EXTEND - EXtending storage Time & ENergy Density of heat pumped heat batteries

Delivering smart electrification of domestic heat through thermal storage and intelligent controls

Sunamp Ltd

January 2026

Acknowledgements

We would like to thank the Department for Energy Security and Net Zero for commissioning this project and for their continued support throughout its duration.

Special thanks go to Dr Gill Davies, whose guidance was instrumental in navigating the project through numerous changes.

We are also grateful to the project's monitoring officers, Aurelia Hibbert and Omotola Adeoye, for their constructive feedback and valuable advice throughout.

We extend our thanks to the consortium partners; myenergi and Energy Systems Catapult, subcontractors, and trial participants, whose contributions were essential to the project.

Finally, we would like to thank the Sunamp team, past and present, for their dedication and hard work in delivering this project.

Contents

Figures

Tables

0. Glossary of Abbreviations

Abbreviation	Full Form / Description
API	Application Programming Interface
ASHP	Air Source Heat Pump
BoP	Balance of Plant
BUS	The Boiler Upgrade Scheme
CHB	Central Heating Battery
COP	Coefficient of Performance
CPD	Continuing Professional Development
DSR	Demand Side Response
DSO	Distribution System Operator
DHW	Domestic Hot Water
ESC	Energy Systems Catapult
ESA	Energy Smart Appliance
EXTxxxx	EXTEND System Identifier (e.g., EXT0002)
FIT	Feed-in-tariff
GSHP	Ground Source Heat Pump
HP	Heat Pump
HX	Heat Exchanger

LDES	Long Duration Energy Storage
LDESS	Long Duration EXTEND Storage System
OTA	Over The Air – software updates over the internet
PCM	Phase Change Material
POU	Point of Use
RTE	Round Trip Efficiency
RSSH	Reverse SSH Tunnel (remote access method)
SC / SSC	System Controller / Sunamp System Controller
SH	Space Heating
SHB	Space Heating Battery
SHC	Smart Heating Controller
SOC	State of Charge
SSM	Smart Scheduler Model
SSH	Secure Shell
TOU / TOUT	Time of Use Tariff
WHEC	Whole Home Energy Controller

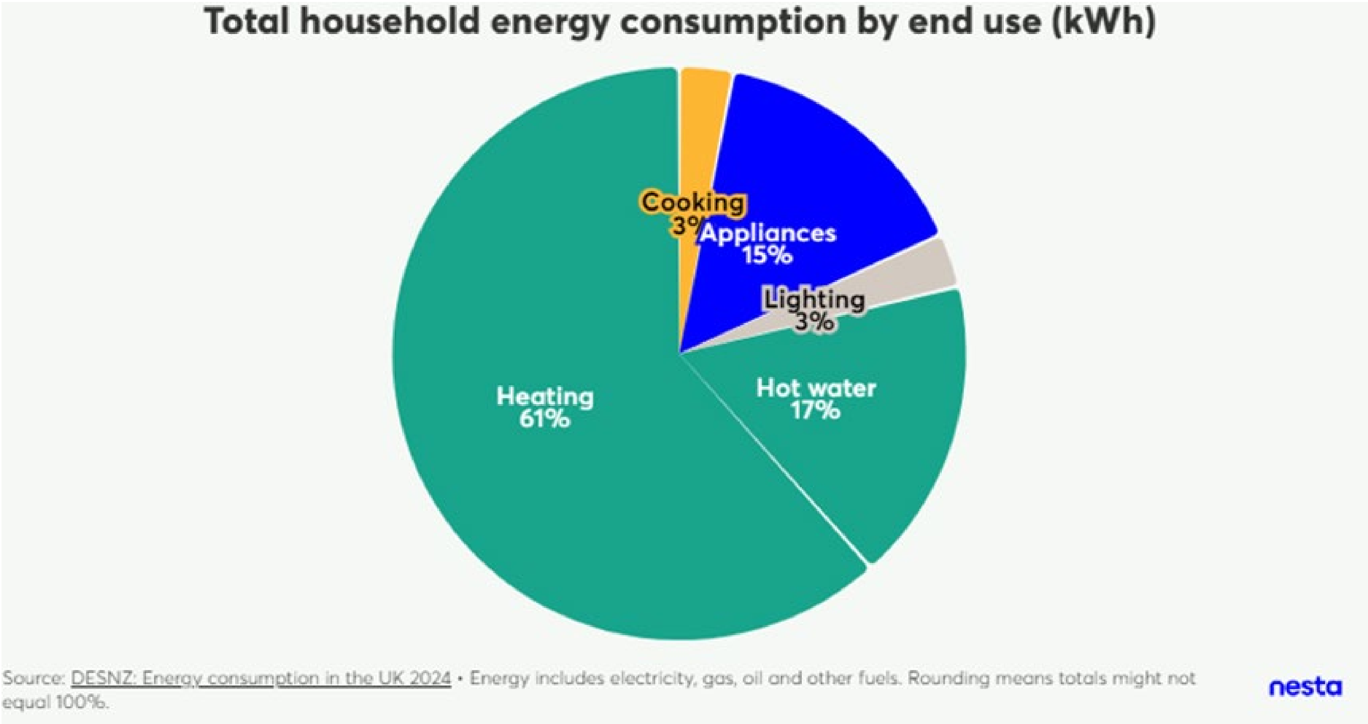
1. Introduction

The EXTEND project was launched under the UK Government's Longer Duration Energy Storage (LODES) innovation programme to address one of the most pressing challenges in the transition to net zero: the electrification of domestic heating. Heating and hot water account for approximately 80% of household energy consumption (Figure 1), with most homes still reliant on gas boilers. Replacing these with electric systems poses significant challenges for the electricity grid, especially during peak demand periods.

The EXTEND system was designed to shift heating loads away from peak times by integrating thermal storage with smart scheduling, enabling households to consume electricity during periods of low carbon intensity and low cost, without impacting the comfort of the consumer. This approach supports grid stability, reduces reliance on fossil fuel "peaker" plants, and allows consumers to benefit from Time of Use Tariffs (TOUT) and even negative pricing events.

By combining heat pumps, phase change material (PCM) thermal batteries which can retain heat for long periods, and a smart control stack, the EXTEND system represents a novel and scalable solution for low-carbon, grid-friendly domestic heating.

Figure 1. Breakdown of domestic energy consumption showing space heating and hot water account for approximately 80% of domestic consumption. (Source: DESNZ: Energy consumption in the UK 2024)

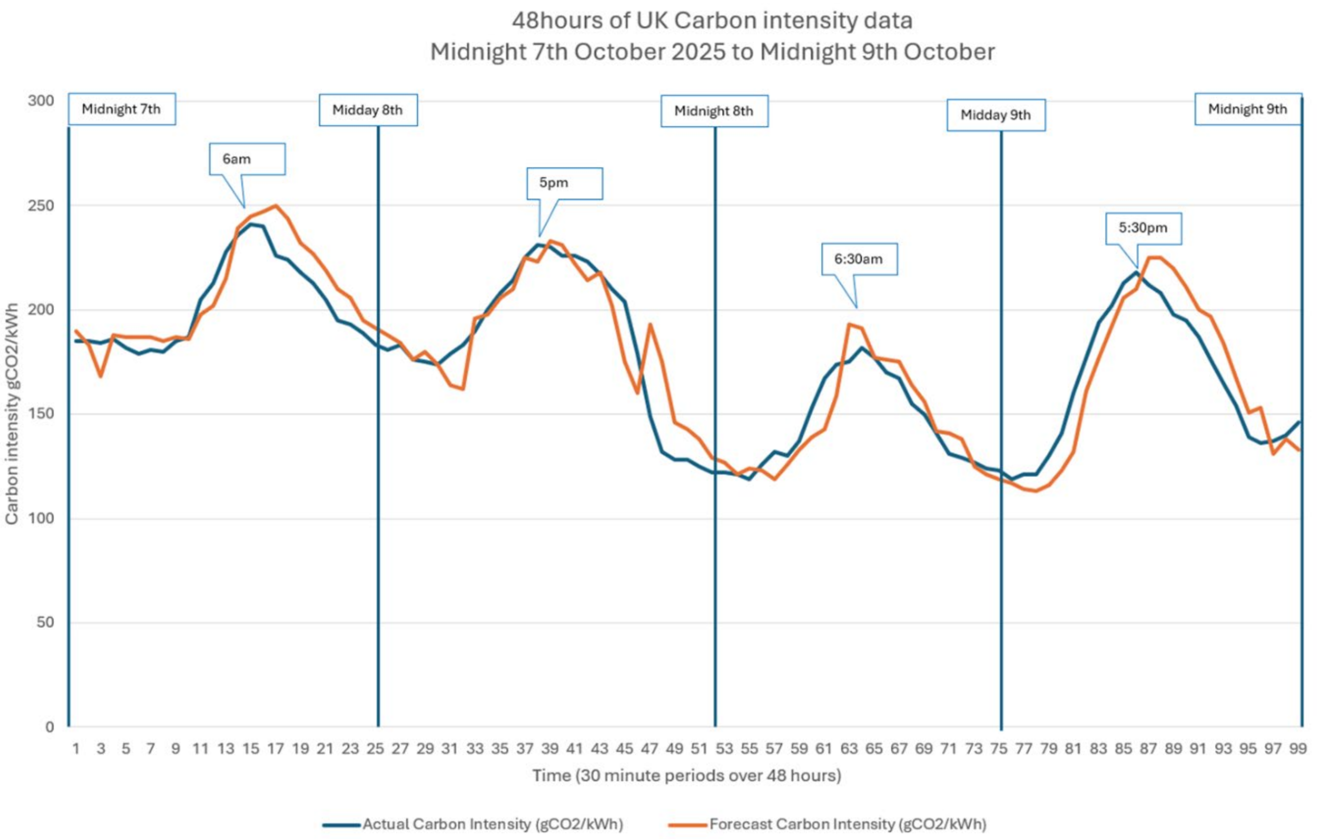


2. Electrification of heat and grid challenges

Electrification of domestic heating is central to the UK's net zero strategy. Space heating and hot water represent the bulk of domestic energy use and rely heavily on fossil fuels. Transitioning from gas to electric heating will significantly increase electricity demand. For example, Sunamp estimate that replacing gas boilers with direct electric heating could increase household electricity consumption by 350–360%, while heat pumps (with a coefficient of performance of 3) would still result in a 117–120% increase. This surge in demand poses challenges for grid stability, especially during peak periods. The UK has electricity interconnectors with the rest of Europe, but all countries are increasingly reliant on intermittent renewable sources such as wind and solar which further complicates the balance of supply and demand.

Demand drives generation so if nuclear generators and renewables cannot meet the demand then gas peakers fill the gap which increases the carbon intensity; see Figure 2 which shows the variation of carbon intensity over 48 hours and peaks at periods of high demand. Without effective load management and flexibility on the system, electrification risks a higher cost system with more generation and network build than may otherwise be necessary. This could include greater reliance on fossil fuel "peaker plants" which are costly and carbon-intensive. To mitigate these challenges, the EXTEND project integrates thermal storage and intelligent control to shift energy use to off-peak periods and align consumption with renewable generation, thereby supporting grid stability and reducing carbon emissions.

Figure 2. Grid electricity carbon intensity over 48 hours in the UK.
https://carbonintensity.org.uk/



3. Overview of the EXTEND system architecture

The EXTEND system (Figure 3) is composed of several integrated components designed to deliver smart, low-carbon heating.

- Heat pump
- Thermino thermal battery for domestic hot water (DHW)
- EXTEND space heating battery (SHB)
- Hydromodule including the smart heating controller (SHC) (Figure 5)
- myenergi Libbi - the Whole Home Energy Controller (WHEC), myenergi eddi and eddi+
- Distribution boards, energy meters (heat and electricity), Modbus temperature sensor and flow meter

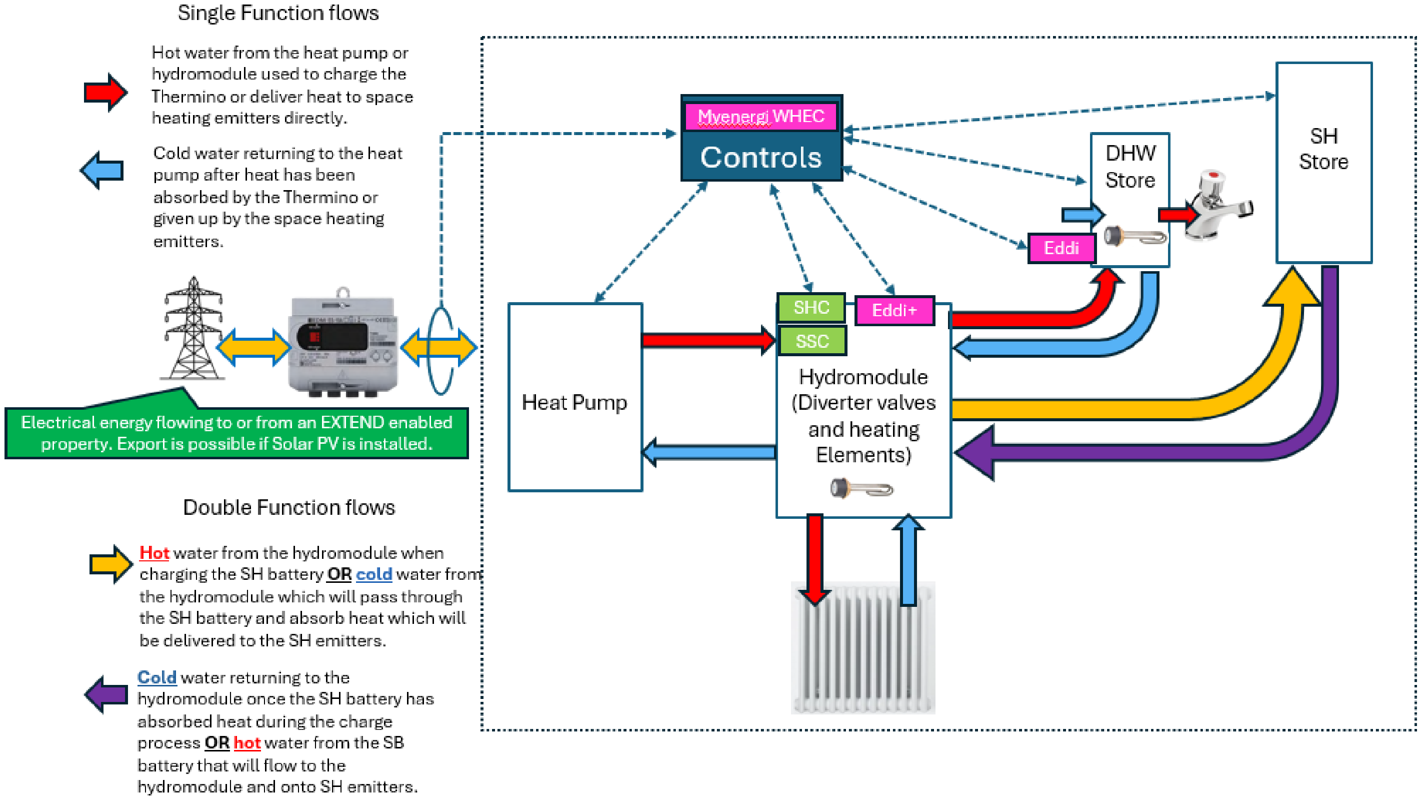
At its core is a heat pump, either an air source or ground source unit, responsible for generating heat. This heat is stored in two types of thermal batteries: the Thermino for domestic hot water and the space heating battery (SHB). Both batteries use Sunamp’s Plentigrade® P58 phase-change material, which offers four times the energy density of water and maintains useful heat for extended periods; see Figure 17 in Chapter 6.

The hydromodule manages fluid routing and control, coordinating the flow of heat between the heat pump, thermal batteries, and heating circuits. Control is provided by the smart heating controller (SHC) and the Sunamp system controller (SSC), which ensure safe and efficient operation.

The Whole Home Energy Controller (WHEC), developed by myenergi, oversees household energy loads and integrates with the Smart Scheduler Model (SSM). The SSM optimises system operation based on user schedules, electricity prices, weather forecasts, and household thermal characteristics.

Together, these components enable the EXTEND system to shift heating loads to periods of low cost and low carbon intensity, while maintaining user comfort and supporting grid flexibility. Photos of an installed system are provided in Figure 6 and Figure 7 at the end of this chapter.

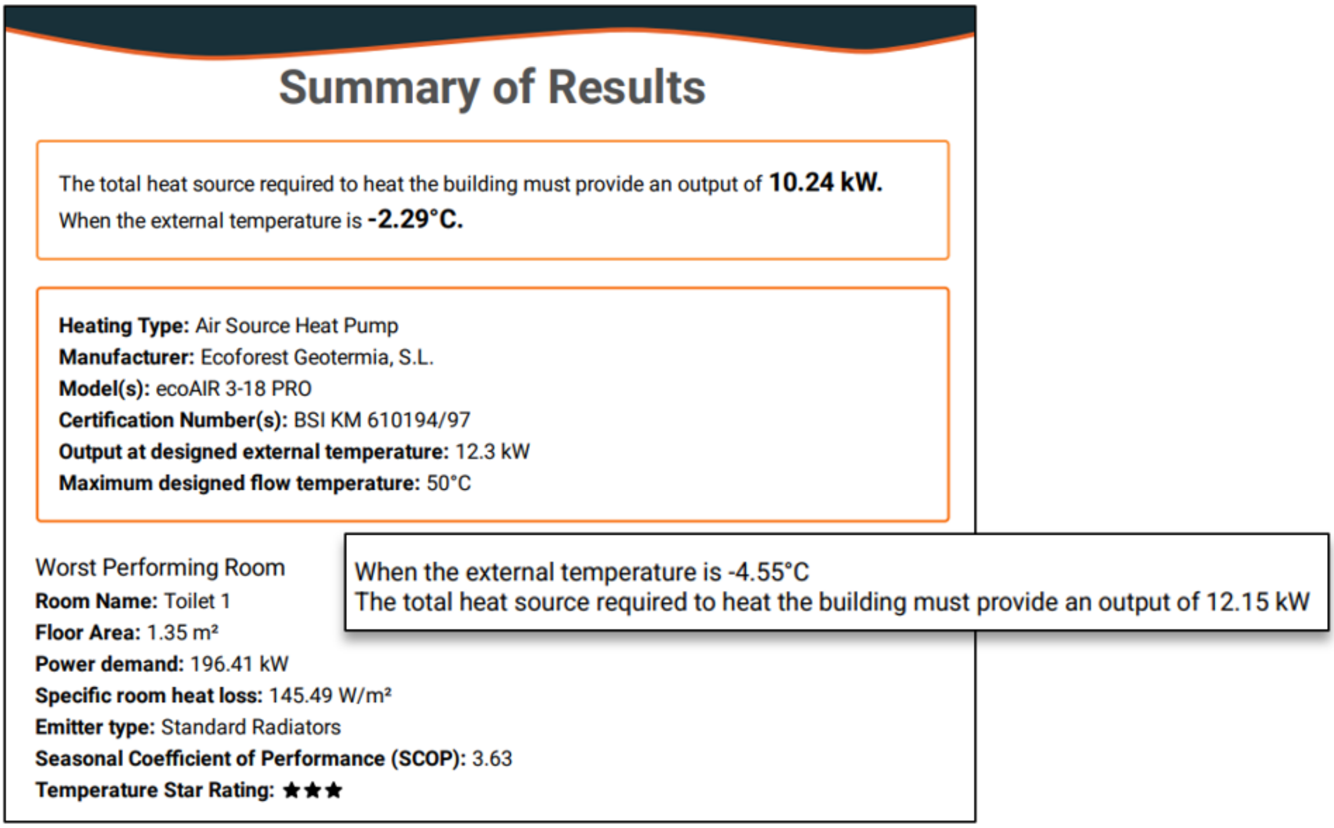
Figure 3. EXTEND system architecture showing integration of heat pump, thermal batteries, and smart controller



3.0 Space heating batteries and capacities

During the trial, two sizes of Thermino and SHB were used; see Table 1 and Table 2 (further below) for energy capacity and physical dimensions. The prototype batteries had capacities of 25kWh and 45kWh. Therefore, if the heat loss of a house was 5kW then the batteries would provide heating for 5 and 9 hours respectively without assistance from the heat pump. The heat losses for all the properties were calculated during the surveys and are based upon the building fabric and a given temperature for the region. An extract from a heat report for a property in Wales is shown in Figure 4 and the insert shows the heat loss calculations for a property in Scotland which will experience more extreme conditions.

Figure 4. Heat loss calculations for a property in Wales (main page) and Scotland (insert) showing the different temperature extremes that the systems are sized to cope with.



Summary of Results

The total heat source required to heat the building must provide an output of **10.24 kW.**
When the external temperature is **-2.29°C.**

Heating Type: Air Source Heat Pump
Manufacturer: Ecoforest Geotermia, S.L.
Model(s): ecoAIR 3-18 PRO
Certification Number(s): BSI KM 610194/97
Output at designed external temperature: 12.3 kW
Maximum designed flow temperature: 50°C

Worst Performing Room
Room Name: Toilet 1
Floor Area: 1.35 m²
Power demand: 196.41 kW
Specific room heat loss: 145.49 W/m²
Emitter type: Standard Radiators
Seasonal Coefficient of Performance (SCOP): 3.63
Temperature Star Rating: ★★★

When the external temperature is -4.55°C
The total heat source required to heat the building must provide an output of 12.15 kW

The heat losses of 10.24kW and 12.15kW are extremes when the external temperatures are significantly below average. Even with these high heat losses, the load shifting capacity of the batteries is in the order of 2-3 hours for the size 1 battery and 3-4 hours for the size 2 battery. When average external temperatures are around 6ºC, the heat losses for these properties will be much lower and closer to the 5kW range, so the batteries can provide significant load shifting.

Over the course of the trial, the period for which the space heating batteries were allowed to discharge was varied. During the middle of the trial, issues with a relay were identified which could cause a circuit board to fail. Until a solution was found, the ability to discharge the battery was either limited or stopped altogether. Testing of the system was then limited to the scheduler performance and ability to charge the SHB from low cost and low carbon energy.

When the battery was allowed to discharge for longer periods of time and soon after the battery had finished charging, the overall efficiency would increase significantly. An issue was found with the 4 port valve used in the prototypes which leaked heat. Therefore, if the battery was discharged quite soon after charging, there was less time for heat to be lost from the battery and more energy to dispatch into the house. The issue with the valve and the control board have since been resolved.

Table 1. Thermino Specifications

Model	Charged to heat pump set point kWh (Litres)	Charged to electric element set point. kWh (Litres)	Dimensions (d x w x h) mm and empty weight (kg)
210 xPlus	9.4 (271)	10.5 (301)	575 x 365 x 870 (187)
300 xPlus	11.6 (333)	14.0 (402)	575 x 365 x 1050 (233)

Table 2. SHB specifications

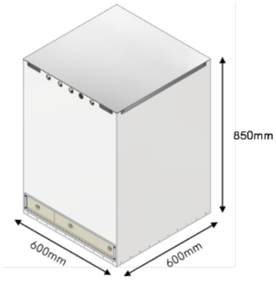
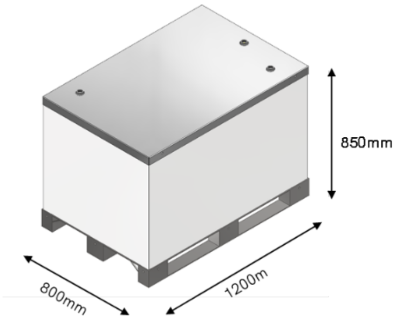
Model	Charged to heat pump set point (kWh)	Dimensions and weight (kg)
Size 1	25	 359 kg
Size 2	45	 708 kg

Figure 5 LDESS 2 hydronic unit CAD model (H: 850 mm W: 410 mm D: 455 mm)

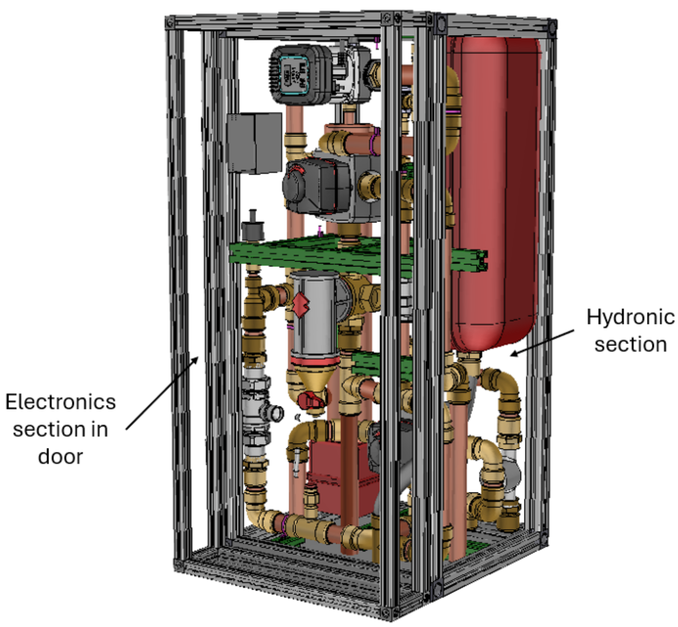


Figure 6. The EXTEND system installation in property EXT0002. Photographs show the hydromodule next to an existing gas boiler, power distribution boards for the system, the SHB, buffer vessel and Thermino.

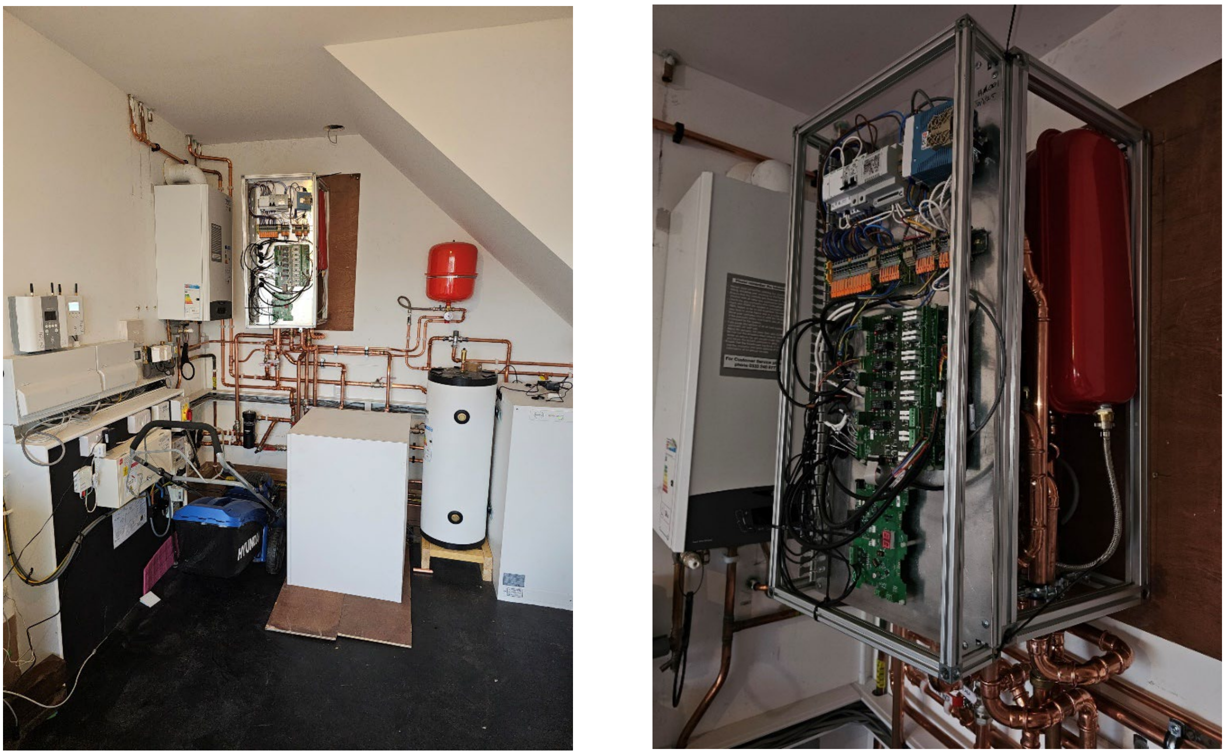


Figure 7. The EXTEND system installation in another property showing the myenegi systems and the pipework below the hydromodule.

4. Field trial methodology and data infrastructure

The EXTEND project's field trial was designed to rigorously evaluate the performance, efficiency, and user experience of the Long Duration EXTEND Storage System (LDESS2) in real-world domestic settings. This section outlines the methodology employed for data collection, logging and analysis, as well as the infrastructure developed to support these activities.

4.0 Data collection and logging

Each EXTEND system was equipped with a smart heating controller (SHC) and a Sunamp system controller (SSC), which together managed the operation of the heat pump, thermal batteries, and ancillary components. These controllers were responsible for collecting telemetry data, including temperature readings, flow rates, power consumption, and operational states. The SHC also recorded user schedules and system configuration parameters.

Data was logged locally on the SHC and uploaded each day to a cloud server where it was formatted and sent to a database ready for analysis.

4.1 Remote access and real-time monitoring

To support diagnostics and system updates, the SHCs were configured to allow remote access by engineers to override control states and push firmware updates. Additionally, an interface was developed to enable real-time monitoring, request system reboots, parameter adjustments and retrieve live telemetry data.

4.2 Reporting infrastructure

Two reporting dashboards were developed to visualise system performance. The first, a real-time dashboard built using RShiny technology, accessed SHC data via a FastAPI interface for systems on the same network. The second, a historic dashboard, leveraged the database to display multi-day performance data. These dashboards provided insights into system efficiency, user comfort, and energy load shifting capabilities.

4.3 Data analysis methodology

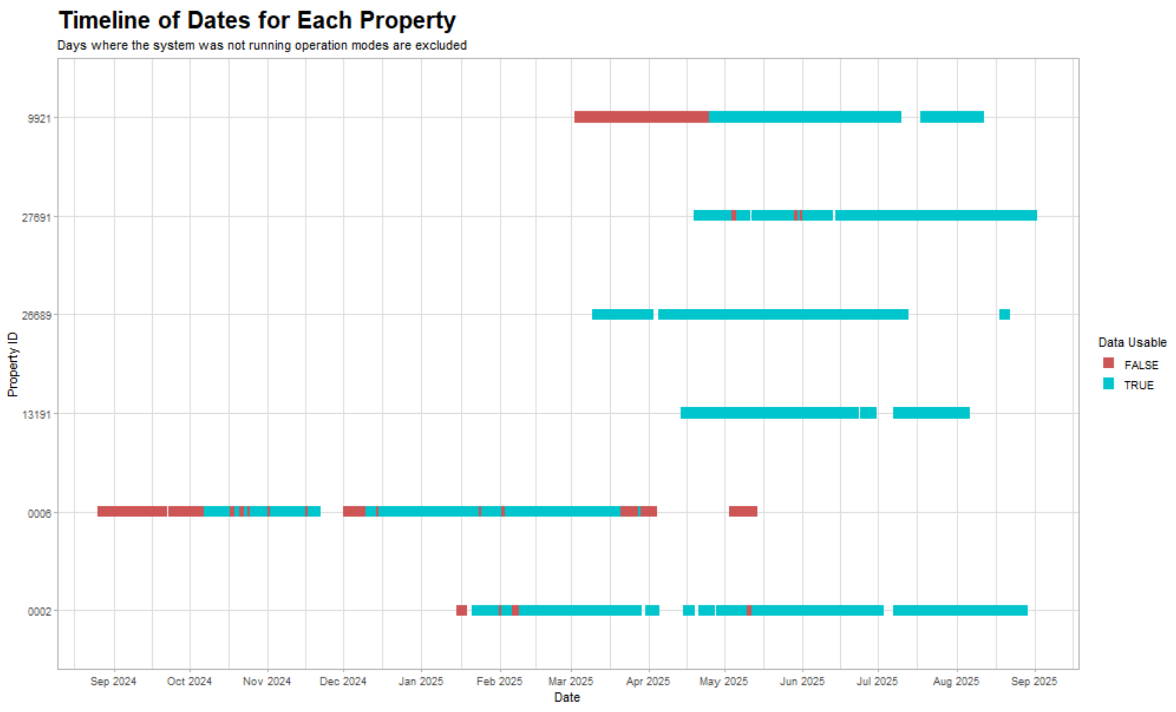
The analysis focused on evaluating heat pump efficiency, system efficiency, user comfort and energy load shifting. Thermal energy transfer was calculated using temperature differentials and flow rates, while electrical energy usage was derived from power meter readings. Efficiency metrics were calculated by comparing thermal output to electrical input.

To ensure accuracy, transition periods around state changes were excluded from the analysis, as sensor readings during these times were prone to anomalies. The analysis also accounted for data gaps and capped time intervals to prevent distortions in energy calculations.

4.4 Summary of available data

Data availability varied across households due to installation timelines, network connectivity issues and hardware faults. The earliest systems installed provided winter performance data, while later installations contributed data primarily from spring and summer. Figure 8 illustrates the availability of usable data across all systems.

Figure 8. Available data for all analysis



4.5 Performance evaluation

This section presents a summary of the analysis undertaken in a separate detailed EXTEND Data Analysis Report which reviewed the EXTEND system's performance from the heat pump efficiency, overall system efficiency, user comfort and energy load shifting perspectives. The analysis is based on telemetry data collected from six deployed systems.

4.6 Heat pump efficiency

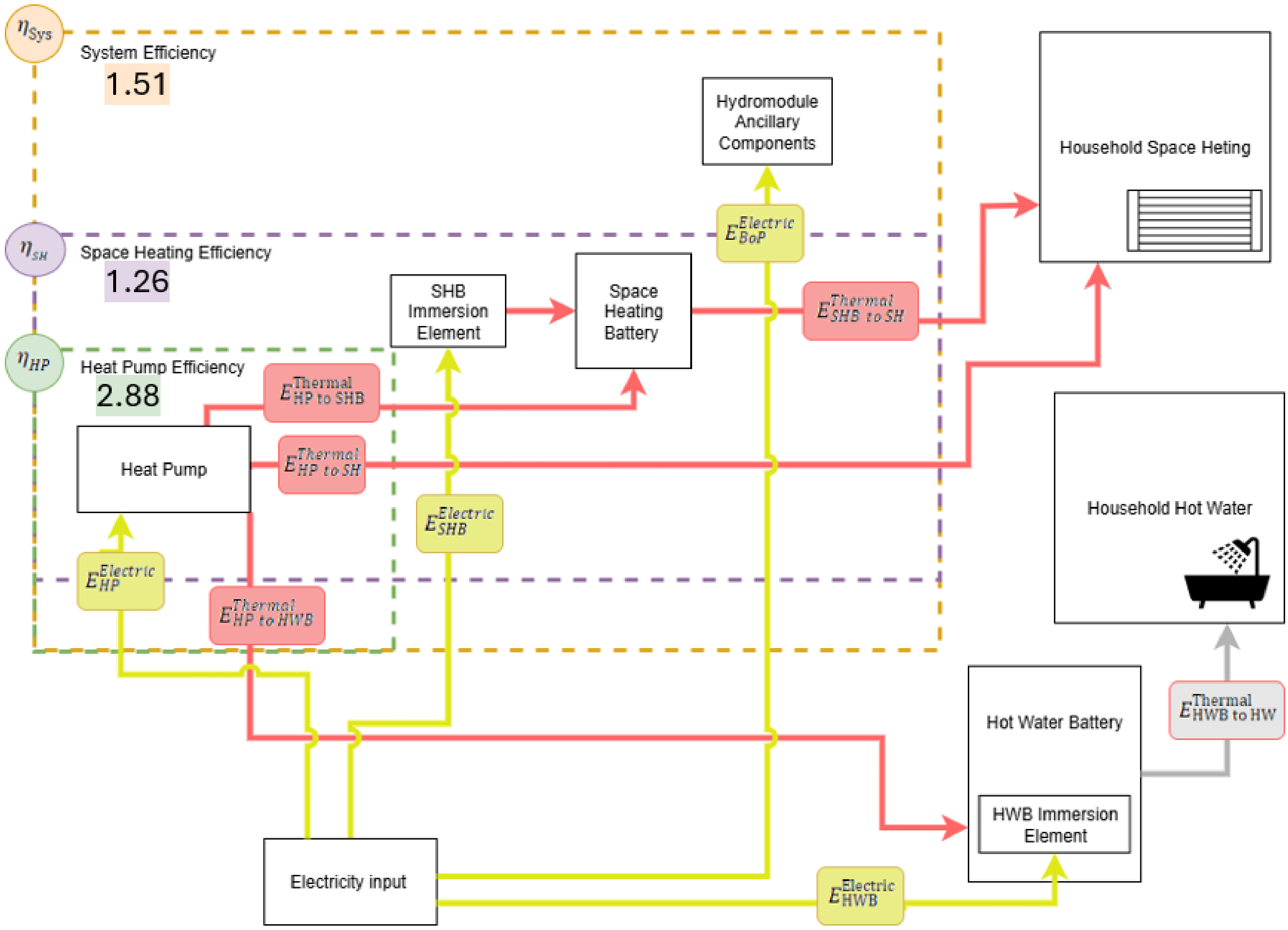
The heat pump component of the EXTEND system demonstrated an average coefficient of performance (COP) of 2.88 across all households, with individual systems ranging from 2.06 to 3.12. This compares favourably with the benchmark COP of 2.95 reported in the Energy Systems Catapult's Electrification of Heat trial. The heat pump efficiency was calculated using temperature and flow sensors located post-hydraulic separation, ensuring accurate measurement of thermal energy delivered to the system.

4.7 System efficiency

The efficiencies are the ratios of the total thermal output to the electrical input (excluding hot water immersion heating). When the discharge time of the heat battery was limited to one hour, the overall efficiency of the system was 1.51, the space heating average efficiency was 1.26 and the heat pump average efficiency was 2.88 (see Figure 9).

When the discharge time was not limited to 1 hour, the total system efficiency, SH system efficiency and heat pump efficiencies were 1.77, 1.72 and 2.92. The reasons for the efficiency variations and opportunities to improve are discussed in section 5.8.1.

Figure 9. Efficiencies at the overall system level, space heating level and just the heat pump level when discharge time of heat battery limited to one hour.



The fact that the average overall efficiency of the EXTEND system is lower than a system with just a heat pump is to be expected because of energy losses associated with the conversions, but the overall efficiency can be increased.

4.7.0 Reasons for lower efficiency

The EXTEND system efficiency can be increased by improving the hydromodule design, replacing the valve and enhancements to the control strategy. Because the EXTEND system involves storage and energy conversions, the efficiency will never be better than that of a standalone heat pump but the money and carbon saving by load shifting, and the benefits provided to the grid, more than make up for the slightly higher energy consumption.

A brief comparison of thermal storage and domestic electric storage as part of solar PV solutions is provided to show that efficiency is not the critical factor. The first domestic electrical battery storage systems were developed to maximise self-consumption of onsite generated solar PV energy and minimise the energy that was exported back to the grid. The GB feed-in-tariff (FIT) provided payments proportional to the amount of energy generated, not exported. Therefore, a homeowner could generate and consume 100% of the energy generated and get the same FIT payment as a homeowner that was only able to consume 10%, 20%, 30% or 40% of the energy.[1] The FIT scheme closed to new applications on the 1st April 2019.

Maximising consumption was possible by charging the battery with surplus energy that the homeowner could not make use of in real-time. The stored energy in the battery is then extracted and converted back to AC electricity when the homeowner needs the energy and when the PV system cannot meet the demand. This is an example of simple load shifting. The system without the battery was more efficient in terms of basic energy conversion from solar to electricity than the system with the battery. There are losses during the charging and discharging of the battery, but the saving provided by avoiding the purchase of the energy from the grid was far greater than the cost of the energy lost during the conversions.

As systems become more complex, have energy consuming components or there are energy conversions required, then there are usually losses and hence efficiencies can drop. But if there are other advantages to compensate for the reduction in efficiency then a system may still be viable and useful.

The function of the EXTEND system is to shift heating loads away from periods of peak demand and support the UK grid on the journey to net zero. If we only consider the heat pump in terms of the electrical energy consumed and the heat generated, the heat pump without storage is the most efficient solution because of its simplicity and no additional energy conversions, even during the peak demand periods of 4pm to 8pm. However, if we compare carbon generation and financial cost of the heat pump and an EXTEND system on a TOUT then carbon and costs can be reduced. If the heat pump without storage ran between 4pm and 8pm, and an EXTEND system released the same amount of heat at the same time, the financial cost and carbon would be lower for the EXTEND system charged from off peak energy. See the calculations shown in 5.10 which show the carbon intensity and cost at different times of the day.

The SHB's single heat exchanger circuit was connected to the hydromodule which controlled the flow of hot water to the battery to charge it and relatively cold water from the space heating circuit to cool or discharge it. The 4-way valve within the hydromodule had relatively poor tolerances. It allowed hot water to escape from the SHB when the system was not in the space heating mode which involved discharging the SHB. The associated heat loss outside of the space heating operations effectively skewed the efficiency. The analysis would imply that the round-trip efficiency of the SHB was much lower than existing Sunamp thermal batteries such as the Thermino which has very low heat losses, as shown in Figure 17 (in the following

[1] https://www.ofgem.gov.uk/environmental-and-social-schemes/feed-tariffs-fit

chapter). The results indicated that the amount of energy that could be extracted during the discharge phase was significantly less than the energy deposited during the charge phase. This is because heat had already been lost ahead of the discharge phase through the valve. It was also difficult to fully insulate the internal pipework of the hydromodule so there were heat losses which further impacted the efficiency.

By increasing the discharge duration period and minimising the time between charge and discharge, the battery had more energy to release as there was less opportunity to leak heat via the valve in the hydromodule. This led to COP values of 1.77 and 1.72 values which are significantly better than the 1.51 and 1.26 figures and are more representative of the expected efficiencies.

Figure 10. Data Analysis Report illustrates the monthly variation in overall system efficiency over time.

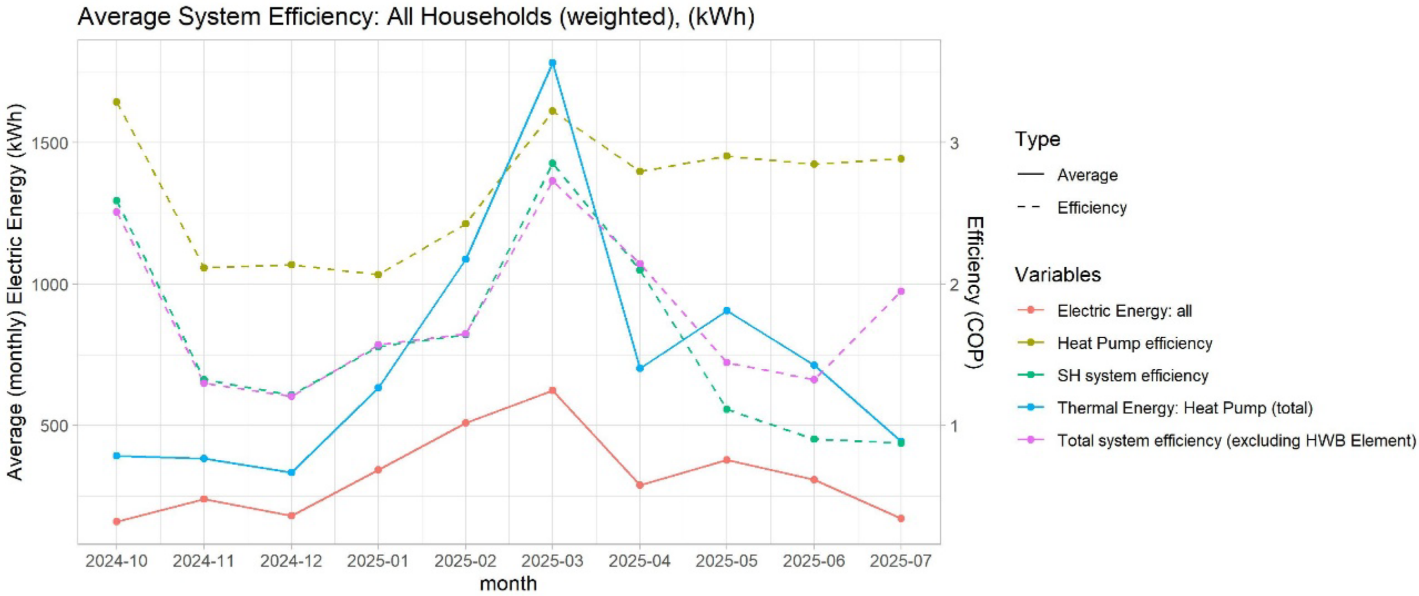


Table 3. All energy categories summary for 550 days of data.

Variable Name	Values (kWh)	Daily Average	% Time in Relevant State	Values (kWh) × % Time in State
Thermal Energy: SHB to Space heating	820.00	1.49	4.88%	40.02
Thermal Energy: Heat Pump to SHB	9886.80	17.98	7.04%	696.48
Thermal Energy: Heat Pump to SH	7351.69	13.37	56.03%	4119.28
Thermal Energy: Total output to SH	8171.70	14.86	4.85%	396.98
Thermal Energy: Heat Pump to HWB	4866.50	8.85	51.15%	2489.26
Thermal Energy: Heat Pump (total)	21899.51	39.83	63.05%	13807.32
Electric Energy: HP to SH	2328.24	4.23	51.15%	1190.92
Electric Energy: HP to SHB	3226.69	5.87	7.04%	227.31
Electric Energy: HP to HWB	2008.68	3.65	4.85%	97.42
Electric Energy: HP	7591.28	13.81	63.05%	4786.19
Electric Energy: SHB	171.84	0.31	0.60%	1.02
Electric Energy: HWB	236.39	0.43	4.61%	10.89
Electric Energy: ancillary components	876.89	1.59	N/A	N/A
Electric Energy: all	8876.41	16.14	N/A	N/A

Figure 10 and Table 3 provide a breakdown of system efficiency by household and month and the length of time systems were operating in various modes. Note the distinction between the heat pump providing heat for space heating (SH) immediately and to the SHB for heating later. Technical challenges required us to change the settings of the scheduler to prohibit usage of the SHB for parts of the trial period. This significantly reduced our ability to show the full capabilities of the SHB.

4.8 User comfort

User comfort was assessed by comparing room temperatures to user-defined setpoints. Across all systems, room temperatures remained within 2°C of the setpoint for over 90% of the time, indicating effective space heating control. Figure 11 shows the data for one property to illustrate this. The hot water battery maintained a state of charge above 75% during scheduled periods, ensuring reliable hot water availability.

Figure 11. Space heating targets for property EXT0002

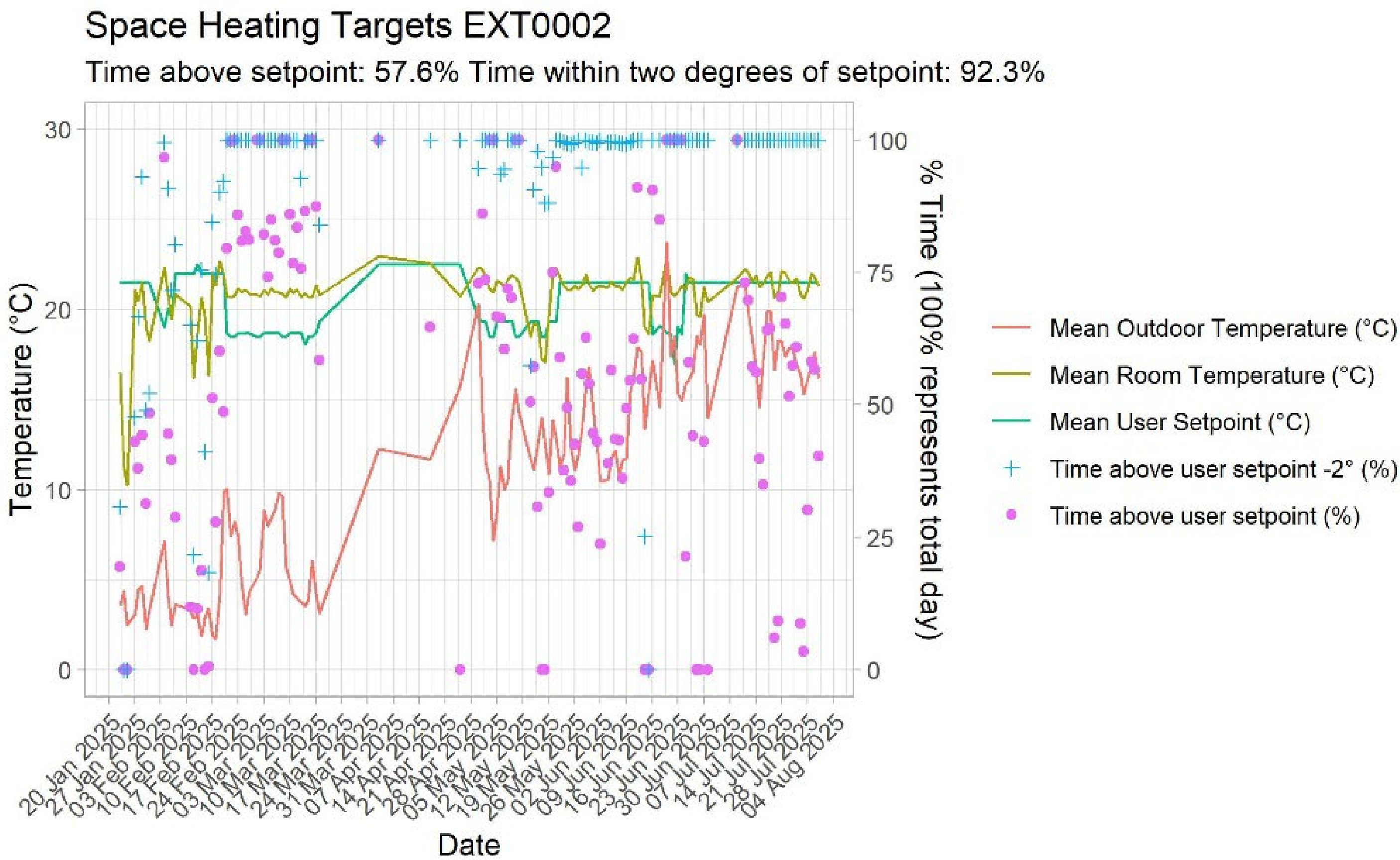


Figure 12. Domestic hot water SOC and requested availability.

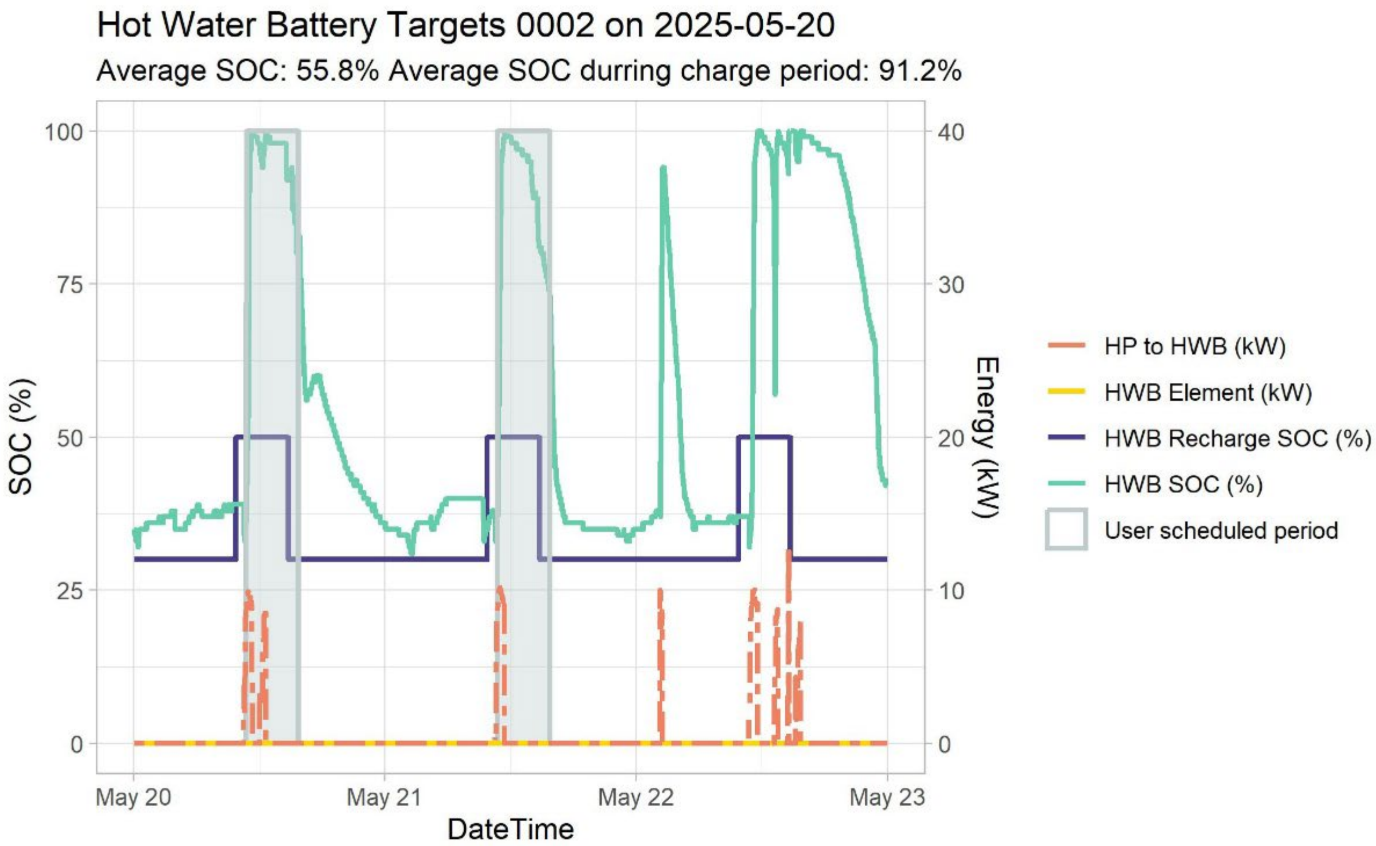


Figure 12 shows the targets (blue and grey lines) and the actual state of charge is shown as the turquoise line. The orange and yellow lines show power transfers during these periods either from the heat pump or electric element.

4.9 Energy load shifting

The EXTEND system successfully shifted energy consumption to periods of lower carbon and cost electricity by responding to Time of Use Tariffs (TOUT). All systems demonstrated net savings, with daily savings ranging from £0.11 to £1.26 depending on household energy use and tariff variability. Figure 15 clearly shows that the power drawn from the grid for heating at periods of high cost, high carbon electricity were avoided. Comfort was maintained by discharging heat from the battery during these times instead of powering the heat pump for heating or charging of the battery. Regression analysis confirmed that savings were positively correlated with daily energy use and tariff deviation. The cumulative savings achieved during the trial were limited by the discharge duration period as discussed in Section 4.1. Because of the poor valve performance, the battery would effectively self-discharge and be ready for recharging to some extent several hours later. The scheduler clearly showed successful avoidance of high-carbon, high-cost periods and responded to negative price periods.

Tables 4,5,6 & 7 provide a worked example of how savings can be achieved by turning off a heat pump during the peak high cost periods and using the heat stored within the SHB.

On a variable or TOUT, the savings were calculated from the difference in the cost of energy that the heating at the time of expensive energy use would have cost and the energy required to charge the battery and then discharge it at the same point in time.

The ideal scenario would be to charge the SHB from low tariff energy during the afternoon when the ambient temperature is typically higher than at night. The higher temperature would mean the heat pump could operate more efficiently (with a higher COP) and the house might require minimal heat input because of solar gain. Also in an ideal world, there would be low-cost low tariff energy because of an abundance of renewable energy on the grid at that point in time, or even negatively priced energy. Several energy companies provide half price energy on a Sunday between 11am and 4pm. Five hours each night would provide enough time to charge a SHB and retain enough heat to overcome the two daily peaks in demand at 6-9am and 4-8pm.

In colder weather where ideally the heat pump is running 24 hours a day, 7 days per week and maintaining the low flow temperatures and delta Ts to maintain the high COPs, the heat pump would have to increase production and the supply temperature to provide heat for the house and to charge the battery. A time when the increased demand could occur (outside of peak demand hours and when there is low-cost, low-tariff energy) would be identified by the scheduler. Clearly there are many factors and time-shifting strategies which will be explored and refined in the future.

An example is provided using real TOUT data in Figure 13 and the associated carbon intensity for this period as shown in Figure 14. Comparing the carbon intensity with the cost of energy and the ability of the scheduler to move consumption to periods of low cost and carbon we can see significant savings can be made. This example involves moving consumption from period B to period A by charging the battery during period A and discharging during period B. This is a single event and just for illustrative purposes to clarify some of the high-level considerations for the scheduler. Two calculations are provided, one for the dynamic agile tariff which involves a negative price event and a more traditional dual tariff time of use account.

Agile tariff calculation

To avoid the high cost of energy during period B, the battery must be charged during period A. The assumption is that heating is also required during period A at the same time as the battery is being charged. If we assume the heat input to the house is constant at 3kW all day, then without storage the heat pump COP would be similar for period A and period B during the same day. The COP will drop in cold weather but for this high level example we will assume it is constant as we are maintaining a low delta T and flow temperatures. If we assume a COP of 3 then the 3kWh of heat will consume 1kWh of electricity, and if we assume a 2 hour period, then we need 2kWh to provide 6kWh of heat. The cost of electricity and carbon during periods A and B are shown in Table 4.

Table 4. A comparison of the cost and carbon generation for two periods A and B on the same day with an agile tariff with a negative price event.

Period	Heat	Electricity	Cost	Carbon
A	6kWh	2kWh	-2p	140g
B	6kWh	2kWh	76p	260g

Clearly if we can avoid consumption in period B, we reduce the cost and carbon generation.

If we were to take the opportunity to charge the battery during period A, we would have to increase the flow temperature of the heat pump to charge the battery which would reduce the COP slightly. To extract the heat from the space heating battery only requires a small pump so the heating cost would be minimal during period B. The higher flow temp from the heat pump would mean the hotter water would be blended with the colder return water from the heating system. For this high-level example, we have kept the heating of the building the same.

For this example, shown in Table 5, we will assume a COP of 2.5 down from 3.

Table 5. A comparison of the cost and carbon generation for two periods A and B with load shifting storage on the same day with an agile tariff with a negative price event.

Period	Heat	Electricity	Cost	Carbon
A	6kWh	2kWh	-2p	140g
A for B	6kWh	2.4kWh	-2.4p	168g
B	6kWh SHB	0.1kWh	3.8p	13g

By time shifting the generation of heat for period B to period A and the extraction of heat from the battery during period B the cost and carbon would reduce by 76-2-2-2.4+3.8 = 73.4p and (140+260) – (140+168+13) = 79g.

Economy 7 or an EV tariff

If we apply the same logic to a more accessible Economy 7 tariff (with low and high rates of 6p/kWh and 29p/kWh), then the financial benefits to the consumer are not quite as great, as shown in Table 6. However, the load shifting benefits the grid and maintains the same carbon reduction.

Table 6. A comparison of the cost and carbon generation for two periods A and B on the same day with a dual tariff supply.

Period	Heat	Electricity	Cost	Carbon
A	6kWh	2kWh	**12p**	140g
B	6kWh	2kWh	**56p**	260g

The same logic as above is used, with an assumed COP of 2.5 down from 3.

Table 7. A comparison of the cost and carbon generation for two periods A and B with load shifting storage on the same day with a dual tariff supply.

Period	Heat	Electricity	Cost	Carbon
A	6kWh	2kWh	**12p**	140g
A for B	6kWh	2.4kWh	**14.4p**	168g
B	6kWh SHB	0.1kWh	**2.9p**	13g

By time shifting the generation of heat for period B to period A and the extraction of heat from the battery during period B the cost reduces by **12+58-12-14.4-2.9** = 40.7p. See Table 7 for the costs for each heating period.

This is just for a two-hour period based upon the TOUT in Figure 13 and a very simplistic case. There are many factors affecting the carbon and cost savings and further research is required to maximise the opportunities. Savings will be significantly greater with longer charges and discharges. To maximise the savings, visibility of the cost of energy and when heat is required is critical so the system can make informed decisions and charge when energy is cheap and discharge when energy is most expensive. Moving to a TOUT from a fixed tariff is required. The heat leakage issue has been resolved so there is no longer a requirement to discharge as soon as possible after charging.

Figure 13. System response against TOUT including a negative price event.

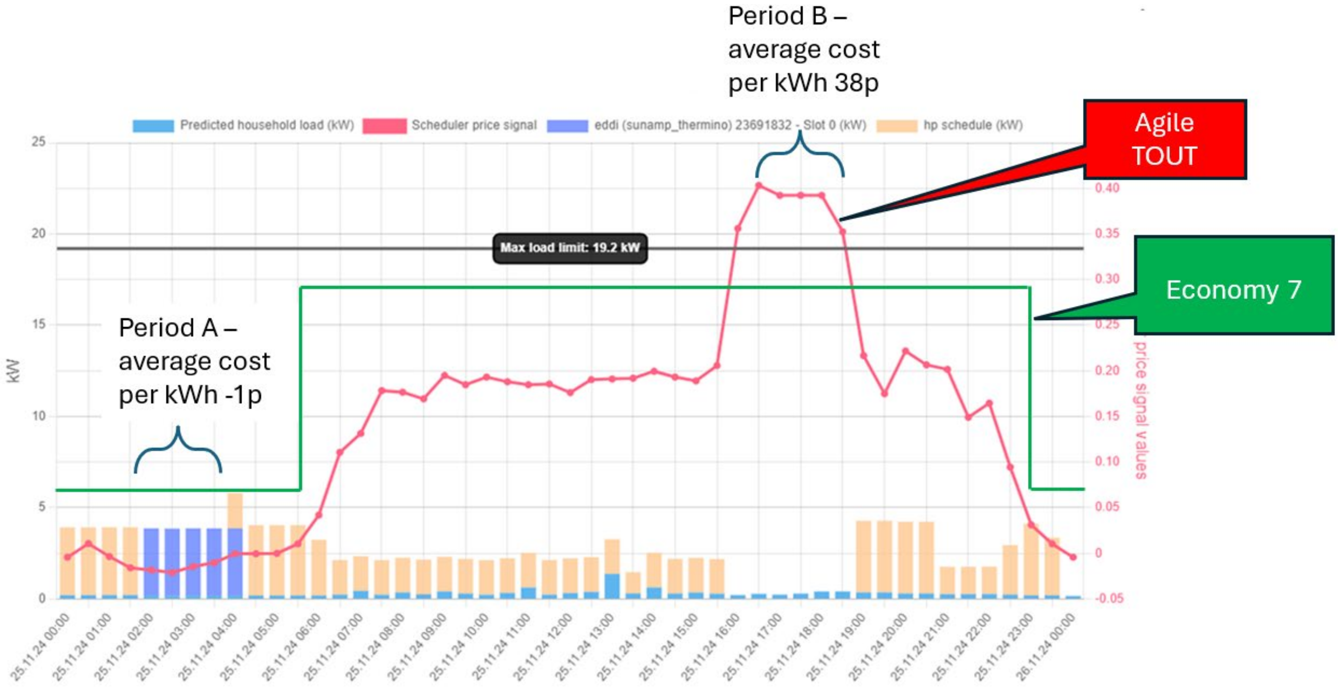


Figure 14. Comparing the carbon intensity with the cost of energy and the ability of the scheduler to move consumption to periods of low cost and carbon we can see significant savings can be made.

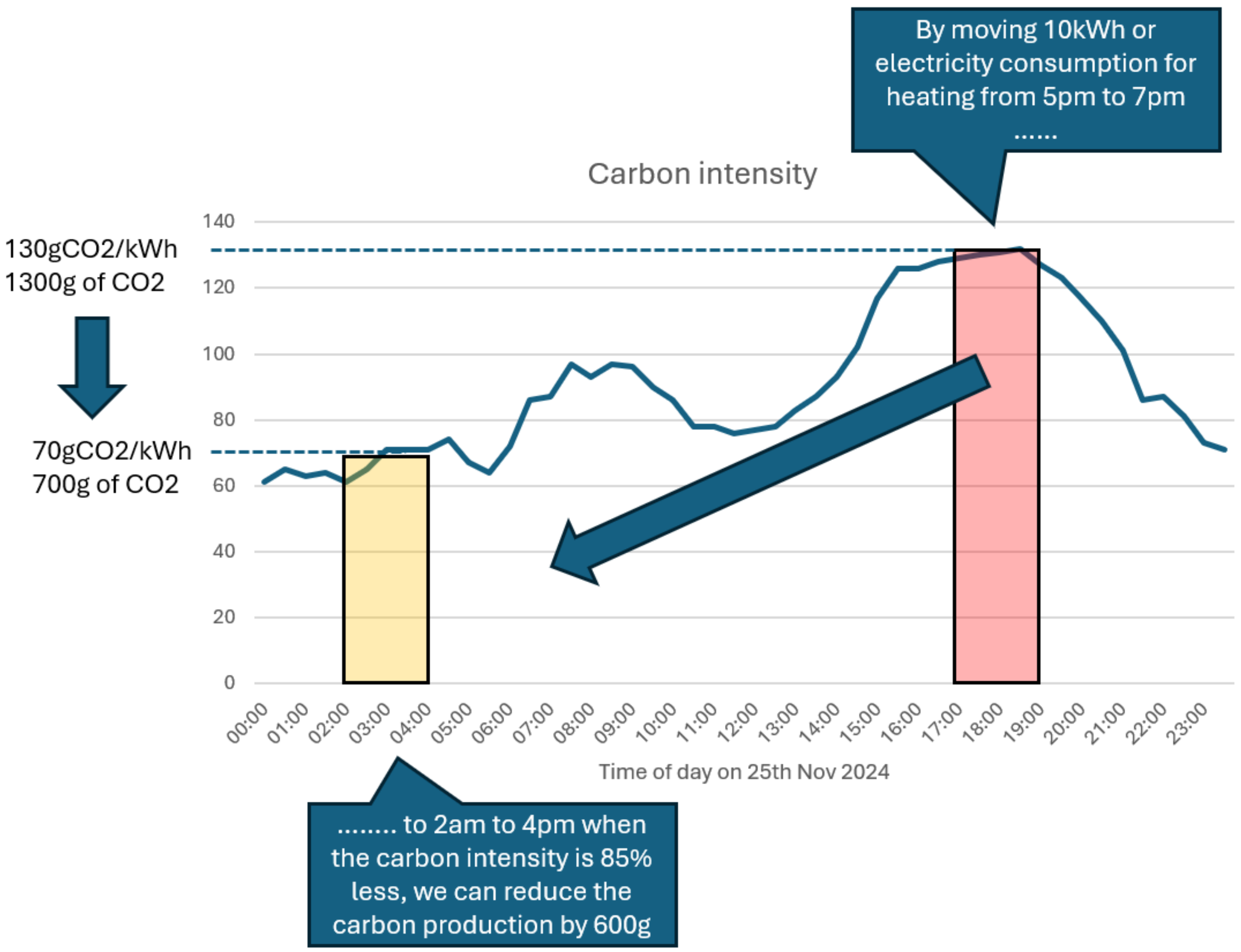


Figure 15. Graph showing power consumption variation with TOU tariff over time showing the system regulated behaviour to minimise cost to the resident.

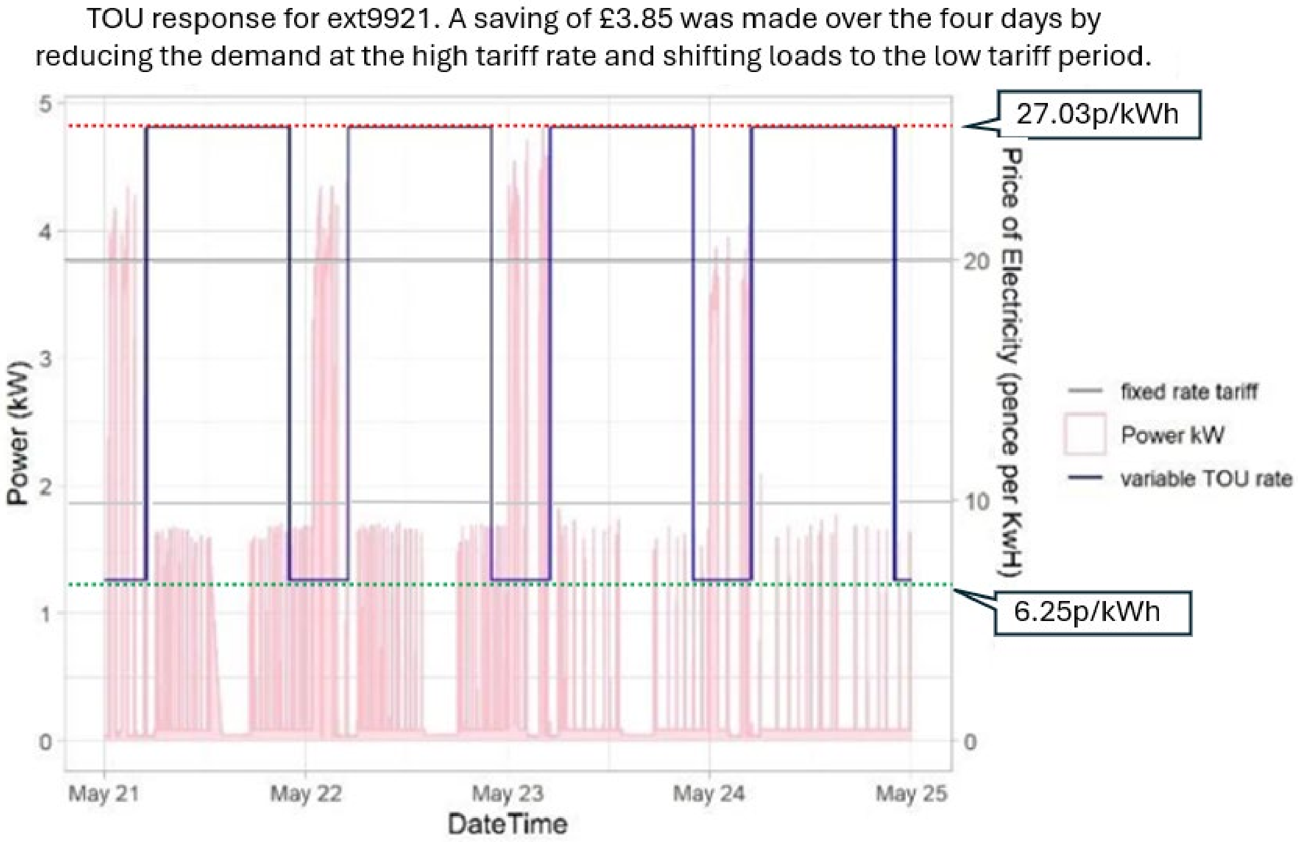


Figure 16. Cumulative financial savings realised by shifting to a variable tariff instead of a fixed tariff.

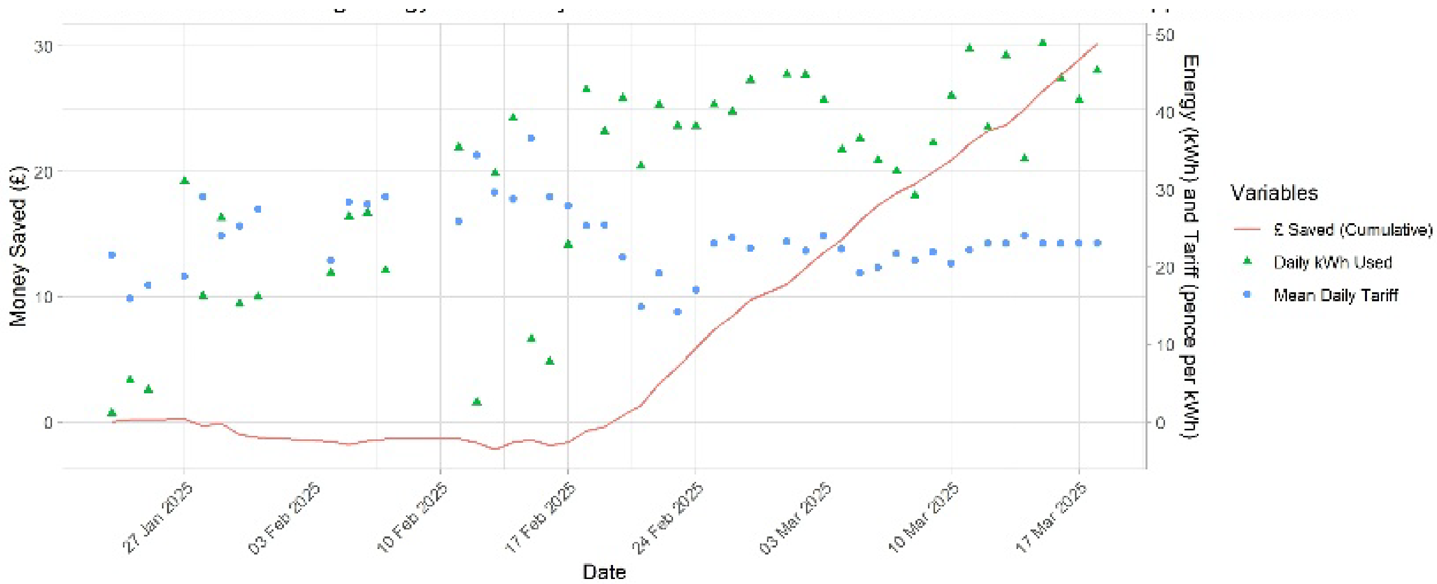


Figure 16 shows the savings from shifting across the sample period for EXT0002. This takes the daily savings and energy usage as shown in Figure 15 and adds it up for each day. For EXT0002, roughly £32 was saved over the course of 47 days from shifting consumption to cheaper times throughout the day. This figure compares the daily £ spent with the average price of electricity on a given day and measures the amount of money saved compared to a scenario where they used the same amount of energy at a constant rate throughout the day (i.e. no time shifting). It is important to note that this number approximates savings from shifting energy to low-cost time periods and excludes the savings from shifting from a tariff with a higher average cost to a lower one. For instance, if we were to compare the daily savings from using the tariff in Figure 15 to one using a flat rate of 27.03 p/kWh, any system that consumes energy during the cheaper period will have “saved money” under this methodology even if it is not efficiently shifting electricity and consumes 99% of its energy in the expensive period. Therefore, to precisely measure the system’s ability to shift energy usage to cheaper periods, average price multiplied by total usage is used as a counterfactual. This methodology underestimates the savings relative to a household that consumes most of its energy during high-cost periods. However, such a system would also likely use less energy overall and therefore, this figure represents a fair estimation of the systems energy shifting capacity.

The financial savings in Figure 16 above were not as high as can be achieved. This was due to the operational issues of the valve discussed earlier. However, the controller demonstrated the ability to shift loads and the intention to release heat at the appropriate time. Figure 17 (in the following chapter) shows the heat decay of a production Thermino and the ability to retain useful heat for 17 days. When installed within a hydronic system that does not allow heat leakage, the multi-week heat storage is useful in shifting heating demands and the use of low carbon energy from renewables.

In summary, the EXTEND system delivered reliable heating and hot water, achieved significant load shifting through the 25kWh and 45kWh SHB, and maintained user comfort. While system efficiency was lower than expected during the trials because of valve issues, the integration of thermal storage and smart controls demonstrated significant potential for future optimisation and scalability.

5. Challenges and lessons learned

The EXTEND project, while successful in demonstrating the potential of smart electrification of heat, encountered a range of technical and deployment challenges that offer valuable insights for future trials. This section outlines the key obstacles faced during the project and the lessons learned, with a view to informing future innovation and deployment strategies in the sector.

5.0 Technical challenges

The initial LDESS1 system design incorporated potassium-formate as the working fluid to enable high-temperature operation. However, this fluid proved incompatible with certain heat pump components, leading to corrosion and system failure. Nitrogen purging was attempted to mitigate oxygen exposure, but the complex pipe network made complete purging impractical. LDESS2 addressed this by switching to water as the working fluid, simplifying the design and improving reliability.

Valve leakage was another issue: 4-port valves allowed unintended discharge from the space heating battery (SHB), reducing system efficiency. Although a better-sealing alternative was identified, it could not be implemented in time for the trial. Sensor accuracy also posed challenges. Clip-on temperature sensors introduced delays and inaccuracies, particularly during state transitions. Future designs will use probe sensors for direct fluid contact to improve responsiveness and accuracy.

Electrical failures were observed due to inductive loads causing relay damage. Snubber circuits were retrofitted to prevent voltage spikes, but several control boards had to be replaced. Software stability was affected by shared UART interfaces, which led to system reboots. Future systems will allocate dedicated channels for logging and control to enhance reliability.

5.1 Deployment challenges

Identifying suitable trial homes proved difficult. The Energy Systems Catapult (ESC) initially struggled to find properties that were suitable for heat pumps from amongst the shortlist after owners had registered interested in trial participation. Many would require radiator upgrades because the properties had high temperature combi-boilers and some properties did not have room for the larger radiators required for the lower flow temperatures required to keep heat pumps operating in their most efficient range. Also, some properties had microbore plumbing which would not have been compatible with the larger radiators either. Sunamp, through the installer network, decided to target homes with old systems that had already had significant repairs conducted upon them, and were no longer financially viable to maintain. These properties already had upgraded radiators and heat loss assessments, thereby reducing retrofit complexity. Working with homeowners familiar with the difference between high temperature radiators (gas boilers) and low temperature radiators (heat pump) avoided the associated learning curve.

The tight installation program schedule was difficult for the installers to fit around other commitments and to travel around the UK to undertake the installs. The documentation was evolving through the project and as the system was complex, some mistakes were made as the guides were misinterpreted early in the program. Additional meetings were scheduled when revised documentation was released to ensure all parties were informed of the releases of new schematics and enhanced version control of manuals was introduced. The commissioning process was complex and required a three-stage approach: initial installation, hydromodule deployment, and final commissioning. This phased strategy allowed for troubleshooting but added logistical complexity.

5.2 Lessons learned

Several lessons emerged from the EXTEND project that are critical for future trials. From a design and engineering perspective, early prototypes should be simplified to avoid over-engineering. LDESS1 was overly complex, whereas LDESS2's streamlined design proved more practical. Standardising components and connectors (e.g. RJ45 instead of uncommon RJ50) can reduce installation errors and improve serviceability.

Software and controls require robust fault recovery mechanisms and support for over-the-air (OTA) updates. The lack of OTA capabilities necessitated site visits for firmware updates, which is unsustainable at scale. The Android app used for system control was intuitive but needs iOS support and improved onboarding for broader accessibility.

Project management lessons include adopting a realistic scope and phased deployment strategy. The original plan for 100 installations was overly ambitious. A phased approach (e.g., 2 → 20 → 100 homes) would have allowed for iterative improvements. Installer training must include smart home technologies such as Modbus and CT clamps, and documentation control should be centralised and enforced.

5.3 Lessons for future trials

Due to program delays it was not possible to install all the systems ready for the winter months, therefore the system was not tested extensively in the most extreme conditions. However, the data from the limited number of properties operating through the winter did demonstrate that the system was able to maintain the required temperatures requested by the residents. To better quantify the performance, more detailed building assessments should be undertaken to understand the building fabric. Trial designs should prioritise homes with existing heat pump infrastructure to minimise retrofit challenges.

Hardware improvements should include redesigning the SHB to fit standard appliance dimensions, improving insulation, and replacing valves with low-leakage alternatives. Software enhancements should enable OTA updates, cloud analytics, and push notifications. Control strategies must be refined to balance user comfort with efficiency and enable dynamic grid response.

5.4 Policy implications and recommendations

The EXTEND project offers valuable insights into the future of smart electrification of domestic heating, highlighting both the technical challenges and feasibility of low carbon heat pumps and thermal storage as a grid friendly solution. The ability to manage the behaviour of multiple systems based upon historical consumption and future energy prices and carbon intensity demonstrated a scalable solution which could provide benefits through aggregation and support the net zero journey. Uptake is further enhanced as the solution supports consumer lead demand side response. Sunamp are supporting the development of standards such as PAS 1878 for Energy Smart Appliances and enabling secure, real-time communication between devices and grid operators. Such standards are critical to maximise the benefits of multi-technology and multi-vendor solutions.

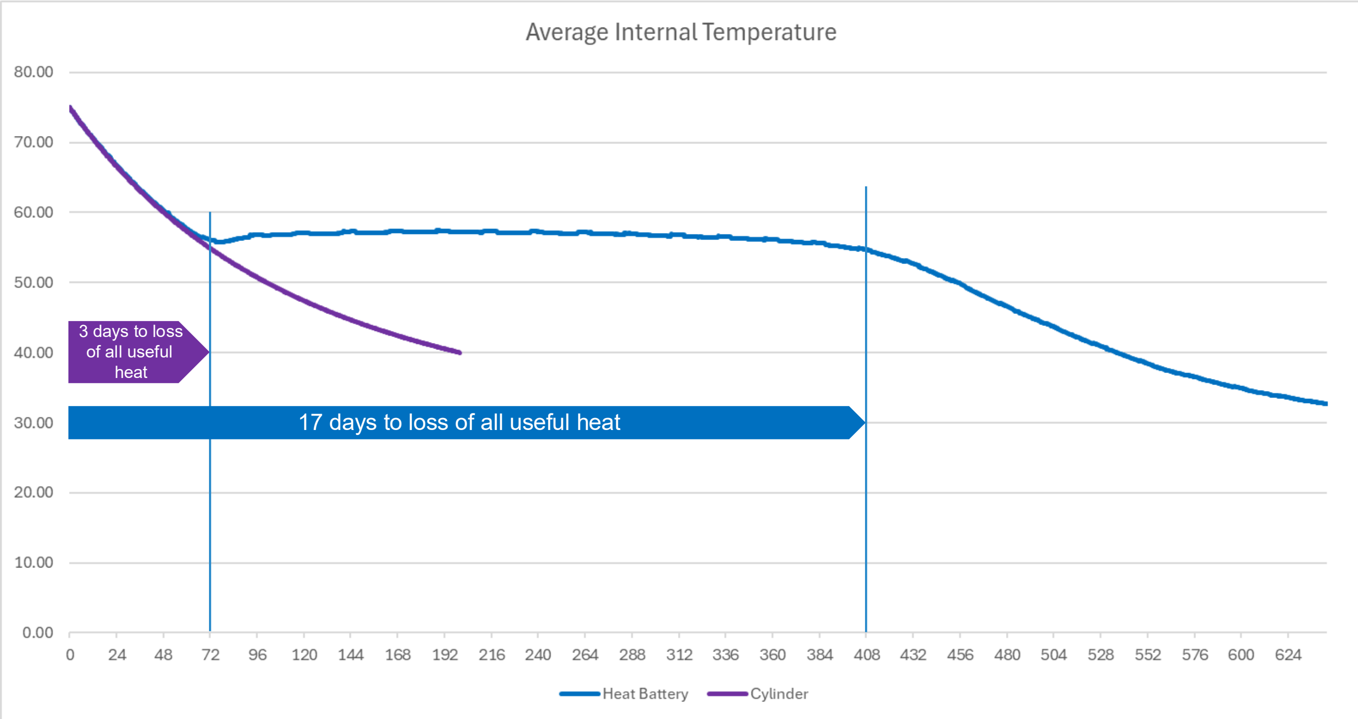
The Boiler Upgrade Scheme (BUS) recognises the flexibility and granular approach required to provide net zero solutions fit for a variety of homes and businesses. Since launching in 2022 the BUS has delivered over £485 million in grants and supported approximately 70,100 heat pump installations (Source: UK Government Warm Homes Plan, January 2026).

A government consultation response published in November 2025 highlighted the innovation and evolution of low carbon solutions since the launch by increasing the breadth of solutions supported by the scheme. Changes to the scheme will allow greater flexibility for consumers in choosing how to install their heat pump. It will also support further growth and innovation in consumer products that combine multiple technologies, such as installations of heat pumps alongside solar PV-powered hot water, electric batteries or thermal storage, which may improve system efficiency and running costs for consumers.

The EXTEND system demonstrated that PCM-based thermal batteries can deliver high energy density, long-duration heat retention, and compact form factors suitable for domestic use. Installations of these technologies will need to be MCS certified and heat batteries will be required to meet the MCS design and installation standard to be eligible for grant funding. Currently there are no product standards for the thermal energy storage performance of heat batteries. Sunamp are keen to support the development of the standards and ensure heat battery consumers in the BUS receive the same quality assurance and consumer protection as those installing heat pumps and other technologies.

Because the Sunamp PCM thermal batteries can retain heat for more than a week, much longer than other domestic heat storage systems, heat can be created from low cost, low carbon energy and dispatched several days later when there is a shortage of renewable generation and when demand must be bolstered by gas peaking plants; see Figure 17.

Figure 17. A graph to show the average internal temperature decay of a thermal battery vs conventional hot water cylinder storage system without any draw off. The diagram shows that the PCM battery when used for SH can retain their heat for a much longer period and retain useful heat to be dispatched when there is a lull in renewable generation.



Smart scheduling and load shifting capabilities were central to the EXTEND system's ability in reducing carbon intensity and energy costs. The system responded effectively to Time of Use Tariffs (TOUT), including negative pricing events, by shifting heating loads to off-peak periods. To maximize these benefits, policymakers should continue to promote the adoption of dynamic pricing models and further ensure that smart heating systems are interoperable with emerging tariff structures by supporting communication standards.

The field trial also revealed the importance of robust commissioning protocols, installer training, and system modularity. Future policy initiatives should include funding for installer upskilling in smart home technologies, including communication standards such as Modbus, energy metering systems and fault diagnostics. Installation approaches based upon independent industry experts and governing bodies is critical and regular Continuing Professional Development (CPD) to ensure the latest approaches are deployed.

To maximise the learning opportunities and benefits, research projects such as EXTEND should be designed around staged introductions of immature systems. Rather than aiming for large field trials early on, a small number of systems should be deployed to allow technology developers to focus on the engineering and control challenges and prove concepts. Once the concept has been tested, attention can turn to manufacturability and supply chain complexities. The revised approach to the EXTEND project showed that a staged rollout, from prototype to small-scale trial, can help identify and resolve technical and logistical challenges early, positioning the technology for subsequent broader development.

Finally, the integration of smart heating systems into demand-side response (DSR) services offers opportunities to increase grid stability. There is significant work underway by DESNZ through the Smart Secure Electricity Systems (SSES) Programme[2] which is looking at energy smart appliances regulations. Thermal storage systems which can shift demand such as EXTEND can participate in modulation services, reducing peak demand and supporting renewable integration.

In summary, the EXTEND project reinforces the need for coordinated policy action across technology development, market design, installer training, and consumer engagement. By supporting smart electrification and thermal storage, the UK can accelerate its transition to net zero while delivering cost-effective and resilient heating solutions for households.

[2] https://www.gov.uk/government/consultations/smart-secure-electricity-systems-sses-programme-first-phase-energy-smart-appliances-regulations

6. Conclusion

The EXTEND project demonstrated the feasibility and potential of integrating smart thermal storage, intelligent control systems, and heat pumps to support the electrification of domestic heating in the UK. Funded under the Longer Duration Energy Storage Innovation (LODES) programme, the project addressed key challenges in shifting heating loads away from peak periods, reducing carbon intensity, and realising benefits from Time of Use Tariffs (TOUT).

The system architecture composed of Sunamp's Plentigrade® P58 phase change material (PCM) thermal batteries, ECOForest heat pumps, and smart scheduling model, was successfully deployed and tested in five households. The properties varied from new build three story houses to barns which had been redeveloped into houses. Field trials revealed that the system could maintain user comfort, deliver reliable hot water, and shift energy consumption to periods of lower cost and carbon intensity. Heat pump efficiency averaged 2.88, and system efficiency (excluding hot water immersion heating) averaged 1.94. It can be inferred that user comfort was consistently maintained, with room temperatures staying within 2°C of setpoints over 90% of the time, and hot water battery state of charge remaining above 75% during scheduled periods.

Despite these successes, the project encountered several technical and deployment challenges. Issues such as valve leakage and sensor issues lead to the controller not responding as quickly as it could. Software was developed by multiple parties so there were the added complications of integration and testing remotely deployed systems. Issues which would have been easier to manage on a single test site close to workshops and engineering teams. The initial LDESS1 system, which used potassium-formate fluid, was ultimately replaced by the more reliable LDESS2 water-based system. Lessons learned from these challenges have informed recommendations for future trials, including the need for simplified prototypes, standardised components, improved fault recovery, and enhanced installer training.

The project also demonstrated the importance of robust data infrastructure and remote monitoring. The Smart Heating Controller (SHC), System Controller (SSC), and Whole Home Energy Controller (WHEC) enabled real-time data collection, remote diagnostics, and dynamic scheduling. Analysis of field data showed that all systems achieved net savings by responding to TOUT schedules, with cumulative savings ranging from £0.11 to £1.28 per day depending on household energy use and tariff variability.

There are several opportunities to improve the EXTEND system efficiency which was lower than simulated. This was largely due to sub-optimal scheduling and heat loss from the space heating battery. Due to heat losses, not all of the heat that was generated from low cost, low carbon energy was available for dispatch later in the day or the following day. This meant the round trip efficiency was lower than it could have been and reduced the overall efficiency. The scheduler logic could be improved to align the correct operating modes with the grid electricity cost and carbon intensity. This would enhance the system's cost-effectiveness.

In conclusion, the EXTEND project has laid a strong foundation for the development of smart, grid-responsive heating systems. It has provided valuable insights into system design, user interaction, and policy implications. With further refinement, the EXTEND architecture can play a pivotal role in supporting the UK’s transition to low-carbon heating and achieving net zero targets.

If you need a version of this document in a more accessible format, please email alt.formats@energysecurity.gov.uk. Please tell us what format you need. It will help us if you say what assistive technology you use.