP was commissioned in late January 2022, replacing traditional storage heaters. There was storm damage to the property in mid-February 2022 with the electrics initially going off and the resident using electric heaters from 27 Feb 2022 to 8 Mar 2022. The Alpha ESS battery with 11kWh usable capacity was operational from July 2022. The solar PV system was commissioned in late September 2023.

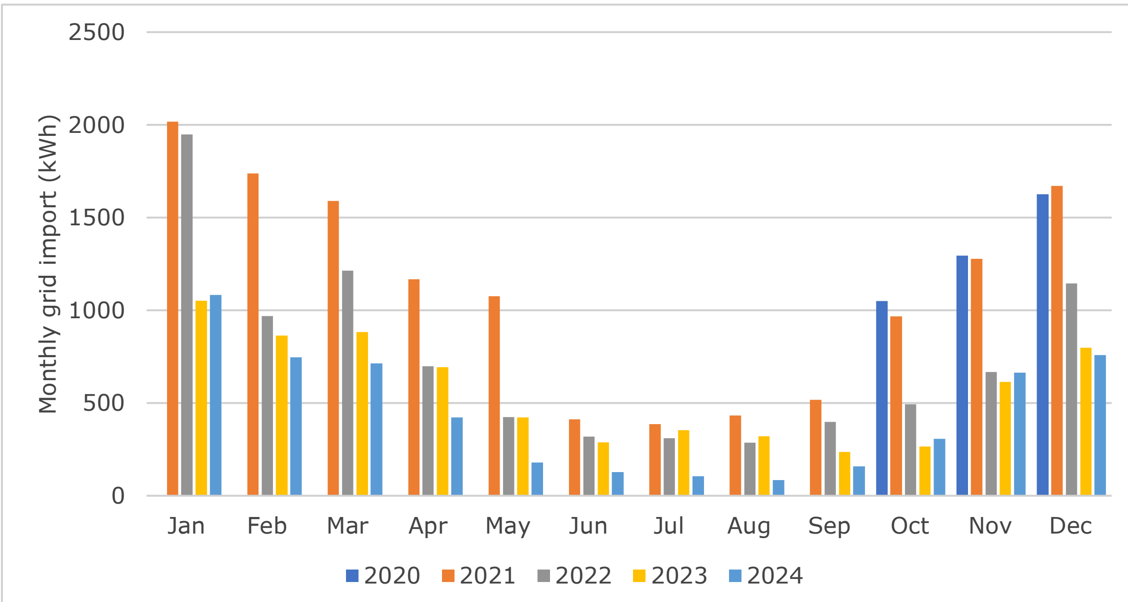

Figure 4.16 Monthly grid import from smart meter data for household B-05 from October 2020 to December 2024

It is apparent there was a decrease of almost 50% in the electricity consumed in January between 2021/22 with the storage heaters and 2023/24 with the ASHP and later the ASHP and solar PV. A similar large decrease in consumption is seen in February between 2021 and 2023/24. Consumption in February and March 2022 should be ignored due to unusual consumption following Storm Eunice.

While significant electricity savings were achieved by replacing the storage heaters with the ASHP, the graph also shows savings from the solar and battery. In April there was a large decrease in consumption from 2021 to 2022/23 after the ASHP was installed. There was a further reduction in April 2024 due to the solar PV. Similar behaviour is apparent in October, with higher consumption in 2020/21 with the storage heaters, a reduction in 2022 from the ASHP and further savings in 2023/24 due to the solar PV. March/April and October are months with higher PV generation and significant electricity use from heating. Significant savings were also apparent from May to September due to the PV.

There appear to be large savings in December after the solar PV was installed. Savings from the solar PV in 2023 and 2024 were smaller at about 80kWh. Much of the variation in this case was due to the external temperature. For the five Decembers analysed, December 2022 was the coldest month with 356.2 degree days. This accounts for lower savings after the ASHP was installed. The month was milder in 2023 and 2024, with 250.1 and 271.2 degree days respectively which was comparable to 2021 with 258.1 degree days.

From 1 Oct 2020 to 30 Sep 2021 when household B-05 had storage heaters, the grid import was 13,307kWh. This decreased to 7,545kWh from 1 Aug 2022 to 31 Jul 2023 with the ASHP and battery while also improving thermal comfort. The addition of solar PV reduced the grid consumption in 2024 to 5,353kWh.

4.6 Electricity consumption of heat pumps

Code	Space heating consumption (kWh)	Space heating output (kWh)	Water heating consumption (kWh)	Water heating output (kWh)	Total heating consumption (kWh)	Overall COP
B-01	2,042	8,337	360	939	2,402	3.86
B-02	2,159	7,412	588	1276	2,747	3.16
B-03	2,480	8,226	1,186	2,577	3,666	2.95
B-04	2,394	8,950	290	665	3,059	3.58
B-05	4,495	17,193	715	1,601	5,210	3.61
B-06	4,336	13,062	575	1,079	4,911	2.88
B-07	4,460	17,879	706	1,950	5,166	3.84

Table 4.17 Electricity consumption and heat outputs in 2024 based on data from the My Vaillant app for the Vaillant aroTHERM plus ASHPs

Seven of the households had storage heaters replaced by high temperature ASHPs with batteries in an earlier project[20]. Vaillant aroTHERM plus 7kW ASHPs were installed with a Vaillant sensoCOMFORT thermostat and Vaillant sensoNET internet gateway for communication. The flow temperature for the space heating was set to 55°C. All the installations used a SunAmp heat battery. This meant that the water heating temperature needed to be set to 60°C rather than 55°C which is more common when using a hot water cylinder. Performance data from these installations was available through the My Vaillant app and data from 2024

[20] Rogers and Hamer (2023), Making heat cheaper, smarter and greener, https://www.nea.org.uk/wp-content/uploads/2023/06/CP1438-Boxergy-NDH-full-report-16-Jan-22.pdf (Accessed 10 Feb 2025)

is shown in table 4.17. The seasonal coefficient of performance (SCOP) for the installations indicated on the MCS certificates was 3.39. This value of coefficient of performance (COP) was exceeded by four of the installations in 2024.

The accuracy of the consumption data from the app was quite high. A Wibeee electricity monitor was fitted for households B-01 and B-03 with one of the CT clamps monitoring the total electricity consumed by the heat pump. For B-01, the My Vaillant app indicated that the ASHP consumed a total of 821kWh between 1 Sep 2024 and 31 Dec 2024. This compared to 858.5kWh measured by the Wibeee monitor, which was 4.6% higher. Over the same period for B-03, the consumption was 1,137kWh with the My Vaillant app and 1,188.9kWh with the Wibeee monitor. The reading from the Wibeee monitor was again 4.6% higher than from the My Vaillant app.

There will be greater error in the reading for B-04 as this system was offline during December 2024 and the first 11 days of January 2025. The daily consumption for the period offline was an average with the total consumption divided by the period offline.

Household B-01 had the lowest consumption in 2024 of the seven ASHPs. The total ASHP consumption of 2,402kWh was 34.6% of the household load measured by the Alpha ESS battery system. This installation had the highest coefficient of performance (COP) over the year of 3.86. This means on average, for every kWh of electricity consumed by the ASHP, there was 3.84kWh of heat produced. This was the first installation to be completed and is likely to have used higher specification insulation for the pipework which may have boosted performance.

Household B-02 had the next lowest consumption by the ASHP in 2024, using 2,747kWh. The space heating consumption was higher, but the space heating output was lower with a lower overall COP of 3.16. A factor in the lower performance of this system could be an extended external pipe run between the ASHP/heat battery and the bungalow.

Installations B-03 and B-07 were both in similar sized houses rather than in bungalows. There was a significant difference in electricity consumption between the two heat pump installations. The space heating consumption for B-03 was only 2,480kWh compared to 4,460kWh for B-07. This was due to the thermostat being set to a higher temperature for B-07. The average temperature for B-07 between 1 Jan 2024 and 1 May 2024 was 20.9°C compared to 17.5°C for B-03. There was a space heating output of 17,879kWh during 2024 for B-07 compared to 8,226kWh for B-03. Household B-07 had the thermostat set to 22.0°C over the whole day through most of the year and this led to a high coefficient of performance of 3.84, the second highest out of the seven installations. However, it also had the second highest electricity consumption. Household B-03 used the programmer and towards the end of the year, the heating schedule was set to

20°C from 05:00 to 17:30 and 18°C from 19:00 to 21:00, with a setback temperature of 15°C at other times.

Household B-05 lived in a bungalow and the ASHP consumed 5,210kWh in 2024 which was the highest of all the installations. As for household B-07, the thermostat was set to 22°C throughout the day over most of the year but was later turned down to 21.5°C. The consistent thermostat temperature led to a high COP of 3.61 which was slightly lower than for B-01 and B-07.

Household B-04 typically had a consistent thermostat temperature through the day. The setting was reduced from about 21.5°C to 19°C in late January 2024. The consistent thermostat setting led to a high COP of 3.58, very similar to B-05. However, the lower thermostat setting of 19°C for much of the year led to a consumption of about 3,059kWh compared to 5,210kWh for B-05.

The total electricity consumed by the ASHP for household B-06 was 4,911kWh, which was the second highest for the installations in bungalows. The coefficient of performance of 2.88 was also the lowest of all the installations. The household typically kept the thermostat set to a constant value and the living room temperature was on average 19.4°C between 1 Jan 2024 and 1 May 2024.

In April 2024, the monthly value for the COP was 3.46 however, the performance of the system deteriorated towards the end of the year with a monthly COP of only 2.2 in November 2024. The heating system seemed to be struggling to bring the room up to temperature and the difference between the measured room temperature and the thermostat temperature could exceed 5°C. This issue was being investigated at the time of writing. A heating engineer suggested that the thermostat might need recalibrating. The technical support team for the manufacturer[21] suggested possible factors leading to a low COP included poorer insulation of pipework, loss of refrigerant from the ASHP, blockage of a filter and poor system design with incorrectly sized radiators and pipework.

Table 4.18 shows the monthly electricity consumption by the ASHP for the lowest and highest consuming households, B-01 and B-05. Both were semi-detached bungalows of the same design with the same number of residents. Household B-01 was away for four days in January and five days in February when the heating was turned off. This led to a reduction in consumption by the heat pump. The thermostat was set to 21 to 22°C throughout the year for B-05. The living room temperature for B-01 was typically between 17.5°C and 20°C.

The space heating consumption of B-05 was more than double that of B-01 between January and August 2024. This was primarily due to the difference in the thermostat settings. The overall coefficient of performance (COP) for B-01

[21] Personal Communication (December 2024), Technical support team, Vaillant

was highest in the Spring and the Autumn reaching a maximum of 4.2 in May 2024. These were months with warmer external temperatures but still significant space heating. Once the space heating level dropped to negligible levels, the COP also dropped. The average COP for water heating for B-01 was 2.61 and ranged from 2.38 in January to 2.81 in August. The average COP for space heating was 4.08 for B-01 and ranged from 3.69 in January 2024 to 4.74 in May 2024.

Month	B-01 Space heating (kWh)	B-01 Water heating (kWh)	B-01 Overall COP	B-05 Space heating (kWh)	B-05 Water heating (kWh)	B-05 Overall COP
Jan 24	410	34	3.6	904.3	48	3.1
Feb 24	246	29	3.9	603.3	48	3.6
Mar 24	283	31	4	669.3	61	3.5
Apr 24	210	34	4.1	459	63	3.8
May 24	86	27	4.2	199	72	3.9
Jun 24	43	51	3.6	146	63	3.9
Jul 24	27	28	3.6	112	59	4
Aug 24	21	21	3.3	65	47	3.7
Sep 24	88	27	4	139	58	3.9
Oct 24	130	24	4.1	252.9	66	4.1
Nov 24	252	23	3.7	453	58	3.7
Dec 24	246	31	3.9	492	72	3.7
Total	**2,042**	**360**	**3.86**	**4,495**	**715**	**3.61**

Table 4.18 Electricity consumption and coefficient of performance for the lowest and highest consuming ASHPs based on data from the My Vaillant app

The space heating consumption for B-05 was about 50% higher in January 2024 than in February. Although the difference in space heating consumption was lower for B-01, the percentage increase between February and January was higher at 67%. This illustrates the large increase in consumption in the coldest weather. January 2024 had 353.9 degree days and was significantly colder than February 2024 with 233.2 degree days or March 2024 with 263.3 degree days.

For B-05, there was still significant space heating consumption throughout the summer. This was due to maintaining the home at 21-22°C overnight as well as on colder days. Having a setback temperature overnight could have reduced consumption but the resident was keen to maintain the warmer temperature overnight to avoid the bathroom being cold at night.

The overall COP for B-05 in 2024 was 3.61 and the monthly COP ranged from 3.1 in January 2024 to 4.1 in October 2024. The average COP for water heating was 2.2 and ranged from 2.02 in January to 2.43 in August. For space heating, the COP in 2024 was 3.83 and ranged from 3.15 in January to 4.85 in August. There was still significant space heating in August and the warmer external temperature improved the efficiency of the heat pump.

Figure 4.19 plots the monthly household load for B-05 based on data from the Alpha ESS battery portal. The amount of this load coming from the space and water heating consumption of the ASHP is included from the My Vaillant app. The consumption of other appliances was obtained by subtracting the ASHP consumption from the total household load.

The household load ranged from 1,194kWh in January 2024 to 324kWh in August 2024. The other consumption consisted of lighting, cooking, the washing machine and the television. This ranged from about 192kWh in August/September to 241 in January. The percentage consumption by the ASHP was 40.7% in August 2024 but increased to 79.8% in January 2024.

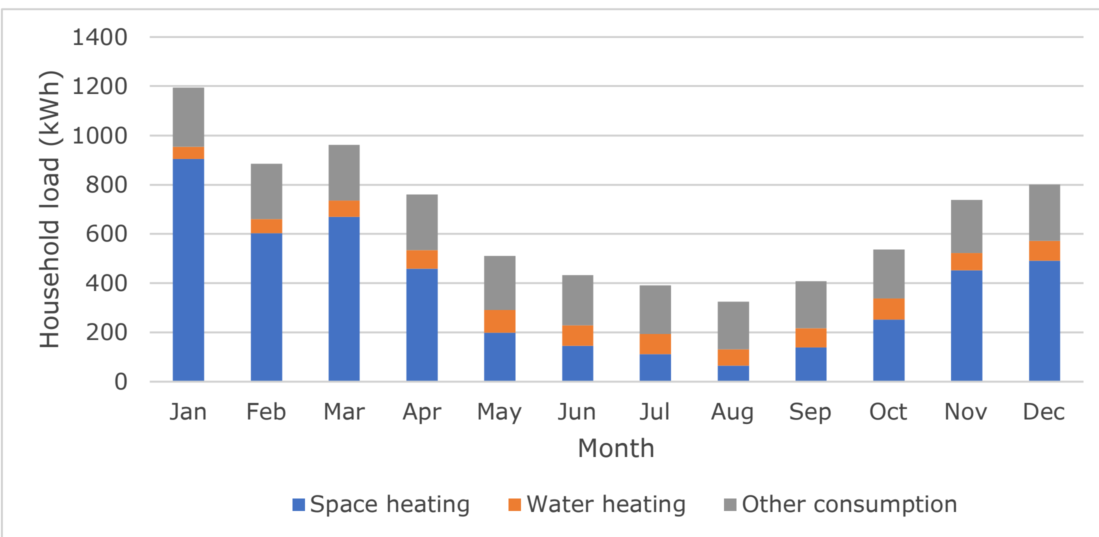

Figure 4.19 Household load for B-05 showing the space and water heating load from the ASHP and the load from other appliances in 2024

The heat pump for household B-02 had the second lowest consumption for the seven Vaillant ASHPs. The household turned off the space heating over the summer with negligible space heating recorded from June to August and very low in May and September. The percentage of the household load used by the heat pump ranged from about 15% in June to August to 62.1% in January 2024.

Household B-01 had the lowest consumption in 2024 out of the Vaillant ASHPs. Consumption by the ASHP made up 60.7% of the household load in January 2024. The resident started using an electric vehicle in February 2024 and there was considerable variation in the monthly load due to EV charging. The consumption by other appliances was between 240 and 334kWh. Consumption by the heat pump was only 11.7 to 13.7% of the total for June to August.

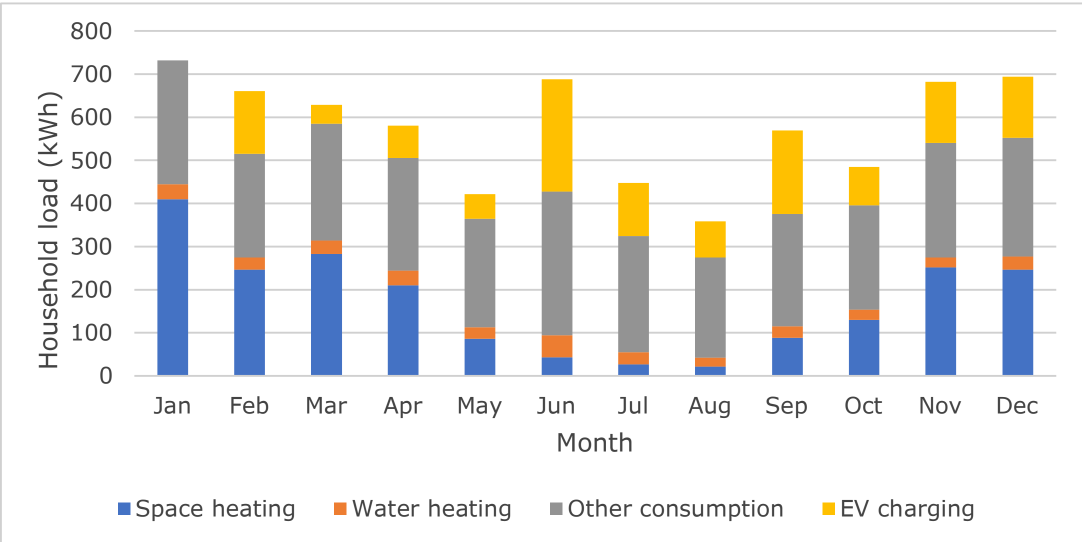

Figure 4.20 Household load for B-01 showing the space and water heating load from the ASHP and load for EV charging and from other appliances in 2024

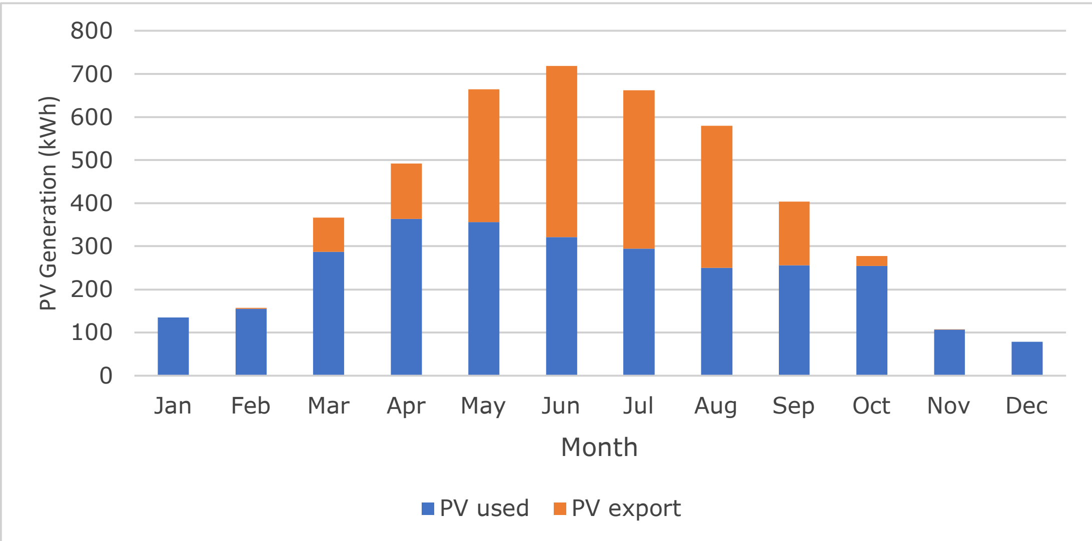

Figure 4.21 Solar PV generation in 2024 for household B-05, showing the generation used in the home and the amount exported to the grid

Figure 4.21 shows a plot of the monthly solar PV generation for household B-05. This includes the amounts used in the home and exported to the grid. The solar PV array was 5.81kW in size and split across an east-west roof and there was an Alpha ESS battery with a usable capacity of 11kWh.

For the months with lower generation (November to February), more than 98% of the monthly generation was used in the home (78 to 155kWh). There is higher generation in Spring and Autumn (March-May and September/October) while there is also space heating demand. During these months, the amount of the solar generation used was between 254kWh and 364kWh, with the highest self-consumption in April 2024. There continued to be high levels of consumption in the summer months with between 250kWh to 321kWh used in the home.

Over the year, household B-05 used 2,857kWh of the 4,642kWh generated. This represented a percentage self-consumption of 61.6%.

4.7 Electricity tariffs and electric heating

Traditionally households with storage heaters would be on an Economy 7 tariff with seven hours of off-peak consumption overnight. The hours of off-peak consumption can vary by region and time of year (i.e. British Summer Time/Greenwich Mean Time). Adding solar PV would reduce the amount of day-time consumption with savings made at peak rate. If the household had energy storage the self-consumption of the solar generation would increase. This could be a battery and/or solar diverter with water heating.

Normally an air-source heat pump (ASHP) would run on a single rate tariff as most of the consumption would be during the day. The households in this project with ASHPs and batteries which replaced storage heaters remained on a time-of-use tariff. In this case the battery charged overnight and then discharged during the peak rate period in the day, helping power the heat pump and appliances. During the coldest weather the battery could be fully discharged by 12:00 to 16:00 and the ASHP would have to be powered using more expensive peak rate electricity during the rest of the day/evening.

Adding solar PV extended the period that the battery could power the home before it was necessary to use peak rate electricity. Figure 4.22 shows a graph from the monitoring portal for the Alpha ESS battery for household B-05. The example was from 26 Jan 2024, a cold sunny day where the solar PV system generated 8.9kWh over the day (shown in yellow). The battery charge is shown in green and charged from midnight to 02:30 when it was 100% charged. During the period the battery was charging, there was consumption of over 5kW from the grid (shown in brown) at the off-peak rate.

The off-peak period ended at 07:00 and the battery began to discharge, powering the heat pump and household appliances (load shown in blue). There was solar PV generation from 08:30 and this helped power the home. In the afternoon, the PV generation exceeded the load from the heat pump and the household appliances. This meant that from about 11:30, the battery started to recharge, reaching a peak of nearly 79% at 15:45. The extra charge in the battery due to the solar PV meant the battery was not fully discharged until about 20:30 instead of about 16:00 to 17:00.

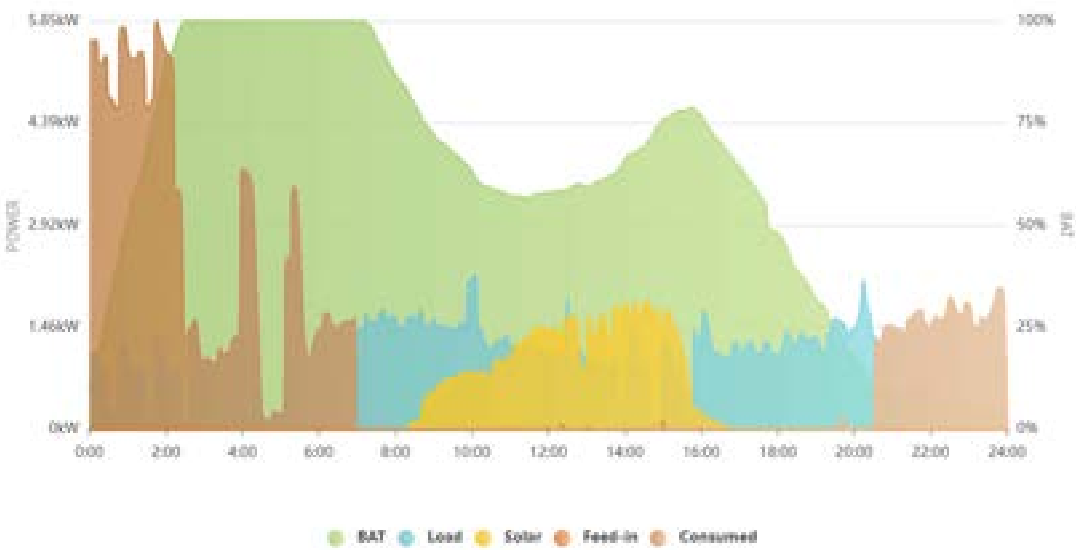

Figure 4.22 Power Diagram from the Alpha ESS battery portal for household B-05 on 26 Jan 2024 showing battery charge, consumption and PV generation

The household consumed all 8.9kWh of the solar generation. This meant the grid consumption on 26 Jan 2024 was reduced by 27.1% from 32.9kWh to 24kWh. The savings in this case were all at the peak rate. The solar PV and battery system also reduced consumption during the 16:00 to 19:00 period of higher demand on the electricity grid which is beneficial to the electricity network.

Households with ASHPs and batteries can also make savings by switching to a smart time-of-use tariff. Tariffs like Cosy Octopus have more than one off-peak period a day. A household with a battery and a high heating demand can potentially charge the battery twice a day and reduce the percentage of consumption at the peak rate.

Electricity tariffs and electric heating and the cost savings that can be achieved are discussed in a separate report for this project[22].

[22] Rogers and Hamer (2025), Evaluating solar PV with electric heating: electricity tariffs (in press)

5. Conclusions, recommendations, and future work

5.1 Conclusions

The project successfully installed 18 solar PV systems which included a total of 11 Mixergy hot water cylinders and two Wondrwall systems

- Solar PV systems with sizes between 3.89kW and 5.81kW were installed in 18 socially rented North Devon Homes properties
- The households receiving installations were all electrically heated and either had ASHPs and batteries, ASHPs, storage heaters and batteries, storage heaters/panel heaters or infra-red heating panels
- The two Wondrwall installations comprised a 5.81kW PV system, 6kWh battery, infrared heating panels which replaced storage heaters and a Mixergy hot water cylinder
- The other nine Mixergy installations were in homes which had hot water cylinders, with three in homes with ASHPs, five in homes with storage heaters and one further installation in a home with infrared heating panels
- Analysis of the EPC score was carried out using RdSAP 2012, with an increase in energy score of between 18 and 43 points due to the solar PV and between two and seven points for the Mixergy cylinder
- The EPC score before installing the solar PV and Mixergy cylinders ranged from E48 to C75 and the post install scores were between B82 and A109
- The infrared panel heaters led to a decrease in the energy score compared to storage heaters, but the solar PV raised the score by about 40 points
- It was not possible to produce EPCs in RdSAP 10.2 as intended as this had not been released during the project, but it is expected that households with battery storage would see further uplifts in the energy score

Households were interviewed and commented on their satisfaction with the heating system and the benefits of the solar PV installation

- Among nine households with ASHPs (eight with batteries), all nine were very satisfied with the amount of control with the heating system and eight were very satisfied with the cost of running the heating system and how warm the home gets when it is cold outside
- There were less favourable responses among the four households interviewed who had storage heaters with three very dissatisfied and one dissatisfied with the cost or running the heating system
- There were also high levels of dissatisfaction among the storage heater households with how warm the home gets when cold outside and the amount of control with the heating system although they were generally considered easy to use
- Among the nine households interviewed with ASHPs, eight strongly agreed that their electricity costs had decreased since the solar PV installation with one household agreeing while six households strongly agreed and two agreed that it was cheaper to heat their house on a sunny day

- All eight households where an ASHP and battery had replaced storage heaters strongly agreed that their new heating system was better than their old one
- Among the four households interviewed with storage heaters, all agreed their electricity costs had decreased since the PV system was installed and while three strongly agreed and one agreed that their electricity cost was lower on a sunny day, all four disagreed that it was cheaper to heat their home on a sunny day
- Resident feedback was particularly positive where solar PV was installed for households with ASHPs and battery storage with comments such as: "I have never had such a warm house. If I ever moved, I would have to have the same heating system and solar PV. The rest of the village are extremely jealous. My son has not had any asthma issues since moving in. This is the best heating system I have ever had for my disability".

Living room and bedroom temperatures were monitored during the heating season before and after the installations

- Household T-06 had storage heaters replaced by an ASHP at the same time as the solar PV system was installed
- The dining room temperature rose from 16.0°C during the pre-installation period to 20.2°C post installation – this was partly due to energy rationing and poorer insulation in the pre-install period with the storage heaters and due to greater use of the heating once the ASHP was fitted
- The post-installation average temperatures ranged from 16.4 to 22.1°C for the households with ASHPs while for the storage heater households the range was 17.1 to 21.6°C
- One of the households with an ASHP used it more like a gas boiler, turning it off when going out and this led to a lower average room temperature and changes in temperature of 5°C or more over short time periods
- Other households preferred to keep the thermostat for the heat pump at a constant temperature and this meant little change in room temperature over the heating season
- For households with traditional storage heaters, there was usually a daily variation in room temperature of about 2.5°C to 3°C as the storage heater charged and discharged as well as a longer-term rise and fall in room temperature affected by the external temperature

The performance of the solar PV systems was assessed using monitoring portals and apps provided by the manufacturer of the inverter or battery system

- Generation of the installations in 2024 ranged from 3,282kWh to 5,652kWh, with the lowest performing system having the smallest array and starting to generate part way through the year
- Six south facing 5.81kW PV systems generated over 5,000kWh in 2024

- The level of solar PV generation in 2024 was lower than predicted by the MCS certificate as there were lower than average hours of sunshine
- A 5.81kW PV system facing south generated more on a sunny day than an east-west facing 5.81kW system; however, on a dull cloudy day, both systems generated less with the south and east/west systems generating similar amounts
- For the households with ASHPs and Alpha ESS batteries, the percentage self-consumption of the solar generation was between 50.2% and 74.3%
- The households with Tesla Powerwall 2 batteries used between 65.6% and 82.8% of the solar generation – this may partly be due to lower PV generation as well as a feature which varied the overnight grid charging based on the predicted PV generation the following day
- The households with ASHPs and Mixergy cylinders used 33.5% and 42.4% of the PV generation
- The Wondrwall systems used a lower percentage of the solar generation at 18% and 35.6% - this was due to high levels of PV generation, one household using very little electricity, and the other only having the diverter for the Mixergy cylinder running correctly from July 2024
- There are losses due while charging and discharging battery storage and these were assessed in the pre-installation period without the solar PV
- Over a year for the Alpha ESS batteries this could be over 200kWh, but it is not clear if the full losses were shown; for the Tesla Powerwall 2 batteries grid charging over a year, the losses were 500-600kWh
- For four of the installations with solar PV and Alpha ESS batteries, the savings from the solar PV system ranged from 2,699kWh to 3,029kWh, with the highest saving for the household with the highest load
- Among the three installations with solar PV and Tesla Powerwall 2 batteries, the savings from the solar PV were between 2,447kWh and 2,808kWh; the savings were likely to be lower than for the Alpha ESS households due to smaller PV systems and lower generation

The grid consumption of 13 of the 18 households was assessed for pre-installation periods compared to 2024 and all households saw savings

- Compared to a pre-installation period of about a year, in 2024, there was a reduction in grid consumption of between 216kWh and 4,569kWh
- While savings from the solar PV were a major factor in the reduction in grid consumption, the reduction was also affected by changes in household consumption due to behaviour change or other installations
- The smallest reduction in grid consumption of 216kWh was seen for household T-06 where in addition to the solar PV and Mixergy installation an ASHP was installed
- There was an increase in the household load for T-06 in 2024 due to higher thermal comfort and the ASHP now heating the living room which had previously been heated by an open fire

- Household B-04 had the largest reduction in grid consumption with a fall of 4,569kWh; this was primarily due to a change in occupancy and reduced thermal comfort, with an approximately 1,000kWh reduction in electricity consumed by the heat pump and savings of about 2,500kWh from the solar PV indicated by the battery monitoring portal
- The annual electricity consumption for household B-05 fell from 13,307kWh with storage heaters to 7,545kWh with an ASHP and battery and reduced further to 5,353kWh with the addition of solar PV

The electricity consumed by the Vaillant aroTHERM plus ASHPs was monitored using the My Vaillant app and performance assessed in 2024

- The electricity consumption of the seven Vaillant aroTHERM plus ASHPs in 2024 ranged from 2,402kWh to 5,210kWh
- The accuracy of the data from the My Vaillant app was assessed using a Wibeee electricity monitor and readings from the Wibeee for two of the installations were 4.6% higher than the readings from the My Vaillant app
- The coefficient of performance (COP) for the installations was between 2.88 and 3.86
- Household B-01 had the lowest heating consumption and the highest COP; this was likely to be due to having higher specification insulation on pipework as well as the thermostat being set relatively low with a typical living room temperature of between 17.5°C and 20°C
- Household B-05 had the highest electricity consumption from the heat pump at 5,210kWh with 4,495kWh for space heating and 715kWh for water heating
- The coefficient of performance for B-05 was high at 3.61 and this was partly due to the thermostat being set to a constant temperature through much of the year
- The high electricity consumption for B-05 was due to a high thermostat temperature of about 22°C; household B-07 where the thermostat was also set to a constant 22°C had the second highest COP (3.84) and the second highest consumption (5,166kWh)
- In January 2024, the space heating consumption by the ASHP for B-05 was 904kWh with a space heating COP of 3.15 and the consumption fell to 65kWh in August, with a space heating COP of 4.85
- A SunAmp heat battery was used for storing heat for hot water; this required a water temperature of 60°C for the phase change material
- The COP for water heating for B-05 ranged from 2.02 in January to 2.43 in August 2024
- The monthly household load for B-05 ranged from 1,194kWh in January to 324kWh in August 2024 and the electricity consumption of the ASHP in January 2024 contributed 79.8% towards the household load
- The ASHPs for households B-01 and B-02 consumed less and in January 2024, their electricity consumption contributed 60.7% and 62.1% respectively towards the household load

There were high levels of self-consumption of the solar generation particularly in winter, spring and autumn

- Household B-05 consumed 98% or more of the solar generation between November and February with 78 to 155kWh used in the home
- There was higher generation in spring and autumn but also quite high space heating demand
- For household B-05 the monthly self-consumption of the solar generation in spring and autumn was between 254kWh and 364kWh, with the highest monthly self-consumption in April 2024

5.2 Recommendations and future work

- This study has shown the benefits of installing large solar PV systems on homes with electric heating, providing large increases in the energy score and significant energy savings for households
- There were significant savings for households after adding solar PV to properties with ASHPs and batteries; more sophisticated integrated systems are now on the market and would be worth investigating
- There are a range of smart time of use tariffs available from electricity suppliers which can improve savings for households with electric heating, particularly if they have battery storage
- Alternative electricity tariffs for electric heating are discuss in a companion report for this project
- The improvements in EPC energy score were determined using RdSAP 2012 which is likely to be replaced in 2025 by RdSAP 10.2
- It would be worth repeating the assessments of the properties once RdSAP 10.2 is available to see whether the uplift from the solar PV is still as high, and what uplift would be provided from battery storage which will be a new measure covered in RdSAP 10.2
- It is important for social landlords to have an energy manager or contractor who regularly checks solar PV and battery systems for performance
- This project identified installation issues with two solar PV systems through comparing performance of similar sized and orientated systems – it is particularly important to monitor and analyse performance of systems in the first few weeks after installation
- Battery systems need to be kept online to monitor the performance of the system, identify faults and maintain the warranty
- During this project there were problems keeping the systems online due to relying on household broadband, with households switching broadband supplier or struggling to pay the bill and having periods offline
- It may be better for landlords to install a wireless router and use this to maintain the internet connection for solar PV, battery and heating systems
- A contribution towards the costs of wireless communication and monitoring could come from the landlord receiving payment for the excess solar generation exported to the grid (smart export guarantee)

- The most common way to connect solar PV inverters with the internet for monitoring is to use a Wi-Fi dongle
- When a household switches broadband router, the solar PV system loses connection to the internet, and it can be difficult to reconnect the dongle and require a site visit
- A more reliable method of connecting a Solis inverter to the internet but with extra costs would be a data logger with both Wi-Fi and 4G connection where the 4G communication is used if the Wi-Fi connection is lost
- Alternatively, there are RF (radio frequency) dongles which communicate with a gateway which has a cable that plugs into the broadband router; it is a simple task to switch cables between an old and new router
- Battery storage systems have a CT-clamp which is used to monitor the grid-import/export and this can be fitted in the wrong orientation at installation, when a smart meter is installed or after work by an electrician
- When the CT-clamp is reversed, it can increase the electricity consumption of the household due to force charging/discharging of the battery
- Battery manufacturers should develop AI modelling to identify when a CT clamp has been reversed and quickly notify the owner or installer
- With some battery systems such as those from Alpha ESS, it is necessary to manually set the level of grid charging – this can mean excess PV export or greater consumption at peak rate times if not optimised
- More battery systems should use AI to predict the level of generation by the solar PV system and consumption by the household for the day ahead
- This would allow the level of grid charging to be varied each day, maximising the use of the solar generation

6. Appendix

6.1 Appendix 1 – Household comments on satisfaction with installations

Code	Technology	Comments
B-01	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, EDF EV electricity tariff	It provides constant heat and hot water. It is very cheap to run. So much better than the storage heaters. I had to use a fire with the storage heaters. The running costs are lower, and the house is warmer. There is nothing like coming back to a warm house rather than a cold one
B-02	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Cosy Octopus electricity tariff	It is definitely cheaper to run. It is completely different to Economy 7 storage heaters. With storage heaters you wanted the heat in the evening at 4.30pm and it wasn't' there. This is 100% better
B-03	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, EDF heat pump electricity tariff	I have never had such a warm house. If I ever moved, I would have to have the same heating system and solar PV. The rest of the village are extremely jealous. My son has not had any asthma issues since moving in. This is the best heating system I have ever had for my disability
B-04	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Economy 7	For me it is brilliant, but I would recommend it to anyone who has the chance. If we hadn't had the system, we wouldn't have been able to have the heating on. We have cheaper electricity throughout the year, but it is much better in the summer
B-05	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Economy 7	There are no disadvantages with the system. The running costs are half that for the storage heaters despite the price rises. I am currently paying £110 per month on Direct Debit. The heating system works perfectly and is much better than storage heaters
B-06	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Economy 7	I am satisfied with it – there have been some teething problems. It is definitely a big improvement over the storage heaters
B-07	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Cosy Octopus electricity tariff	It is a lot cheaper to run. The controls can be confusing, but once set it only needs changing twice a year. It is low maintenance and hands off. One issue is the need for Wi-Fi. In a rural area, we can have frequent power cuts, and the Wi-Fi broadband can go offline. It is good for the elderly and better than storage heaters. It is effective at heating the home
T-06	Solar PV, ASHP, Mixergy cylinder, Tesla Powerwall 2 battery, Cosy Octopus electricity tariff	It is more efficient. The home is warmer in every room which improves our quality of life. It is more effective with regards to cost, and we spend less and get more heat. We feel good that we have solar PV on the home and are making a positive contribution. What makes it work is the solar PV, heat pump, battery and Cosy Octopus tariff. If one element was missing, the impact would be significant. The connectivity with the apps

		takes it to another level and we can always check performance
AC-03	Solar PV, ASHP, Mixergy cylinder, Single rate electricity tariff	I am very pleased with the system, and it is much cheaper (after PV and Mixergy installations) with only five months when there are greater costs during the winter
T-03	Solar PV, traditional storage heaters, Mixergy cylinder, Tesla Powerwall 2 battery, Economy 7 tariff	When the sun is out, it is an excellent system. My main concern is if there is an issue with the Tesla battery in the future as that is the lynchpin for the whole system.
T-09	Solar PV, Dimplex Quantum storage heaters, Mixergy cylinder, Tesla Powerwall 2 battery, Economy 7 tariff	It has been great during sunny days. Being able to heat hot water from the sun has been fantastic. Since the installation there has been seamless interaction between the solar panels and the battery. On a sunny day in summer, the solar and battery can provide most of the electricity. Some weeks, the solar and battery meant we used only £3-£4 of electricity in the week.
SH-01	Solar PV, traditional storage heaters/panel heaters, Mixergy cylinder, Economy 7 tariff	The solar PV is lowering costs, and we can see when it is generating on the app. The Mixergy cylinder is good and there is always enough hot water.
SH-02	Solar PV, traditional storage heaters/panel heaters, Mixergy cylinder, Economy 7 tariff	We have definitely found benefit in the summer which makes a massive difference. With a young child we needed to do more washing. The Mixergy cylinder is smaller than the old one but heats up faster and keeps in the heat better than the old one.
W-01	Wondrwall Solar PV, infrared heating panels, Growatt battery, Mixergy cylinder, Economy 7 tariff	In terms of running costs, it is alright. Have low electricity costs in the summer. Struggled with the automated system and wasn't able and not interested in using the tablet (controller) and needed time switches fitted. Happier now that the heating times have been changed, and a new electric radiator (with time switch) has been fitted. Legs and feet were cold with the heating (infrared panels). Having the radiator lower down helps and feet are less cold as a result.
W-02	Wondrwall Solar PV, infrared heating panels, Growatt battery, Mixergy cylinder, Economy 7 tariff	Would be better if (the IR panels) were not on the ceiling as heat might be lost through the ceiling. It provides a comfortable level of heat, but some might not find it good enough. Have been hoping to control the system via my phone but this never worked. The solar and battery system works fine and quite pleased with it. (Note Mixergy cylinder not used)

6.2 Appendix 2 – Issues affecting monitoring or installations

Code	Technology	Comments
B-01	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, EDF EV electricity tariff	The solar PV system was installed in late August 2023. Some of the Alpha ESS inverters at other sites initially had incorrect settings or export limitation. After these issues were investigated, B-01 still was generating half the amount of B-02 and B-06. This was due to a wiring issue with one of the strings of the solar PV installation. The battery was not working for much of December 2023, but all the issues were resolved at the beginning of January 2024.
B-02	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Cosy Octopus electricity tariff	No issues during the monitoring period for this project apart from getting Alpha ESS to adjust settings to remove export limitation
B-03	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, EDF heat pump electricity tariff	There were regular periods offline in 2023. This was due to issues with household broadband and an issue with the battery in summer 2023. The roof needed replacing prior to solar PV being installed. There was a change of household in February 2024 leading to different levels of consumption. There were some further internet connection issues, perhaps due power cuts
B-04	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Economy 7	Broadband and monitoring offline for extended periods: late Aug 2024 to late Oct 2024 and Dec 2024 to mid-Jan 2025. This affected monitoring for both the solar PV, grid consumption and ASHP consumption.
B-05	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Economy 7	No issues during the monitoring period for this project apart from getting Alpha ESS to adjust settings to remove export limitation
B-06	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Economy 7	There had been teething problems with the ASHP since installation. The system had the lowest COP of the seven Vaillant ASHPs in 2024. Performance deteriorated towards the end of the year and the causes were being investigated at the time of writing.
B-07	Solar PV, ASHP, SunAmp heat battery, Alpha ESS battery, Cosy Octopus electricity tariff	Fault with Alpha ESS hybrid inverter from late November 2023 which meant the PV system and monitoring was offline from early December 2023 to mid-January 2024. Also, short periods offline due to switching broadband router and possibly power cuts
T-06	Solar PV, ASHP, Mixergy cylinder, Tesla Powerwall 2 battery, Cosy Octopus electricity tariff	CT clamp for Mixergy cylinder reversed a couple times affecting solar diverter. Loss of connection for Solis monitoring after change of broadband router. Later fitted a Solis RF logger for monitoring the solar PV.

AC-03	Solar PV, ASHP, Mixergy cylinder, Single rate electricity tariff	There were issues with the Solis hybrid inverter which was later replaced and a loss of connection for the Wi-Fi dongle after a change of broadband router. This meant data was only available from October 2023 with some gaps in data in October and December 2023. The CT clamp for the Mixergy cylinder was reversed for just over 2 weeks in September 2024.
AC-04	Solar PV, ASHP, Mixergy cylinder, Economy 7 tariff	Heating of the hot water for the Mixergy cylinder was only being provided by the solar diverter. When the cylinder called for heat from the heat pump there was no response. This issue was resolved in December 2024 after being noticed in November. Prior to that there was plenty of hot water.
T-03	Solar PV, traditional storage heaters, Mixergy cylinder, Tesla Powerwall 2 battery, Economy 7 tariff	Mixergy solar diverter has been interacting with the Tesla Powerwall 2 battery so that the diverter has not been water heating with excess PV generation as intended. Settings have been adjusted to optimise performance until Mixergy can resolve the issue
T-09	Solar PV, Dimplex Quantum storage heaters, Mixergy cylinder, Tesla Powerwall 2 battery, Economy 7 tariff	Mixergy solar diverter has been interacting with the Tesla Powerwall 2 battery so that the diverter has not been water heating with excess PV generation as intended. Settings have been adjusted to optimise performance until Mixergy can resolve the issue
SH-01	Solar PV, traditional storage heaters/panel heaters, Mixergy cylinder, Economy 7 tariff	This was the last installation to be commissioned in March 2024. The PV system tripped and went offline from late March to mid-April and for a week in November 2024. The monitoring for the grid consumption with the hybrid inverter did not work correctly, with the consumption following the PV generation. Replacing the CT clamp did not resolve the issue. The household initially struggled to understand how to use the Mixergy cylinder. They thought an isolator switch for the cylinder was a boost button and were controlling the cylinder with this, increasing consumption. The isolator switch later failed causing the system to go offline for a period. This led to reduced data from the Mixergy cylinder and higher electricity consumption.
SH-02	Solar PV, traditional storage heaters/panel heaters, Mixergy cylinder, Economy 7 tariff	The CT clamp for the Solis hybrid inverter was initially fitted in the wrong orientation. This meant the system was not recording the correct grid consumption and PV export. This was resolved in early June 2024. It took a few weeks to get the Mixergy cylinder running correctly with issues initially around fitting the CT clamp and later having the orientation reversed for a few days in March 2024.
IC-01	Solar PV, infrared heating panels, Mixergy cylinder	The CT clamp for the Mixergy cylinder was initially fitted in the wrong orientation with this issue resolved on 23 Mar 2024. There was a loss of the internet connection for the Mixergy cylinder from 23 Apr 2024 to 18 May 24. The residents switched broadband router and the Solis inverter lost internet connection from late November to mid-December 2024.

W-01	Wondrwall Solar PV, infrared heating panels, Growatt battery, Mixergy cylinder, Economy 7 tariff	There were initially connectivity issues with the internet. The household struggled using a tablet computer to control the system. The automated relays for the heating panels were taken out in December 2023 and replaced with timer switches for the infrared panels. The infrared panels were controlled by the timer switches for the rest of the monitoring period. There was damage to the solar diverter for the Mixergy cylinder at the time the PV system was installed. The immersion heater kept tripping out after the Legionella cycle but this was resolved after the immersion heater was replaced. No online monitoring of the solar PV system was provided by Wondrwall for NEA/NDH. An Orsis S2 smart generation meter was later fitted to allow monitoring of the system.
W-02	Wondrwall Solar PV, infrared heating panels, Growatt battery, Mixergy cylinder, Economy 7 tariff	The automated relays were taken out in December 2023 and replaced in April 2024. The household wanted to control the system via a mobile phone but there were difficulties getting the Amazon AWS login to work. The resident decided not to use the Mixergy cylinder as there was limited hot water demand and the resident felt it took too long for hot water to come through to the tap, wasting water. No online monitoring of the solar PV system was provided by Wondrwall for NEA/NDH. An Orsis S2 smart generation meter was later fitted to allow monitoring of the system.

National Energy Action (NEA) is the national fuel poverty and energy efficiency charity. We've worked across England, Wales, and Northern Ireland for over 40 years, to ensure that everyone in the UK can afford to live in a warm, safe and healthy home.

We work together with frontline practitioners, companies, regulators and the government for customers in vulnerable circumstances to make positive changes.