# Evaluating solar PV with electric heating with North Devon Homes: Wondrwall



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## 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.

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## Executive Summary

### Project Overview

Installation of infra-red heating panels can be a lower cost option to installing an air-source heat pump and wet central heating system when replacing storage heaters. The savings from the cheaper infrared heating panel system could be put towards a solar PV and battery system which can help reduce heating costs for the household, particularly in the spring and autumn.

The project installed two Wondrwall systems which combined infrared heating panels with solar PV, battery storage, a smart hot water cylinder and an intelligent home energy management system. This was compared against a control property where the household fitted their own infrared panels, and a solar PV system of the same size was installed along with a smart hot water cylinder.

North Devon Homes (NDH) was the project lead. Wondrwall was the system designer and arranged for the solar PV and battery system to be installed. James Electrics Contracting Ltd carried out the electrical works such as fitting the infrared panels and removing the storage heaters. RES Devon Ltd fitted the smart hot water cylinder. NEA assisted with resident liaison, partner liaison, data collection and evaluated the project.

### Wondrwall technology and installations

The two Wondrwall systems were installed in a pair of semi-detached bungalows in North Molton. These were single bedroom properties that had external wall insulation fitted prior to 2015. The control property was a semi-detached bungalow in Witheridge. This was a two-bedroom property which had external wall insulation completed by October 2023.

The project started in September 2022 and the Wondrwall systems were installed in October 2023. The Wondrwall system combined infrared heating panels, solar PV, battery storage, a smart hot water cylinder and smart light switches with sensors. The solar PV systems were south facing arrays of 5.81kW capacity. There was a hybrid inverter and battery which had a maximum discharge power of 5kW and usable storage capacity of 6kWh. The smart hot water cylinder was supplied by Mixergy and a 150-litre cylinder with solar PV diverter was used. The Wondrwall properties had 5 x 450W infrared heating panels fitted on the ceiling along with a 300W electric towel rail in the bathroom. Internet connectivity was provided by a wireless router with SIM card.

Control for the system was provided by a tablet computer. This was able to turn on and off lights in the house and the infrared heating panels. A heating schedule could be set on the tablet with the temperature sensor in the light switch providing thermostatic control for the infrared panel.


Figure ES1
(a) Hybrid inverter and battery (b) Smart hot water cylinder (c) Wondrwall light switch

The control household fitted their own infrared heating panels between December 2020 and February 2022. A south facing 5.81kW solar PV system was installed in late September 2023. This used a Solis hybrid inverter which provided additional monitoring but did not include battery storage. The 120-litre Mixergy smart hot water cylinder was installed in late February 2024 but was not operating correctly until late March 2024 as the current transformer (CT clamp) for the solar diverter was initially installed in the wrong orientation.

The average cost per property of installing the Wondrwall system and completing the electrical and plumbing work was £18,455. The installation cost for the solar PV system and smart hot water cylinder for the control household was £9,472 but £739 of this was the extra cost of using the Solis hybrid inverter.

Energy Performance Certificates (EPCs) were produced for the three properties under RdSAP 2012. Replacing the storage heaters with infrared heating panels led to a decrease in the energy score of about 10 points. However, the large solar PV system and smart hot water cylinder caused a significant uplift, with the post-installation energy score for the Wondrwall properties achieving A94. The control property behaved in similar way and achieved a final score of A92.

## Issues affecting the project

Household W-01 had an older resident who struggled with computers and smart phones. The resident was not comfortable using the Wondrwall tablet computer to control the heating. As a result, the Wondrwall automated relays for the infrared heating panels were removed for this household and replaced with timer switches. This meant it was not possible to assess the Wondrwall system operating with a programmer, thermostat and occupancy sensors.

There were issues with the smart hot water cylinder for W-01 where the cylinder regularly tripped after the Legionella cycle. Replacing the immersion heater resolved this problem. The solar diverter for the cylinder initially did not operate as intended due to the current transformer being installed in the wrong orientation. This was resolved in early July 2024.

Household W-02 rarely heated the home before the Wondrwall installation and only used the infrared heating panels a few times during the monitoring period after the Wondrwall installation. The household was a very low energy user and was happy to have the home at low temperatures which would be unacceptable to most households.

Household W-02 had an electric shower and limited other hot water demand. The resident decided not to use the Mixergy smart hot water cylinder as it took too long for hot water to come through the pipes, preferring to boil a kettle to wash dishes. If the bath is replaced by a mixer shower cubicle in the future, the resident is likely to use the Mixergy cylinder for hot water.

## Social analysis

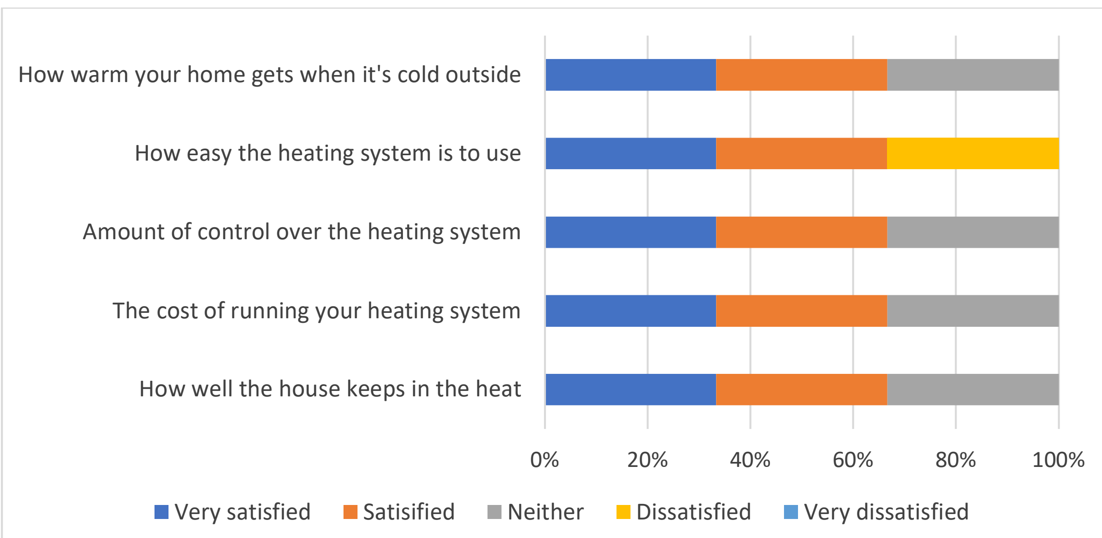


Figure ES2 Satisfaction with the heating system

The two Wondrwall households (W-01 and W-02) and the control household IC-01 were asked about their satisfaction with the heating system. IC-01 answered very satisfied to all the questions in figure ES2. W-01 was dissatisfied with how easy the heating system was to use. For the other questions, one of the Wondrwall households was satisfied while the other was neither satisfied nor dissatisfied.

The households were also asked whether they agreed or disagreed with a series of statements (figure ES3). Control household IC-01 strongly agreed with all the statements. W-01 and W-02 also strongly agreed that their electricity cost was lower on a sunny day. W-01 strongly agreed it was cheaper to heat the house on a sunny day while W-02 thought it was not applicable as the resident did not heat the home on a sunny day. W-01 and W-02 agreed that their electricity costs had decreased since the solar PV system had been installed.

While W-02 agreed that the current heating system was better than the old heating system, W-01 disagreed.

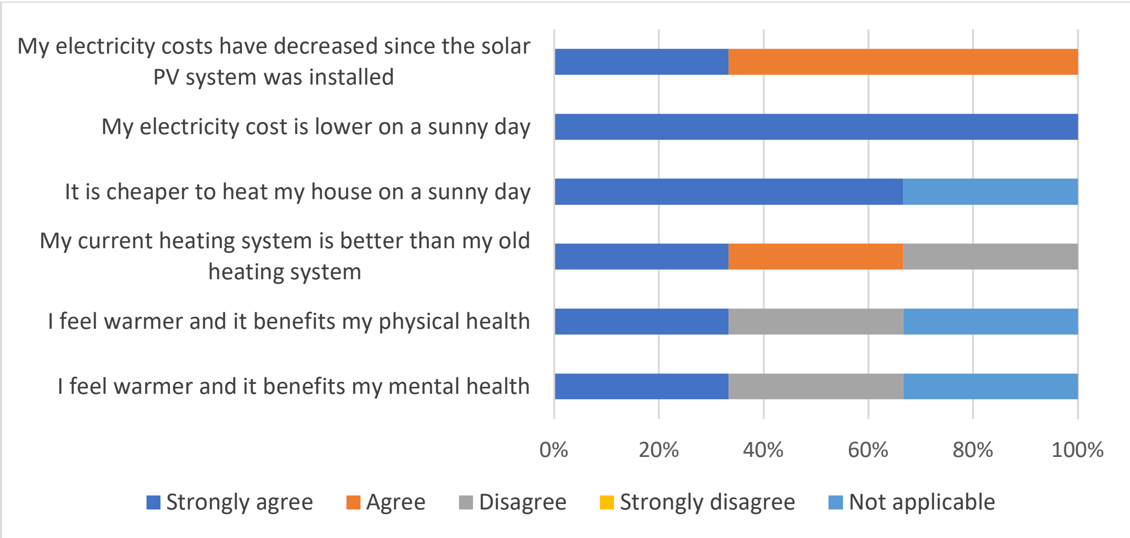


Figure ES3 Assessing the benefits of the installations

Although household IC-01 strongly agreed that they felt warmer and it benefited their physical and mental health, W-01 disagreed with the statement and W-02 thought it was not applicable. Household W-01 required heating throughout the winter in the living room. There was lower satisfaction with the infrared heating panels which left the resident cold in the lower half of the body. As a result, additional supplementary heating was used.

## Temperature and humidity

Household W-01 had the hall infrared panel running 24 hours a day during the heating season, heated the living room in the afternoon/evening and did not heat the bedroom. Household W-02 rarely heated the home before or after the Wondrwall system was installed. Household IC-01 heated the bedroom more than the living room; other areas with greater heat were the hall and kitchen.

During the heating season from 1 Nov 2022 to 1 May 2023 before the Wondrwall installation, the average living room temperature for W-01 was 18.1°C. However, the resident was away from mid-December 2022 to mid-February 2023 and there was reduced heating in the home over this period. The average living room temperature in November 2022 was 19.3°C.

The average living room temperature for W-02 over the pre-installation heating season was 12.3°C. Electricity monitoring suggested the storage heaters were used for about 10 days over the heating season.

The average bedroom temperature for IC-01 from 1 Nov 2022 to 1 May 2023 was 17.65°C, but this was a period prior to the external wall insulation being installed and the cavity wall insulation had been extracted for some of this period.

For the heating season after the installations from 1 Nov 2023 to 1 May 2024, the average temperature in the living room for W-01 was 18.2°C. This was barely higher than for the previous year which included a period when the resident was away for two months. However, the infrared panels were timed to come on from early afternoon to evening and the average temperature during the 5pm-9pm period was 19.7°C.

Household W-02 continued to rarely use the heating and the average temperature in the living room over the heating season was 12.1°C. The resident was warned by NEA staff of the risks of living in a cold home over an extended period.

For household IC-01, the average bedroom temperature over the heating season was 19.1°C, an increase of 1.4°C compared to the previous heating season. This improvement was likely to be due primarily to the external wall insulation having been fitted during the previous summer and reducing the loss of heat.

The average relative humidity during the pre-installation heating season ranged from 71.8% for the living room for W-01 to 79.6% for the living room for W-02. The minimum humidity for all the properties ranged from 63% to 72% which meant the humidity was outside the optimum range of 40% to 60%.

For the post-installation heating season, the average humidity ranged from 65.7% for the living room for W-01 to 81.25% for the bedroom for W-02. The maximum humidity was between 79.5% for the bedroom of IC-01 to 95% for the living room of W-02. The minimum relative humidity was between 40% for the bedroom for IC-01 and 65.5% for the bedroom of W-02.

## Solar generation and electricity consumption

| | W-01 | W-02 | IC-01 |
|---|---|---|---|
| Household consumption (kWh) | 6,460 | 999 | 7,097 |
| PV generation (kWh) | 5,531 | 5,224 | 5,116 |
| Grid import (kWh) | 4,466 | 96 | 5,144 |
| Grid export (kWh) | 3,540 | 4,285 | 3,168 |
| Battery charge (kWh) | 2,480 | 674 | 0 |
| Smart meter grid import (kWh) | 4,686 | | 5,136 |

Table ES4 Summary of consumption and generation data for the Wondrwall households and control property in 2024

The solar PV systems were operational during the whole of 2024 and table ES4 summarises data collected from the hybrid inverters. Also shown is the grid import from smart meter data.

The solar PV systems generated less electricity in 2024 than was predicted on the MCS certificate for the PV installations. This was likely to be due to there being less sunshine in 2024 compared to usual, with 1,333 hours of sunshine in England SW and South Wales compared to 1,542 hours for the same region over a 20-year average between 2000 and 2019[1].

The PV generation in 2024 for W-01 was 5,531kWh while 4,686kWh was imported from the grid. This meant the household was net positive, with more PV generation than grid import. For W-02, the household was strongly net positive, with 5,224kWh of PV generation in 2024 and just 346kWh of grid import between 10 Jan 2024 and 31 Dec 2024. Household IC-01 was close to net-zero with 5,116kWh of PV generation and 5,136kWh of grid import.

Figure ES5 plots the monthly PV generation for W-01 in 2024, showing how much of the generation was used in the home and how much was exported to the grid. Over the year, 1,971kWh of solar generation for W-01 was consumed in the home which was a percentage self-consumption of 35.6%. Less of the solar generation was consumed for W-02 with just 939kWh and a percentage self-consumption of 18%. This was due to the low electricity demand of the household. IC-01 consumed 1,947kWh of the solar generation, a self-consumption level of 38%. The household did not have a battery like the Wondrwall households but there was a Mixergy smart hot water cylinder and solar diverter.

[1] 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)

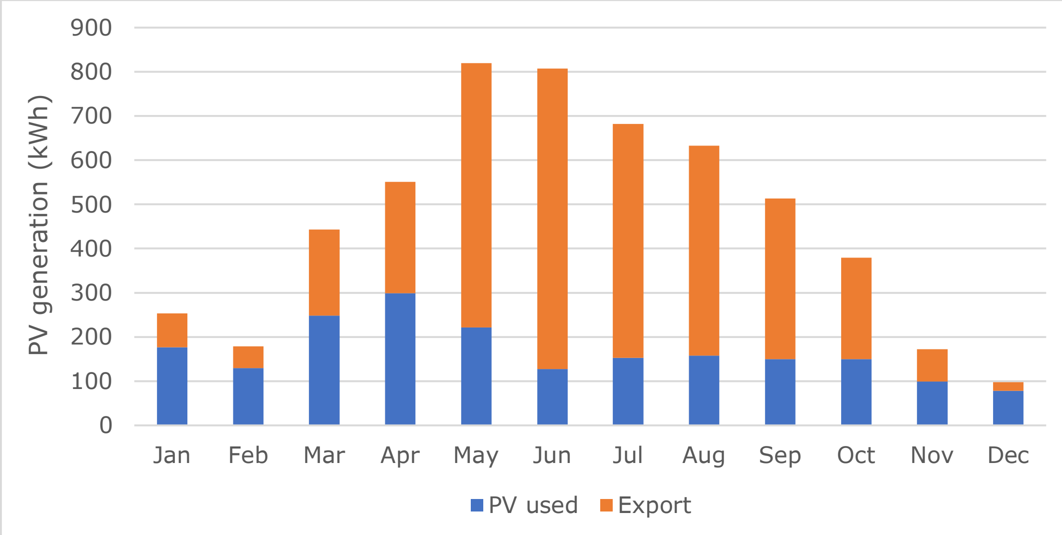


Figure ES5 Graph of PV generation for household W-01 for 2024 based on data from the Wondrwall hybrid inverter

Initially there were teething troubles with the Wondrwall installation for W-01 and this led to a higher monthly electricity consumption in October and November 2023. After the Wondrwall installation, the off-peak Economy 7 electricity consumption fell for W-01 while the peak-rate consumption rose.

A plot of the monthly electricity cost for household W-01 on Economy 7 is shown in figure ES6 assuming a peak-rate cost of 30p/kWh and off-peak rate of 12.5p/kWh. The cost in November 2023 was higher due to teething troubles with the Wondrwall system. The costs in December 2022, January 2023 and February 2023 were lower than normal due to the resident being away from mid-December 2022 to mid-February 2023.

The electricity cost on Economy 7 over 2024 was £835.70 for household W-01. This compares to £782.69 during the pre-installation period from 1 Oct 2022 to 30 Sep 2023 which included the winter period when the resident was away for two months. An assessment was also made for the electricity cost for W-01 had the resident been on a single-rate tariff. Assuming a single-rate tariff of 24p/kWh, the cost of the electricity used would have been £1,124.70.

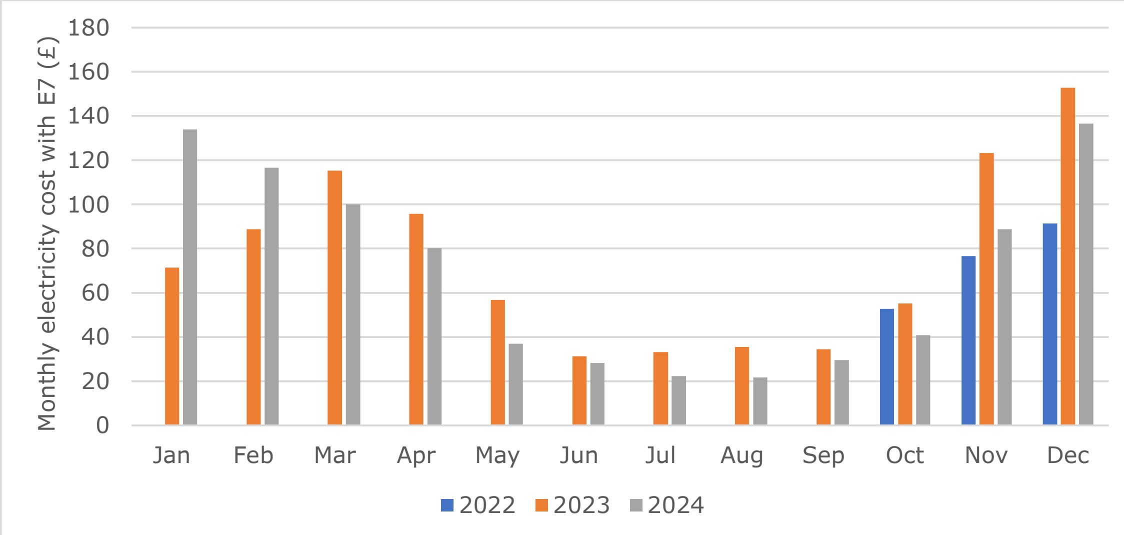


Figure ES6 Graph of monthly electricity cost for household W-01 assuming a peak rate of 30p/kWh and off-peak rate of 12.5p/kWh

Table ES7 shows the electricity consumption and electricity cost for household W-02 over two periods of approximately a year before the Wondrwall installation and another period after the Wondrwall installation. During the pre-installation periods, the electricity import was about 1,350 to 1,450kWh with an electricity cost of £340 and £328. After Wondrwall was installed, the electricity import was just 346kWh over 356 days and the electricity cost was £74.20. Note that this does not include the standing charge of about 69p/day. This made an annual standing charge of about £252, much greater than the cost of the electricity consumed by W-02.

| Start date | End date | No. of days | Peak rate (kWh) | Off-peak (kWh) | Total consumption (kWh) | Electricity cost (£) |
|---|---|---|---|---|---|---|
| 15 Apr 21 | 21 Apr 22 | 371 | 914 | 523 | 1,437 | £339.58 |
| 14 Oct 22 | 19 Oct 23 | 370 | 905 | 452 | 1,357 | £328.00 |
| 10 Jan 24 | 31 Dec 24 | 356 | 176.7 | 169.5 | 346.2 | £74.20 |

Table ES7 Electricity consumption and cost on Economy 7 for household W-02 over approximately 12-month analysis periods

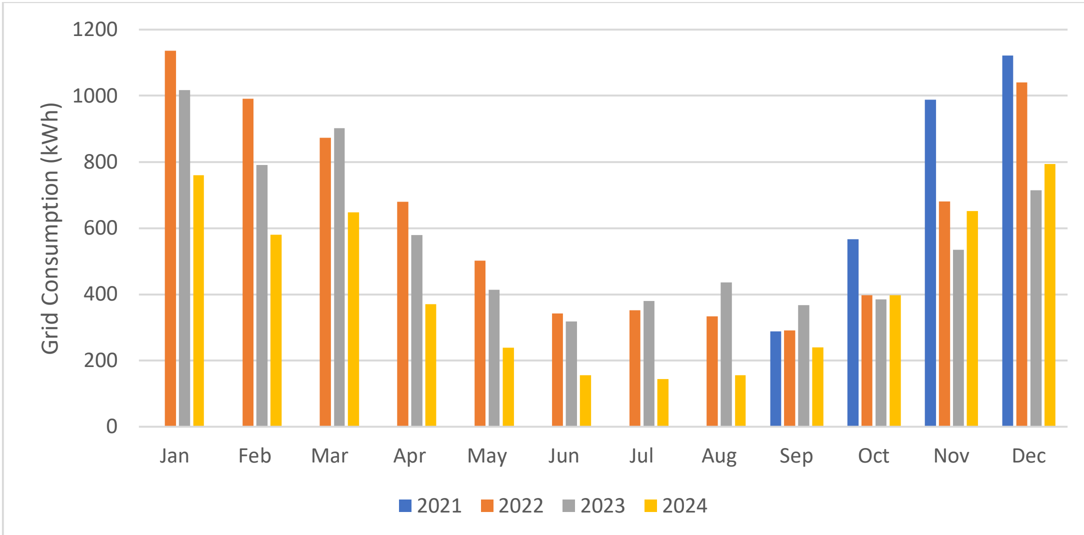


Figure ES8 Graph of monthly electricity consumption for control household IC-01 from smart meter data covering the period 1 Sep 2021 to 31 Dec 2024

Figure ES8 shows a plot of monthly grid import for control household IC-01. The annual import was 7,620kWh in 2022 and fell to 5,136kWh in 2024. There was a drop in monthly consumption from November 2023 after the solar PV system and external wall insulation (EWI) had been fitted. The EWI is likely to have led to warmer room temperatures and some of the reduction in grid consumption in early 2024. However, 145.5kWh of solar generation was used in the home in January 2024, 113kWh in February, 179kWh in March and 246kWh in April.

Household IC-01 switched from Economy 7 to a single-rate tariff after they stopped using their storage heaters and installed infrared heating panels. Using a single-rate tariff of 24p/kWh, the electricity cost in 2022 was £1,829 and this fell to £1,641 in 2023. In 2024 with a full year with the solar panels operational and 9 months with the Mixergy cylinder, the electricity cost had fallen to £1,233.

The electricity costs were also modelled for Economy 7 using half-hourly smart meter data. The costs in 2022 and 2023 would have been about £300 higher on Economy 7 due to the low percentage off-peak consumption (12.1% and 9.4%). In 2024, the percentage off-peak consumption increased to 26.6% due to less grid import during the day because of the solar generation along with overnight charging of the Mixergy hot water cylinder. The electricity cost would have been about £70 lower in 2024 with the single-rate tariff than with Economy 7.

For comparison, Wondrwall household W-01 consumed 4,686kWh in 2024, with 69.5% of the consumption at the off-peak rate for Economy 7. The high percentage off-peak consumption was due to overnight charging of the battery and smart hot water cylinder along with use of an infrared panel and towel rail overnight. This consumption profile meant the electricity cost on Economy 7 was only £835.70. Had the resident been on a single-rate tariff, the cost would have been £1,124.70, closer to the £1,233 for household IC-01.

**Other import and export tariffs**

Households W-01 and W-02 originally had storage heaters, and these charged overnight on an Economy 7 off-peak tariff. It normally takes seven hours to charge a storage heater to a sufficient level to heat a home on the coldest of days. With the Wondrwall heating system, charging the electrical battery and hot water cylinder may only take about two hours and so seven hours of off-peak electricity overnight is not necessarily needed. This opens opportunities for alternative smart time-of-use tariffs.

The Octopus Flux tariff was designed for battery storage and has an off-peak period from 02:00 to 05:00 and a peak-rate period from 16:00 to 19:00. At other times of day, it is close to the single-rate tariff. The off-peak period for Octopus Flux would allow sufficient time for the battery and smart hot water cylinder to charge overnight. For much of the day, the tariff rate would be cheaper than for peak-rate for Economy 7. The charge of the battery could be maintained to allow sufficient charge to get through the peak-rate period from 16:00 to 19:00.

There are other smart time-of-use tariffs offered by energy suppliers but many of these are tied to households having electric vehicles or heat pumps. Cosy Octopus is an example of a heat pump tariff with off-peak periods from 04:00 to 07:00, 13:00 to 16:00 and 22:00 to 00:00. There is also an expensive peak-rate period from 16:00 to 19:00 while at other times, the unit rate is similar to a single-rate tariff. There is potential for the Wondrwall battery to charge in both the early morning and early afternoon off-peak periods and provide power at other times, minimising consumption during the late afternoon peak-rate period. Suppliers need to stop restricting tariffs such as these to those with heat pumps. Some households who have had Wondrwall installations have been able to switch to the Cosy Octopus smart time-of-use electricity tariff.

Payments are also available for solar PV export from the smart export guarantee (SEG). On this project it was decided for the landlord to receive this payment due to issues of maintaining equity among tenants with solar PV and around administering the SEG account after a change in tenancy.

**Conclusions**

- The project successfully installed Wondrwall smart heating systems in two homes and compared the performance against a control household with infrared heating panels, solar PV and a smart hot water cylinder
- EPCs were produced for the Wondrwall properties under RdSAP 2012 and the final energy score after these installations was A94
- It was not possible to test the Wondrwall systems operating as designed due to one household requiring timer switches to be fitted and another rarely using the heating
- Household W-02 had low hot water demand and did not use the smart hot water cylinder because too much water was drawn before it became hot
- Having multiple contractors installing the Wondrwall systems made the installation process more complex for the households and the landlord
- Control household IC-01 was generally more satisfied with the heating system than Wondrwall households W-01 and W-02 but had higher electricity costs
- The resident in household W-01 noted that the infrared heating panel on the ceiling heated the upper half of the body and left the lower half cold
- All three households strongly agreed that their electricity cost was lower on a sunny day and W-01 and IC-01 both strongly agreed it was cheaper to heat their home on a sunny day
- The average living room temperature for W-01 and W-02 did not change significantly between the pre- and post-installation winter heating seasons with W-01 at 18.2°C post installation and W-02 averaging 12.1°C; there was an increase in the average bedroom temperature for IC-01 from 17.65°C to 19.1°C most likely due to installation of external wall insulation
- The Wondrwall installations were net positive homes in 2024, generating more electricity than they imported from the grid, with the control property close to achieving net zero
- The electricity cost for W-01 on Economy 7 was £835.70 in 2024, somewhat higher than the £782.69 pre-installation but during this period, the resident was away from mid-December to mid-February
- Household W-02 was a low electricity user and imported 1,350-1,450kWh from the grid in two approximately year-long periods before Wondrwall was installed; in a post installation period of just under a year, the grid import was 346kWh
- The electricity cost for W-02 was £340 and £328 for the two pre-installation periods compared to £74.20 for the post-installation period
- Household IC-01 was on a single-rate tariff and in 2024 after the installations, the electricity cost was £1,233 which was about £70 lower than the cost would have been on Economy 7
- Advanced time-of-use tariffs can benefit households with Wondrwall installations but suppliers can limit access to tariffs to certain technologies

# 1. Project overview

## 1.1 Introduction

With plans to decarbonise domestic heating, there is interest in electric heating technologies for off-gas grid homes and as an alternative to heating with gas in new build homes. Installation of air-source heat pumps is often recommended. However, for homes with storage heaters, retrofitting a wet central heating system and heat pump can be a significant cost[2].

An alternative to a heat pump is to fit electrically powered infrared heating panels in each room which is a cheaper option than a new wet central heating system. The heat pump has the benefit of being able to produce about three units of heat for each unit of electricity consumed. Savings from the cheaper infrared heating panel system could be put towards a solar PV and battery system which can help reduce the heating costs for the household, particularly in the spring and autumn.

Wondrwall has produced an intelligent home energy management system which combines multiple technologies with the aim to provide a low carbon home which has low running costs. The system combines infrared heating panels, solar PV, battery storage and a smart hot water cylinder. The system has smart light switches with 13 different sensors which can detect when to heat rooms based on occupancy. This aims to reduce electricity consumption while ensuring residents are comfortable.

North Devon Homes identified a pair of semi-detached properties to have Wondrwall installations. These 1950s era bungalows previously had external wall insulation which should reduce heat losses. They had south-facing roofs suitable for a larger solar PV system. The existing traditional storage heaters were not well suited to one of the households where the resident was a shift-worker and wanted heating available at different times of the day. Another household who bought their own infrared heating panels and subsequently had solar PV installed was used as a control property to compare to the Wondrwall installations.

The project was part of the wider 'Evaluating Solar PV with Electric Heating' project which was funded by the Energy Industry Voluntary Redress Scheme and installed a total of 18 solar PV systems. Other parts of the project examined Mixergy smart hot water cylinders and solar PV with other types of electric heating, with and without battery storage. There are separate project reports for the Mixergy smart hot water cylinders and solar PV with other types of electric heating and also one investigating costs with different electricity tariffs.

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[2] Rogers and Hamer (2023), Making heat cheaper, greener and smarter, https://www.nea.org.uk/wp-content/uploads/2023/06/CP1438-Boxergy-NDH-full-report-16-Jan-22.pdf (Accessed 25 Nov 2024)

## 1.2 Project partners

The lead for the project was North Devon Homes (NDH), a non-profit making housing association and registered charity. NDH provides homes for rent distributed across the area of North Devon District Council. In total there are 3,271 socially rented domestic properties, with 584 properties having storage heaters in 2025.

Wondrwall was the system designer and arranged for the solar PV and battery system to be installed. James Electrics Contracting Ltd, the planned electrical maintenance contractor for North Devon Homes carried out the electrical works, removing the storage heaters and fitting the infrared panels and smart light switches. RES Devon Ltd fitted the smart hot water cylinder.

A member of the Innovation and Technical Evaluation team at NEA assisted with resident liaison, partner liaison, data collection and evaluated the project.

## 1.3 Context

The Wondrwall smart heating system was used in a new-build development in West Gorton, Greater Manchester built by Keepmoat Homes in partnership with Manchester City Council[3]. Heating was supplied by a combination of electric underfloor heating and infrared heating panels. The Wondrwall system also included solar PV, battery storage, a smart hot water cylinder and light switches in each room with 13 sensors including for occupancy, temperature and humidity.

The housing developer Redrow carried out a trial of the Wondrwall system from February 2022 to March 2023 in one of their large three-bedroom Oxford Lifestyle new-build homes[4]. The trial compared the Wondrwall system including a 3.4kW PV system with a control property with a gas boiler in a standard Oxford style house. Both properties had similar occupancy and were built to Part L 2013 building regulations. These were larger and more modern houses compared to the smaller bungalows in this study.

The electrically-heated house consumed 5,757kWh over the year, with 40% of this used for space heating. The property generated more electricity than it consumed from May to August, but consumption was over 1,000kWh per month in the winter. The control household used 7,781kWh of gas over the year and 2,901kWh of electricity.

[3] Burton (2020), Keep all options on the table to decarbonise heat, https://www.localgov.co.uk/Keep-all-options-on-the-table-to-decarbonise-heat/51264 (Accessed 25 Nov 2024)
[4] Infrared Heating and Solar Panel Trial, Case Study Report, https://www.redrowplc.co.uk/media/swck3jtw/infrared-heating-and-solar-panel-trial.pdf (Accessed 25 Nov 2024)

The current study aimed to investigate the performance of the Wondrwall system as a retrofit in social housing.

## 1.4 Project timeline

The project started in September 2022. The households to receive installations were identified by North Devon Homes and surveys were carried out by Wondrwall. NEA fitted pre-installation monitoring in October 2022 and a quotation for the installation was provided by Wondrwall in November 2022.

The Wondrwall systems were installed in October 2023. These had been delayed due to issues with the grid application. The performance of the solar PV, temperature and humidity and grid consumption were monitored in the post-installation period up to the end of December 2024. The project evaluation was completed by the end of February 2025.

The control household had fitted their own infrared heating panels between December 2020 and February 2022. The solar PV system was fitted at the end of September 2023. This household had been a control property in an earlier project[5].

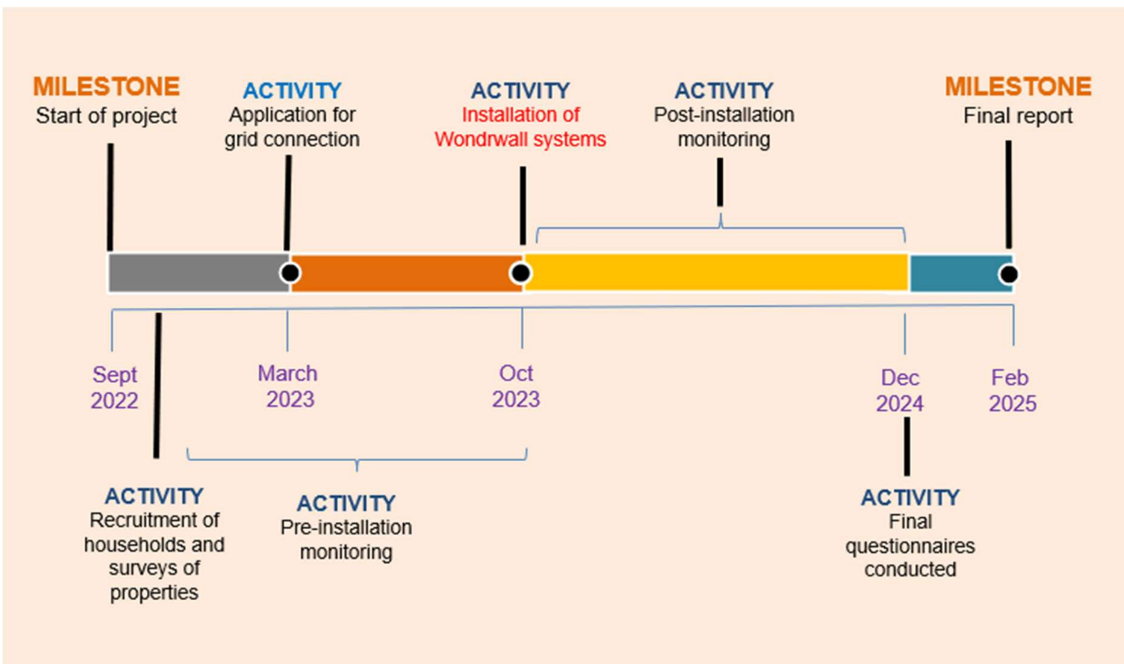


Figure 1.1 Timeline for the Wondrwall project

[5] Rogers and Hamer (2023), Making heat cheaper, smarter, greener, https://www.nea.org.uk/wp-content/uploads/2023/06/CP1438-Boxergy-NDH-full-report-16-Jan-22.pdf (Accessed 26 Nov 2024)

## 1.5 Wondrwall technology and installations


Figure 1.2
(b) Hybrid inverter and battery (b) Smart hot water cylinder (c) Wondrwall light switch

The Wondrwall system combined infrared heating panels, solar PV, battery storage and a smart hot water cylinder. The system had smart light switches with 13 different sensors which can detect when to heat rooms based on occupancy. This aims to reduce electricity consumption while ensuring residents are comfortable.

The solar PV installations had 14 x Trina 415W modules, making a south-facing array of 5.81kW. Although the inverter and battery were branded as Wondrwall, the models used were manufactured by Growatt. The GBLI6532 battery had a usable capacity of 6kWh and a maximum discharge power of 5kW. The battery warranty was for 10 years.

The smart hot water cylinder was supplied by Mixergy, and a 150-litre cylinder was fitted with a solar PV diverter. Each of the properties had 5 x 450W infrared heating panels fitted on the ceiling, with a 300W electric towel rail in the bathroom. To provide internet connectivity, a wireless router was used for each property as one household did not have broadband. This also aimed to avoid issues over the reliability of broadband Wi-Fi where households may switch supplier.

Control for the system was provided by a tablet computer. This was able to turn on and off lights in the house and the infrared heating panels. A heating schedule could be set on the tablet with the temperature sensor in the light switch providing thermostatic control for the infrared panel.

For comparison, a control household was selected where the residents had installed their own infrared heating panels. These had been fitted as they disliked the storage heaters which had been installed. A 5.81kWh south-facing solar PV system was fitted with a Solis hybrid inverter but no battery was installed at this property.

## 1.6 Issues affecting the project

| Issue | Description and mitigation |
|---|---|
| **Installation delays** | There was a delay in the Wondrwall installations due to it taking longer than expected for Wondrwall to obtain a grid connection agreement from National Grid. |
| **Installation issues** | The initial setup of the monitoring and control for the Wondrwall system was less straightforward due to issues with the SIM cards used for the wireless router. |
| **Control of the Wondrwall system** | One of the households had an older resident who struggled with computers and smart phones. The resident was not comfortable using the Wondrwall tablet computer to control the heating. There were also initially concerns about connectivity. As a result, the Wondrwall automated relays were taken out for the first winter and replaced with manual or timer controls.<br>In April 2024, the second household had the automated relays replaced to allow control from the Wondrwall tablet. The second household was keen to control the Wondrwall system using their mobile phone. Unfortunately, it was not possible to get the login for system to work via Amazon Web Services. |
| **Wondrwall monitoring** | Wondrwall monitored the solar generation, battery charge and discharge, grid consumption and export as well as room temperatures and humidity via the solar/battery system and Wondrwall light switches. They provided no access to a portal for NDH or NEA to monitor performance of the systems. The only data available was provided in historic reports or data compiled by Wondrwall. |
| **Generation meter** | There were significant differences between the readings for the generation meters for the two Wondrwall installations. This was due to the installer used by Wondrwall not fitting bi-directional generation meters with the DC coupled hybrid battery system. The significant differences in readings were due to one household charging the battery overnight from the grid and the grid discharge being recorded as generation.<br>Orsis S2 smart generation meters were fitted by NDH with monitoring on the Orsis Energise portal. This allowed remote monitoring of the solar PV with the value of solar generation calculated taking into account grid charging. |

| | |
|---|---|
| **Smart hot water cylinder** | One of the residents did not use the smart hot water cylinder due to the water consumption before hot water came through the taps.<br><br>The other cylinder had several issues. The main circuit and solar PV diverter appeared to have been blown during installation of the solar PV. The cylinder regularly tripped after the Legionella cycle. After the immersion heater was replaced, this issue no longer occurred.<br><br>The CT clamp was initially fitted in the wrong orientation which meant the solar PV diverter did not power the immersion heater at times of excess solar generation. |

## 2. Details of properties

### 2.1 Location of the installations

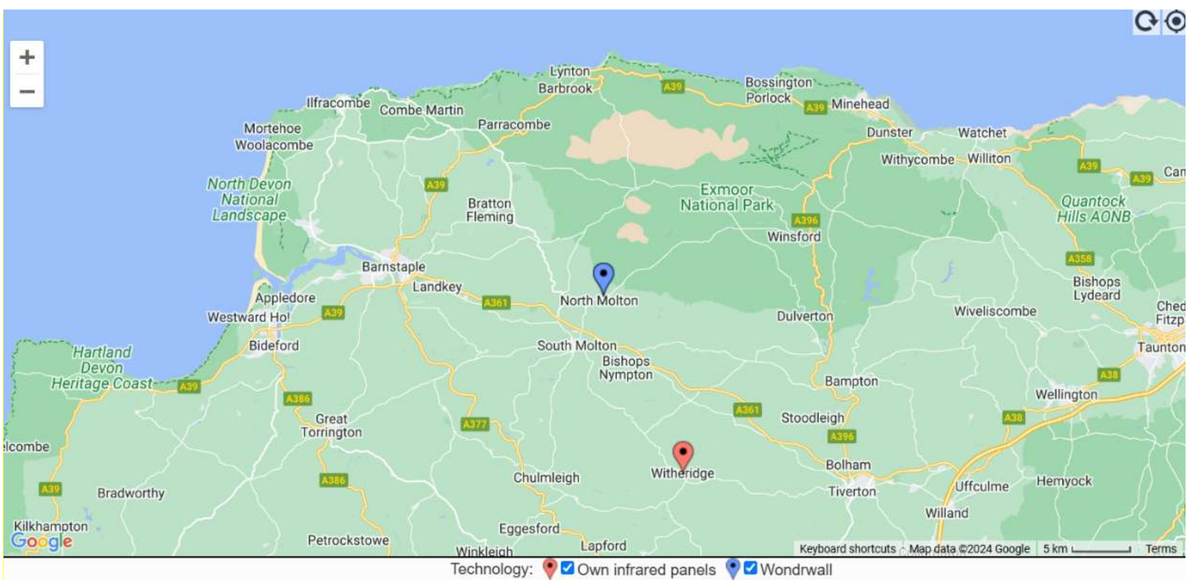


Figure 2.1 Map showing the location of installations[6]

The two Wondrwall installations were in North Molton while the control household with their own infrared heating panels was in Witheridge. All the properties were semi-detached bungalows, with the two households having Wondrwall installations next door to each other.

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

## 2.2 Details of the properties, installations and households

Figure 2.2 Semi-detached bungalows which had Wondrwall installations

| Code | Technology | EPC score before install | EPC score after install | Floor area (m2) |
|---|---|---|---|---|
| W-01 | Wondrwall | D58 | A94 | 48 |
| W-02 | Wondrwall | D58 | A94 | 48 |
| IC-01 | IR panels + PV | E47 | A92 | 57 |

Table 2.3 Monitored properties

The bungalows having Wondrwall installations were single-bedroom properties with a floor area of 48m$^2$. The systems were fitted in October 2023 and had a 5.81kW solar PV system with 6kWh battery. The cost of the infrared panels, smart light switches and PV and battery installation was £11,837 per property. The average cost for supplying and installing the smart hot water cylinders was £2,948. The average cost for the electricians to install the infrared panels was £2,592, with additional labour of £672 due to issues and £406.80 for materials. This made a total installation cost per property of £18,455.

In an earlier project, storage heaters were removed, and a wet central heating system was installed for two houses and five semi-detached bungalows[7]. The cost for the plumbing and electrical work (excluding fitting the heat pump) ranged from £5,676+VAT to £7,130+VAT at a time of higher costs after the COVID pandemic.

Energy Performance Certificates (EPCs) were produced after the installations using RdSAP 2012. Households W-01 and W-02 had an energy score of D58 with the old storage heater system. Installing infrared panel heaters and no solar PV decreased the energy score to E48. However, once the solar PV system and

[7] Rogers and Hamer (2023), Making heat cheaper, smarter and greener, p.47-49, https://www.nea.org.uk/wp-content/uploads/2023/06/CP1438-Boxergy-NDH-full-report-16-Jan-22.pdf (Accessed 13 Jan 2025)

smart hot water cylinder had been installed, the energy score increased to A94. Most of this uplift was due to the large solar PV system with three points coming from the smart hot water cylinder. Battery storage provided no uplift on the EPC in RdSAP 2012 but there will be benefit in RdSAP 10.2 once introduced.

The EPC for IC-01 with infrared heating panels and a standard hot water cylinder had an energy score of E47. This increased to A92 once the 5.81kW solar PV system and Mixergy cylinder were installed. The uplift from the Mixergy cylinder was seven points for this property. This larger uplift may primarily be due to the household being on a single-rate electricity tariff.

The Wondrwall properties had external wall insulation fitted prior to 2015. Both had a single resident. One was retired and over 80 years old and typically at home all day. The other was between 60 and 70 years old and was a full-time shift-worker.

Before the Wondrwall installations, there were storage heaters in the living room, bedroom and hall, with fan heaters in the kitchen and bathroom. Household W-01 typically used the living room and hall storage heaters from October to May but did not heat the bedroom. Household W-02 typically did not heat the home and only rarely used the living room storage heater in the coldest weather.

Following the Wondrwall installations, there were 2 x 450W infrared heating panels fitted to the ceiling in the living room and single 450W panels fitted in the bedroom, hall and kitchen. There was also a 300W towel rail fitted in the bathroom and another towel rail fitted in the airing cupboard for W-01.

For household W-01, the infrared heating panels were kept on timers rather than using the occupancy sensor and thermostat provided by the smart light switch. The hall panel was run continuously with the living room panels on a timer from early afternoon until mid-evening. The bedroom and kitchen panels were not used. The towel rail in the bathroom ran all the time while the rail in the airing cupboard was on a timer from 4am to 8am.

Some supplementary heating was used by the resident. An electric oil-filled radiator had been used over the winter in the living room. In September 2024 a plug-in electric radiator was fitted with a timer and thermostat and one of the infrared heating panels in the living room was disconnected. A smart hot water cylinder was fitted in the loft which replaced the old cylinder in the airing cupboard. Initially there were issues with the CT clamp in the wrong orientation causing the solar diverter not to heat the water at times of excess solar generation. There were also problems with the cylinder tripping out after the Legionella cycle. This was resolved after the immersion heater was replaced.

As before, household W-02 rarely heated the house. The infrared heating panels in the living room were used about three times in total over the winter with the other panels not used. The towel rail in the bathroom was used only three to four times. The old hot water cylinder was replaced by a smart hot water cylinder (manufactured by Mixergy). At the time of writing, the resident had an electric shower and did not use the bath. The resident decided not to use the smart hot water cylinder as it took too long for hot water to come through to the taps. Instead, a kettle was boiled for washing dishes.

Control property IC-01 was a two-bedroom semi-detached bungalow with two retired residents aged over 70 years. This household had also been control property C-01 in an earlier project[8]. The household did not like the storage heaters in the property and fitted their own infrared heating panels on the walls as an alternative. The six panels that were installed were manufactured by a variety of companies and ranged in power output from 350W to 700W. The main panels used were in the hall (650W) and the kitchen (350W), with the bedroom panel (400W) used in cold weather.

External wall insulation (EWI) was fitted under the social housing decarbonisation fund during the project. The old fibre cavity wall insulation (CWI) was extracted and replaced by thermal bead. This meant there was no CWI from about October 2022 to March 2023 while the cavity dried out. It took quite a few months to complete the EWI and this was finished in October 2023.

The 5.81kW solar PV system (same size as the Wondrwall installations) was commissioned on 27 Sept 2023. This used a Solis hybrid inverter which provided additional monitoring of the grid import and export. Unlike the Wondrwall systems, there was no battery. The cost of the solar PV system was £6,796. Upgrading to the hybrid inverter added £739 to the installation cost.

A 120-litre Mixergy smart hot water cylinder was fitted which was smaller than the 150-litre cylinders used with the Wondrwall installations. The cost to supply and install this was £2,656. The Mixergy cylinder was fitted in late February 2024. The CT clamp for the solar diverter was initially fitted in the wrong orientation and this was not resolved until late March. The total installation cost for the solar PV and the Mixergy smart hot water cylinder was £9,472.

[8] Rogers and Hamer (2023), Making heat cheaper, smarter and greener, p.124-131, https://www.nea.org.uk/wp-content/uploads/2023/06/CP1438-Boxergy-NDH-full-report-16-Jan-22.pdf (Accessed 13 Jan 2025)

## 2.3 Methods of monitoring

The temperature and humidity in the living room and bedroom of the properties were monitored by NEA using Lascar EasyLog EL-USB-2 temperature and humidity loggers[9]. Wondrwall was able to collect temperature and humidity data from the smart light switches but NEA and NDH were not provided with this data.

Households W-01 and IC-01 had smart meters fitted from before the start of the project. Household W-02 had a smart meter fitted in February 2024. Meter reading data was obtained from the electricity suppliers. Household IC-01 signed up to the Carbon Coop PowerShaper monitor portal[10] which allowed access to half-hourly smart meter data.

Household IC-01 had an electric vehicle which was charged two or three times a month from the household electricity supply. The household stopped using the vehicle part way through 2024. It was possible to identify days with abnormally high electricity consumption using the PowerShaper monitor portal and normalise to remove power consumed while charging the electric vehicle.

Wondrwall was able to monitor the solar PV generation, household consumption, grid import and export and battery charge via the monitoring for the battery storage system. NEA was provided with monthly values from this data for 2024.

Orsis S2-M SmartGen meters were fitted as generation meters for the Wondrwall installations in August 2024[11]. This was to allow independent monitoring of the solar PV systems via the Orsis Energize monitoring portal.

For the control household IC-01, data on solar PV generation and grid consumption was available via monitoring for the Solis hybrid inverter. Electricity consumed by the Mixergy cylinder and the amount of water heating powered by the solar diverter was obtained from the Mixergy installer monitoring portal. A Wibeee Box[12] electricity monitor was fitted in August 2024 which measured the household consumption, solar PV generation and consumption by the immersion heater of the Mixergy cylinder.

[9] Lascar Electronics, EasyLog EL-USB-2, https://lascarelectronics.com/data-loggers/temperature-humidity/el-usb-2/ (Accessed 13 Jan 2025)
[10] Carbon Co-op, PowerShaper Monitor, https://carbon.coop/portfolio/smart-meter-data-service/ (Accessed 13 Jan 2025)
[11] Orsis S2-M SmartGen single phase electricity meter, https://www.orsis.co.uk/products/smartgen/ (Accessed 13 Jan 2025)
[12] Wibeee Box: the most effective general circuit consumption meter on the market, Smilics Techologies, https://smilics.com/en/wibeee-products/wibeee-box/ (Accessed 13 Jan 2025)

# 3. Social analysis

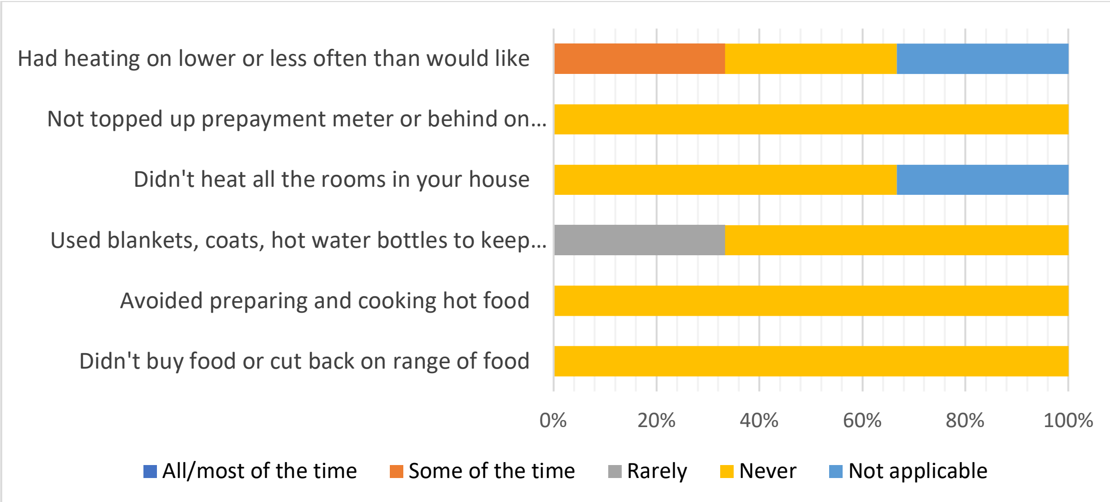


Figure 3.1 Behaviour indicators for fuel poverty

The Wondrwall and control households were asked how often they did a series of actions due to concern over cost, before and after the installations. For each household, the responses were the same for before and after the installations. Household W-01 had the heating on lower or less often due to concern over cost some of the time. The household was never behind on the electricity bill or behaved in the other ways due to cost.

Household W-02 rarely used blankets or coats and was never behind on the electricity bill or avoided preparing and cooking hot food or cut back on buying food due to the cost. The resident only occasionally used the heating in the coldest weather, but this was not due to concern over cost. As a result, the first and third questions were answered not applicable.

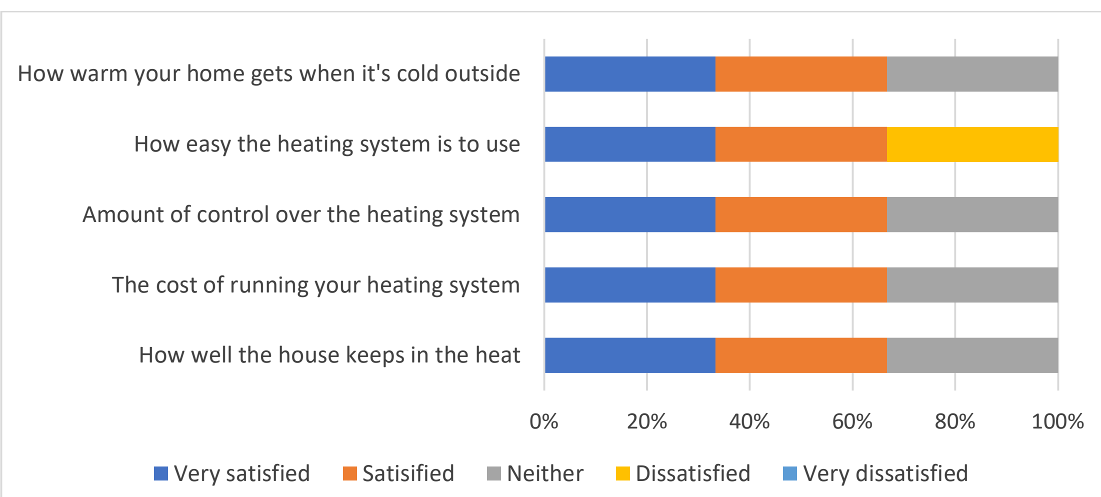


Figure 3.2 Satisfaction with the heating system

Household IC-01 answered never to all the questions in figure 3.1. When the households were asked if they could keep the whole house comfortably warm in winter when it was cold outside, all three households answered mostly yes rather than mostly no.

The households were asked a series of questions (figure 3.2) about their satisfaction with the heating system. The control household IC-01 with their own infrared heating panels responded very satisfied to all the questions.

Household W-01 was satisfied with how warm the home gets when cold outside, the amount of control over the heating system and the cost of running the heating system. The household was neither satisfied nor dissatisfied with how well the house kept in the heat and was dissatisfied with how easy the heating system was to use. Given that the resident was unable to use the Wondrwall control panel and relied on timers set by others for the heaters, this was an understandable response.

Household W-01 mentioned on many occasions that while the infrared panels on the ceiling heated the upper body, they left the lower part of the body cold. The resident at times used an electric footwarmer but was concerned over tripping with it. Only after an electric radiator with a thermostat was fitted in the living room was the resident happier about the level of thermal comfort provided, particularly with the lower body.

Household W-02 was satisfied with how easy the heating system was to use and with how well the house kept in the heat. The household was neither satisfied nor dissatisfied with how warm the home gets when cold outside, the amount of control over the heating and the cost of running the heating system. This was because the resident only used the heating panels three times over the winter.

Only household W-02 used the Wondrwall control tablet. The household agreed to understanding how to use the Wondrwall tablet, that it was easy to use, and it helped better control the heating. The household disagreed that it was helpful to look at the Wondrwall tablet and that they used the tablet to turn on and off the lights.

The Wondrwall and control households were asked whether they agreed or disagreed with a series of statements in figure 3.3. Household W-01 agreed that electricity costs had decreased since the solar PV system had been installed. They strongly agreed that the electricity cost was lower on a sunny day, and it was cheaper to heat the house on a sunny day. The household disagreed that the new heating system was better than the old heating system and that they felt warmer, and it benefited their physical and mental health.

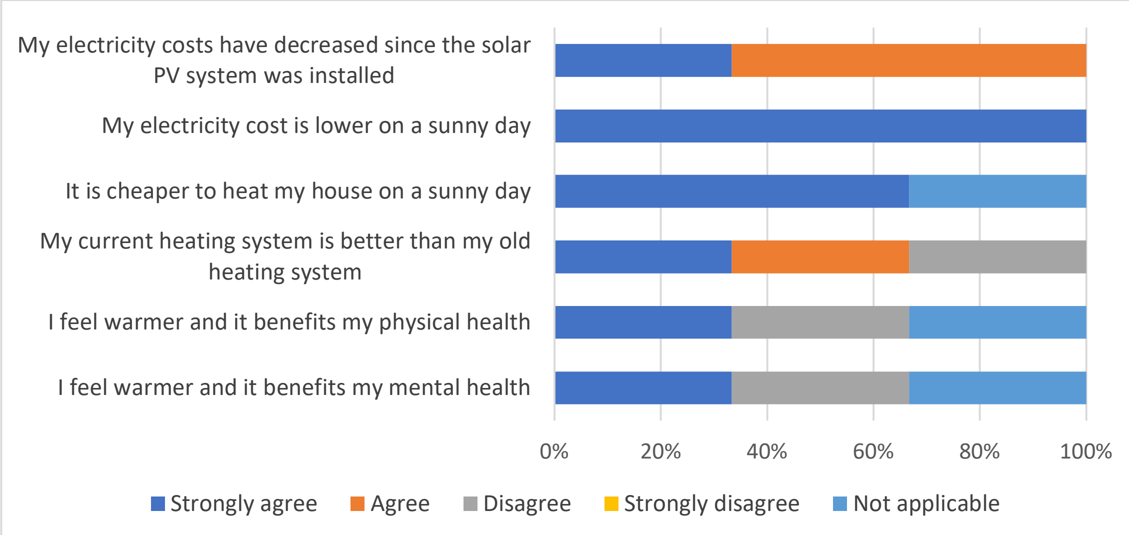


Figure 3.3 Assessing the benefits of the installations

Household W-02 strongly agreed that the electricity cost was lower on a sunny day. The resident agreed that electricity costs had decreased since the solar PV system had been installed and that the current heating system was better than the old heating system. The household answered not applicable that it was cheaper to heat the house on a sunny day and that they felt warmer, and it benefited their physical and mental health. This was because the resident rarely ever used the heating.

The control household strongly agreed with all the statements in figure 3.3 including those that they felt warmer, and it benefited their physical and mental health.

Household W-01 required heating throughout the winter in the living room. There was lower satisfaction with the infrared heating panels which left the resident cold in the lower half of the body. As a result, additional supplementary heating was used. Household W-02 rarely used the previous heating system with the storage heaters. Installation of the infrared heating panels with the Wondrwall system which could be used on demand did not encourage the resident to use the heating system more. The control household was very satisfied with the infrared heating panels they fitted. The panels seemed to provide a high level of thermal comfort. Fitting them on the walls rather than the ceiling may have helped.

# 4. Technical monitoring

## 4.1 Temperature and humidity

| 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 |
| W-01 Living Room | 18.08 | 22.50 | 12.50 | 2.48 | 18.11 | 22.00 | 13.00 |
| W-01 Bedroom | 15.58 | 19.00 | 11.50 | 1.53 | 15.59 | 18.50 | 12.00 |
| W-02 Living Room | 12.26 | 21.50 | 7.00 | 2.04 | 12.40 | 19.50 | 7.00 |
| W-02 Bedroom | 11.59 | 16.00 | 8.00 | 1.58 | 11.70 | 16.00 | 8.00 |
| IC-01 Living Room | 15.42 | 19.50 | 12.00 | 1.41 | 16.01 | 19.50 | 12.50 |
| IC-01 Bedroom | 17.65 | 21.00 | 15.00 | 1.10 | 17.73 | 21.00 | 15.50 |
| Maximum | 18.08 | 22.50 | 15.00 | 2.48 | 18.11 | 22.00 | 15.50 |
| Minimum | 11.59 | 16.00 | 7.00 | 1.10 | 11.70 | 16.00 | 7.00 |
| Average (Mean) | 15.10 | 19.92 | 11.00 | 1.69 | 15.26 | 19.42 | 11.33 |

Table 4.1 Temperature measured during the heating season before installations

The temperature and humidity were recorded at the monitored properties using Lascar EasyLog EL-USB-2 loggers[13] with readings taken every half hour. Loggers were fitted in both the living room and the bedroom. Table 4.1 shows average, maximum and minimum values of temperature recorded during the heating season prior to installations.

The average temperature in the living room for W-01 was 18.1°C between 1 Nov 2022 and 1 May 2023. The resident was away from mid-December to mid-February. It is likely there was some heating left on in the property during this period as the overnight consumption was still 13-20kWh/day. However, the average temperature in the living room during this period was 15°C and it was 14°C in the bedroom. Before going away, in November 2022, the average living room temperature was 19.3°C and it was 16.6°C in the bedroom.

Household W-02 rarely used heating. The average temperature in the living room over the pre-installation heating season was 12.3°C with a maximum value of 21.5°C and minimum of 7°C.

Data from a Tinytag View 2 logger and current clamp suggested the living room and hall storage heaters in W-02 were used for five days in December during the coldest weather which raised the temperature to the maximum value of 21.5°C. There were also four days in late January when one storage heater was used and one day in early March when it is likely two storage heaters were used. The average temperature in the bedroom was colder at 11.6°C as this was never

[13] Lascar EasyLog EL-USB-2, Lascar Electronics, https://lascarelectronics.com/data-loggers/temperature-humidity/el-usb-2/ (Accessed 13 Jan 2025)

heated. The resident was warned by an NEA staff member on more than one occasion about the health risks of living in a consistently cold home[14].

The average temperature in the living room of control property IC-01 during the pre-installation heating season was 15.4°C. Over that period, the temperature ranged from 12°C to 19.5°C. The living room was used less often than the bedroom which was heated more. The average bedroom temperature was 17.65°C and the temperature ranged from 15°C to 21°C. Cavity wall insulation (CWI) was absent for most of the heating season. This had been extracted, allowing the cavity to dry, before replacing it with thermal bead CWI and subsequently installing external wall insulation. The absence of the insulation was likely to have led to an increased electricity bill and reduced temperatures.

| 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 |
| W-01 Living Room | 18.19 | 23.50 | 12.00 | 1.79 | 19.68 | 23.50 | 14.00 |
| W-01 Bedroom | 16.95 | 22.50 | 12.50 | 2.11 | 17.04 | 22.00 | 13.00 |
| W-02 Living Room | 12.10 | 17.00 | 5.00 | 1.66 | 12.33 | 16.00 | 7.00 |
| W-02 Bedroom | 12.03 | 15.00 | 7.50 | 1.43 | 12.12 | 15.00 | 8.00 |
| IC-01 Living Room | 18.03 | 21.00 | 15.00 | 1.10 | 18.32 | 20.50 | 16.00 |
| IC-01 Bedroom | 19.07 | 21.50 | 16.00 | 0.93 | 19.20 | 21.00 | 16.00 |
| Maximum | 19.07 | 23.50 | 16.00 | 2.11 | 19.68 | 23.50 | 16.00 |
| Minimum | 12.03 | 15.00 | 5.00 | 0.93 | 12.12 | 15.00 | 7.00 |
| Average (Mean) | 16.06 | 20.08 | 11.33 | 1.50 | 16.45 | 19.67 | 12.33 |

Table 4.2 Temperature measured during the heating season after installations

Table 4.2 shows temperatures for the Wondrwall and control properties for the heating season after the installations. The average living room temperature for W-01 was 18.19°C, which was barely higher than the value the previous year despite the resident being away part of the time and turning down the heating. However, the average temperature during the 5pm to 9pm period was higher at 19.68°C. The infrared panels in the living room were controlled by time switches, coming on in the early afternoon and turning off mid-evening. This led to the warmer temperature between 5pm and 9pm. The bedroom infrared heating panel was not used, and any warmth was provided by the panel in the hallway. The average bedroom temperature was 17°C.

There were teething troubles with this installation due to connectivity issues and the resident being unable to use the control. This led to colder room temperatures in late November and early December before the time switches were fitted.

[14] Balogun et al (2023), Health inequalities: Cold or damp homes, House of Commons Library, https://researchbriefings.files.parliament.uk/documents/CBP-9696/CBP-9696.pdf (Accessed 19 Dec 2024)

For household W-02, despite installation of a heating system which could be more easily used on demand, there was no improvement in room temperatures. The average temperature in the living room and bedroom was 12°C and the resident made little use of the heating. The living room temperature fell as low as 5°C in the middle of January 2024.

For the heating season from 1 Nov 2023 to 1 May 2024, the cavity wall insulation for household IC-01 had been replaced by thermal bead and external wall insulation had been installed. The average temperature in the bedroom, where one of the residents spent most of the time had increased from 17.65°C to 19.1°C. The less frequently used living room also saw an average temperature increase from 15.4°C to 18.0°C. The improved wall insulation led to warmer room temperatures in 2023-24.

Manufacturers note that infrared heating panels warm the walls, floor and ceiling rather than the air[15]. This may lead the room to feel warmer at lower air temperatures. IC-01 normally felt cosy and warm with the infrared heating panels.

| 01 November 2022 To 01 December 2022 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Tech Ref | Average Humidity (%RH) 24 hours | Maximum Humidity (%RH) 24 hours | Minimum Humidity (%RH) 24 hours | Std Dev Humidity (%RH) 24 hours | Average Humidity (%RH) 5pm to 9pm | Maximum Humidity (%RH) 5pm to 9pm | Minimum Humidity (%RH) 5pm to 9pm |
| W-01 Living Room | 71.77 | 81.50 | 63.00 | 2.27 | 72.27 | 81.50 | 64.00 |
| W-01 Bedroom | 75.66 | 87.50 | 65.00 | 2.04 | 75.78 | 87.50 | 71.50 |
| W-02 Living Room | 79.60 | 92.50 | 66.50 | 4.09 | 80.00 | 92.50 | 68.50 |
| W-02 Bedroom | 78.51 | 83.50 | 71.00 | 2.21 | 78.21 | 83.00 | 72.00 |
| IC-01 Living Room | 79.34 | 85.00 | 72.00 | 2.54 | 79.17 | 85.00 | 72.50 |
| IC-01 Bedroom | 72.62 | 79.50 | 64.50 | 3.06 | 72.60 | 79.50 | 67.00 |
| Maximum | 79.60 | 92.50 | 72.00 | 4.09 | 80.00 | 92.50 | 72.50 |
| Minimum | 71.77 | 79.50 | 63.00 | 2.04 | 72.27 | 79.50 | 64.00 |
| Average (Mean) | 76.25 | 84.92 | 67.00 | 2.70 | 76.34 | 84.83 | 69.25 |

Table 4.3 Relative humidity measured during the heating season before installations

Table 4.3 shows the relative humidity in the living room and bedroom of the three properties during the pre-installation heating season. Adverse health effects are minimised by maintaining the relative humidity in rooms between 40 and 60%[16].

It is apparent that the minimum humidity for all three homes was 63% or above and greater than the optimum range for relative humidity. The average relative

[15] How do infrared panels work, Herschel infrared panels, https://www.herschel-infrared.co.uk/how-do-infrared-heaters-work/ (Accessed 19 Dec 2024)
[16] Arundel et all (1986), Indoor health effects of relative humidity in indoor environments, Environmental Health Perspectives, Vol 65, pp. 351-361, https://pmc.ncbi.nlm.nih.gov/articles/instance/1474709/pdf/envhper00436-0331.pdf (Accessed 19 Dec 2024)

humidity was between 71.8% and 79.6% and was higher in rooms where the average temperature was lower. The maximum relative humidity for the living room of W-02 was 92.5%. Such high values of relative humidity make rooms prone to damp and mould.

| 01 November 2023 To 01 May 2024 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Tech Ref | Average Humidity (%RH) 24 hours | Maximum Humidity (%RH) 24 hours | Minimum Humidity (%RH) 24 hours | Std Dev Humidity (%RH) 24 hours | Average Humidity (%RH) 5pm to 9pm | Maximum Humidity (%RH) 5pm to 9pm | Minimum Humidity (%RH) 5pm to 9pm |
| W-01 Living Room | 65.70 | 88.00 | 41.50 | 5.54 | 65.03 | 88.00 | 48.00 |
| W-01 Bedroom | 70.91 | 88.00 | 40.00 | 7.48 | 70.83 | 83.00 | 48.50 |
| W-02 Living Room | 78.31 | 95.00 | 55.50 | 7.10 | 79.15 | 93.50 | 60.50 |
| W-02 Bedroom | 81.25 | 89.00 | 65.50 | 4.04 | 80.96 | 89.00 | 65.50 |
| IC-01 Living Room | 74.25 | 84.00 | 53.00 | 4.01 | 74.07 | 84.00 | 53.00 |
| IC-01 Bedroom | 69.37 | 79.50 | 54.00 | 3.73 | 69.21 | 79.00 | 54.00 |
| Maximum | 81.25 | 95.00 | 65.50 | 7.48 | 80.96 | 93.50 | 65.50 |
| Minimum | 65.70 | 79.50 | 40.00 | 3.73 | 65.03 | 79.00 | 48.00 |
| Average (Mean) | 73.29 | 87.25 | 51.58 | 5.31 | 73.21 | 86.08 | 54.92 |

Table 4.4 Relative humidity measured during the heating season after installations

Values of relative humidity during the heating season after installations are shown in table 4.4. The average relative humidity in the living room for household W-01 decreased from 71.8% to 65.7% the following year. In the bedroom there was a reduction in average relative humidity from 75.7% to 70.9%. These reductions are likely to be due to more consistent heating of the rooms over the 2023-24 heating season.

The relative humidity in W-02 after the installations was again high as the average room temperatures were only about 12°C. The average relative humidity in the living room was 78.3% and the relative humidity reached a maximum of 95% during the post-installation heating season.

With improved insulation and higher room temperatures in IC-01, there were falls in relative humidity. The living room humidity fell from 79.3% to 74.25% while the relative humidity in the warmer bedroom fell from 72.6% to 69.4%.

There was little change in the maximum humidity for IC-01 between the pre- and post-installation heating seasons. However, there was a significant drop in the minimum humidity. For the living room, this fell from 72% to 53% and in the bedroom, it fell from 64.5% to 54%.

A large reduction in minimum humidity was also apparent for W-01 with the value for the living room decreasing from 63% to 41.5% and for the bedroom from 65 to 40%. There were reductions in relative humidity for all properties in the second half of April 2024 suggesting this effect may be weather-related.

## 4.2 Solar generation and electricity consumption

| | W-01 | W-02 | IC-01 |
|---|---|---|---|
| Household consumption (kWh) | 6,460 | 999 | 7,097 |
| PV generation (kWh) | 5,531 | 5,224 | 5,116 |
| Grid import (kWh) | 4,466 | 96 | 5,144 |
| Grid export (kWh) | 3,540 | 4,285 | 3,168 |
| Battery charge (kWh) | 2,480 | 674 | 0 |
| Smart meter grid import (kWh) | 4,686 | | 5,136 |

Table 4.5 Summary of consumption and generation data for the Wondrwall households and control property in 2024

The solar PV systems were operational during the whole of 2024 and table 4.5 summarises data collected from the hybrid inverters. Also shown is the grid import from smart meter data.

The solar PV installations of the two Wondrwall systems generated 5,531 kWh and 5,224 kWh in 2024. This compares to the estimated annual generation of 6,321 kWh on the MCS certificate. The annual PV generation for IC-01 was also lower than expected with 5,116 kWh compared to 6,223 kWh on the MCS certificate. There was less sunshine in 2024 compared to usual with 1,333 hours of sunshine in England SW and South Wales compared to 1,542 hours for the same region over a 20-year average between 2000 and 2019[17].

The household consumption measured by the hybrid inverters was 6,460kWh for W-01, 999kWh for W-02 and 7,097kWh for control property IC-01. Wondrwall used the following formula for a more accurate estimate of the grid import:

Import = Household consumption – (PV generation – grid export)

The grid import estimated using this method for W-01 was 4,466kWh and for W-02 was just 96kWh. The grid import recorded with the Solis hybrid inverter for IC-01 was 5,144kWh. Daily smart meter data was available for W-01 and IC-01. The smart meter grid import in 2024 for W-01 was 4,686kWh, 220kWh higher than estimated from the Wondrwall/Growatt hybrid inverter data. For IC-01, the grid consumption recorded by the smart meter was 5,136kWh which was 8kWh lower than measured by the Solis hybrid inverter. Household IC-01 had an electric vehicle until part way through 2024. It was estimated that the grid consumption in 2024 excluding the EV charging was about 5,053kWh.

Household W-02 was an unusually low electricity user, and this lowered the accuracy of the estimated the grid import. Data from the hybrid inverter suggested the grid import over the year was 96kWh. Meter readings between 10

[17] 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)

Jan 2024 and 31 Dec 2024 recorded a grid consumption of 346kWh. The resident rarely used the heating, did not use the smart hot water cylinder and used few electrical appliances.

Comparing the PV generation with the grid import, Wondrwall households W-01 and W-02 generated more electricity from the solar panels than was imported from the grid. Household IC-01 imported only slightly more electricity than was generated by the solar panels. Overall, these installations had or were close to net zero electricity consumption over the year.

Using the PV generation and grid export figures from the hybrid inverters, the amount of solar generation consumed in the home can be calculated. For W-01, 1,971kWh of solar generation was consumed with 35.6% self-consumption. The low electricity demand at W-02 meant that only 939kWh of the solar generation was consumed in the home, with a percentage self-consumption of just 18%.

The consumed solar generation for IC-01 in 2024 was 1,947kWh, which was only slightly lower than for W-01. The percentage self-consumption of the solar generation was slightly higher at 38%. Although IC-01 did not have a battery, there was a Mixergy smart hot water cylinder with a solar diverter which consumed some of the PV generation.

The battery charge in 2024 was 2,480kWh for W-01 and 674kWh for W-02. Both these households were on an Economy 7 tariff. Much of the battery charge for W-01 was from grid charging overnight on the off-peak tariff to minimise consumption during the peak-rate period. During the heating season, the monthly battery charge was between 204 and 323kWh. During the spring/summer when there was more solar generation, the monthly battery charge for W-01 was between 124 and 174kWh.

For W-02, the battery charge was between 60 and 69kWh per month during the heating season (with some overnight charging). From May to August 2024, the battery charge was between 38 and 50kWh per month. Part of the reason for the low battery charge for W-02 was the low household consumption which meant the battery was regularly close to fully charged.

## 4.3 Case study – Wondrwall household W-01

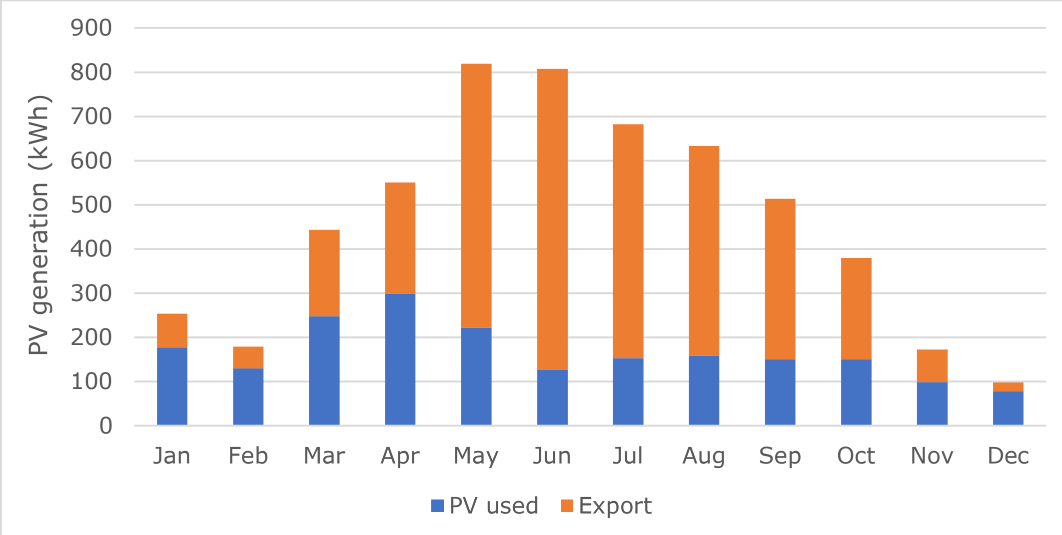


Figure 4.6 Graph of PV generation for household W-01 for 2024 based on data from the Wondrwall hybrid inverter

As mentioned earlier, the annual generation in 2024 for W-01 was 5,531kWh for the 5.81kW solar PV system. Figure 4.6 plots the monthly PV generation and shows how much of this was used in the home and how much was exported to the grid. The monthly PV generation used in the home ranged from 78kWh in December 2024 to 299kWh in April 2024. The monthly percentage self-consumption of the solar generation was only 15.7% in June 2024 but as high as 69.7% in January 2024 and 79.6% in December 2024.

The large 5.81kW solar PV system led to high levels of electricity exported to the grid in summer. However, during the heating season, much of the electricity generated by the solar panels was consumed by the Wondrwall household. The greatest savings were made in March and April 2024, colder months where there is typically higher solar PV generation.

A plot of the monthly off-peak electricity consumption of household W-01 is shown in figure 4.7. The resident was away from mid-December 2022 until mid-February 2023, which meant the off-peak consumption was lower than normal. It should be noted that some heating was still running while the resident was away, with the monthly off-peak consumption 500-600kWh.

The Wondrwall system was fitted in October 2023 and there was a drop in the off-peak consumption from October 2023 to May 2024. Previously there was normally overnight charging of storage heaters in the living room and hallway as well as the hot water cylinder.

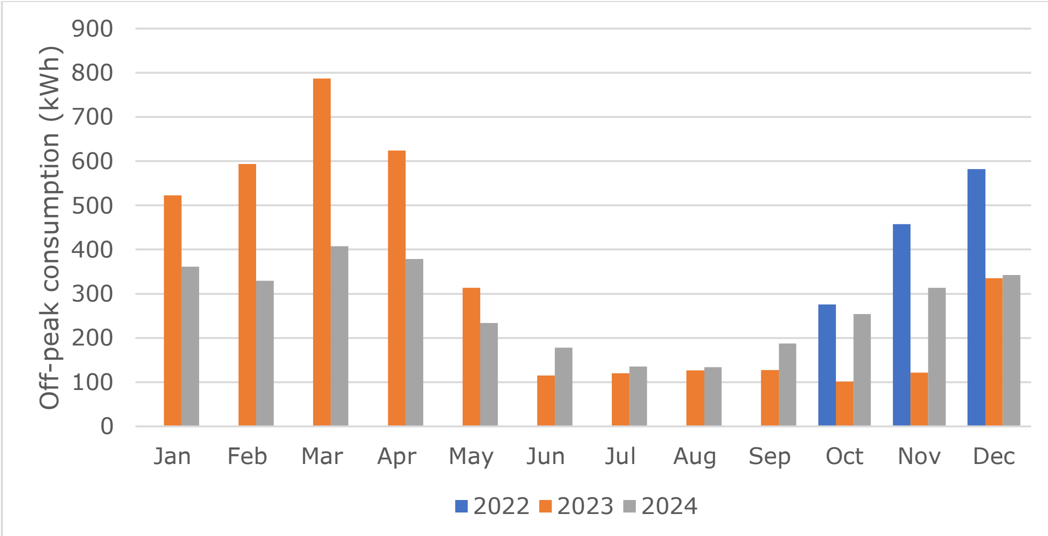


Figure 4.7 Graph of monthly off-peak electricity consumption for household W-01 from smart meter data covering the period 1 Oct 2022 to 31 Dec 2024

After the Wondrwall system was fitted in October 2023, the 450W infrared panel in the hallway was normally used all the time during the heating season. The 300W towel rail in the bathroom was also on all the time, with the towel rail in the airing cupboard running from 4am to 8am. These heaters were likely to use about 6.15kWh of off-peak electricity overnight.

In addition to this, there was the smart hot water cylinder. This typically used 2-4kWh overnight from January to May 2024. The solar diverter was fully operational from early July 2024. With water heating from the excess solar generation, this will have reduced the overnight water heating, particularly in sunnier months. There was also overnight charging of the battery on the off-peak tariff. It is likely there was a full 6kWh overnight charge during winter months of January and February 2024, to help power the infrared heaters during the peak-rate period.

Figure 4.8 shows the peak-rate electricity consumption for household W-01. When the property had storage heaters, the monthly peak-rate consumption was typically 55 to 65kWh. It was slightly lower in January and February 2023 when the resident was away. There was a significant increase in peak-rate consumption from October 2023 to April 2024 after the Wondrwall system was fitted. The particularly high rates in October and November 2023 are likely to be due to teething issues with the Wondrwall system and extra use of supplementary heating. The automated relays for the infrared heating panels were taken out in December 2023 and replaced with timer switches. Subsequently, the resident was still often using supplementary heating in the form of an oil-filled electric radiator.

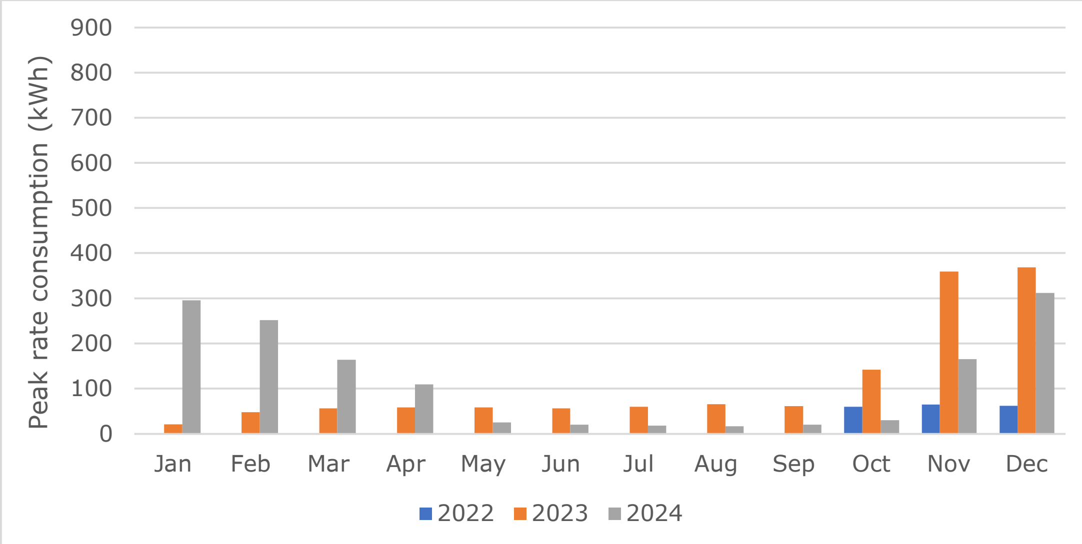


Figure 4.8 Graph of monthly peak-rate electricity consumption for household W-01 from smart meter data covering the period 1 Oct 2022 to 31 Dec 2024

From May to October 2024, the peak-rate consumption was lower than with the storage heaters due to the solar PV generation, discharge of the battery and more limited heating. The consumption in November 2024 was 46% of the value the previous year when there were teething problems with the Wondrwall system. However, the peak-rate consumption was still more than double that in November 2022. The peak-rate consumption was 312kWh in December 2024 compared to 369kWh the year before. This was despite it being a colder month in December 2024 compared to the year before.

A graph plotting the monthly electricity cost for household W-01 is shown in figure 4.9. The household remained on Economy 7 and the data assumes a peak-rate tariff of 30p/kWh and off-peak tariff of 12.5p/kWh.

The costs in December 2022, January 2023 and February 2023 were lower than would normally be expected due to the resident being away from mid-December 2022 to mid-February 2023. Had the resident not been away, the monthly electricity cost was likely to be closer to those in 2024 with the Wondrwall system. Between March 2024 and October 2024, the monthly cost was lower than the same months in earlier years with the storage heaters. The cost was slightly higher in November 2024 compared to November 2022.

Over 2024, the electricity cost on Economy 7 was £835.70 for household W-01. This compares to £782.69 for the period 1 Oct 2022 to 30 Sep 2023 with the storage heaters. However, this includes the period the resident was away from mid-December 2022 to mid-February 2023. With normal occupancy, it is likely there would have been little difference in the electricity costs.

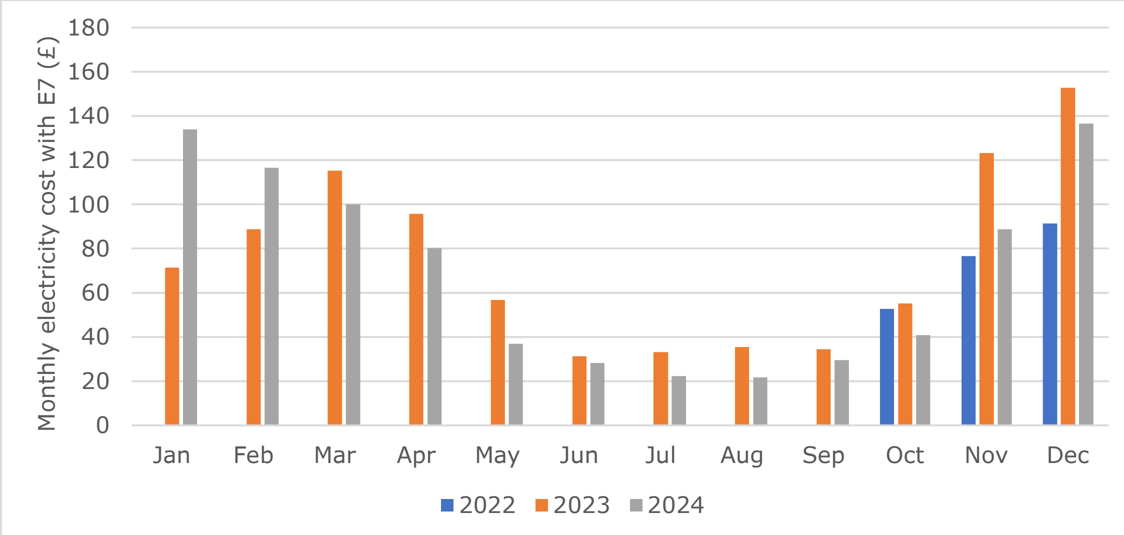


Figure 4.9 Graph of monthly electricity cost for household W-01 assuming a peak rate of 30p/kWh and off-peak rate of 12.5p/kWh

An assessment of the electricity cost was also made assuming household W-01 was on a single-rate tariff. In this case the typical unit rate at the time of writing was 24p/kWh. This meant the electricity cost in 2024 would have been £1,124.70. For the period of 1 Oct 2022 to 30 Sep 2023 before the Wondrwall systems was fitted, the cost would have been £1,276.69. Both periods were higher than on the Economy 7 tariff. The pre-installation period had a higher electricity cost despite the resident being away from mid-December 2022 to mid-February 2023.

## 4.4 Case study – Wondrwall household W-02

| Start date | End date | No. of days | Peak rate (kWh) | Off-peak (kWh) | Total consumption (kWh) | Electricity cost (£) |
|---|---|---|---|---|---|---|
| 15 Apr 21 | 21 Apr 22 | 371 | 914 | 523 | 1,437 | £339.58 |
| 14 Oct 22 | 19 Oct 23 | 370 | 905 | 452 | 1,357 | £328.00 |
| 10 Jan 24 | 31 Dec 24 | 356 | 176.7 | 169.5 | 346.2 | £74.20 |

Table 4.10 Electricity consumption and cost on Economy 7 for household W-02 over approximately 12-month analysis periods

Table 4.10 shows the peak and off-peak rate electricity consumption for household W-02 for two approximately 12-month periods before the Wondrwall installation and a period after the system was fitted. The electricity cost was calculated using the same unit rates as for W-01 of 30p/kWh peak rate and 12.5p/kWh off-peak rate.

During the two pre-installation periods, household W-02 used 1,437 and 1,357kWh over periods of 371 and 370 days respectively. 63.6% of the consumption was at the peak rate during the first analysis period and 66.7% was at the peak rate for the second analysis period. The household rarely used the storage heaters or the hot water cylinder which were the main consumers of off-peak electricity. The electricity cost for the two pre-installation periods was £339.58 and £328 respectively.

The duration of the post-installation analysis period was slightly shorter at 356 days. However, there was a significant reduction in total electricity consumption, from over 1,300kWh to only 346.2kWh. The electricity cost over the period from 10 Jan 2024 to 31 Dec 2024 was £74.20. This was not the total electricity bill as there was also a standing charge of about 69p/day. This made an annual standing charge of £251.85, considerably higher than the cost of the electricity consumed by W-02.

## 4.5 Case study – Control household IC-01

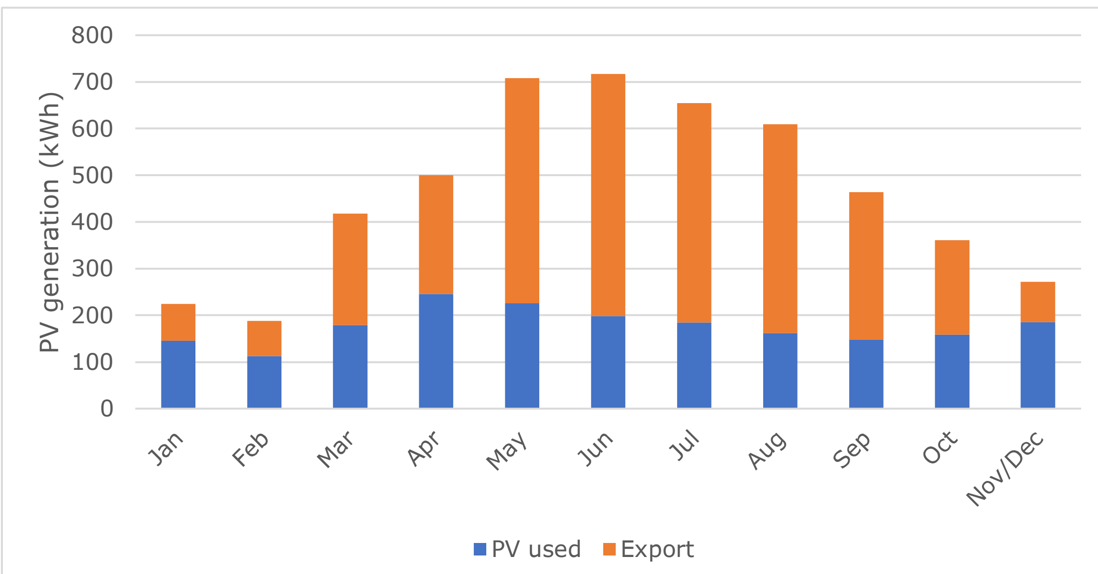


Figure 4.11 Graph of PV generation for control household IC-01 for 2024 based on data from the Solis hybrid inverter

Figure 4.11 shows a graph of solar PV generation for household IC-01 in 2024. Note that data for November and December is combined as the inverter was offline on 1 Dec 2024 and no meter readings could be collected. This graph can be compared to figure 4.6 for household W-01.

Over 2024, the PV generation was 5,116kWh compared to 5,531kWh for household W-01. The PV generation consumed was broadly similar between households IC-01 and W-01 despite W-01 having battery storage as well as a smart hot water cylinder. Between May and August 2024, the monthly PV generation consumed for IC-01 was between 162.5kWh and 225.8kWh compared to between 127kWh and 222kWh for W-01. Household W-01 consumed greater PV generation between January and April 2024.

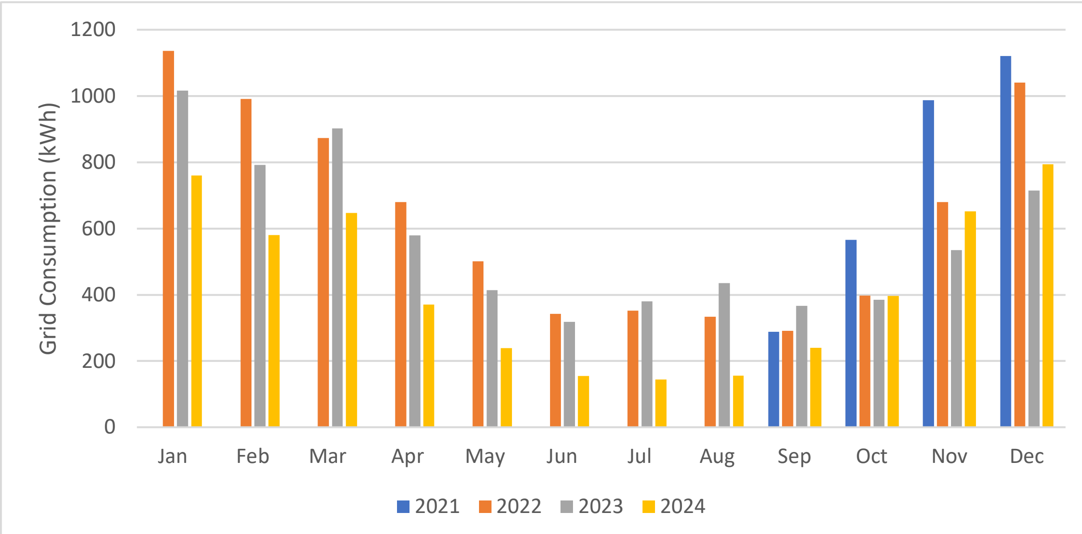


Figure 4.12 Graph of monthly electricity consumption for control household IC-01 from smart meter data covering the period 1 Sep 2021 to 31 Dec 2024

A plot of the monthly electricity consumption for household IC-01 is shown in figure 4.12. The solar PV system was commissioned on 27 Sep 2023. The Mixergy smart hot water cylinder was initially commissioned on 23 Feb 2024. However, initially the current transformer for the solar diverter was fitted in the wrong orientation. This meant the diverter was initially powering the immersion heater at times when there was not excess solar generation and could include periods overnight. This issue was resolved on 23 Mar 2024, leading to greater consumption of the solar generation by the Mixergy smart hot water cylinder.

There was a significant reduction in grid consumption compared to earlier years from December 2023 to August 2024. There were changes to the insulation of the property over the analysis period in figure 4.12. The cavity wall insulation was extracted and the cavity allowed to dry out between about October 2022 and March 2023. Over the following months, external wall insulation (EWI) was installed, and this was completed in October 2023.

The EWI is likely to have led to warmer room temperatures and some of the reduction in grid consumption in early 2024. However, 145.5kWh of solar generation was used in the home in January 2024, 113kWh in February, 179kWh in March and 246kWh in April 2024.

Household IC-01 switched from Economy 7 to a single-rate tariff after they stopped using their storage heaters and installed infrared heating panels. Using a single-rate tariff of 24p/kWh, the electricity cost in 2022 was £1,829 and this decreased to £1,641 in 2023. In 2024 with a full year of the solar panels running and 9 months with the Mixergy cylinder, the electricity cost had fallen to £1,233.

The electricity costs were also modelled for Economy 7 using half-hourly smart meter data. The costs in 2022 and 2023 would have been about £300 higher on Economy 7 due to the low percentage off-peak consumption (12.1% and 9.4%).

In 2024, the percentage off-peak consumption increased to 26.6% due to less grid import during the day because of the solar generation along with overnight charging of the Mixergy hot water cylinder. In 2024, the electricity cost would have been about £70 lower with the single-rate tariff compared to Economy 7.

| Year | Total consumption (kWh) | % off-peak | Electricity cost (£) Single rate | Electricity cost (£) Economy 7 |
|---|---|---|---|---|
| 2022 | 7,620 | 12.1 | £1,829 | £2,125 |
| 2023 | 6,839 | 9.4 | £1,641 | £1,939 |
| 2024 | 5,136 | 26.6 | £1,233 | £1,302 |

Table 4.13 Annual electricity consumption for control household IC-01 with electricity costs for single rate (24p/kWh) and Economy 7 tariffs (30p/kWh peak, 12.5p/kWh off-peak)

For comparison, Wondrwall household W-01 consumed 4,686kWh in 2024, with 69.5% of the consumption at the off-peak rate for Economy 7. The high percentage off-peak consumption was due to overnight charging of the battery and smart hot water cylinder along with use of an infrared panel and towel rail overnight. This consumption profile meant the electricity cost on Economy 7 was only £835.70. Had the resident been on a single-rate tariff, the cost would have been £1,124.70, closer to the £1,233 for household IC-01.

## 4.6 Other import and export tariffs

Households W-01 and W-02 originally had storage heaters, and these charged overnight on an Economy 7 off-peak tariff. It normally takes seven hours to charge a storage heater to a sufficient level to heat a home on the coldest of days.

With the Wondrwall heating system, charging the battery and hot water cylinder may only take about two hours and so seven hours of off-peak electricity is not necessarily needed overnight. This opens opportunities for alternative smart time-of-use tariffs. Figure 4.14 plots the electricity cost over the day for three Octopus time-of-use tariffs.

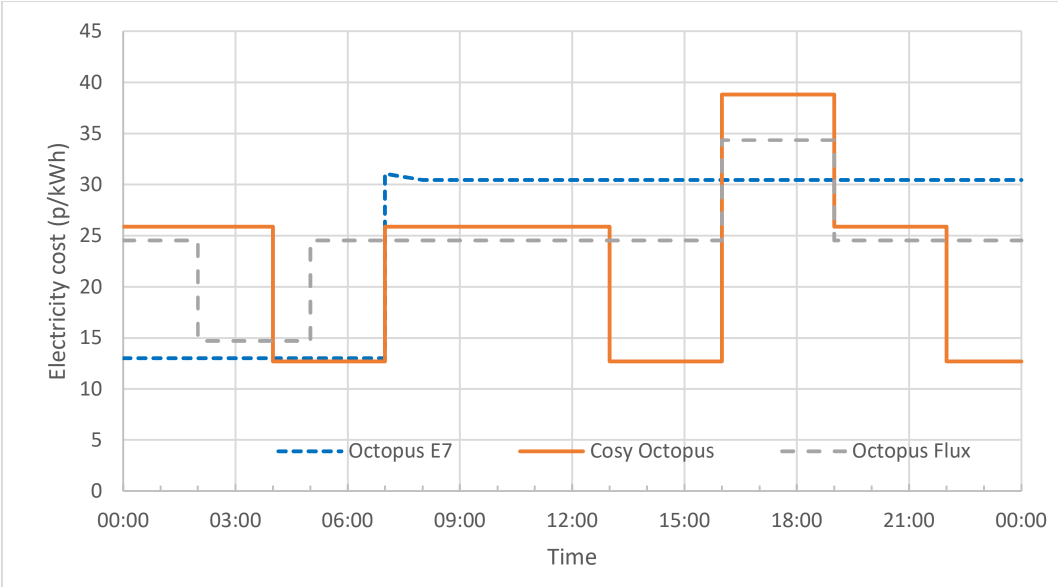


Figure 4.14 Electricity cost over the day for three Octopus time-of-use tariffs for the period from 1 Jan 2025 to 31 Mar 2025

The Octopus Flux tariff was designed for battery storage and has an off-peak period from 02:00 to 05:00 and a peak-rate period from 16:00 to 19:00. At other times of day, it is close to the single-rate tariff.

The off-peak period for Octopus Flux would allow sufficient time for the battery and smart hot water cylinder to charge overnight. For much of the day, the tariff rate would be cheaper than for peak rate for Economy 7. The charge of the battery could be maintained to allow sufficient charge to get through the peak-rate period from 16:00 to 19:00.

There are other smart time-of-use tariffs offered by energy suppliers. Many of these are tied to households having electric vehicles or heat pumps. Cosy Octopus is a heat pump tariff which would be well suited to operate with Wondrwall. There are off-peak periods from 04:00 to 07:00, 13:00 to 16:00 and 22:00 to 00:00. There is also an expensive peak-rate period from 16:00 to 19:00 while at other times, the unit rate is similar to a single-rate tariff.

The battery and hot water cylinder could charge on the early morning off-peak rate on Cosy Octopus. There is potential for the battery to recharge in the afternoon and be fully charged in advance of the peak-rate period from 16:00 to 19:00. The infrared heating panels could also be powered at the off-peak rate in the early afternoon. This would increase the percentage of off-peak consumption for the household and lower bills.

EDF at the time of writing has a heat pump tariff with similarities to Cosy Octopus. This has off-peak periods from 04:00 to 07:00 and 13:00 to 16:00 with the unit cost similar to the single-rate tariff at other times.

It is important that energy suppliers are flexible over eligibility for tariffs and allow households with technologies like Wondrwall to benefit from advanced time-of-use tariffs such as those offered for customers with heat pumps. Some households with Wondrwall installations have been able to switch to Cosy Octopus.

The smart export guarantee (SEG) is an export tariff where the system owner or resident is paid for electricity exported to the grid. These tariffs can typically pay between 5p/kWh and 15p/kWh at the time of writing.

The SEG can improve the savings and payback for owner-occupiers in particular. Export payments during the sunnier months when there are higher levels of export to the grid can compensate for the higher electricity costs in winter due to greater electric heating.

For rented properties there are issues over whether the landlord or the tenant should claim the export tariff. In this project it was decided that North Devon Homes would claim the SEG export tariff. The SEG can be complicated to claim from energy suppliers and the administration of the account after changes in tenancy would be complex and time-consuming.

There was also the issue around equity among tenants. Households with solar PV with payments from the feed-in tariff (FiT) only receive free electricity and none of the FiT payments. This has often been an issue of confusion between tenants and landlords. Having some tenants claiming the SEG export tariff may only make this worse. The SEG payments could also help the landlord fund further solar PV installations in the future.

North Devon Homes has fixed costs associated with the Wondrwall systems. There is the cost of the SIM card for the wireless router which communicates with the Wondrwall network. Wondrwall recommends using a SMARTY 15GB data-only plan with a current cost of £9 per month or £108 per year. The system can occasionally exceed 2GB of data use when updates are carried out. A 2GB data plan was not considered suitable as there would be occasional extra data charges.

The installations also had a smart generation meter fitted and the annual cost for the Orsis SIM card and portal is £22.80+VAT per year. The SEG payments could also contribute towards the maintenance costs for the system.

The PV export for household W-01 was about 3,540kWh in 2024. North Devon Homes were offered a rate of 8p/kWh for the SEG export tariff. This would equate to a payment of £283.20 for household W-01 in 2024.

## 5. Conclusions

**The project successfully installed Wondrwall smart heating systems in two homes and compared performance with a control household**

- Electric storage heaters were removed and Wondrwall smart heating systems were installed in two semi-detached bungalows each with one bedroom and external wall insulation
- The Wondrwall systems included a 5.81kW solar PV system, a 6kWh battery, a smart hot water cylinder and infrared heating panels
- The performance was compared against a control property where the residents fitted their own infrared heating panels on the walls
- Control property IC-01 also had a 5.81kW solar PV system installed along with a smart hot water cylinder and external wall insulation
- Energy Performance Certificates were produced in RdSAP 2012; replacing storage heaters with infrared panel heaters led to a reduction in the energy score of about 10 points, but the addition of the large solar PV system and smart hot water cylinder meant the energy score for the EPC subsequently rose from E48 to A94
- Similar behaviour was seen for the control property where addition of the solar PV system and Mixergy cylinder caused the energy score of the EPC to increase from E47 to A92

**The households with the Wondrwall installations did not use the systems as intended with some features were not utilised**

- Household W-01 had an older resident who was unable to use the Wondrwall tablet to control the heating system
- The automated controls for the infrared heating panels had to be replaced with timer switches for household W-01
- Household W-02 rarely used the heating before or after the Wondrwall installation; with W-01 also controlling the infrared heating panels on timer switches it was not possible to test the automated control of the heating based around resident occupancy
- Household W-02 decided not to use the smart hot water cylinder as it was felt the water consumption was too high before hot water came through the tap; the resident preferred to boil a kettle to wash dishes

**There was positive and negative feedback from the residents over different aspects of the Wondrwall system**

- Having multiple contractors installing the Wondrwall systems made the installation process more complex for the households and the landlord
- Household W-01 who regularly used the heating was satisfied with how warm the home got when it was cold outside, the amount of control of the heating system and the cost of running the heating system but was dissatisfied with the ease of use

- The resident also noted that the infrared panels on the ceiling warmed the upper half of the body and left the lower half cold; this issue was resolved after a thermostatically controlled electric radiator was fitted in the living room
- Household W-02 was satisfied with the ease of use of the heating system but was neither satisfied nor dissatisfied with how warm the home got, the amount of control of the heating and the cost of running the heating as the heating system was rarely used
- The control household IC-01 was very satisfied with how warm the home got when cold outside, the ease of use, the amount of control of the heating system and the cost of running the heating system
- Wondrwall households W-01 and W-02 both agreed, and IC-01 strongly agreed that electricity costs had decreased since the solar PV system had been installed
- All three households strongly agreed that their electricity cost was lower on a sunny day and W-01 and IC-01 both strongly agreed it was cheaper to heat their home on a sunny day
- When asked if the new heating system was better than the old heating system, IC-01 who fitted their own infrared panels strongly agreed, W-02 agreed and W-01 disagreed

**The temperature and humidity in the living room and bedroom was measured before and after the installations**

- For household W-01 over the heating season before Wondrwall was installed, the average living room temperature was 18.1°C, but this included the period from mid-December 2022 to mid-February 2023 when the resident was away and the level of heating in the home reduced; in November 2022, the average living room temperature was 19.3°C
- For the heating season after Wondrwall was installed, the average temperature in the living room for W-01 was 18.2°C but over the 5pm-9pm period, the average was 19.7°C due to the infrared heating panels running on a timer in the afternoon and evening
- Household W-02 rarely used the heating before or after the Wondrwall installation; in the heating season before installation, the average living room temperature was 12.3°C while over the heating season after the installation it was 12.1°C
- The resident in household W-02 was warned by NEA staff of the risks of prolonged exposure to low room temperatures
- Control household IC-01 used the bedroom more than the living room; in the heating season before the solar PV system and external wall insulation (EWI) was installed, the average living room temperature was 15.4°C and the average bedroom temperature was 17.65°C
- For the heating season after installation of the solar PV and EWI, the average bedroom temperature for IC-01 was 19.1°C and the average living room temperature was 18.0°C.

- The warmer room temperatures for IC-01 during the post installation heating season were likely to primarily be due to the addition of the external wall insulation

**The Wondrwall installations generated more electricity from the solar panels than was imported from the grid**

- In 2024, the Wondrwall households were net positive homes, generating more electricity from the solar panels than was imported from the grid
- The PV system for household W-01 generated 5,531kWh while there was 4,686kWh of electricity imported from the grid
- Household W-02 imported just 346kWh between 10 Jan 2024 and 31 Jan 2024 while the solar PV system generated 5,224kWh over the year
- Control household IC-01, also with a 5.81kW solar PV system, was close to net zero over the year, generating 5,116kWh from the solar panels and importing 5,136kWh from the grid
- Household W-01 used 1,971kWh of the solar generation (35.6%) in the home while the lower electricity demand of W-02 meant only 939kWh of the solar generation was self-consumed (just 18%)
- Control household IC-01 used 1,947kWh of the solar generation in the home in 2024; while this household did not have a battery as for W-01, there was a smart hot water cylinder and PV diverter

**The electricity consumption and costs were assessed before and after the installations**

- There was a fall in the monthly off-peak consumption and rise in peak-rate consumption after the Wondrwall installation for household W-01
- Electricity costs were assessed for Economy 7 using a tariff rate of 30p/kWh for peak rate and 12.5p/kWh for off-peak
- For the period 1 Oct 22 to 30 Sep 23 when household W-01 had storage heaters, the cost of the electricity on Economy 7 was £783 but this included a period from mid-December 2022 to mid-February 2023 when the heating was on lower due to the resident being away from home
- During 2024 with the Wondrwall system operational, the electricity cost for household W-01 was assessed to be £836; had the resident been at home throughout the pre-installation monitoring period, it is likely the electricity costs would have been closer
- For household W-02 where the resident was a long-term low energy user, for two periods of just over a year before the Wondrwall installation, the grid import for the household was 1,350 – 1,450kWh; this compared to 346kWh for a period of just under a year after the Wondrwall installation
- The electricity costs for household W-02 for the two pre-installation periods were £340 and £328 compared to £74 for the post-installation period
- Control household IC-01 imported 7,620kWh from the grid in 2022, 6,839kWh in 2023 and 5,136kWh in 2024 after the installations

- Despite IC-01 having greater satisfaction with the infrared heating panels than the Wondrwall households, the electricity bills were higher
- IC-01 was on a single-rate tariff and assuming a unit rate of 24p/kWh, the cost was £1,829 in 2022 and £1,641 in 2023; the percentage off-peak consumption was less than 13% for these years which meant the electricity cost for the simulated Economy 7 tariff would have been about £300 more than for the single-rate tariff
- In 2024, the grid consumption of IC-01 was 5,136kWh and the electricity cost on the single-rate tariff would have been £1,233; the percentage off-peak consumption was higher in 2024, most likely due to reduced grid import during the day due to the solar PV and consumption of the Mixergy smart hot water cylinder overnight; the electricity cost on Economy 7 would have been about £70 higher in 2024 than for the single-rate tariff
- Households W-01 and W-02 had lower electricity bills than IC-01 in part due to lower household consumption but also due to W-01 being on Economy 7 and having a higher percentage of off-peak consumption due to the battery storage and some space heating use overnight

**The Wondrwall smart heating system is likely to be better suited to alternative time-of-use electricity tariffs**

- Households W-01 and W-02 both remained on an Economy 7 electricity tariff during the study
- The new heating system does not require seven hours of cheap electricity overnight as for storage heaters since the battery and smart hot water cylinder can charge in a couple of hours
- Other advanced time-of-use tariffs may be well suited to the Wondrwall system, but energy suppliers can require households to have an electric vehicle or heat pump to access these tariffs
- These tariffs may have more than one off-peak period per day, allowing the Wondrwall battery to charge twice a day and reduce the amount of peak-rate consumption
- Potential tariffs include Octopus Flux and heat pump tariffs from EDF or the Cosy Octopus tariff
- Energy suppliers need to widen the eligibility to advanced time-of-use tariffs and not restrict them to homes with certain technologies
- Some Wondrwall customers have been able to switch to Cosy Octopus
- Income is also available due to payments for solar PV export through the smart export guarantee (SEG); however, it is likely landlords will want to receive this payment due maintaining equity with other households, the complexity of transferring the SEG with changes of tenancy and extra maintenance and running costs from the solar PV/battery

***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.***