Net Zero Terrace
End of Testing Report

Network Innovation Allowance

End of Testing Report

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1. Introduction

1.1 Project Context

1.1.1 Net Zero Terrace Overview

The Net Zero Terrace (NZT) project aims to establish an affordable, scalable pathway for retrofitting terraced homes. This is achieved by combining building fabric improvements, low-carbon heating through shared ambient loops and ground-source heat pumps, and community energy initiatives such as community solar and storage, with energy coordinated via a Smart Local Energy System (SLES). This addresses the poor energy efficiency and limited space of many terraced homes, where conventional air-source heat pumps can be difficult to install, while aiming to reduce energy costs, carbon emissions and pressure on the electricity network.

The Home Energy Management System (HEMS) is a foundational element of the architecture. Operating as the local intelligence hub, the HEMS coordinates domestic assets and connects individual households to broader community and network platforms. Successful HEMS integration is essential to:

- Reduce energy bills for residents, including vulnerable households.
- Maintain home-user comfort parameters.
- Improve resident thermal comfort.
- Unlock benefits of demand-side flexibility.
- Increase the self-consumption of locally generated energy.
- Support grid services.

1.1.2 SLES Architecture and the Role of the HEMS

Within the NZT architecture, the HEMS interfaces directly with home-level assets, including domestic battery systems, solar PhotoVoltaic (PV) inverters, Ground Source Heat Pumps (GSHPs), smart hot-water cylinders, smart Thermostatic Radiator Valves (TRVs), and thermostat systems.

The testing programme detailed in this document ensured that the HEMS could effectively fulfil its role within a community-scale SLES, providing the localised control necessary to aggregate and visualise behind-the-meter devices, respond to external flexibility and tariff signals, and maintain a safe, comfortable environment for consumers.

1.2 Purpose and Objectives

1.2.1 Purpose of Testing

The purpose of the HEMS testing programme was to provide an evidence based and repeatable assessment process to support the selection of an appropriate HEMS for the SLES architecture. Testing was designed to evaluate the capability of commercially available HEMSs within a controlled laboratory environment, enabling direct comparison of their suitability against the requirements defined in the NZT programme.

The objective of testing was to establish an evidence base that could support HEMS selection and identify the extent of additional development necessary for the selected HEMS to meet the functional and technical requirements of the NZT SLES architecture. This reduces deployment risk by enabling an informed technology selection process and providing early validation of integration, control and interoperability requirements prior to implementation.

To provide a representative testing environment, the laboratory test rig was configured using assets aligned to those installed within the Rossendale three home demonstrator (a parallel Innovate UK funded "Net Zero Living" project). This enabled the assessment of HEMS capabilities against a realistic domestic technology stack. The assets and test methodology were defined within the NZT HEMS test rig specification and the HEMS test specification respectively.

Testing was undertaken across three progressive phases following the commissioning of the test rig:

- Test Rig Development and Commissioning
- Phase 1: HEMS Connectivity and Communication Testing
- Phase 2: Native Capability Testing
- Phase 3: External Control and Optimisation Testing

1.2.2 Purpose of This Document

This report summarises the results and learnings obtained from the laboratory testing of the shortlisted HEMS providers against the test cases defined within the NZT HEMS test specification. It provides a structured assessment of HEMS integration, monitoring and control capabilities across the core domestic assets evaluated during testing, including: Domestic Hot Water (DHW) systems, Heat Pumps and TRVs, Battery Energy Storage Systems (BESS) and Inverters and Solar PV Systems.

In addition to presenting the testing outcomes, this document provides the evidence base required to define current off-the-shelf HEMS capabilities and compare these against the requirements of the NZT SLES architecture. The findings presented within this report are intended to directly inform the subsequent NZT HEMS gap analysis report and HEMS interoperability strategy.

Specifically, this document covers:

- **Building & Documenting the Test Rig Architecture:** Detailed and evidenced the completed setup, commissioning, and validation of the physical testing environment designed to mimic a home.
- **Developing the Software Development Environment:** Developed and configured a software environment to connect, monitor, and record data from all the smart energy devices, through the HEMS.
- **Presenting Phased Testing Evidence:** Delivered findings from phased testing regarding capabilities including data integration, interface usability, and data export capabilities.
- **Analysing Future System Interoperability:** Evaluated the feasibility of integrating third party signals and user interfaces required for integration with Community Energy Management System (CEMS) frameworks and Distribution Network Operator (DNO) signals, to inform future DNO and CEMS interface design.
- **Defining Development Gaps:** Identified functional gaps between current market solutions and the requirements of the NZT project, to feed into the NZT HEMS gap analysis report.

1.2.3 Project Governance and Assurance

The testing program was delivered under a collaborative project governance framework to ensure compliance with the overarching system functional requirements:

- **Looped Energy Communities (LEC)** was responsible for sourcing equipment, setting up and commissioning the test rig, and executing the structured testing phases to scope and program.

- **Buro Happold (BH)** acted as the Design Authority, conducting regular reviews of the testing processes, outputs, and progress. BH also served as the witness for acceptance testing and documenting observations.
- **SP Electricity Northwest (SP ENW)** provided feedback on the test rig design and reviewed the test results to ensure alignment with operational grid requirements and future CEMS demonstrations.

2. Testing Framework

2.1 Reference Documentations & Following Project Deliverables

The testing was conducted in accordance with the following NZT documents:

- **HEMS Test Rig Specification:** Outlined the scope and requirements for the design, assembly, and commissioning of the lab-based HEMS test environment. The requirements in the document covered the physical and network architecture requirements of the LEC testing facility, along with meeting safety and documentation standards required for witnessed acceptance testing by project partners.
- **HEMS Test Specification:** Outlined the testing approach, refined from the original two-phase structure into three. This was done to separate basic asset integration and native HEMS functionality from additional tests assessing HEMS response to external SLES signals. Phase 3 specifically addresses HEMS-to-CEMS readiness, strengthening the link from HEMS testing to gap analysis, interoperability strategy, and future SLES implementation.

The outcomes of this testing feed into the following documents:

- **HEMS Gap Analysis Report:** Documents the findings from the HEMS testing activities and assess the current tested HEMS functionality against the CEMS specification, test specifications, and the HEMS MVP criteria (within the NZT MVP Definition Iteration 2 document). Based on the testing results, proposed solutions will be identified to address any functional gaps and ensure compatibility with the wider system requirements.
- **HEMS Interoperability Strategy:** Outlines the requirements and approach for achieving HEMS interoperability with the SLES framework. It will define how gaps identified in the D6.2 HEMS Gap Analysis Report will be addressed to meet system architecture and integration requirements. The strategy will cover the required functionality and development approach, with delivery expected through an Agile sprint-based methodology.
- **Witness Testing Report:** Records observations, findings, and results from the witness testing activities undertaken during the project including evidence of system performance, interoperability testing outcomes, and issues or recommendations identified.

2.2 Testing Scope and Limitations

The test rig provided a representative environment to compare HEMSs and assess suitability for progression into the NZT project. Testing focused on integration performance, data visibility, control pathways, response to external signals, and readiness for future HEMS-to-CEMS interaction. The setup did not replicate real-world thermal, hydraulic, installation, or customer conditions. Results therefore reflect evidence of integration performance under controlled lab conditions to support the selection of the HEMS with the most suitable route to SLES integration, rather than validation of field performance.

Key constraints within testing included simulated PV input, a static hot water tank, lab-based ground loop conditions, and limited supplier-specific integration routes, which were considered when interpreting the results. Whilst the assessment was primarily based on physical laboratory testing, relevant discussions with suppliers were also used to provide context where capabilities could not be directly tested, including situations where integrations, asset compatibility, or functionality had not yet been commercially developed or made available. These discussions were used to support interpretation of the findings and identify potential future development opportunities.

This report is not a procurement assessment or commercial endorsement, and any deployment decision would require further commercial, legal, cyber security, operational, and field validation.

2.3 Structured Testing Phases

The testing programme was structured into pre-testing and three formal test phases, as outlined in Table 1. Pre-testing covered initial rig set-up and commissioning equipment. Phases 1 to 3 then assessed each HEMS in increasing levels of complexity, moving from basic asset connectivity through to native HEMS capability and external control readiness.

Table 1 – Summary of the key focus and activities for each stage of testing.

Testing stage	Focus	Summary of activity
Pre-testing: Test Rig Development & Commissioning	Physical setup and asset validation	Pre-testing identifies and documents the laboratory assets and equipment to be included within the testing programme, as well as the HEMS providers selected to participate in the assessment.
Phase 1: Connectivity & Communication	Basic HEMS connectivity and data access	The test rig was built and commissioned in line with the HEMS test rig specification, with core assets installed, connected and individually validated prior to HEMS integration. Each HEMS was then connected to assess communication with the installed assets and access to core telemetry. Physical integration requirements, communication routes and asset-specific configuration steps were documented, with integration findings recorded as pass/fail outcomes with supporting commentary.
Phase 2: Native Capability Testing	HEMS functionality, usability and asset control	Each HEMS was tested for its native operational capability, including asset visibility, control functions, scheduling, data capture, interface usability and export capability. Results were captured in a structured test inventory with laboratory observations and supporting evidence where available.
Phase 3: External Control & Optimisation	HEMS to CEMS readiness and external signal response	Testing focused on whether each HEMS could interact with external systems, including a Fairer Warmth user interface and a remote CEMS. This included testing Application Programming Interface (API)-based data reads, schedule updates, price signals and asset setpoints from an external control server.

This phased approach allowed the project team to separate basic asset integration from wider SLES-readiness. It also provided a clear evidence route from rig commissioning and HEMS functionality testing into the NZT HEMS gap analysis report and HEMS interoperability strategy, and future SLES implementation planning. The testing schedule in **Error! Reference source not found.**, shows the original test plan agreed with the laboratory team including intended entry and exit criteria for each phase, along with the evidence outputs required to demonstrate completion.

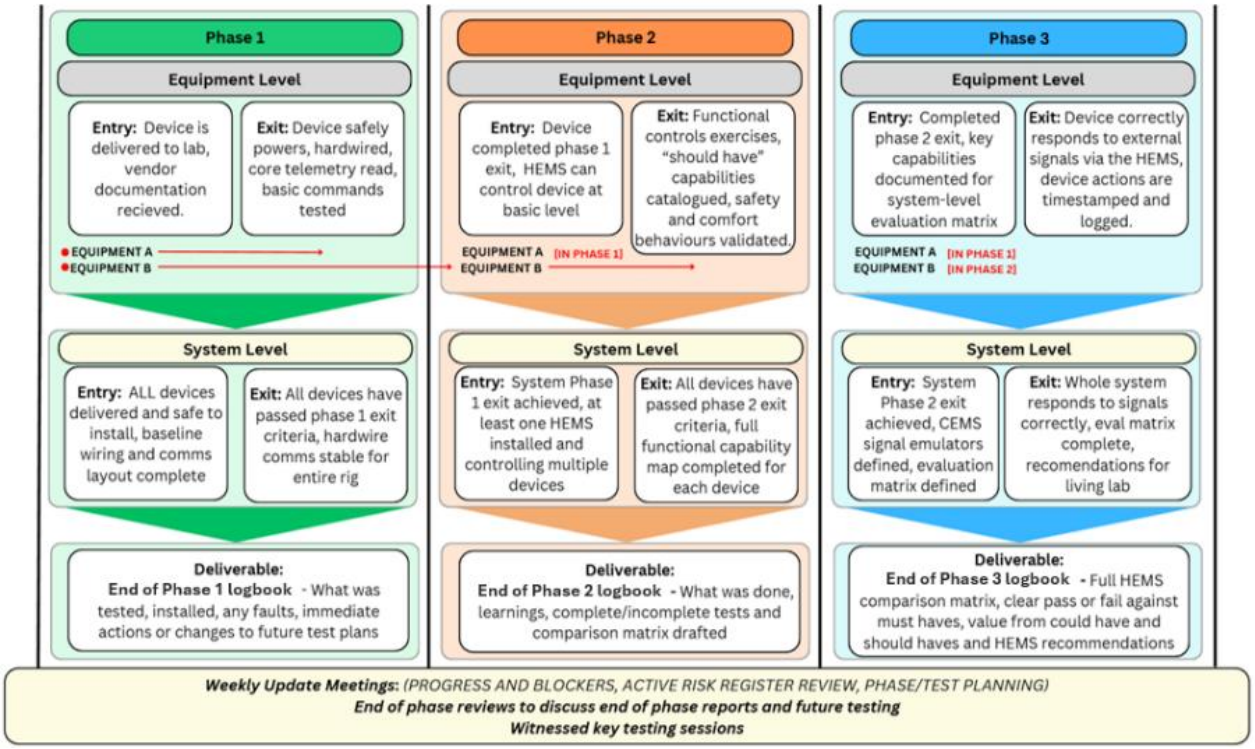


Figure 1 - Testing schedule

2.4 Results Capture and Documentation

Results across all three testing phases were captured using a combination of structured observation records, photographs, screenshots, and vendor discussion notes. Each testing phase had a defined set of requirements, which are described in more detail throughout this document and provided in the appendices. During testing, these requirements were further broken down into specific, actionable tasks, with each task assigned its own test ID. Results were recorded progressively throughout the testing programme and linked to the relevant requirement and test ID, allowing them to be traced back to the original testing requirements.

Phase 1 findings were recorded as a write-up of the commissioning process, with content structured by asset and HEMS platform. These findings were supported by screenshots of the HEMS dashboards and native apps, alongside photographs of the physical test rig. A Phase 1 test checklist mapped each test ID to its parent requirement, identified whether testing was at rig or individual HEMS level, and provided a traceable record of the commissioning test undertaken and the outcome observed (pass/fail).

Phase 2 results required more detail than a pass/fail outcome and were therefore recorded in a structured spreadsheet that provided an inventory of learnings against each requirement and test ID. Each test ID was divided into sub-rows for the specific asset tested, with columns capturing lab observations, HEMS limitations, and supporting evidence for each HEMS platform. Screenshots and records of anomalies were linked to the relevant test ID where applicable. This structure allowed findings to be captured in greater detail and reviewed by requirement, asset, or HEMS platform.

Phase 3 used a similar spreadsheet to capture an inventory of learnings for Home Assistant, where physical integration testing was undertaken. For SmartQube and Passiv/Levelise, where direct lab testing was not possible within the programme scope, findings were captured through vendor discussions and available product documentation. Questions asked within vendor meetings focused on resolving specific points against the relevant test IDs. These findings are clearly identified throughout the report as vendor-stated rather than lab-verified.

Relevant photographic and screenshot evidence has been included in the main report or compiled in the Appendices.

3. Test Rig Development and Commissioning

The HEMS test rig was designed and commissioned in line with the NZT HEMS test rig specification for a lab-based simulation of a single home within the Net Zero Terrace scheme. The specification defined fourteen requirement categories, covering structural design, electrical and thermal capacity, communications architecture, instrumentation, safety, and simulation capability. Its purpose was to verify HEMS performance, safety, and interoperability under controlled laboratory conditions before deployment in the Lab.

3.1 The Test Rig Equipment & Components Set Up

Testing was conducted at LEC's laboratory facility using a purpose-built HEMS test rig designed to replicate the key elements of a residential energy installation under controlled conditions. Table 2 below outlines the key physical domestic energy assets that the LEC lab was equipped with, including the method of testing its integration into the rig:

Table 2 - List of Physical Hardware Assets Included in the Test Rig.

Asset Type	Reason for Testing	Model (As Tested)	Method of Testing Rig Integration
Domestic Hot Water (DHW) Tank	Simulate a flexible thermal load with inherent energy storage capability and scheduling potential	Mixergy Cube X	DHW tank is visible & controllable through Mixergy app.
Ground Source Heat Pump (HP)	Simulate an electrical load with inherent scheduling potential	EcoForest L3 230 1-6 PRO	HP is visible & controllable through EcoForest app.
Thermostatic Radiator Valve (TRV)	Provision of room-level heat demand indication	Tado TRV Device	TRV visible & controllable through Tado app.
Battery & Inverter (B/I)	Controllable electrical storage enabling bidirectional grid interaction	FoxESS: H1-5.0-E-G2-WL (Inverter) FoxESS: EP6 (Battery & PV interfacing)	Battery is visible & controllable through FoxESS app.
Home Energy Management System (HEMS)	Aggregation, monitoring, and, where supported, direct control of connected assets	3 Selected, More Details in Section 3.3 Below	Interaction with HEMS vendor interface & Connectivity with other assets in the rig (Covered in Phase 1 Testing).

Where real-world conditions could not be replicated directly, controlled emulation was used to maintain representative behaviour within the laboratory. The LEC lab was therefore equipped with the following simulations:

- **A simulated PV system** was used to replicate domestic PV generation. This was achieved using a programmable DC power supply controlled through scripted time-varying generation profiles (informed by local irradiance profiles), with PV output visible through the FoxESS platform.
- **The heat pump's ground source** was simulated using external pipework and an inline immersion heater (Willis heater) to provide a controllable thermal source in place of a buried ground array. The circuit was filled, pressurised, and air-purged to ensure stable operation and integrated directly into the heat pump loop.

The following additional conditions applied to the test rig configuration:

- **Domestic hot water draw-off** was not implemented as part of the test rig; consequently, the hot water tank operated as a filled static system throughout testing.
- **Network Architecture:** A dedicated 4G router (MERCUSYS MB115-4G) provided local networking and internet access, replicating a typical domestic setup while enabling controlled assessment of both cloud-based and local integrations. During Phase 1, devices were connected via the Looped Demo SSID.

3.2 HEMS Providers Overview

3.2.1 Selecting HEMS Providers for Testing

Detailed in the associated document, the 'Finalisation of HEMS Providers', initial engagement with a series of HEMS suppliers was guided by high-level functional requirements aligned with the SLES objectives. These focused on consumer comfort, energy optimisation, and system flexibility through automated heating control, adaptive learning, energy monitoring, intelligent scheduling, and integration with technologies such as heat pumps, PV, battery storage, TRVs, and IoT sensors. Requirements also included interoperability with future flexibility services and compatibility with the emerging CEMS functionality.

To assess these potential solutions, an evaluation matrix was developed to compare the HEMSs against the project requirements using weighted scoring criteria. The assessment considered technical and commercial maturity, including Technology Readiness Level (TRL) and Commercial Readiness Level (CRL), alongside user interface quality, third-party asset integration, use of external data sources, heating and electrical load control, diagnostics, and support for open standards:

Supplier engagement was also considered as part of the selection process. In particular, the project considered each supplier's willingness to collaborate with the project team during integration and testing.

3.2.2 Commissioned Home Energy Management Systems

Following the HEMS market evaluation, three HEMS providers were selected (See Table 3) based on their market presence and potential role within the wider SLES framework.

Table 3 - Summary of HEMS Providers Used in Testing.

HEMS Device	Provider	Description
Home Assistant Green (HA)	Open Home Foundation	Open-source smart home hub for device automation.
SmartQube Hub	QEnergy AI	AI-driven HEMS optimisation and automation platform.
Passiv Smart Thermostat (PST) & Levelise Hub *(tested as a combined solution)*	PassivUK	Intelligent home heating control and optimisation. Optimised for heat pumps.
	Levelise	Centralised HEMS monitoring, integration, and energy management, focused on battery optimisation.

Further details on the technical specification of these HEMS units can be found within the NZT SLES NIA HEMS Specification document, and below are a brief explanation of each HEMS device and their core functionalities:

Home Assistant: HA is an open-source smart home hub that enables users to remotely control their Internet of Things (IoT) energy devices. It consists of versatile, customisable dashboards to enable users to display information about their home devices, as well as automation options to set schedules and user preferences[1]. By using a rule-based automation system, it enables complex routines and remote monitoring while maintaining local data control to ensure user privacy and offline functionality.

SmartQube: The SmartQube is a device developed by QEnergy Artificial Intelligence (AI) that connects and manages home energy devices through a single hub. Using AI-driven optimisation, it monitors real-time user energy usage, tariffs, weather forecasts, and connected assets - including batteries, heat pumps, solar PV systems, and smart appliances - to automatically control energy consumption. The system forecasts demand and generation to reduce electricity costs, maximise solar self-consumption, lower carbon emissions, and optimise financial returns[2].

Passiv Smart Thermostat (PST) & Levelise Hub: Passiv is a smart thermostat device designed to control heat pumps, optimising their use to smart energy tariffs and solar PV generation, enabling reductions on home user energy bills[3]. It functions by learning a home's thermal characteristics and using local weather forecasts to preheat spaces at the most efficient times, which can increase heat pump efficiency by up to 17%[4]. Additionally, it integrates with time-of-use energy tariffs and rooftop solar panels to automatically shift heating loads to periods when electricity is cheapest or free, reducing overall energy bills.

The Levelise hub is a smart energy management solution designed to be integrated with solar and battery storage devices, optimising use and performance of these assets, to reduce bills and optimise revenue[5]. By operating a battery according to the needs of the electricity grid, Levelise can earn their users money by shifting their energy consumption away from peak times, through charging and discharging in response to grid demand or fluctuating electricity prices.

[1] https://www.home-assistant.io/
[2] https://qenergy.ai/smart-qube
[3] https://www.passivuk.com/
[4] https://www.passivuk.com/passiv-smart-thermostat/
[5] https://www.levelise.com/

4. Phase 1 Testing: Connectivity & Communication to HEMS Software

Before evaluating the control capabilities of each HEMS, Phase 1 focused on commissioning the test rig and establishing reliable communication between the HEMSs and connected energy assets within a controlled laboratory environment. The scope was intentionally limited to commissioning, connectivity, and interoperability testing, while optimisation algorithms, tariff response, and community-level coordination were reserved for later phases. The primary objectives were to safely commission each asset, establish communication with the HEMSs, assess the practicality of different communication methods, and identify interoperability barriers such as documentation gaps, configuration complexity, and vendor-imposed constraints. To provide a structured and traceable basis for testing, Phase 1 was governed by six key requirements, each addressing a distinct aspect of system readiness, with the full list provided in Appendix A – Phase 1 Testing Requirements.

Testing followed a consistent process for each asset: physical installation and wiring, commissioning through the native vendor application, and subsequent integration of the assets with the HEMS devices. Where multiple communication pathways were available, including local protocols and cloud APIs, each was assessed.

4.1 Asset Installation and Commissioning Outcomes

This section details the installation, configuration, and commissioning of the energy assets and HEMSs within the laboratory test environment. Appendix B – Test Rig Commissioning Evidence contains photographs of the test rig items and screenshots of vendor applications, providing evidence of successful asset integration and functional operation.

4.1.1 Mixergy Hot Water Tank

Mixergy uses patented stratified heating technology to provide real-time visibility of hot water availability and optimisation based on tariffs and renewable forecasts, with claimed integration across PV and heat pump systems for some of their products. For the Cube X product family, published datasheet specifications include physical dimensions and electrical requirements, including physical dimensions and power supply requirements (16A supply at 230V). The Cube X was selected for the test rig because it provided a compact smart hot water cylinder suitable for testing digital monitoring, charge level visibility, electric heating control and HEMS integration within a simplified laboratory setup.

In this testing, the tank was connected to mains power and filled with water to enable normal sensing and communications behaviour. It was not connected to a heat pump for the purpose of this asset testing, as the specific hot water tank supplied (CubeX) does not support direct integration with a heat pump, therefore, only the internal electric heating element was used. Domestic hot water draw-off was also not implemented. The tank therefore operated as a static filled system, sufficient to validate communication with the HEMSs, response to control setpoints, and the ability of the hot water system to respond to external control signals, including flexibility events and other optimisation instructions.

The Cube X includes a thermostatically controlled mixing outlet, which allows stored water to be delivered at a consistent temperature above typical domestic supply level. This enables hotter water to be stored and then mixed down at the point of use, allowing a smaller volume of stored water to provide a greater volume of usable hot water at the required temperature. This characteristic can increase thermal storage flexibility, supporting greater utilisation of low-cost electricity, renewable generation and future flexibility service provision, despite the relatively compact tank size.

Vendor App Commissioning: Native commissioning via the Mixergy mobile app was straightforward. As described in the Mixergy Cube X user guidance, scanning the QR code on the tank linked the unit to a user account, and any target level adjustments set in the app were applied immediately, with heating relay activation audibly confirmed. In the lab setup, the tank was connected via hard-wired Ethernet to the site router, meaning app access and remote control depended on network and internet (Wide Area Network (WAN)) availability. The app (Figure 2) displayed hot water level, temperature, and energy use over time. A daily automated high-temperature pasteurisation cycle was observed for legionella cleansing, typically running overnight but configurable. With no hot water draw-off during testing, energy use was low (around 1 kWh/day) and mainly reflected standing heat losses, indicating strong thermal retention. As with other asset apps, some end-user controls via the Mixergy app, including schedule settings and target setpoints, overlap with controls available through the HEMS integrations (detailed more in Phase 2), highlighting a governance consideration for community-scale deployments where occupant app-access may need to be managed, or intentionally designed into the control architecture to avoid conflicts with system-level optimisation.

Also, because the app relies on the home network and vendor cloud services, visibility and remote control depend on a stable Ethernet/Local Area Network (LAN) connection and, where applicable, internet access; loss of connectivity will degrade or remove app-based monitoring and control. This reinforces the importance of local, well-documented integration pathways (e.g. Modbus/Transmission Control Protocol (TCP) where available) to support more resilient operation.

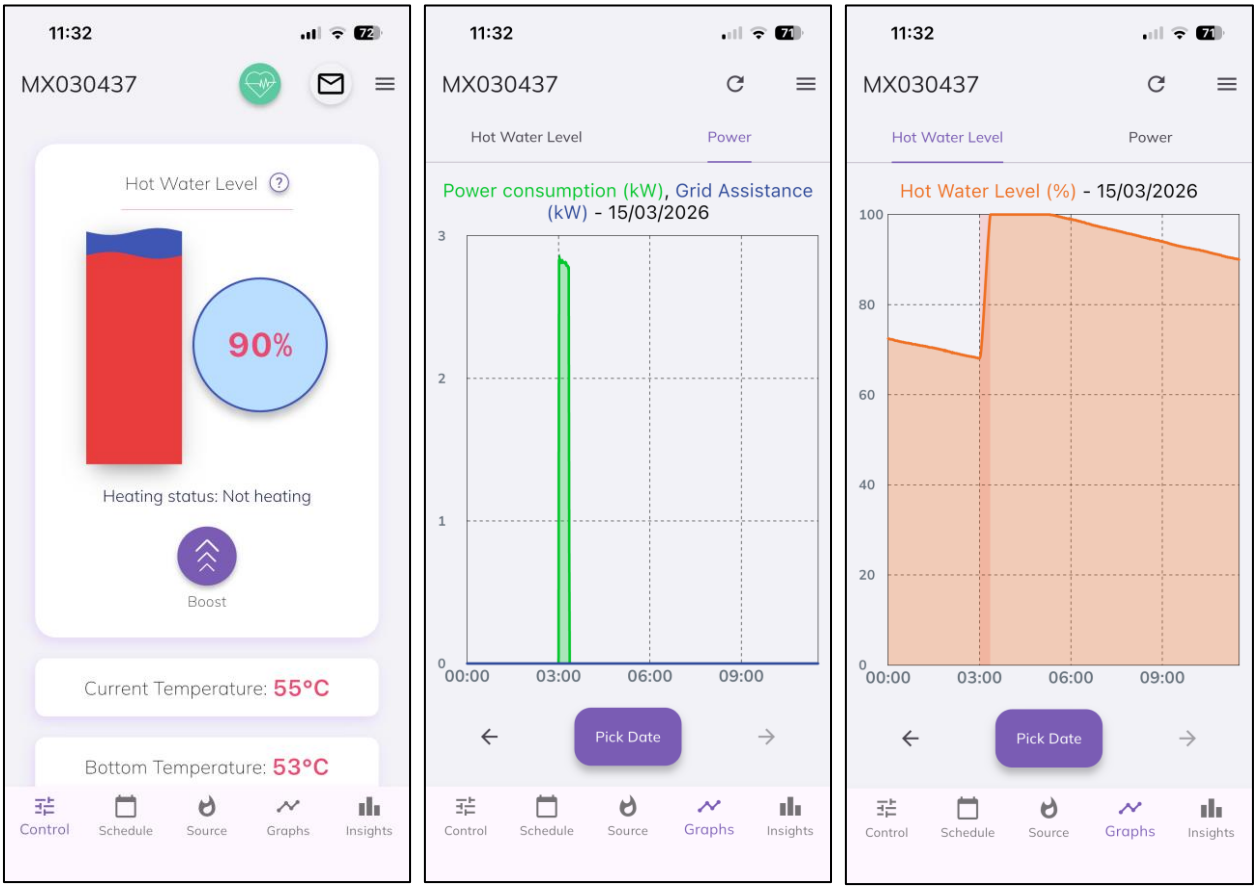


Figure 2 - Images from the native Mixergy app showing (left) hot water level and ability to boost, (middle) electricity use, and (right) hot water level as a function of time.

4.1.2 EcoForest Heat Pump

Commissioning the EcoForest HP (HP) required more involved setup than the other assets. Two hydraulic connections were made; the ground loop (emulated via external pipework and a Willis immersion heater), and the central heating circuit (two radiators connected in parallel, one permanently open to maintain minimum flow). Once connections were complete, the system was filled and pressurised with air release valves installed at high points to purge air from the circuit and support stable circulation.

Electrically, the heat pump was supplied from a 16A single-phase circuit. An external temperature sensor and thermostat input were wired in to simulate normal operation. Although the terminal block labelling for the temperature sensor was slightly unclear, the terminal numbering matched the operating manual, allowing correct connection. The thermostat input was configured to emulate a room thermostat calling for heat via an open/close signal. Finally, the supplier-provided EcoForest Easynet gateway was connected via RS485 using a 30 m cable to support integration testing with the HEMS devices.

Vendor App Commissioning: The EcoForest heat pump was connected to the supplier-provided Easynet gateway, which provides access to system status and settings via a dedicated interface. The gateway was initially commissioned locally via Ethernet and then connected to the laboratory network and internet through a MERCUSYS MB115 4G router. Once online, the EcoForest interface displayed a system schematic with key operating data, including loop pressures (left image in Figure 3 below, showing about 2 bar for the ground/heat pump loop and 0.9 bar for the heating loop), as well as programming and setpoint options. Data is exchanged with the heat pump controller via a Modbus-based interface, so similar telemetry could be exposed to third-party HEMSs if access and register mapping are available to be configured. The interface also provided basic control (on/off) and live performance data including electrical demand, COP, instantaneous power, and power factor.

The gateway's installer menu provided access to advanced configuration parameters, including communications settings such as the baud rate and device ID used for the controller interface. It also enabled adjustment of key control logic, including the weather compensation (heating) curve (Figure 3 on the right), which defines the target flow temperature as a function of outdoor temperature, as well as domestic hot water setpoints, where applicable. These settings directly influence the heat pump's operational behaviour and efficiency, and form part of the control framework that an external HEMS may seek to monitor or influence for optimisation purposes.



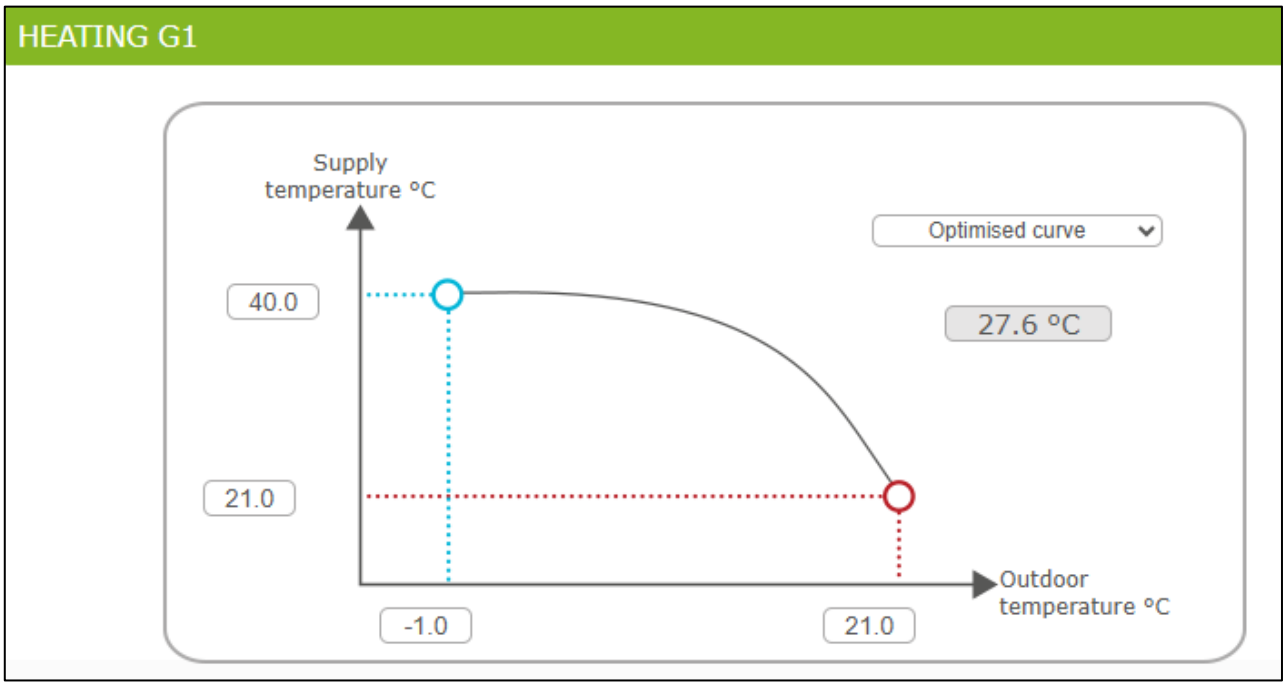


Figure 3 – (Top Image) Eco Forest gateway connection. (Bottom Image) Installer panel images from EcoForest heat pump.

4.1.3 Tado TRV

The Tado smart thermostat system, used to represent room-level heat demand signalling and zoning, was the simplest asset to install physically. Three key components were commissioned: the Tado Internet Bridge, which provides connectivity to the Tado cloud service, was powered and connected to

the laboratory router via Ethernet; the Smart Radiator Thermostat, providing per-radiator temperature measurement and valve control, was installed on one of the central heating radiators; and the room thermostat / Wireless Temperature Sensor, used to measure room temperature and generate a heat demand signal, was positioned nearby as an independent temperature reference. Once paired, both the TRV and room thermostat reported ambient temperatures correctly, confirming that the tado ecosystem was functioning as expected, prior to HEMS integration.

Vendor App Commissioning: The native Tado app (shown in Figure 4) supported scheduling, manual overrides, geofencing (home/away control based on occupant location), and open-window detection, typically included within the Auto Assist feature set (but availability depending on subscription and product version). The app also provided system status information and, in some configurations, energy insights and reporting to help users understand heating demand and system performance. Configuration settings remained directly accessible to end users through the app, presenting similar governance considerations to the other vendor applications within a community-coordinated context. In addition, app functionality depended on the Internet Bridge and continuous cloud connectivity.

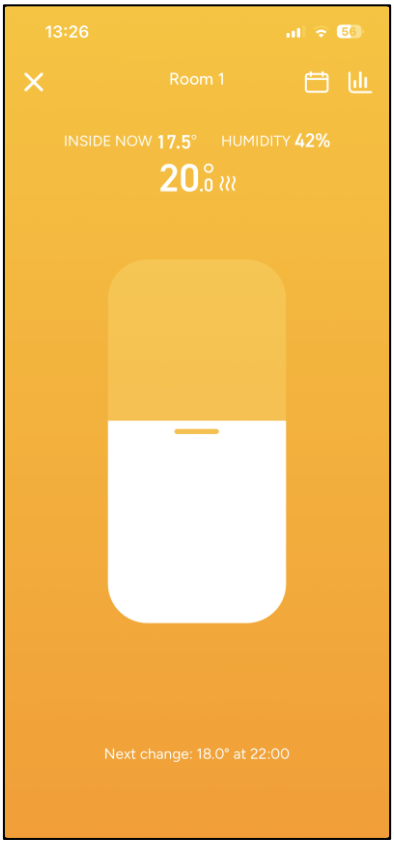


Figure 4 - Example of room temperature control within the Tado app.

4.1.4 FoxESS Hybrid Inverter, Battery, and PV Supply

The Fox ESS inverter and EP6 battery were straightforward assets to commission, largely due to the use of manufacturer-supplied pre-terminated cabling and clear documentation. The commissioning sequence was as follows: the inverter was energised via a 16A mains lead from an AC supply, the battery was then connected to the inverter using the pre-supplied power cables and CAN bus link for BMS communication. A current transformer was installed for grid import/export measurement at the point of connection, and RS485/Modbus wiring was installed to enable HEMS monitoring and control. Modbus communication operated reliably, allowing immediate validation of live telemetry and interface behaviour; Home Assistant used an RS485-to-Universal Serial Bus (USB) adapter, while

SmartQube and Levelise were connected directly via their RS485 ports. Once commissioned, the system operated as expected, with PV input emulated using a programmable DC supply controlled by scripts based on time, date, and historic solar generation data to produce time-varying profiles. This allowed the inverter to operate as though connected to real PV generation without requiring physical solar panels, enabling repeatable testing under controlled laboratory conditions.

Vendor App Commissioning: The FoxCloud mobile application was straightforward to set up. Following account creation and Ethernet connection of the inverter, the app provided immediate remote visibility of real-time operating data, including PV generation, battery State of Charge (SoC), AC voltage and frequency, and grid import/export. It also provided historical energy summaries, error summarise, and basic device configuration functions.

The app (Figure 5) provided access to inverter control settings, including charge and discharge mode, scheduling, and battery reserve limits. These functions are useful for commissioning and diagnostics, but they also create a potential governance consideration for future deployment. If occupants or unauthorised users can manually adjust schedules, operating modes or reserve levels, this could conflict with community-level optimisation or agreed control strategies. Future deployment would therefore need clear controls around user permissions, control hierarchy, audit logging and whether users can access all device functionality through vendor applications.

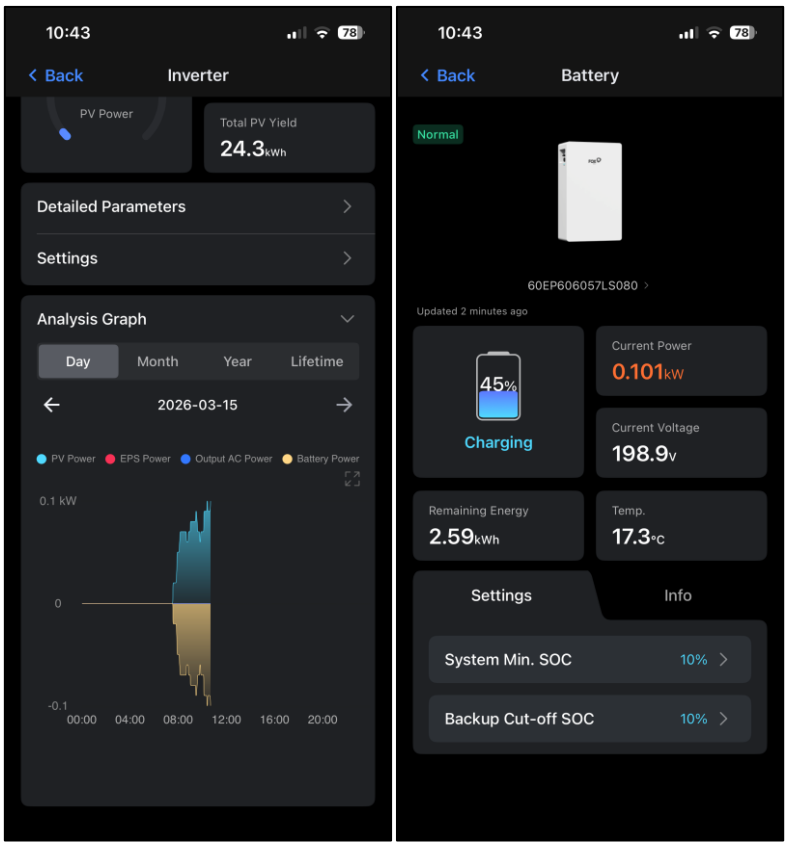


Figure 5 - Example Screenshots from Fox Cloud App (Manufacturer Supported)

4.1.5 HEMS Installation & Commissioning

Asset commissioning began by connecting the HEMSs to the laboratory network via the dedicated 4G router (MERCUSYS MB115-4G) to bring them online.

Home Assistant connected to the router network with minimal effort, with the web interface available almost immediately and no credential provisioning or network reconfiguration required. Asset integration could therefore begin within minutes of powering on the device.

The application was highly customisable. On the back end, all available asset registers (essentially any Modbus connected device with its own register) could be imported and viewed, as shown in Figure 6. Depending on the asset vendor, some registers were controllable while others were read-only. Once registers of interest are integrated, users could create customised dashboards ranging from simple control buttons (e.g. on/off control button for a heat pump) to more detailed room-level views, including charts, energy flows, and overview summaries (Figure 7).

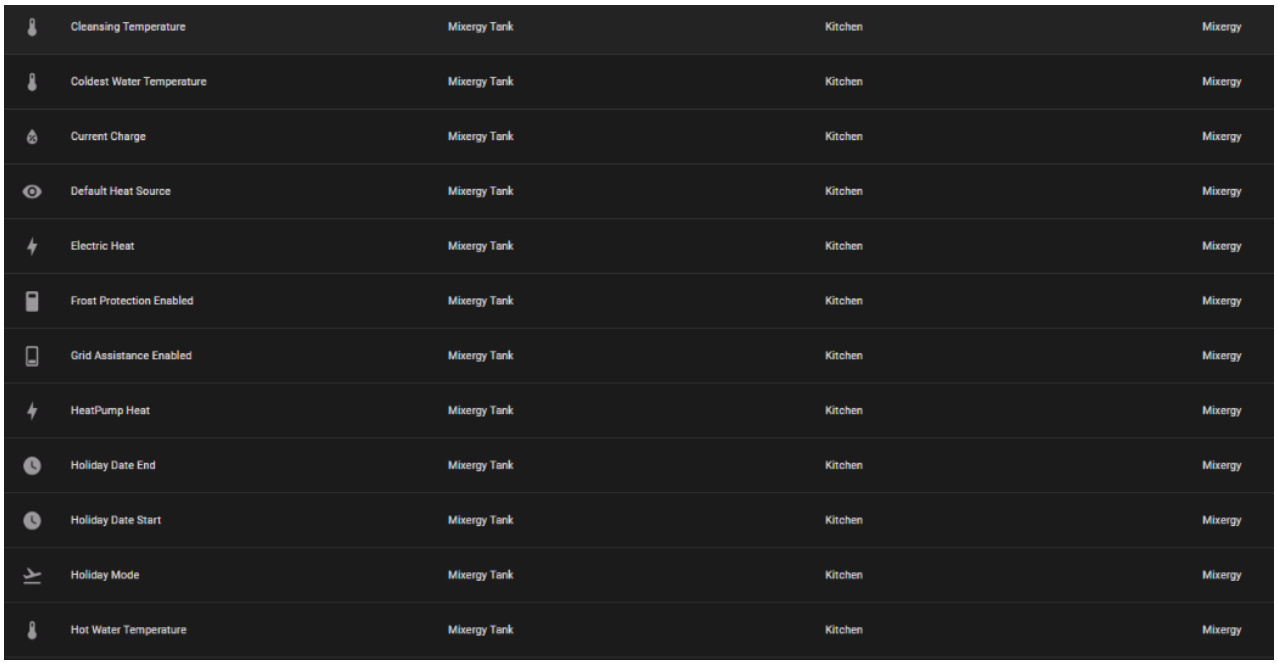


Figure 6 - Example view of listed asset registers available to add to customisable dashboard.

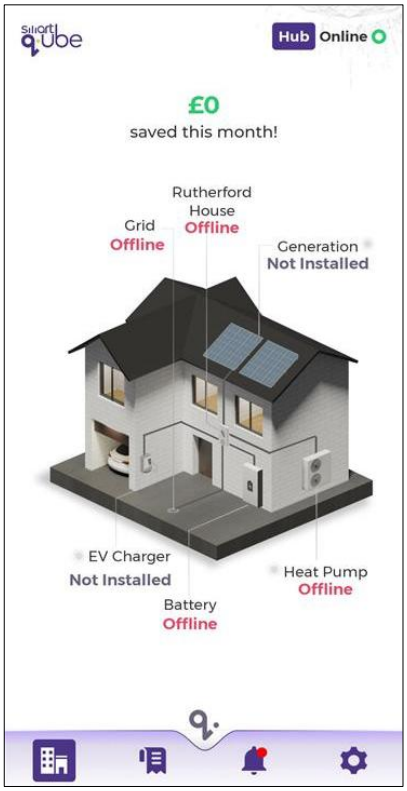


Figure 7 – Example of configurable charts and dashboards in Home Assistant.

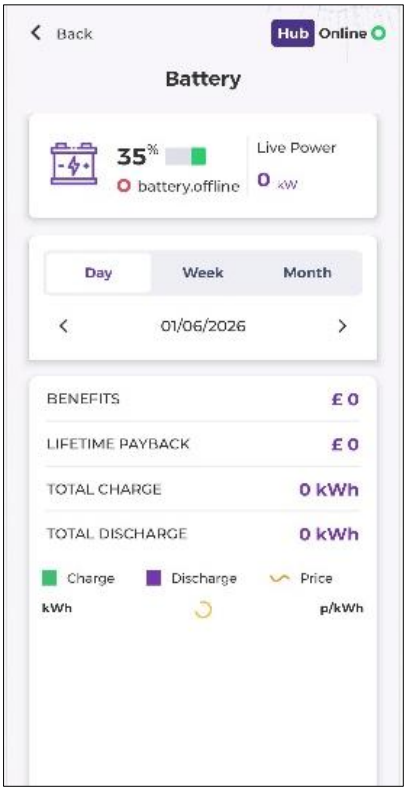
SmartQube required additional setup as installation guidance and installer access information had to be obtained from the manufacturer. The default network settings were incompatible with the router's IP/DHCP configuration, so manual network parameter reconfiguration was required to achieve stable LAN connectivity. Once online, SmartQube provided two web-based interfaces: a homeowner dashboard for day-to-day oversight (Figure 8) and an installer interface for commissioning and more detailed configuration (Figure 9). Their mobile app provided a simple and user-friendly resident interface, as shown below, but offered limited direct controls. This is because SmartQube is designed to manage most asset operation and optimisation automatically. Compared with Home Assistant, which exposes a wider range of entities via Modbus, SmartQube's user-facing dataset is more limited. This is suitable for resident oversight but does not provide the necessary access to detailed engineering diagnostics.

During testing, the vendor worked with the project team to add selected asset registers to the installer dashboard with additional registers available for future incorporation. The homeowner dashboard remained less adaptable, as it is designed as a standard interface across SmartQube customers.

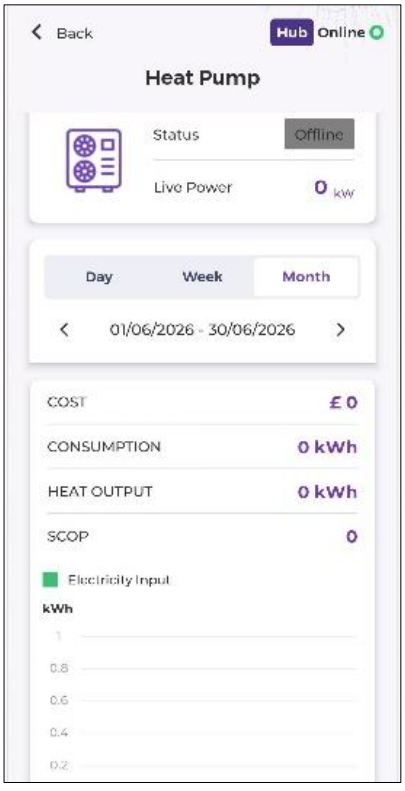
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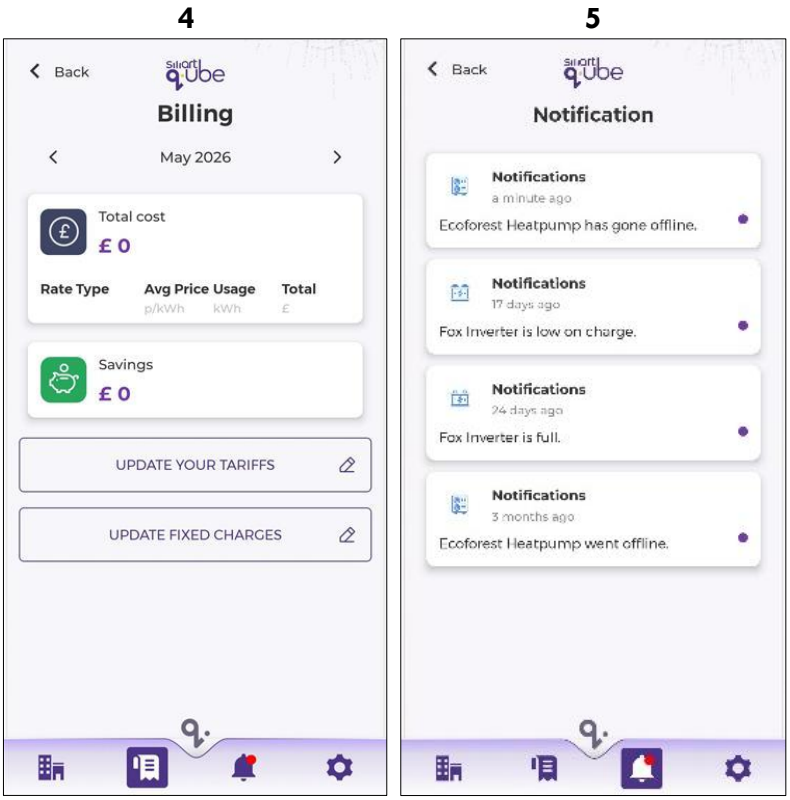


Figure 8 – Screenshots of SmartQube Phone Application (before assets are linked up).

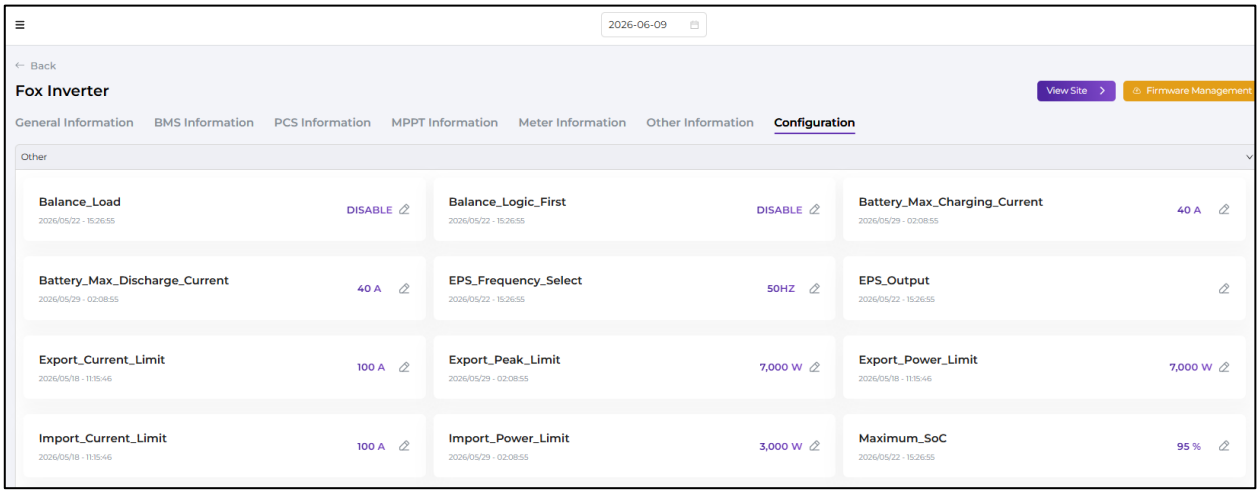


Figure 9 - Screenshot of the online installer dashboard showing backend configuration settings added with QEnergy's assistance.

The **Passiv** system consisted of three main components: the Passiv Hub, Programmer Unit, and Smart Thermostat (see Appendix B – Test Rig Commissioning Evidence). The Hub required only mains power and a wired internet connection, acting as the communications gateway to the wider Passiv platform. The Programmer Unit, installed adjacent to the heat pump, required mains power, a wired connection to the thermostat, an RS485 connection to the Hub, and a wired connection to the HP controller to provide switching control. The thermostat required a single wired connection to the Programmer Unit.

Installation and commissioning were straightforward, with stable communications, monitoring, and control functionality established quickly. The primary user interface was the Passiv mobile app (

Figure 10), which provided a simple and intuitive experience. Compared with SmartQube, it offers residents greater direct control, including adjustment of temperature setpoints and heating settings, while optimisation and asset management functions remain managed by the Passiv platform.

Passiv UK also provided access to its Partner Portal demo, used by installers and partners to monitor and manage connected heat pump systems. The portal demonstrated the type and level of operational data available from a representative heat pump installation, although this depends on the data exposed by each heat pump manufacturer via Modbus communications and therefore varies between heat pump manufacturers and models. While the consumer app displays energy consumption data at hourly intervals, the Partner Portal provides higher-resolution monitoring, with some data points available at up to one-minute granularity.

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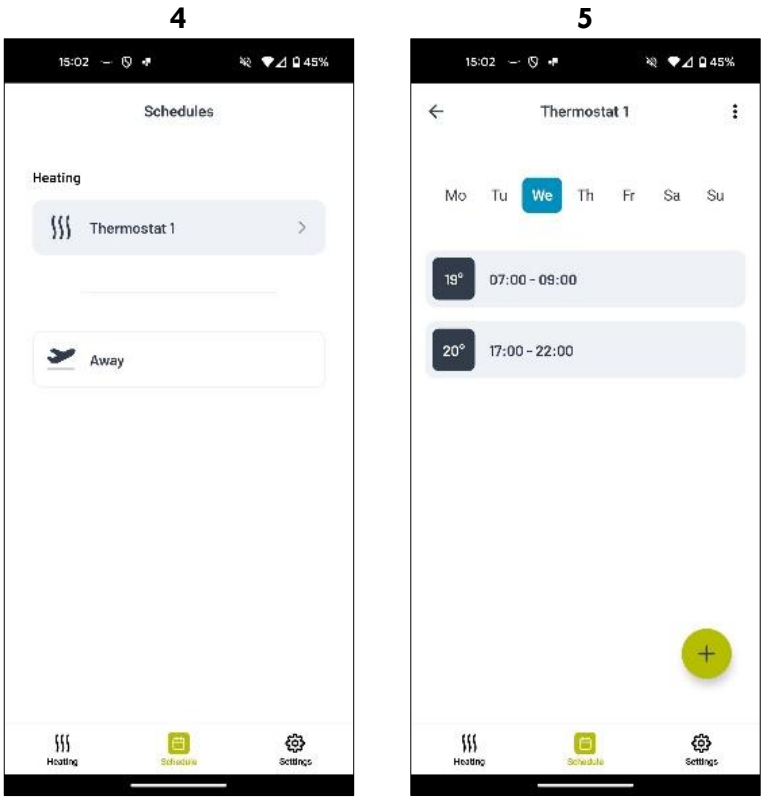


Figure 10 - Screenshots of Passiv Phone Application.

Installation of the **Levelise** hub was relatively straightforward, requiring connections to the grid supply, the battery inverter, and the internet connection. The platform typically assumes a separate AC-coupled PV inverter connection. In the test rig configuration, however, the simulated PV array was integrated through the FoxESS inverter, so no suitable AC PV connection was available within the existing lab configuration. PV visibility and optimisation functionality were therefore not assessed during this testing, although this was not considered a significant limitation given that direct user control of PV generation is not expected and the Levelise platform has an established commercial track record of PV visualisation and optimisation.

Initial commissioning attempts of the Levelise hub triggered a ground fault in the inverter. The root cause could not be confirmed during testing, and it was not possible to determine whether the issue originated from the Levelise hub, the FoxESS inverter or the specific lab configuration. Following reset and reinstallation of the FoxESS equipment, stable communication and connectivity between the inverter and the Levelise hub were successfully established.

The Levelise application provided a simple and intuitive user interface (Figure 11), displaying live data for household electricity consumption, generation (kWh), battery power (W), and grid import/export power and energy (kWh). Battery/inverter status was clearly indicated using a colour-coded symbol: blue indicates participation in grid services, green indicates normal operation, yellow indicates an error, and red indicates a system fault.

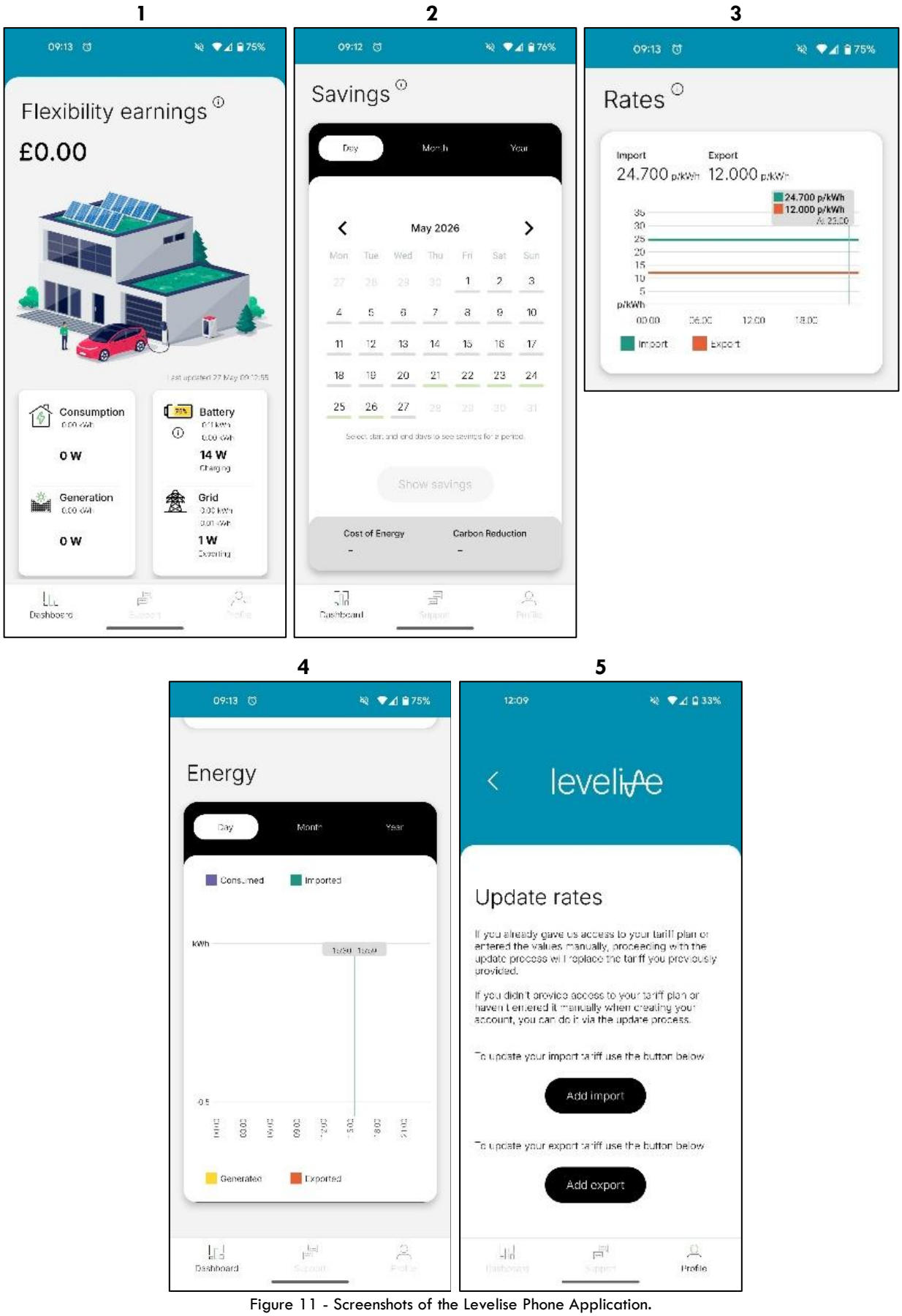


Figure 11 - Screenshots of the Levelise Phone Application.

4.1.6 General Commissioning Observations and Conclusions

The test rig communications infrastructure included an industrial router providing WAN and LAN connectivity, hardwired Modbus communications, and a Modbus sniffer for diagnostics and communications verification. All testing was conducted under appropriate electrical safety controls, including Residual Current Device (RCD) protection and standard commissioning and operational safety procedures. Overall, the variation in ease of asset integration demonstrated that, even where standard interfaces such as Ethernet or RS485 are supported, the ease of practical installation depended heavily on documentation quality, credential provisioning, installer accessibility, and compatibility with standard domestic network configurations. The process also highlighted the value of laboratory-based integration testing in identifying and resolving interoperability and commissioning issues prior to large-scale residential deployment.

4.2 Evaluation of Asset Integration with HEMSs

4.2.1 Mixergy Hot Water Tank

Mixergy was integrated with **Home Assistant** via the standard cloud API over Ethernet. This provided visibility of tank temperatures, charge level, heating status, immersion element power and energy, and user-level controls. Onboarding was quick and required no additional wiring. Local Modbus/TCP integration with Home Assistant was not achieved during testing. The Phase 1 unit included a dedicated lead for Modbus/TCP, and connection via the Mixergy Universal Serial Bus (USB) adapter was attempted through multiple configuration routes. However, a stable local Modbus connection was not established within the test period. This means that, while cloud-based integration with Home Assistant was demonstrated, local wired integration with Home Assistant was not verified and further testing would be required if deemed a “Must have” function.

For **SmartQube**, the list of Modbus registers for the Mixergy tank was provided to the SmartQube team. Using the wired internet connection, which enabled the Modbus server to be visible via an Internet Protocol (IP) address, the SmartQube team established access to both the read and write registers for the Mixergy tank. This integration appeared to operate successfully during lab testing.

Mixergy integration was not demonstrated through the **Passiv** configuration during this testing. The Mixergy tank used in the lab did not provide a direct heat pump connection route, and no alternative integration route was established, meaning the platform could not be shown to monitor or control the tank within the lab setup. Initial discussions with Passiv indicate that their system is typically compatible with hot water cylinders connected via a heat pump, where Passiv controls the immersion heater through the heat pump controller interface. However, feedback from the Passiv technical team confirmed that the Passiv Smart Thermostat is not compatible with Mixergy cylinders. There is no clear mechanism to disable or isolate Mixergy’s native smart functionality within the cylinder hardware, and without an established integration route, both systems would attempt to control hot water production independently, leading to conflicting operation. As a result, concurrent operation would require disabling Passiv’s ecoHeating function, removing the benefits of its smart control strategy.

The outcome is that Mixergy integration was successfully demonstrated through Home Assistant using the cloud API and through SmartQube using Modbus register access. Local Modbus integration with Home Assistant, and Mixergy integration through Passiv and Levelise, remain unproven within the tested lab configuration.

4.2.2 EcoForest Heat Pump (HP)

The EcoForest heat pump successfully communicated with **Home Assistant**, and the Home Assistant interface remained stable throughout testing. A number of heat pump alarm events were visible within Home Assistant. These appeared to be related to the laboratory ground loop arrangement, including occasional low ground loop pressure alarms. Despite these alarms, Home Assistant was able to communicate with the heat pump effectively. Heating was successfully commanded on and off through automations and the data shown in Home Assistant matched the values displayed locally on the heat pump interface.

SmartQube successfully integrated with the heat pump locally via RS485/Modbus using the provided serial settings and device ID. This enabled polling of key values including electrical input, heat output, and power factor. Further telemetry and control capability would require additional backend Modbus register mapping by QEnergy. The testing demonstrated local communication and selected data visibility; however, the available laboratory conditions did not allow the full range of heat pump operating states to be assessed. Further testing under a more representative thermal loop would be required to confirm SmartQube control and monitoring capability across wider heat pump operating conditions.

The **Passiv** system connected directly to the internet via the Passiv hub. The hub was linked by RS485 to the programming device and thermostat, enabling local communication with the heating controls. The internet connection was provided using a wired link from the router, after which the system became visible within the Passiv application with minimal setup. Passiv typically supports heat pump integration via either full Modbus or simpler relay control, depending on heat pump compatibility. Prior to testing, the Passiv team did not expect full integration with the EcoForest heat pump to be available. In this context, establishing relay-based operation was a positive test outcome, as it demonstrated that the Passiv system could provide a basic control route within the lab setup.

This configuration allowed basic heating control to be demonstrated, but did not provide the level of telemetry, diagnostics or optimisation that would be available through full Modbus integration. Passiv has confirmed through discussions that more complete heat pump integration is available and has been tested in their own lab with other supported models, although this has not yet been independently verified by the team through a lab visit to their site. Passiv can also develop additional integrations where required, but these would need to go through their internal approval and prioritisation processes. This creates a programme consideration for future deployment, as heat pump selection and HEMS integration requirements would need to be agreed early if detailed monitoring and optimisation are required.

No direct communication path between **Levelise** and the EcoForest heat pump was established during testing. The evidence suggests that Levelise optimised the connected battery asset in response to the electrical demand associated with heat pump operation, rather than directly monitoring or controlling the heat pump itself. Nothing in the Levelise documentation or configuration settings reviewed during testing indicated that Levelise was configured to provide direct heat pump control in this arrangement. Direct heat pump integration should therefore be treated as unverified for the tested EcoForest configuration.

A key limitation observed across the EcoForest and HEMS devices was that certain commissioning settings could not be adjusted from within the HEMS, including parameters affecting system performance and efficiency such as heat pump flow temperature settings. These settings must be configured via the EcoForest gateway during installation or commissioning. This creates an installation constraint, where either closer integration with the heat pump vendor will be required to expose these settings within the HEMS, or the required configuration approach must be better defined and

reflected in clear 'NZT installation guidance' to ensure optimal home-level system performance, operational requirements, compatibility, and consistency across installations.

4.2.3 Tado TRV

Three Tado integration routes were tested in **Home Assistant**. The standard cloud API integration was not successfully established, as it entered a persistent re-authentication loop every 10-20 seconds. A community integration, Tado CE, was then tested, but did not expose the required temperature entities for the thermostats or TRVs, preventing reliable data ingestion. Connectivity was ultimately achieved via Matter, an interoperability standard intended to support local commissioning and control of smart home devices across vendor ecosystems. This provided wireless visibility and control of the TRV through Home Assistant.

Integration with **SmartQube** was not achieved in this configuration. Tado does not provide a local Modbus pathway and SmartQube did not support the Tado cloud API within the tested set up. SmartQube is understood to support other TRV assets, such as those that support Zigbee communications protocols, so this should be treated as a compatibility limitation with the selected TRV rather than a general limitation of the SmartQube platform.

The **Passiv** and **Levelise** joint solution does not support TRVs or micro-zoning, as this conflicts with Passiv's optimisation approach.

Tado integration was not required for basic heat pump operation, provided there was sufficient flow and a valid heat demand signal. However, the absence of reliable room-level TRV integration limited the ability to test zoning, demand shaping, room-level setpoints and more granular comfort optimisation within the lab setup.

4.2.4 FoxESS Hybrid Inverter, Battery, and PV Supply

The FoxESS system was successfully integrated into **Home Assistant** via a local RS485 Modbus RTU connection to the inverter, using a USB-to-serial converter connected to the Home Assistant device. A community-developed Modbus integration enabled immediate connectivity and exposed a comprehensive range of battery and inverter telemetry, including State of Charge, State of Health (SoH), temperature, voltage, PV generation, grid import/export, and operating status. Control settings configured within Home Assistant were reflected promptly on the Fox ESS device, demonstrating reliable bidirectional communication. As the integration used a direct local connection, telemetry and control functionality remained operational independently of the FoxCloud service or external internet connectivity.

The Fox ESS inverter was integrated into **SmartQube** using a direct RS485 connection. After wiring, SmartQube could detect the Fox device and display basic operational data on its dashboards. The user interface displayed a limited set of user-facing metrics, including battery charge/discharge kWh logging and CO2 savings. The installer dashboard displayed more metrics, including battery power, SoC, and PV performance, but exposed approximately a quarter of the signals available in Home Assistant. QEnergy confirmed that additional data can be exposed via backend configuration, but this requires specific support rather than a self-service setup.

Levelise was able to interface with the FoxESS inverter via RS485 using the Levelise Hub 2, confirming a viable integration pathway. Phase 1 testing showed that the Fox ESS exposes local Modbus/RS485 telemetry and control points that can support core monitoring and battery dispatch, subject to appropriate configuration and register mapping. However, the Levelise control approach - focused on maximising self-consumption, tariff arbitrage, export optimisation, and flexibility market participation to optimise user savings - did not provide default user-facing controls for battery

operation. Control is therefore managed through the Levelise optimisation platform rather than direct resident interaction or a separate installer system; it has not yet been confirmed by the vendor how this optimisation logic could be adapted to support wider SLES-level objectives.

4.3 Summary & Conclusions of Phase 1

Table 4 summarises the Phase 1 integration outcomes across the assets and HEMSs tested. The results show that most core asset connections were achieved, with the strongest integration performance observed where local data pathways were available, particularly Modbus over RS485.

Local connections provided the most direct route for telemetry and control, and reduced reliance on internet access, vendor authentication and cloud API stability. Cloud-based integrations were often quicker to commission but introduced additional dependencies that would need to be considered in any future deployment.

Table 4 - Summary of Energy Asset Integrations & Connectivity with HEMS Devices.

Asset	Home Assistant	SmartQube	Passiv & Levelise
Mixergy (DHW)	Pass	Pass	Not Tested *(due to further integration requirements)*
EcoForest (HP)	Pass	Pass	Pass - Passiv
Tado (TRV)	Pass	Not Tested *(Tado not compatible)*	N/A *(TRV affects Passiv's optimisation)*
FoxESS (B/I)	Pass	Pass	Pass - Levelise
Solar Array (PV)	Pass	Not Tested *(register incorporation requires SQ development time)*	Not Tested *(due to further integration requirements)*

Home Assistant provided the widest immediate access to local Modbus data and offered flexibility over how data and controls could be configured. SmartQube provided a more structured vendor-managed interface, with additional data exposure dependent on backend register mapping by QEnergy. Passiv and Levelise integrations were straightforward to commission where the tested assets were compatible with their intended control routes, but some integrations could not be fully assessed within the lab configuration.

Where tests did not pass, or where integrations could not be assessed, the outcome was recorded as part of the test evidence. These findings are important because they identified the practical integration gaps, asset compatibility requirements and supplier dependencies that would need to be addressed before any future deployment.

Overall, Phase 1 confirmed that the test rig provides a practical basis for comparing HEMS integration routes. It also highlighted a key trade-off for future development: vendor-managed systems could reduce upfront development effort but may create dependency on supplier support and configuration, while open-source routes such as Home Assistant provide greater adaptability but require more internal development and integration resource.

Phase 2 included further vendor discussions to fill gaps and document HEMS to asset communication.

5. Phase 2 Testing: Native Capability Testing

A well-designed HEMS should provide reliable monitoring, accurate data capture, and robust control functionality to support both end users and wider energy system objectives. Alongside enabling effective operation of connected devices, the system should present clear information through its user interface, maintain dependable communications, and effective alarm/event logging. This phase evaluated each of the HEMS against these functional and operational requirements. A requirements table, developed from the wider SLES HEMS requirements, is included in Appendix C – Phase 2 Testing Requirements and forms the basis of the Phase 2 assessment criteria and review sections.

5.1 Pre-Capability Testing Note on Vendors

Home Assistant: Home Assistant is an open-source platform offering pre-made code modules that can be imported for devices such as FoxESS inverters. Its flexibility allowed for rapid integration, configuration and customisation to meet specific integration and testing requirements. All assets were able to be tested.

SmartQube: Testing with SmartQube was more involved due to the need for vendor input. The vendor supported the project pro-bono, joining bi-weekly calls to guide register integration and answer technical questions. All registers and backend configuration had to be programmed manually, which made testing setup slower and less iterative than other platforms. Despite this, the SmartQube team provided clear guidance and support throughout the testing process. Tado TRVs are not compatible with SmartQube and so this was not tested, however other TRVs are noted by the vendor to be currently compatible with the HEMS.

Passiv & Levelise: Passiv and Levelise are designed to operate as a joint HEMS solution, with the Passiv Smart Thermostat (PST) optimising heat pump operation and the Levelise battery optimiser managing battery charging and discharging.

Testing of Passiv's full suite of capabilities could not be achieved given the chosen assets for NZT project and the subsequent lab configuration. The PST supports two installation modes:

- ***Full Modbus/RS485 integration:*** Provides deep telemetry, advanced analytics, and full optimisation.
- ***Relay control:*** Compatible with any heat pump, offering basic on/off control but limited telemetry and no data exchange.

As Passiv did not support full Modbus integration with the lab's selected EcoForest heat pump at the time of the testing, testing was limited to relay control mode. Consequently, telemetry was restricted, with no data available on energy consumption or coefficient of performance (COP) – a measure of the heat pump's efficiency - and control functionality was limited. Hot water control was managed directly by the heat pump and could not be integrated with Mixergy within the lab configuration, as the relay-control setup did not provide the required data exchange or control functionality. TRVs are not compatible with Passiv's optimisation approach and were excluded. Testing therefore focused primarily on heat pump optimisation through the Passiv Smart Thermostat. Any functionality that could not be verified in the laboratory was supplemented through vendor discussions and desktop research.

For Levelise, testing focused exclusively on battery optimisation, its primary role within the integrated Passiv-Levelise solution. Direct PV integration could not be assessed because the laboratory's synthetic PV system was connected directly to the FoxESS inverter and did not provide a suitable AC or DC connection to the Levelise hardware. However, as most PV generation was absorbed by the battery before export, the resulting charging, self-consumption, and import/export behaviour of the battery

provided sufficient evidence to assess Levelise's optimisation behaviour, despite the absence of direct PV generation data.

Where existing and planned functionalities could not be fully assessed within the laboratory environment, clarification was sought from Levelise to supplement the test findings. Initial discussions were constructive and were considered within the assessment where supporting information was available. Some further information requested during the later stages of testing was not available within the assessment period and could not therefore be used to validate specific capabilities.

The results and conclusions presented are based on the evidence available at the time of testing and, where a capability could not be confirmed through either lab testing or supplementary information, it has been recorded in the test results as:

> ***"[Capability test] remains outstanding and has not been confirmed by the vendor".***

5.2 Results

Tables 5-13 summarise lab-observed capabilities and limitations for the three HEMSs across the assets they were tested against. 'Other Notes' column includes vendor documentation references where relevant; these were not necessarily lab verified results. In the following tables, the assets have been simplified to the following acronyms:

- Battery & Inverter – **B/I**
- Solar Array – **PV**
- Heat Pump – **HP**
- Mixergy Tank – **MXGY**
- Tado TRV – **TRV**.

Phase 2 testing results were assessed against their relevant phase 2 requirements, outlined in Appendix C – Phase 2 Testing RequirementsAppendix C – Phase 2 Testing Requirements.

5.2.1 P2-R1 Capability discovery and documentation

Testing established what built-in capabilities exist across each HEMS with their connected devices and recorded these capabilities and any constraints.

Table 5 – Summary of P2-R1 Capability Discovery and Documentation Assessment

	Lab Observed Capabilities	Limitations	Other Notes from Vendors/Documentation
Home Assistant	• **B/I** exposed the broadest entity set, 84 entities including full sensor coverage (State of Charge (SoC), State of Health (SoH), temperature, voltage, grid import/export, Battery Management System (BMS) kWh remaining) and controllable work modes (force charge/discharge, self-use, feed-in first, peak shaving) with adjustable max/min charge power and SoC limits. • Clear dashboard statistics for **PV** power, current, voltage, and production graphs showing where output was directed (battery vs home). • **HP** controls confirmed: on/off, enable/disable heating, and electrical power consumption limit. Flow temperature adjustment was not clearly available during initial testing. **TRV** displayed controllable target temperature settings.	• No pre-set direct ability to link personal tariffs. 'Peak shaving' and 'feed-in first' modes serve as proxies, but do not directly ingest tariff data, unless an automation/optimisation is developed for this. • The EcoForest gateway cannot be used for visualisation simultaneously with Home Assistant (HA) control, it must be disconnected before HA commands are issued.	• Current integrations use Modbus registers. Alternative connection types (Zigbee, wireless Modbus) would require different registers and protocols.

	• Exposed backend controls of **MXGY** (cleansing temperature, frost protection, target temperature) and a solid sensor set including current charge, hot water temperature, target charge, voltage, and frequency. Holiday mode was visible but not controllable from the HEMS User Interface (UI).	• MXGY holiday mode visible but not natively controllable from HA, no toggle available in the HEMS UI. • There was no physical Human-Machine Interface (HMI) for HA, the phone app & online dashboard are the sole interfaces, which raises digital exclusion considerations for users without smartphone access.	
SmartQube	• Smart Qube (SQ) has two dashboards: a user dashboard providing high-level energy summaries (cost in £, electricity usage in kWh, carbon savings in kgCO2e) and an installer dashboard with configurable controls. • The user dashboard did not expose direct asset controllability. SQ's algorithm learned consumption patterns and incorporated tariff data to optimise usage autonomously. • The installer dashboard did not natively host asset controls, but it could be configured by QEnergy to include controls for any requested entities. • Installer dashboard controls validated in the lab for **MXGY** tank boost (near-immediate response) and **HP** (via QEnergy back-end execution). • **B/I** charge/discharge commands from the SQ dashboard did not produce consistent observable behaviour. Inverter repeatedly reverted from feed-in tariff to self-use mode. A reliable BESS control pathway has not yet been demonstrated. QEnergy identified a likely root cause; however, compatibility with alternative BESS platforms was confirmed by the vendor from other client deployments, suggesting an asset-specific issue.	• User dashboard does not allow direct asset control; only monitors and visualises data. Battery charge/discharge commands from the dashboard were inconsistent in the lab. Inverter frequently reverted from feed-in tariff mode to self-use mode, limiting reliable control. • There was no physical HMI for SQ, the phone app & online dashboard are the sole interfaces, which raises digital exclusion considerations for users without smartphone access.	• Vendor identified likely root causes for battery/inverter issues. Required some programming development but possible to resolve. SQ have experience with other BESS platforms and an established client base, suggesting future deployments could be more robust.
Passiv (HP & MXGY) & Levelise (B&I)	• Passiv app displayed a simple user interface, with three main tabs: one to read/set current & target thermostat temperature, one to set schedules, and one to configure settings, optimisation states, summer modes, and set personal tariffs. Values were cross-checked against an independent lab thermostat (**TRV**) and confirmed accurate. • Simple on/off relay control of the **HP** confirmed, with immediate response; front display icon changed colour from grey to red to indicate active heating. • Hot water tank (**MXGY**) and deeper analytics not enabled for the lab-based **HP**, but during disconnection tests, two further interfaces became visible in the app; a hot water control interface showing hot water charge percentage, time and target percentage scheduling, and a boost-now function, and an analytics page, where further COP and £ saving data would have been stored. Full details of these pages not verified from the lab set-up.	• Further visibility including energy consumption and Coefficient of Performance (COP) appeared to be available based on the HP connection but was not accessible in the current lab configuration, due to the lab's selected heat pump. • Similarly, for MXGY, Hot water control is managed via the HP's controller interface, making MXGY integration testing unavailable in this set up. • No obvious minimum temperature setpoint visible in the app.	• Vendor indicated that greater HP visibility could be established where a compatible HP is used with Full Modbus/RS485 integration: this would provide deeper telemetry visibility, advanced analytics, and full optimisation. • Hot water tank functionality (charge %, scheduling, boost-now modes) would be possible in other configurations, with a compatible hot water tank. Vendor confirmed that Passiv is not compatible with Mixergy

	• Current room heating temperatures and active schedules displayed within application, same across Passiv app and Programmer & Thermostat HMIs.		Hot Water Cylinders due to competing smart controls.
	• Levelise app provided a simple, clean app interface, live figures displayed for household consumption, generation (kWh), battery current power (W), and grid import/export power and total energy (kWh). • **B/I** status is clearly communicated through a colour-coded symbol: blue = in use for grid services, green = working normally, yellow = displaying an error, red = faulty system. • Users could input their specific import and export tariff rates, which Levelise uses to optimise battery operation. • FAQ page included in the app to explain payment calculations and savings to users.	• No user controls or manual configurations beyond tariff input, the platform is intentionally designed as a set-and-leave optimisation system. • When Levelise was connected, force charge/discharge mode was no longer visible on the FoxESS HMI, Levelise appeared to take exclusive control of the inverter and removed lower-level manual access in the tested configuration. • There was no physical HMI for Levelise, the phone app is the sole interface, which raises digital exclusion considerations for users without smartphone access.	• *Additional user controls, alerts, fault notifications or external integration capabilities remain outstanding and have not been confirmed by the vendor.*

5.2.2 P2-R2 Smart Meter Data Access and Compatibility

This review assesses the stated smart meter data access capabilities of each HEMS based on vendor discussions, published documentation and available technical information. No direct smart meter integration testing was undertaken within the laboratory environment.

Table 6 - Summary of P2-R2 Smart Meter Data Access and Compatibility Assessment

	Other Notes from Vendors/Documentation	Limitations

Home Assistant	• HA supported smart meter data through multiple integration routes (e.g. direct integrations and gateway-based), enabling real-time and historical energy monitoring across hourly, daily, weekly, monthly, and yearly views[6]. • Various integrations allowed, including Smart Meter Equipment Technical Specifications (SMETS)2 via Data Communications Company (DCC) and Hildebrand Glow[7].	• Compatibility depended on meter type, supplier, and which third-party integration is used, there was no single native pathway, and the user or installer must select and configure the appropriate integration for their specific meter and energy supplier.
SmartQube	• Confirmed compatible with smart meters, including half-hourly, Automated Meter Reading (AMR), and smart meter data, to support home energy optimisation and analytics.	• Vendor confirmation is still required on supported meter standards SMETS1/dcc2), manufacturer compatibility, DCC access route, Consumer Access Device (CAD) pairing support, and data export capability, none of this has been formally declared by QEnergy.
Passiv & Levelise	• Passiv did not integrate with any smart meters. An existing API integration with Octopus Energy provides electricity tariff data, but this is a tariff feed rather than smart meter (half-hourly consumption) data [Email from Passiv's Technical Team]. • Smart meter integration was not on its roadmap at the time of the testing, though may be anticipated in the future through initiatives such as the STAT project (including integration of the Passiv Hub with UK smart metering infrastructure without additional hardware), but is not available commercially today[8].	• No smart meter integration solution exists today. Tariff data via Octopus is not a substitute for half-hourly consumption data and would not meet this requirement as currently implemented. • Smart meter access may be road mapped via the STAT project rather than available today.
	• Levelise's support documentation indicated that Levelise needs half-hourly consumption data to support grid service participation and demand/generation optimisation[9].	• Specific meter standard compatibility (SMETS1 vs SMETS2), the technical access route (DCC, CAD, or supplier API), and supported meter manufacturers are not confirmed in available documentation, direct vendor clarification is required.

[6] https://haprofs.com/connect-a-smart-meter-with-home-assistant-complete-guide-and-integration/
[7] https://www.home-assistant.io/integrations/?search=n3
[8] https://www.passivuk.com/insight/passiv-uk-to-develop-new-smart-heat-pump-control-hub-as-part-of-heat-pump-ready-programme/
[9] https://support.levelise.com/hc/en-gb/articles/11179805542172-Why-do-you-need-access-to-my-Half-Hourly-Data

5.2.3 P2-R3 Local Available Operational and Telemetry Data Access

Testing established how the HEMS records, stores, and retains operational and telemetry data and records data availability, resolution, retention, traceability, and contextual information.

Table 7 - Summary of P2-R3 Local Available Operational and Telemetry Data Access Assessment

	Lab Observed Capabilities	Limitations	Other Notes from Vendors/Documentation
Home Assistant	• **B/I** provided real-time tracking of charge/discharge power (kW) and SoC (%), with charge and discharge data recorded in separate graphs. • **HP** logging confirmed for electrical power demand (kW), room temperature (°C via tado), COP, and heating on/off state. • Long list of **MXGY** sensors available, including current charge, hot water temperature, target charge, and voltage. Updates to and from the physical asset were faster on the physical HMI (the tank itself) than in HA for both HEMS-initiated and tank-initiated boost requests. Holiday mode status was visible in the HEMS UI when active.	• No native direct control link between TRV temperature setpoint and HP, this will need to be automated. • B/I work mode state (charge/discharge) is not directly readable in HA, it must be inferred from the power supply (positive/negative), as there was no feedback register confirming current state (unless programmed). • Frequent data point omissions observed in battery records, likely due to communications interruptions, or faulty connection into HEMS. Historic data appeared to record only on change of state or loss of comms, a potential issue for the NZT FairerShare algorithm and community-level monitoring.	• HA recorder and database was highly configurable. • The recorders' typical default is to retains raw state data for ~10 days, with long-term hourly statistics retained indefinitely at reduced resolution[10]. However, this length of retention could be altered in the configuration directory, depending on user requirements[11].
SmartQube	• Telemetry data was limited by default in both dashboards. Working with QEnergy, additional registers were successfully added to the installer dashboard on request, confirmed in the lab. • **B/I** charge/discharge data observed to update every 30 minutes; SoC updates approximately every 5 minutes; **HP** statistics update every 30 minutes.	• User dashboard intentionally high-level & view unlikely to be expanded significantly for telemetry depth. • Installer dashboard telemetry expansion requires QEnergy involvement for each new register request.	• *Capability for finer-resolution data and data back-fills following connectivity outages remain outstanding and have not been confirmed by the vendor.*

[10] https://community.home-assistant.io/t/data-retention/444859
[11] https://thehomesmarthome.com/optimizing-home-assistant-database-data-retention/

	• Historical data exportable as Excel files at 30-minute granularity for all assets. Data retained for 10 years on AWS. • Vendor indicated that some updates to the user dashboard may be possible, but it is generally kept at a high level.	• 30-minute export resolution may be insufficient for real-time community monitoring, depending on future SLES monitoring requirements.	
Passiv & Levelise	• Live tracking of heating temperature and active schedules for **HP** was clearly displayed within the Passiv application. • Basic thermostat boost function confirmed; boosting via the app produced an immediate response in the **HP** relay control and the front screen changed colour to red to indicate active heating. • Analytics page and domestic hot water tabs were unavailable for our lab set up. But demo page was tested/used: clear statistics and graphical visuals to provide the estimated costs, kWh consumption for the HP and hot water, and COP efficiency of the HP provided. Operational data can be viewed at daily, monthly or annual level.	• No clear log of control actions or state changes in Passiv app. • Analytics page could not be configured for the lab setup and requires compatible heat pump/assets. Other entities, such as instantaneous power draw (kW), were therefore not visible. • The app uses an icon that changes colour to indicate when heating is on or off, which generally functions as intended. However, during a heat pump fault condition (the HP HMI showed a 14 minute requirement before accepting a new control command), this was not alerted in the app, and control functionality was therefore limited.	• App and portal update every 5 mins. Back-end data access could be offered but is not currently available front-end. • The hub has local storage, so if Wi-Fi goes down, performance data was stored locally and backlogged to the cloud on reconnection. • Online Passiv Portal demo provided an overview of operational data, including scheduled settings, current telemetry, and historical data graphs for multiple telemetry points (e.g. asset on/off status and temperature). Also, a log of control actions/state changes.
	• Live dashboard provides real-time figures for **B/I** power consumption, generation, and grid import/export. • Carbon and cost savings data available broken down by revenue stream (export, arbitrage, flexibility, self-consumption, efficiency) at day/month/year granularity. Data displayed in 30-minute granularity. • App provides a look-back function; users can view historical energy consumption and savings achieved over time. • When the hub was disconnected from the internet, the installer menu showed a red light indicating offline status. No key alerts or notifications were shown in the user-facing app profile besides the battery icon turning red. • Savings data appeared to extend back up to 4 years prior, but retention length needs vendor confirmation. This is only a limitation if longer retention is required by future SLES use cases.	• Data traceability: no clear notifications or alert that the battery was offline besides colour of battery icon changing in the Levelise app. The same limitation was observed for Levelise Hub disconnection. • Data currently only visible every 30 minutes; wider CEMS architectures and DSO response systems may require a finer level of granularity.	• *Back-end data granularity, data retention period, backfill behaviour and available export routes remain outstanding and have not been confirmed by the vendor.*

5.2.4 P2-R4 User Schedule Execution (& Constraint Enforcement)

Testing established what schedules, preferences, and operational constraints can be configured natively through the HEMS user interface.

Table 8 - Summary of P2-R4 User Schedule Execution Assessment

	Lab Observed Capabilities	Limitations	Other Notes from Vendors/Documentation
Home Assistant	• **B/I** work mode automations successfully tested, including combinations of automating work mode, SoC limit, and power discharge limit in a single automation. Confirmed as a viable mechanism for the NZT FairerShare algorithm. Invalid SoC inputs rejected for the battery: setting maximum SoC lower than minimum (or vice versa) triggers a fault correctly. • **MXGY** hard limits confirmed: maximum temperature 80°C enforced by the asset; min/max charge states automatically maintain a 5% minimum separation. • HA automations are stored in configuration and persist across reboots. • **TRV** thermostat: 30°C hard limit enforced by the device; cannot be exceeded. • PIN code protection available on the battery HMI to prevent home users from changing work mode at the physical device.	• Updating battery target SoC mid-automation is limited; once automation is sent (e.g. to discharge to 35%), the automation must complete fully before a further adjustment is made (e.g. 25% target). However, this behaviour may also provide a safeguard against rapid successive battery configuration changes, which may help reduce unnecessary switching or conflicting control requests. • Battery charge/discharge requests did not always execute when asset reached ~45°C; safe from an asset perspective but no alarms/faults to indicate the issue. • Increasing Mixergy charge target via HA automation works but does not reflect updated value in HEMS UI; better visibility required. • HA automations act only when assets are online. If assets become disconnected, then the next HA automation will only enact once reconnected.	• N/A
SmartQube	• Back-end programming by QE successfully executed a **MXGY** tank 'user' schedule. • Tado **TRVs** not compatible; Zigbee TRVs supported as alternative. • PIN code protection available on the battery HMI to prevent home users from changing work mode at the physical device.	• User-defined schedules are not natively configurable via either dashboard, they conflict with SQ's optimisation algorithm and can only be programmed by QEnergy given a precise list of times, setpoints, and registers. • Comfort settings are not natively configurable, though setpoint control registers can be added to the installer dashboard by QEnergy on request. • Input validation not enforced (e.g. setting battery max SoC lower than min was accepted).	• Vendor Roadmap: user comfort settings (e.g. minimum home temperatures) are planned for future development. • Vendor indicated that custom schedules for vulnerable or elderly customers are feasible but easier to implement at onboarding than retrospectively. • *Viability of scaling personalised schedules remains outstanding and has not been confirmed by the vendor.*
Passiv & Levelise	• **HP** Schedule creation and deletion worked correctly (execution time, duration and setpoints can all be applied). Scheduled	• Maximum heating constraint active from installation: a setpoint of 30°C was accepted by the app but the effective limit remained at 24°C due to configuration	• Passiv regulates home temperature between schedules gradually using low-temp top-up heating, improving COP and avoiding abrupt changes.

	target temperatures updated immediately when schedules were applied or removed. • Temperature inputs are not free-form, values must be selected from a Passiv pre-set list, with a permitted heating range of 7–30°C. Invalid inputs not possible.	applied to the HP at commissioning; no alert of this fault identified via the app. • Maximum heating limits within Passiv are not user-configurable after setup and must be updated in the HP vendors configuration settings. Coordination of commissioning settings would be required to ensure HP limits align with user comfort requirements. • Mixergy: not possible to test with laboratory configuration.	• Comfort is set by target temperatures; no explicit upper/lower limits. Vendor indicated that temperatures may overshoot by 1-2°C before flexibility events.
	• No user-configurable schedules for **B/I**. Levelise is a fully automated optimisation platform. The system decides when to charge and discharge based on tariffs and grid signals without user input. • Users can input import/export tariff rates which the optimisation engine uses, this is the only configuration available to users. • PIN code protection available on the battery HMI to prevent home users from changing work mode at the physical device. However, it was noted that Levelise appeared to take control of the HMI.	• No schedule creation, editing, or deletion capability by design. • No comfort setpoints or temperature bands, Levelise does not interact with heating or hot water assets in the current lab setup. • No ability to set fixed charge or discharge windows manually, the system makes all timing decisions autonomously.	• Levelise website indicates that battery scheduling preferences can be configured[12]; however, this functionality was not visible in the app version available during testing and may be account-dependent, under development, or not yet generally available. • *Availability of additional user configurations, and higher-level CEMS influence over battery control and scheduling remains outstanding and has not been confirmed by the vendor.* • *Levelise indicates coordination of battery, solar, HP and other energy assets[13]; however, understanding of broader multi-asset optimisation (e.g. heat pump and hot water) remains outstanding and has not been confirmed by the vendor.*

5.2.5 P2-R5 Native Optimisation Logic and Objective Interaction

Testing established whether native optimisation exists and records optimisation objectives, inputs, user controls, and interactions with schedules and comfort constraints.

[12] https://support.levelise.com/hc/en-gb/articles/25872989011740-How-to-schedule-your-battery
[13] https://www.levelise.com/levelise-app-2/

Table 9 - Summary of P2-R5 Native Optimisation Logic and Objective Interaction Assessment

	Lab Observed Capabilities	Limitations	Other Notes from Vendors/Documentation
Home Assistant	• Successfully trialled the execution of tariff-response automations, e.g. HP successfully read a synthetic electricity price and switched HP on for one hour when price fell below a defined threshold (£0.10/kWh), as planned.	• No native built-in optimisation engine. All logic must be explicitly programmed via automations or external integrations. No optimisation functions operate passively or autonomously without programmed logic. • No schedule vs optimisation interaction to test as there is no competing native optimisation logic in HA.	• Tariff API integration and optimisation to be explored for assets if HEMS is taken forward.
SmartQube	• SQ algorithm continuously optimises battery charging and home energy usage based on smart tariffs, home consumption patterns, weather forecasts, and asset data. • Optimisation is automatic and always active, not user toggleable.	• Asset priority logic must be explicitly provided to QE; it is not visible or configurable by the user or community operator in the UI. • User defined schedules (not native to the app) and manual boost temporarily override the active optimisation. • Fallback behaviour during internet loss or cloud disconnection was not confirmed and remains a key question for resilience testing.	• A defined asset priority logic (i.e. which asset receives available energy first) would need to be configured by QEnergy to align with the community-level objectives. • *Confirmation of whether optimisation operates across both local and cloud-based systems, and associated fallback behaviour during disconnection, remains outstanding and has not been confirmed by the vendor.*
Passiv & Levelise	• Two native **HP** optimisation modes confirmed, both user-toggleable: • Solar optimisation: operates the HP to use excess PV generation. • EcoHeat mode: learns home heating patterns and pre-heats ahead of scheduled periods, adding lower-temperature windows around schedules to prevent the home from cooling between them.	• No additional limitations observed during testing.	• 'Solar Optimisation' effectiveness may be reduced where battery storage is present, because battery will import most of the excess solar. [Passiv app]. • Optimisation works around user schedules rather than overriding them. Schedules define when and to what temperature rooms are heated; Passiv adjusts HP start time, flow temperatures, duration, and weather compensation behaviour around those schedules.

	• Optimisation engine appeared to operate continuously and autonomously, no user-facing optimisation toggle was identified. • Savings are broken down by optimisation type in the app (export, arbitrage, flexibility, self-consumption, efficiency), providing visibility of which optimisation strategies are generating value.	• Optimisation objective hierarchy (e.g. self-consumption vs flexibility market participation vs arbitrage) is not visible or configurable by the user or community operator.	• Levelise operates as a Virtual Power Plant (VPP) operator, households participate in grid balancing services as part of a wider fleet, generating revenue from flexibility markets year-round[14]. • Optimises battery charge and discharge based on supplier tariffs and flexibility markets, targeting self-consumption maximisation, tariff arbitrage (charge cheap, discharge expensive), export optimisation, and flexibility market participation. • Levelise indicated that their optimisation logic could be disabled if required to function with the NZT Fairer Share algorithm and requirements of the SLES. • Further understanding of whether community-level objectives or external price signals from a CEMS would override or influence the Levelise optimisation engine remains outstanding and have not been confirmed by the vendor.

5.2.6 P2-R6 Manual Override Handling and Precedence

Testing established how manual user overrides interact with schedules and optimisation and records override mechanisms, precedence, duration, persistence, and logging behaviour.

Table 10 - Summary of P2-R6 Manual Override Handling and Precedence Assessment

	Lab Observed Capabilities	Limitations	Other Notes from Vendors/Documentation
Home Assistant	• Physical overrides of assets (e.g. manually 'boosting' the MXGY and changing the work mode of the **B/I**) confirmed and visible in the relevant asset vendor's apps. • User overrides can take precedence over automations or schedules until the next automation is executed.	• In some cases, physical HMI adjustments (e.g. boosting MXGY) do not update the target temperature register in HA, making the override invisible to HEMS. Physical boost can also exceed the maximum charge level set in the HEMS UI. • HA has no physical HMI; control is via app/online dashboard only, raising digital exclusion risks for users without smartphone access needing overrides.	• Override logging (who/what triggered a state change, timestamp) is understood to be available via HA's logbook integration. It may be that this has to be added to the HA configuration.yaml file[15].

[14] https://www.levelise.com/blog/maximising-returns-how-uk-homeowners-can-monetise-battery-storage-systems-with-levelise/
[15] https://www.home-assistant.io/integrations/logbook

		• No native option exists in the HEMS UI to activate/deactivate Mixergy Holiday Mode. When active, the tank is not controllable via HEMS, and schedules/CEMS flex events would be blocked, including during user absence. This may require coordination with Mixergy to adjust the setting or disabling Holiday Mode to support SLES participation. • HA has no native override precedence framework; priority logic between competing automations and manual commands must be explicitly defined/programmed.	
SmartQube	• Manual user overrides from within the HEMS are not a native part of SmartQube's algorithm. • Installer dashboard allows 'heat now' and Mixergy boost commands. Commands via back-end execute within ~2 seconds; dashboard updates in 10-20 seconds. Vendor indicated that user overrides, such as physically selecting 'heat now' on the asset, can take place but will temporarily pause or override the SQ and community optimisation logic. • SQ app logs when maximum target states are achieved e.g. when the battery reaches full charge.	• Physical HMI overrides (e.g. physically boosting the MXGY) do not always update the target temperature register in HEMS, so the override is invisible to the HEMS. No active flag or state was displayed in the UI when an override was triggered. • No physical HMI for SQ, the phone app/online dashboard is the sole interface, which raises digital exclusion considerations for users without smartphone access wanting to override. • Battery charge/discharge overrides sent from installer dashboard are not fully functional; may require continuous back-end command loop to be programmed. • End users cannot directly override controls through the dashboard; their only influence on asset operation is by updating tariff and fixed-charge settings, which inform the optimisation algorithm.	• Vendor indicated that installer or user overrides (if incorporated) would pause or override community optimisation logic. • *Asset response time to tariff updates (relevant for future CEMS integration) and backend visibility of potential future user overrides remain outstanding and have not yet been confirmed by the vendor.*
Passiv & Levelise	• Manual overrides were available via both the Passiv app and thermostat HMI, with the remaining override duration clearly displayed on the interfaces. • When applied during an active schedule, override durations defaulted to the end of the scheduled period, with the option for users to adjust the duration. • Override reversion was successfully tested: a schedule set to 21.5°C with an override to 18°C until 2:00pm correctly reverted to 21.5°C at 2:00pm and maintained the scheduled setpoint thereafter. Correct reversion and schedule resumption were also confirmed when the hub was disconnected and reconnected.	• No additional limitations observed during testing.	• N/A
	• When Levelise was connected, force charge/discharge mode was no longer accessible on the FoxESS HMI. Levelise appeared to take exclusive control of the inverter.	• There is no physical HMI for Levelise, the phone app is the sole interface, which raises digital exclusion considerations for users without smartphone access.	• *Whether Levelise can receive and act on override commands sent from external systems (e.g. CEMS) is not confirmed and remains outstanding and has*

		• No manual override capability was available to users, and no clear mechanism was identified to override the optimisation engine from the app or a local interface. • The removal of HMI-level battery controls when Levelise is connected is a constraint; community operators and installers lose the ability to manually intervene at the asset level.	*not yet been confirmed by the vendor.*

5.2.7 P2-R7 Single Asset Operational Behaviour Under Defined Use Cases

Testing established how assets operate in isolation, under normal and constrained single-asset operating conditions and records response latency and command handling.

Table 11 - Summary of P2-R7 Single Asset Operational Behaviour Assessment

	Lab Observed Capabilities	Limitations	Other Notes from Vendors/Documentation
Home Assistant	• **B/I** repeatedly responded quickly and reliably under normal conditions; commands from the HEMS UI were reflected in the real operating mode of the battery as confirmed via the inverter. • HEMS delivered fault signals when a control action was attempted whilst the asset connection was down. • **HP** and **MXGY** response was fast, unless controls were switched too rapidly, in which case it often required a waiting period of approximately 14 minutes between work mode changes for the **HP**.	• Fault messages did not clearly indicate the cause. It was not possible to determine from the error whether the issue was a connection/comms fault or a schedule conflict from the native asset app. • Possible instability was observed when too many commands were sent simultaneously. The root cause, such as connection limitation or command queuing, was not confirmed.	• Conflict between HEMS and native asset app control is a known integration risk for all the HEMS; a governance model defining control authority is required for community deployment.
SmartQube	• QEnergy confirmed back-end command execution within approximately 2 seconds. Installer dashboard changes take approximately 10–20 seconds to register. • UI updates values instantly; however, historical export data (e.g. battery SoC) updates only every 30 minutes.	• Safety limit enforcement and device failure behaviours were not fully tested in the lab due to the requirement for vendor presence for most backend testing and associated time constraints on their availability. • Whether SmartQube rejects, clips, or logs commands that breach asset boundaries (SoC limits, DHW/heating temperature bands, inverter export limits) remains unconfirmed. Initial testing showed invalid inputs could be entered in the installer dashboard; some fields turned red to indicate invalid values, but entry and trial execution were still possible, with no alert indicating the command was invalid. • Additional planned latency, constraint, and interruption testing with QEnergy could not be completed due to limited vendor availability	• *Confirmation of in-depth constraint enforcement behaviour and whether boundary breaches are logged or blocked remains outstanding and has not yet been confirmed by the vendor.*

		to implement and action schedules, as support was provided on a pro-bono basis. Consequently, only limited backend testing of these assets was possible.	
Passiv & Levelise	• Heat pump response to app commands and schedules was near-immediate with audible relay switching. • Command acceptance handling was disabled when the Passiv hub was offline, but local control remained usable via the Passiv programmer & thermostat.	• Certain **HP** operational parameters (e.g. flow temperature curves) are controlled at heat pump level (within the EcoForest gateway) and not configurable via Passiv. When the HP was constrained by these settings, for example by the HP's configured maximum heating temperature, Passiv could not override HP configuration because the asset-level settings took precedence. • The **HPs** internal 14-minute relay protection delay is not exposed in the app, meaning users receive no warning when commands are blocked by this constraint. App-based scheduling and overrides were unavailable while offline.	• N/A
	• **B/I** basic optimisation and grid export functionality were confirmed as operational, with the system maximising self-consumption during daytime demand and higher solar availability and exporting to the home and/or grid during evening periods of low demand when the battery was fully charged. • A tariff change from flat rate (24.7p/kWh) to time-of-use (20p/kWh standard, 12p/kWh overnight) showed no clear optimisation response; battery export remained largely unchanged and no grid imports occurred, likely due to sufficient PV generation, preventing validation of overnight charging behaviour. • Battery status indicator correctly reflected system state, showing green during normal operation and yellow during an Asset-triggered error state.	• Response latency of optimisation decisions was not measured, as SQ's optimisation is a black box with no dashboard visibility of when Levelise receives the tariff or grid signals; only the end outcomes (e.g. battery charging) are observable, not the signal, so action response times for future CEMS integration remain unclear. • Safety limit enforcement (battery SoC min/max, inverter export limits) was not explicitly tested because user controls were not available. It is understood that these are managed by the inverter/battery firmware rather than Levelise's system. • Constraint enforcement and error logging behaviour were not confirmed due to lack of user input capability (no option to intentionally input invalid commands). Likewise, the platform's response to asset boundary breaches remains unknown and would require targeted testing with the vendor.	• *Whether Levelise controls any constraint enforcement/safety limits, or whether these are managed natively by the vendor asset, remains outstanding and has not yet been confirmed by the vendor.*

5.2.8 P2-R8 Multi-Device Coordination and Prioritisation

Testing established how the HEMS coordinates multiple assets and records prioritisation logic, optimisation behaviour, and performance under constrained operating conditions.

Table 12 - Summary of P2-R8 Multi Device Coordination and Prioritisation Assessment

	Lab Observed Capabilities	Limitations	Other Notes from Vendors/Documentation

Home Assistant	• Multiple assets were able to be controlled, monitored and managed throughout testing. • Some low-level coordination was automated during initial testing, for example linking **HP** control to **TRV** setpoints and switching the HP relay off once the setpoint was achieved.	• No native coordination or prioritisation logic between the devices was observed.	• N/A
SmartQube	• No asset prioritisation was observed; however, short-term **battery** charging/discharging (see limitations) and **HP** on/off operation occurred simultaneously under SmartQube connection.	• Multi-device testing across seasonal scenarios not yet completed. • Vendor confirmed asset priority hierarchy must be explicitly provided to QEnergy. This was not natively configurable or visible in the UI. • Issues with reliable battery control meant that extended stability testing (minimum 1 hour continuous) of multi-asset operation was not formally completed and recorded.	• QEnergy indicated that the SQ optimisation algorithm operates across seasonal scenarios, optimising across tariffs, consumption patterns, and asset prioritisation hierarchies defined by the community operator. • A main incoming meter is required for accurate load-following and BESS management.
Passiv & Levelise	• Reasons provided 5.1, TRVs and MXGY were not tested, with only the **HP** assessed via the Passiv app; therefore, implications of multi-asset behaviour on optimisation were not evaluated. *Smart TRVs would disrupt Passiv's optimisation.*	• Multi-device coordination testing was not completed due to Passiv being incompatible with TRVs, and the incompatible selected MXGY tank used in the lab environment.	• Vendor indicated that DHW and space heating prioritisation is based on ambient temperature forecasts, user-defined hot water demand, and tariff signals, with the system determining the most economical heating period (e.g. overnight vs alternative times). • Domestic hot water could work alongside Passiv, but the correct compatible configuration and model were not set up in the lab, so this integration was not tested.
	• Multi-device coordination testing was not completed for Levelise as the **HP & MXGY** assets were to be managed by Passiv in this joint approach. • **B/I** coordination was inferred from observed export behaviour, indicating basic battery decision making. When the battery was full from PV generation, the system switched to discharging and/or grid export.	• PV was not directly connected to Levelise due to unavailable connections in existing lab set-up; the lab's PV is synthetic and linked directly into the FoxESS, rather than through a direct AC/DC connection. The lab would require a separate inverter to connect into the Levelise terminals. • Full linked home-level coordination between Levelise and Passiv was not assessed due to incompatibilities with lab assets and configuration.	• *Confirmation of vendor priority logic remains outstanding and has not yet been confirmed by the vendor.*

5.2.9 P2-R9 Disconnection and Fallback Behaviour

Testing established how the HEMS and connected assets respond to communication loss and recovery and records fallback behaviour, alerting, state persistence, and resynchronisation processes.

Table 13 - Summary of P2-R9 Disconnection and Fallback Behaviour Assessment

	Lab Observed Capabilities	Limitations	Other Notes from Vendors/Documentation
Home Assistant	• On **B/I** connectivity loss, SoC was recorded as 'unavailable' and updated correctly once communication was restored. • The last commanded state was retained during disconnection. If discharging at the time of lost connection, the battery continued to discharge until reaching a safety or setpoint limit. • **B/I** telemetry logging was a bit intermittent and inconsistent, possibly due to an issue with the hard-wired communication link. **MXGY** & **HP** logging remained stable. • The activity log clearly showed when assets became unavailable and when communication was restored.	• Time-series data for all the assets was not backfilled by default and requires further investigation. • HA did not natively back-fill all telemetry gaps from connectivity outages. Gaps are recorded as 'unavailable' in the historian. • Status display did not always immediately reflect the actual system state following reconnection.	• Initial investigation (desktop research) suggests reconfiguration of native local storage is possible. This will be required in further development.
SmartQube	• Disconnection of assets to SQ were visibly shown as 'offline' alerts on the app and dashboard's notifications page.	• No native controls of assets were available; configured controls were unusable during asset disconnection tests. • Fallback behaviour for schedules requires back-end vendor setup (was not a native configuration) and was therefore not tested in the lab. • Scheduling is not end-user configurable; system relies on learned consumption patterns rather than pre-planned schedules.	• *Fallback and recovery behaviour following 4G, Wi-Fi, or Modbus communication loss remains outstanding and unconfirmed by the vendor. This includes operation during disconnection, handling of missed schedules, user notifications, automatic optimisation resumption, data backfilling following reconnection, and asset-specific recovery behaviour.*
Passiv & Levelise	• Active schedules and overrides of **HP** were correctly reapplied after reconnection. Local control remained available throughout internet disconnection. Offline status was clearly indicated in the app. • Local control remained available during internet disconnection via the physical programmer and thermostat. Frost protection, schedules, away mode, and thermostat adjustment remained functional offline. • App controls became available again on reconnection, indicating the system had re-established connectivity.	• On hub disconnection, the app displayed the thermostat as offline with a 'problem downloading heating schedule' error. Manual overrides and schedule changes were not possible via the app whilst offline.	• Vendor indicated that data from the outage period is backfilled upon reconnection. • Pre-set tariff schedules persist locally. If set for a future period, they continue running and optimising without internet connectivity. • Vendor indicated that heating learning runs locally on the hub; Solar optimisation is the exception, as it relies on forecast data and cannot run without connectivity. DHW prioritisation is determined by ambient temperature for the day ahead, hot water demand set by the owner, and tariff.

	• Levelise Hub disconnection testing showed that the installer menu displayed a red light, indicating offline status. • Following disconnection, the reported operational status (e.g. charging/discharging) remained unchanged and did not update during the outage, indicating that it likely reflected the last known state rather than the battery's actual operating state. • A day of asset disconnection and reconnection did not result in any backfilled data.	• No other clear alerts or notifications were visible in the user-facing app profile during the disconnection; the offline state was only observable from the battery icon. • Battery behaviour during the communications outage could not be verified, (e.g. whether it held its last state, reverted to default, or continued autonomous operation). No data was available for the disconnection period following reconnection, and the FoxESS HMI could not be accessed to confirm the battery operating mode during the test.	• Vendors' site indicates that the Levelise Hub requires a broadband internet connection for its battery optimisation[16]. • *Intended fallback operation, data backfilling, recovery of telemetry gaps, and recovery behaviour following loss and restoration of connectivity have not been confirmed by the vendor.*

[16] https://support.levelise.com/hc/en-gb/articles/10121452281628-Does-the-system-need-to-be-connected-to-the-Internet

5.3 Summary & Conclusions of Phase 2

Phase 2 testing identified that all tested HEMSs would require some degree of further development, integration work, or configuration to fully meet the current NZT requirements. Table 14 evaluates each HEMS against each phase 2 requirement, defined in Appendix A – Phase 1 Testing Requirements, based on a 1-5 ranking system defined as follows:

1. Not demonstrated during testing, and no evidence indicates the capability currently exists; or testing indicates the capability does not function.
2. Not demonstrated during testing, further vendor documentation or discussions required to confirm, or they have suggested the capability could potentially be developed; but there are no confirmed plans to implement it.
3. Not demonstrated in the laboratory, but vendor evidence, documentation, existing deployments, or product roadmap indicate the capability exists or is planned for development.
4. Capability partially demonstrated in the laboratory, or demonstrated with limitations, configuration changes, vendor intervention, or unresolved issues requiring future development.
5. Capability fully demonstrated in the laboratory and operated reliably without material limitations.

Table 14 - Evaluation table of HEMS providers against Phase 2 requirements.

Requirement ID	Requirement Title	Home Assistant	Smart Cube	Passiv + Levelise	
P2-R1	**Capability discovery and documentation**	**5** - Extensive telemetry, controls and asset capabilities demonstrated across all tested assets.	**4** - Most capabilities identified, but battery control remained unreliable and some controls required vendor intervention.	**4** - Heat pump scheduling, comfort controls and optimisation capabilities were demonstrated, but hot water functionality could not be fully verified with the laboratory configuration.	**4** - Battery monitoring, tariff optimisation and export management capabilities were demonstrated, but functionality was limited to battery and inverter assets.
P2-R2	**Smart Meter Data Access and Compatibility** ***(Not Lab Tested)***	**3** - Multiple smart meter integration pathways identified through vendor documentation, no DCC integration lab tested.	**3** - Vendor confirmed compatibility, but supported standards, access methods and meter compatibility were not formally evidenced.	**1** - No smart meter integration capability was available. Vendors have confirmed that Smart Meter integrations are in early development, but this functionality is not currently supported.	**3** - Vendor documentation indicated a dependency on half hourly consumption data, but the integration route and meter compatibility were not confirmed.
P2-R3	**Local Available Operational and Telemetry Data Access**	**5** - Extensive operational, telemetry and historical data access demonstrated across all connected assets.	**4** - Telemetry and long-term storage were demonstrated, but data granularity, retention and export functionality remained partially unconfirmed.	**4** - Heat pump operational data, schedules and historical information were demonstrated, although some analytics functionality was unavailable in the laboratory configuration.	**4** - Battery operational and historical performance data were demonstrated, but data granularity, retention and export functionality remained partially unconfirmed.

P2-R4	**User Schedule Execution**	**5** - Schedules, constraints, automations and user settings successfully created, modified and executed in the laboratory.	**3** - Scheduling functionality was successfully tested via back-end configuration; however, it is not currently available through the user interface, and discussions on whether personal schedules would be possible as the community scales are still outstanding.	**5** - Heating schedules, comfort settings and user controls were fully demonstrated and operated as expected.	**1** - User scheduling functionality was not available, as battery operation is fully automated by design.
P2-R5	**Native Optimisation Logic and Objective Interaction**	**4** - Optimisation behaviour was demonstrated through custom automations; no native optimisation engine exists.	**4** - Optimisation was demonstrated, but optimisation objectives and dictating asset priorities lacked transparency.	**5** - Native heating optimisation modes were demonstrated and their interaction with schedules and comfort settings was clearly evidenced.	**4** - Battery optimisation was demonstrated, but optimisation priorities and interaction with external control systems remained unclear.
P2-R6	**Manual Override Handling and Precedence**	**4** - Override functionality was demonstrated, although override visibility and precedence require additional configuration to improve.	**2** - Override control actions via the HEMS relied on installer controls and vendor intervention rather than user accessible functionality.	**5** - Heating overrides, duration control and automatic schedule reversion were fully demonstrated and operated reliably for the HP.	**1** - No user accessible battery override mechanism was identified during testing.
P2-R7	**Single Asset Operational Behaviour Under Defined Use Cases**	**5** - Assets responded reliably to commands, constraints and disconnection scenarios with only minor limitations observed.	**3** - Basic operation was demonstrated, but extensive constraint and latency testing could not be completed.	**4** - Heat pump command execution, scheduling and local fallback behaviour were successfully demonstrated, although the same for DHW could not be tested in the current lab set up.	**3** - Battery optimisation behaviour was observed, but command handling, latency and constraint enforcement could not be fully assessed.
P2-R8	**Multi-Device Coordination and Prioritisation**	**3** - Multiple assets coordinated through custom automation, but no native prioritisation logic was demonstrated.	**2** - Vendor indicated multi asset optimisation capability, but battery control issues prevented full verification.	**1** - Multi asset coordination could not be assessed as compatible domestic hot water and TRV integrations were unavailable within the laboratory configuration.	**1** - Multi asset coordination could not be assessed as testing was limited to battery and inverter operation.
P2-R9	**Disconnection and Fallback Behaviour**	**4** - Asset recovery and state persistence were demonstrated, although telemetry backfilling was not fully achieved.	**2** - Disconnection alerts were observed, but fallback and recovery behaviour remained largely unverified.	**5** - Heating schedules, local control and recovery following reconnection were fully demonstrated.	**2** - Offline status was identifiable, but battery behaviour, optimisation recovery and data continuity following disconnection could not be confirmed.

As shown in Figure 12, Phase 2 testing identified that none of the tested HEMS fully met the defined requirements without additional development required.

Please note that Passiv and Levelise were evaluated separately in this section; however, they were considered as a combined solution rather than standalone whole-home HEMS solutions. Generally, Passiv focuses on heat pump and domestic hot water operations, optimisations and controls, whilst

Levelise focuses on battery storage, PV and tariff optimisation, and flexibility service participation. Individual platform scores therefore reflected performance only within their respective asset scope and should not be interpreted as representing complete whole home HEMS capability. Assessment of the combined Passiv and Levelise solution is discussed separately within the technology selection analysis.

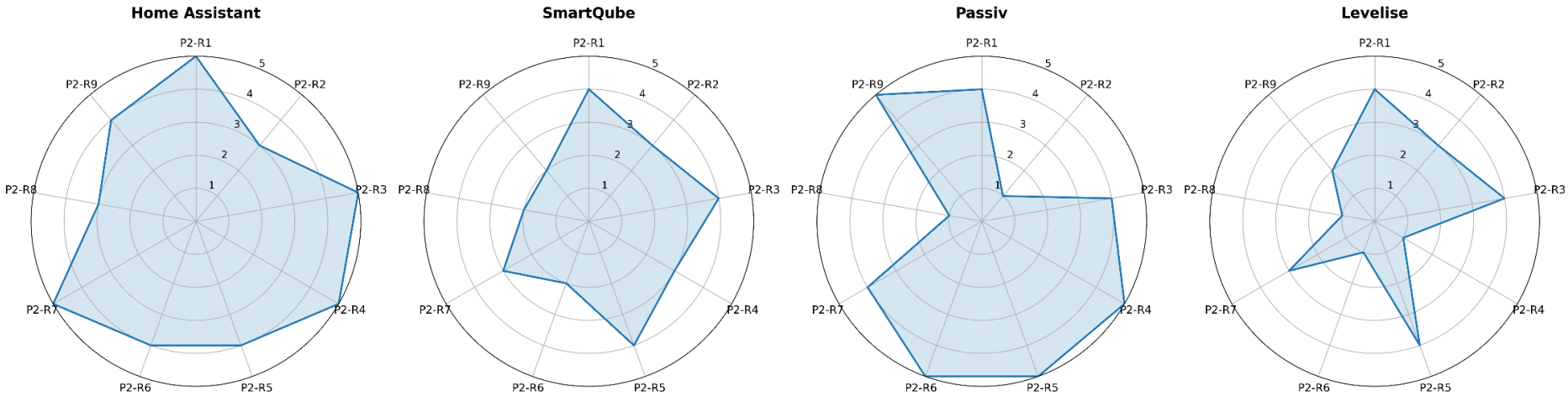


Figure 12 - Radar plots to evaluate each HEMS against Phase 2 key requirements

Across all HEMSs, governance for conflict resolution between HEMS and native asset apps remains a priority. Without clearly defined control authority, conflicting commands could undermine reliability, for example, schedules set via the native FoxCloud app sometimes conflicted with HEMS commands.

Overall, Phase 2 testing demonstrated that each HEMS option offers a different balance of capability. Home Assistant demonstrated the broadest range of lab-tested visibility, control functionality and integration flexibility. SmartQube demonstrated a structured, vendor-managed optimisation approach, although some functionality could not be fully evidenced within the laboratory environment. Passiv and Levelise demonstrated strong, well-developed optimisation logic within their respective domains of heat pump and battery optimisation. However, because they were assessed as a combined package, and because some Levelise-specific confirmations remain outstanding, the results should be treated as indicative of the package's potential rather than full validation of whole-home coordination.

For NZT, the most suitable option depends on the preferred operating model: an open and highly adaptable platform, a managed commercial optimisation service, or a split-platform approach using specialist HEMS functions by asset type.

6. Phase 3 Testing: External Control & Optimisation

6.1 Key Objectives

Phase 3 testing assessed whether the HEMS could communicate and interoperate effectively with upstream systems, including a consumer facing application and a simulated CEMS interface, to help optimise for SLES-wide objectives. The aim was to verify that the HEMS could receive and respond to external control signals while maintaining household comfort and protecting connected assets. Through this, the testing also explored each HEMS's potential to participate in future flexibility services and local energy schemes through its ability to respond to external optimisation and control signals.

A list of Phase 3 requirements was developed through team workshops and wider SLES project requirements. These requirements, provided in Appendix D – Phase 3 Testing Requirements, were used to guide the results presented in the following section.

Purpose of the Testing and Vendor Considerations

All HEMS solutions assessed during testing were selected due to demonstrated capability and recognised value within different domestic energy management applications. Phase 3 testing was undertaken to identify the solution most closely aligned with the specific requirements of the NZT SLES architecture, particularly in relation to external integration, interoperability and future flexibility services. The results presented in this section therefore reflect suitability for the NZT use case and testing scope, and should not be interpreted as a broader assessment of the overall quality, capability or commercial value of any individual product.

6.2 Testing Overview

6.2.1 HEMS Testing

This phase intended to provide the HEMSs with a controlled environment to assess interoperability with simulated external signals. Due to commercial constraints, physical integration testing was only undertaken with **Home Assistant**, reflecting its open-source architecture and the ability to develop the required integration routes within the project scope. Equivalent integrations with SmartQube and Passiv/Levelise would have required commercial vendor-led development beyond the available programme budget, timescales, and scope. As such, the Home Assistant results provide the primary technical evidence for external service integration, demonstrating that the underlying architecture is technically feasible.

For **SmartQube** and **Passiv**, vendor discussions and reviews of capability documentation were conducted in place of direct testing to capture current and road mapped external integration capabilities. All capabilities described are vendor-stated and have not been verified in the lab. These discussions were used to identify potential future integration routes, subject to vendor confirmation, delivery timelines and development funding. These discussions are documented to support vendor selection and future integration planning.

Initial conversations with **Levelise** were positive and indicated strong development capability. However, the level of technical input required to fully evaluate the platform against the Phase 3 requirements was not obtained within the available operational timeframe. This made assessment of potential bespoke, non-native and future integration capabilities limited. Consequently, any gaps identified within the Phase 3 findings, for Levelise and where applicable other HEMS providers, should not be interpreted as an absence of capability, unwillingness to develop a capability, or

inability to deliver a future solution, but rather as an inability to verify those capabilities within the available testing window.

6.2.2 External Signal Development and Testing

Physical testing of the **Fairer Warmth** user interface with the HEMS was carried out to demonstrate the feasibility of this integration. Testing focused on the Mixergy Hot water tank, however, all assets added to the Home Assistant based HEMS are connected using the same protocol and controlled in the same manner. Because the solar PV, inverter, and battery assets primarily support system-level optimisation (e.g. grid optimisation) rather than direct resident comfort, data was provided to users as view-only and user-facing controls were omitted. These may be included in future phases if required, along with additional telemetry for user visibility.

Physical testing of a potential integration with a simulated **Cloud-based Integration Test Platform** included the battery/inverter, heat pump, TRVs, and Mixergy tank. A test dashboard was internally developed to act as a prototype MVP of the CEMS, to meet minimum testing objectives. It functions as a simulated CEMS, using an external API to read and write registers in Home Assistant to control connected assets, mimicking how a real CEMS might issue commands to adjust home-level demand up or down.

The CEMS was implemented as a test dashboard emulating the monitoring and control functions of a real Community Energy Management System. Assets receive simplified control requests, or community-level signals (e.g. tariff or flexibility-style instructions), after which the HEMS is expected to update accordingly. A feedback loop was also implemented, with the HEMS synthesising and returning asset-level data to the CEMS test dashboard in near real time.

6.3 Results

Phase 3 testing results are assessed against their relevant phase 3 requirements, outlined in Appendix C – Phase 2 Testing Requirements.

6.3.1 External Signal Handling and Asset Status Visibility (P3-R1, P3-R2)

This testing assessed whether the HEMS could establish a communication link with an external user platform, such as Fairer Warmth (FW), and that the platform can retrieve and display real-time asset status data from the HEMS. This includes key parameters such as battery SoC, DHW temperature, and heat pump setpoint. The intended outcome was for the data to be presented through clear, user-focused visualisations, demonstrating the core data visibility layer that enables users to monitor and understand the status of their home energy devices.

Home Assistant: Lab Testing Result

A successful communication link was established between the Fairer Warmth (FW) platform and the Mixergy hot water cylinder. Key operational parameters, including current and target tank temperature and tank charge level, were visible within the FW interface (**Error! Reference source not found.**) and verified against corresponding values in Home Assistant. This demonstrated successful end-to-end integration between the FW platform and a physical laboratory asset via the HEMS.

At the time of testing, direct integration of the battery, inverter, and solar PV system had not yet been implemented. However, a functional mock-up (**Error! Reference source not found.**) demonstrated how these assets could be incorporated into the FW interface, indicating that additional devices could be integrated using the same approach. Future heat pump and TRV integration is expected to follow the same approach, requiring the addition of the relevant data registers within FW.

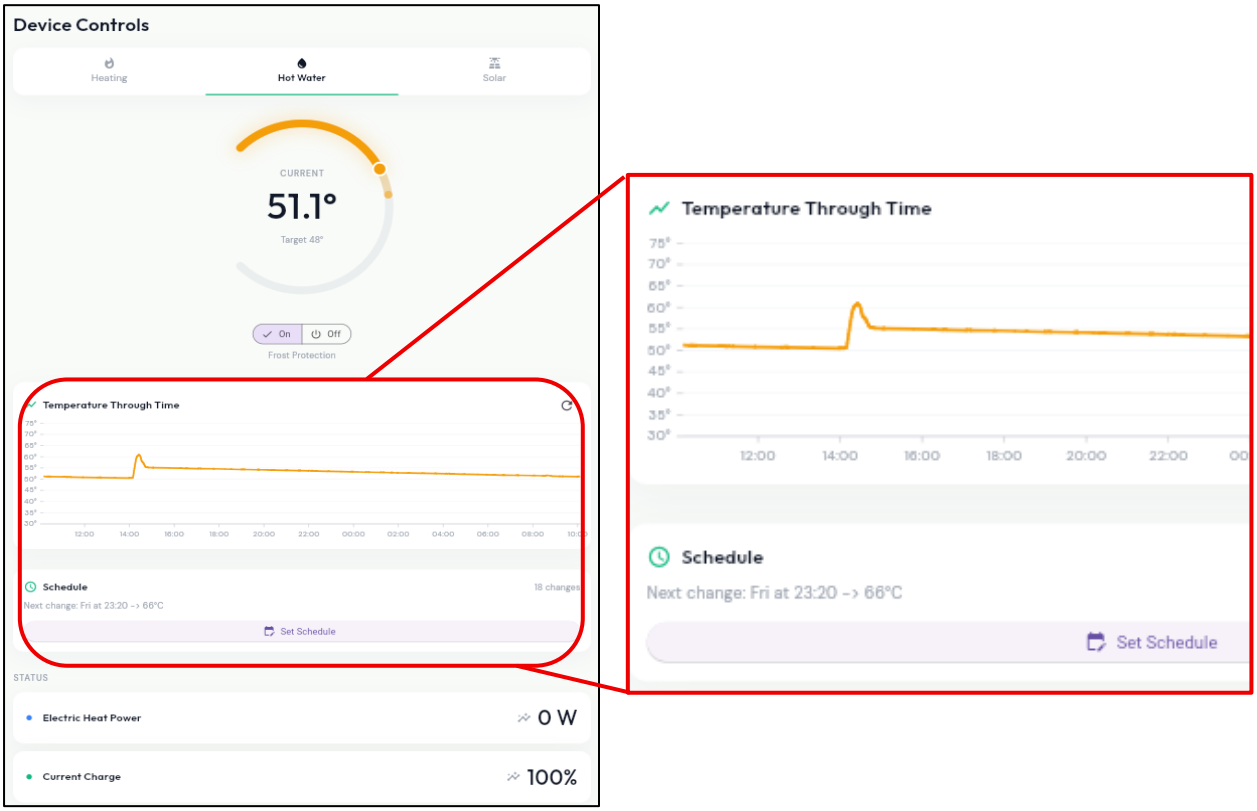


Figure 13 - Mixergy Readability into Fairer Warmth App.

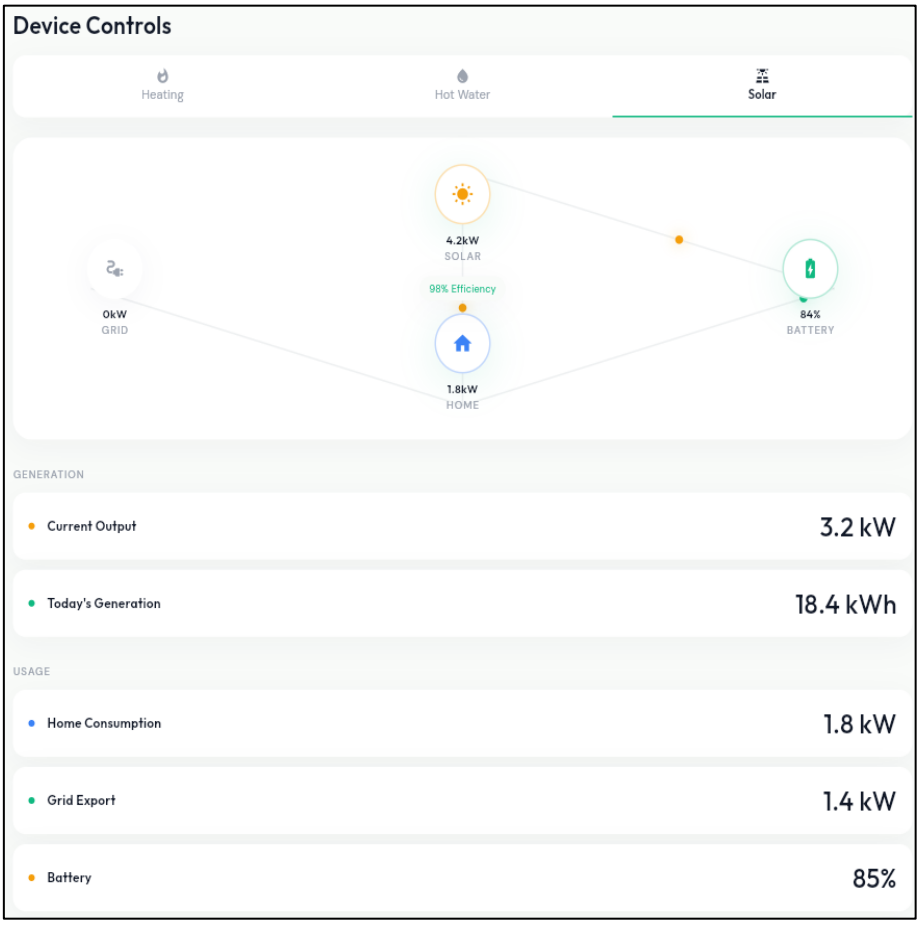


Figure 14 - FW Mock-Up of Solar & Battery Telemetry Points.

Changes to the Mixergy target temperature made in Home Assistant were successfully reflected in the FW platform, together with the resulting tank charge level updates. This provided evidence of the data feedback loop between the HEMS and the user-facing platform. An update latency of approximately 1-2 minutes was observed, which was acceptable for the requirements tested in this phase but may require optimisation if future use cases require faster DSO signal response times.

While additional telemetry, such as instantaneous electric power, was not yet available within FW, the platform is intended to prioritise a simple, user-focused interface centred on comfort outcomes rather than detailed technical asset data.

SmartQube: Vendor Discussion Summary

Discussions with QEnergy indicated that SmartQube's existing analytics and visualisation platform (installer dashboard) could be adapted to support integration with an external user interface such as FW. Given SmartQube's existing web-based monitoring capabilities, exposing asset status data - including battery SoC, DHW temperature, and heat pump setpoint - to an external platform appears feasible in principle. However, enabling third-party access to this data would require development within QEnergy's back-end architecture and cannot be achieved through a self-service integration. Formal confirmation of the technical feasibility, scope, and implementation requirements, including the provision of data via an API or other external interface, would need to be discussed further if SmartQube is considered for future integration.

The data resolution available to external platforms also remains unconfirmed. Current SmartQube exports provide battery SoC data at approximately five-minute intervals, while battery charge/discharge and heat pump performance data are visually available at 30-minute intervals.

Passiv/Levelise: Vendor Discussion Summary

Discussions with Passiv indicated that integration with a third-party platform may be achievable through the development of a public API, although the specific integration route is not currently confirmed. While Passiv provides limited native user-facing visibility, exposing asset and operational data to an external platform such as FW appears technically feasible. Passiv already participates in flexibility schemes through Voltalis, which acts as an aggregator and can override customer-defined schedules in response to flexibility signals. This provides a relevant example of external system interaction with Passiv managed assets and suggests that external interaction with Passiv-managed assets is possible. However, the specific mechanism required to integrate with FW or a CEMS would require bespoke development and has not yet been defined.

The data resolution available to external platforms also remains unconfirmed. The Passiv app currently provides hourly consumption data, while the installer portal can display certain data streams at up to one minute granularity, although this varies by data type. The level of data access and refresh rates that could be made available through a future external interface would require further confirmation from Passiv, if this solution is taken forward.

6.3.2 External Signal (User) Control (P3-R3)

This testing assessed whether an external platform could send control signals to the HEMS, such as user defined comfort settings, schedules, or setpoints, and whether the HEMS correctly acts on them alongside its own internal scheduling/optimisation logic. This assessed the user-facing control pathway from FW to the home assets.

Home Assistant: Lab Testing Result

A successful control pathway between the Fairer Warmth (FW) platform and the Mixergy hot water cylinder (through the HEMS) was demonstrated for both immediate and scheduled actions (See **Error! Reference source not found.** and **Error! Reference source not found.**). Direct changes to the target tank temperature made through FW were successfully communicated to HA and reflected in the Mixergy asset, which subsequently charged towards the updated setpoint.

Likewise, a schedule created within FW to heat the tank from 40°C to 55°C at 06:30 was automatically transferred to the HA calendar within approximately one minute and executed successfully at the specified time, with the resulting asset status and temperature changes subsequently visible within the FW platform. This fast end-to-end latency for schedule synchronisation will be considered important for maintaining responsive system behaviour and supporting user comfort requirements.

The calendar is stored locally within the HEMS, meaning that scheduled actions would continue to run even if connectivity to the CEMS or upstream platform were lost.

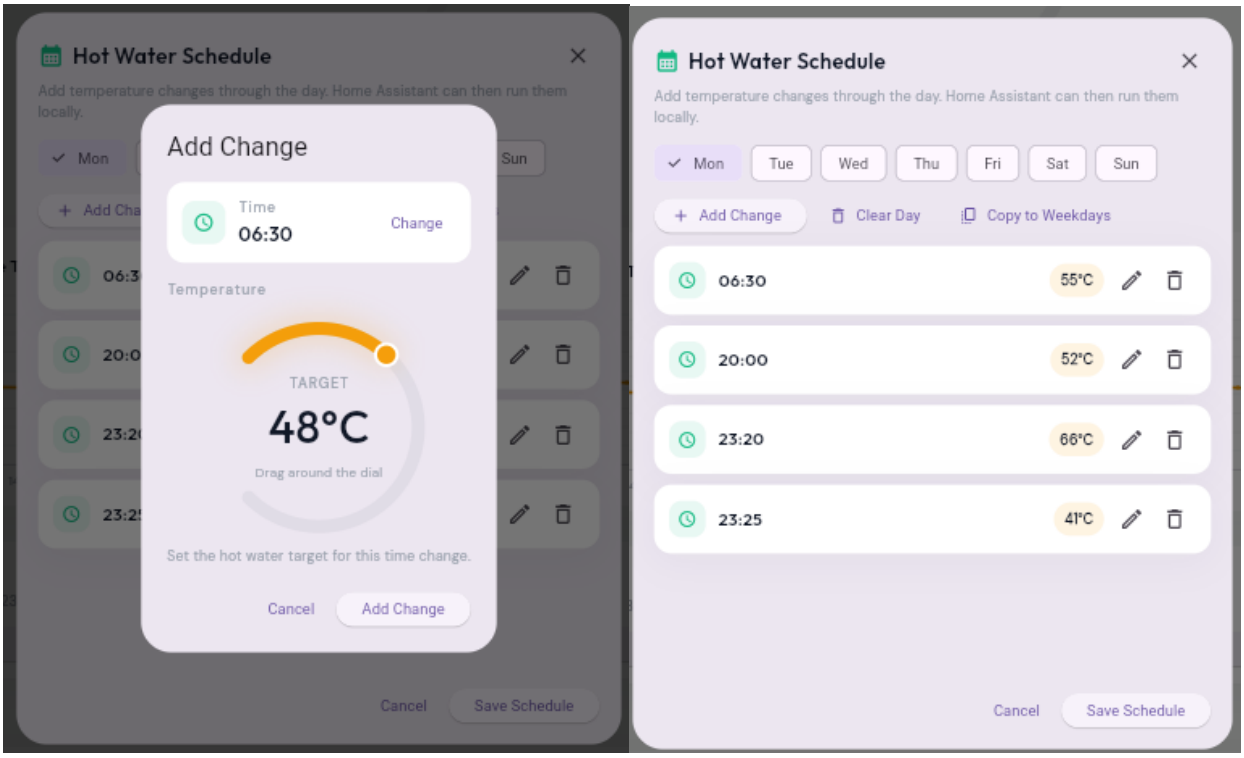


Figure 15 - User controls and scheduling actions performed through the FW platform.

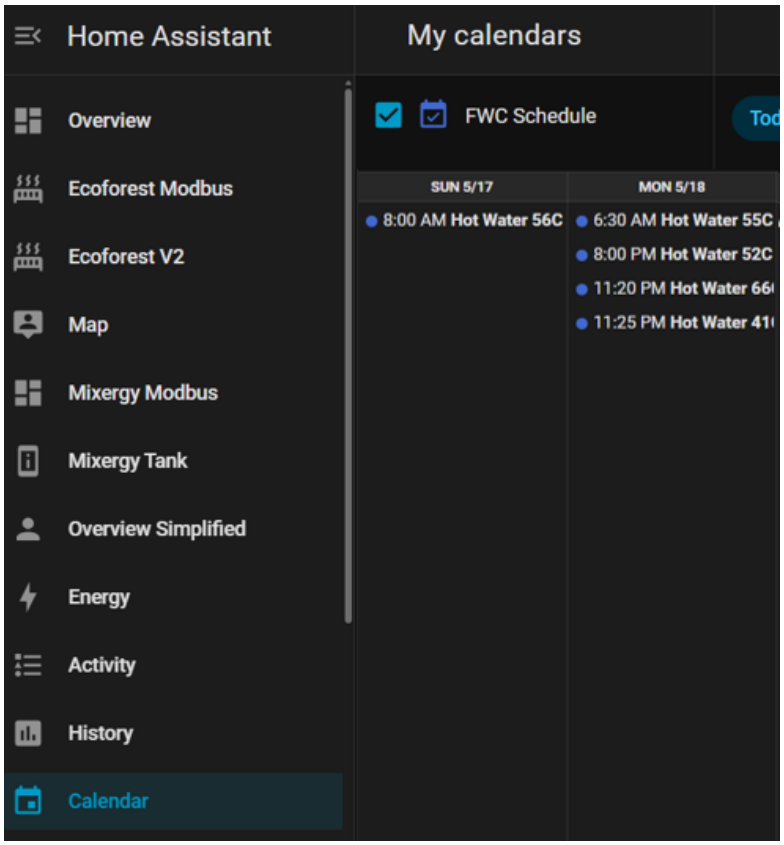


Figure 16 - Corresponding schedule update in HA, confirming successful transmission and implementation of the control signal.

This testing provided evidence of a viable end-to-end user control pathway from FW, through the HEMS, to a physical asset. It demonstrated that user-defined schedules and comfort settings could be communicated, executed, and reflected back to the user interface in the tested configuration. However, no existing optimisation or control logic is in place within HA to assess the interaction with these signals; this logic would need to be developed and validated in future development.

The inclusion of additional user controls, such as holiday mode or asset on/off functionality, remains under consideration. The current design assumption favours maintaining asset availability for CEMS optimisation during periods of user absence, enabling continued participation in flexibility services. However, the successful demonstration of control implementation through FW indicates that such functionality could be added, if required as part of future platform development.

SmartQube: Vendor Discussion Summary

Discussions with QEnergy indicated that enabling direct user control of SmartQube-connected assets through an external platform such as FW may be technically feasible but is unlikely to be a near-term development priority for them, due to commercial considerations. Any third-party control functionality would need to be implemented through SmartQube's back-end systems and carefully coordinated to avoid conflicts with its optimisation algorithms and control strategies.

SmartQube does not currently support user boost or override functions via its user dashboard. Any manual override is instead performed directly at the physical asset level, via associated asset applications, or through the installer dashboard. In cases where a user overrides an asset locally, this action temporarily takes precedence over SmartQube's optimisation for a period defined within QEnergy's backend logic, however, this duration was not verified. Further development with the vendor would be required to formalise and expose priority handling, duration, and reversion rules.

QEnergy indicated that user preferences and comfort constraints, such as minimum indoor temperature settings, are planned for inclusion in the future roadmap. Consequently, while user control functionality is expected to evolve, and third-party control remains a potential future capability, its technical feasibility, implementation requirements, and alignment with SmartQube's control architecture remain subject to further vendor engagement.

Passiv/Levelise: Vendor Discussion Summary

Passiv indicated that a public API could enable third-party platforms, such as FW, to exchange control signals and user-defined settings with the Passiv platform. This appears consistent with Passiv's existing external interaction route through Voltalis, although the specific route for Fairer Warmth has not been defined. Any control integration with a separate third-party platform would require vendor-led development and should be treated as a potential future capability rather than a currently available feature.

6.3.3 CEMS Integration and Data Synchronisation (P3-R4, P3-R5)

This testing assessed whether the HEMS could communicate bidirectionally with a test dashboard used to emulate the monitoring and control functions of a CEMS (described in further detail in Section 6.2.2), and respond to a tariff-based signal, as a proxy for DSO-style constraints.

The purpose of these tests was firstly, to assess whether control actions and energy usage data could remain synchronised across HEMS and 'CEMS' platforms, including responsiveness, traceability, connectivity variation, and near real-time performance; and secondly, to evaluate whether the HEMS could receive, interpret, and act on tariff signals by adjusting operational behaviour (e.g. increasing demand below defined thresholds). Together, this demonstrates core functionality required for future DSO/CEMS integration.

Home Assistant: Lab Testing Result

Two-way communication was established between the emulated CEMS platform and the tested assets (See Figure 17). In the lab setup, the CEMS test dashboard included the battery/inverter system, heat pump, TRVs, and Mixergy hot water tank, which were made visible and controllable within the system.

For the battery and inverter system, key parameters such as SoC, operating mode, inverter power, and temperatures were visible in the test dashboard. Successful control was demonstrated, with changes between self-consumption/charge/discharge work modes executed via the dashboard and correctly reflected in the HEMS.

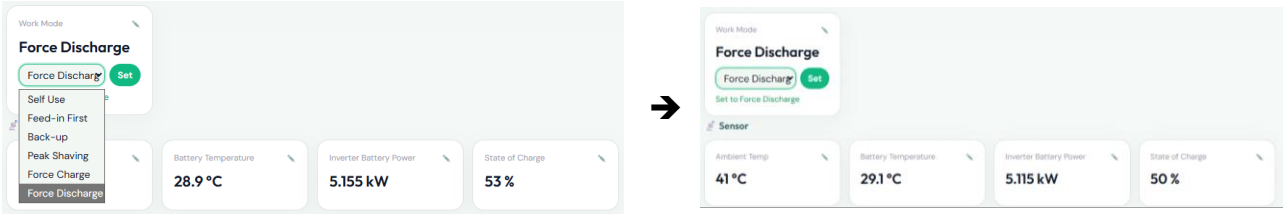


Figure 17 – (Left) CEMS test dashboard showing control interface of the FoxESS battery/inverter system. (Right) Updated dashboard state following successful execution of the control command.

For the heat pump and TRVs, operating states and setpoints were visible within the CEMS. Bidirectional communication was confirmed for radiator flow temperature, buffer setpoints, on/off status, and TRV target temperature. However, additional HA automation development is still required to fully integrate TRV control with heat pump optimisation logic. For the Mixergy hot water tank, temperature and charge level were visible in the CEMS (see Figure 18), with successful control of

target temperature and charge percentage. End-to-end testing demonstrated that a target charge set in the CEMS was correctly executed by the HEMS, with charging terminating at the specified setpoint.

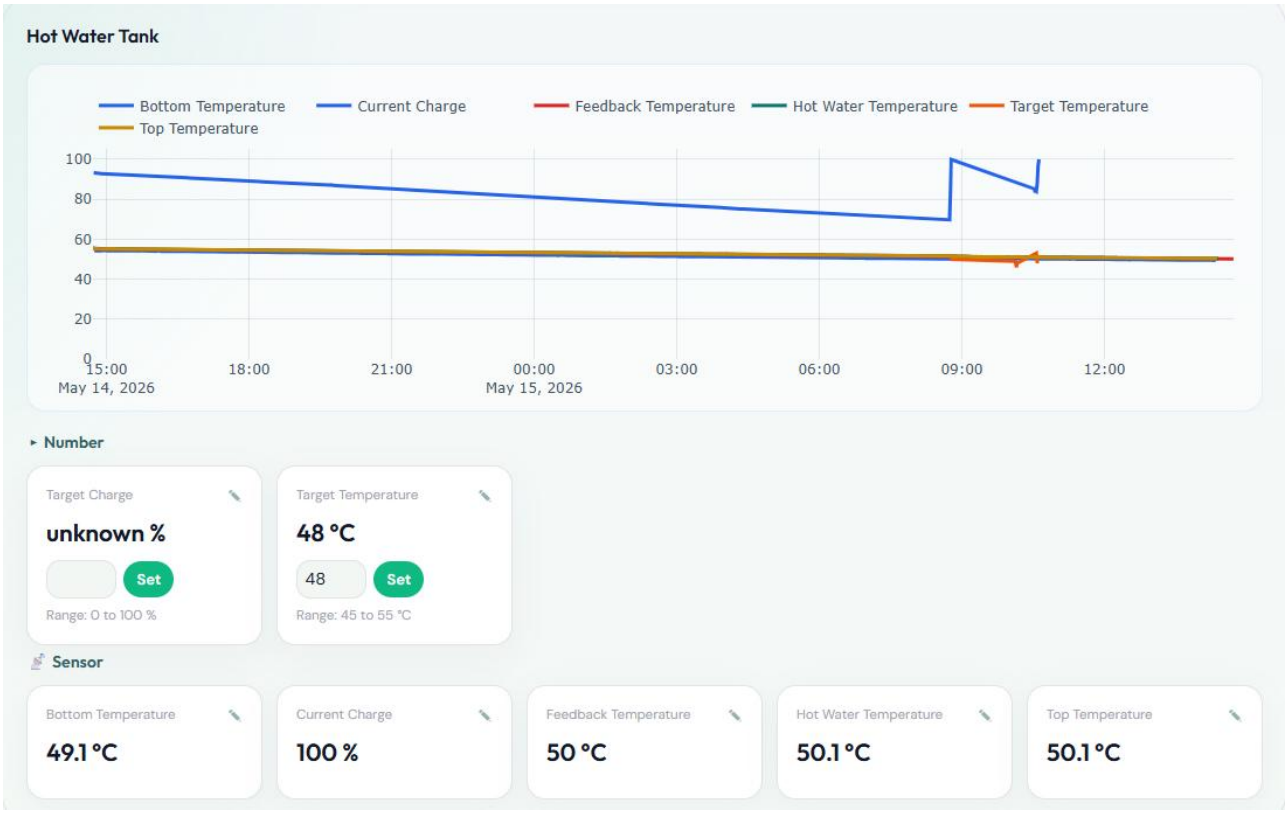


Figure 18 - Mixergy controls and analytics from CEMS test dashboard.

Schedule based control was not yet implemented within the CEMS test dashboard; however, a viable implementation pathway into HA was demonstrated via the FW integration using a calendar-based approach, confirming feasibility.

In terms of data synchronisation, update latency between HEMS and CEMS was consistently under 2-3 minutes across all asset groups. Time-series alignment of historic data was also confirmed across all assets. Battery and Mixergy data showed consistent tracking of SoC, charge/discharge events, target charge, and temperature, with a resolution of approximately one second (battery) and one minute (Mixergy). Heat pump setpoints and operating states were similarly aligned across both systems. The laboratory CEMS test dashboard retained historical data until manually cleared, however, longer-term storage is expected to be handled via a dedicated data platform. Control actions are not yet logged within the CEMS, but this is identified as a future development requirement to enable full traceability of flexibility events. Future work will also focus on improving data storage and enabling aggregation of multi-HEMS datasets for community-level analysis.

One potential form of the CEMS/DSO implementation is a tariff-based signal that instructs the HEMS to increase or decrease household electricity consumption in response to wider market prices and DSO constraints. This approach was tested in Home Assistant using a DCC smart meter rate to emulate a dynamic electricity tariff (demonstrated in **Error! Reference source not found.**). A simple automation was configured to monitor a synthetic electricity price and adjust home operation accordingly. The trial was successful: the heat pump switched on for one hour whenever the price fell below a defined threshold (£0.10/kWh), demonstrating successful tariff-response automation. This was an initial proof-of-concept trial designed to validate the basic functionality. Further development and testing would

be required to support more nuanced tariff structures, additional flexibility of assets, and more sophisticated control responses under a wider range of operating conditions. The other two HEMSs assessed already include built-in tariff optimisation functionality.

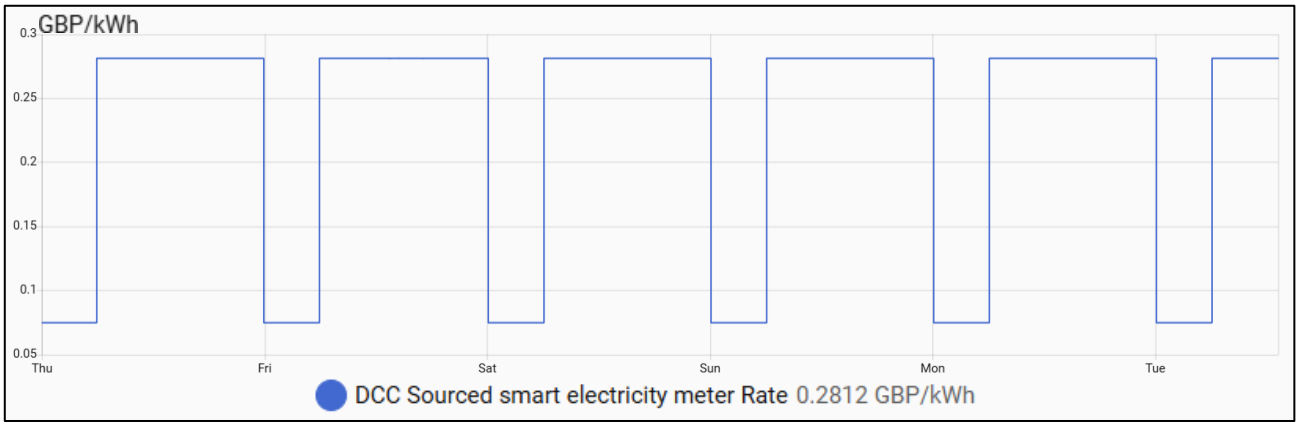


Figure 19 - DCC source smart electricity meter rate, visualised in HA. Rates range from 0.075 - 0.2812 GBP/kWh.

Overall, testing demonstrated end-to-end bidirectional control and visibility across all asset groups, with scheduling functionality, optimisation logic, and control action logging still requiring further development.

SmartQube: Vendor Discussion Summary

QEnergy's VPP roadmap includes integration with community-level systems to support near real-time monitoring and aggregation. Control via a CEMS using synthetic tariff or flexibility signals aligns with this roadmap, with similar mechanisms reported by Q Energy as being applied in commercial and industrial deployments, where high-level 'smart tariff' signals are translated by SmartQube into automated home-level optimisation. Key technical details required for this integration, including API structure, communication protocol, latency, data resolution, synchronisation approach, and support for bidirectional data exchange with the CEMS, have not yet been formally confirmed.

In this model, the CEMS provides signals rather than direct device commands, with SmartQube handling local optimisation. It remains unconfirmed whether SmartQube's responses to CEMS signals will be logged and fed back to the CEMS to close the feedback loop. Current SmartQube exports provide battery SoC data at five-minute intervals and battery/heat pump performance data at 30-minute intervals; availability of higher-frequency data for near real-time monitoring requires further confirmation, if this is deemed a future requirement of the system.

Passiv/Levelise: Vendor Discussion Summary

Passiv already participates in flexibility and aggregation services through Voltalis, providing a working precedent for external signal-based control of heat pump assets. Levelise operates as a separate aggregator focused on battery storage, with heat pump flexibility identified as a future roadmap item rather than a current capability. The longer-term intention is for Passiv and Levelise to integrate as sister companies, covering heat pump and battery flexibility together, though this remains in development with undisclosed timelines.

This indicates that the underlying mechanisms for external flexibility coordination already exist within the wider Passiv/Levelise ecosystem, but have not yet been brought together or applied across the full multi-asset deployment used in this testing programme.

For Passiv, back-end data is available at approximately five-minute resolution and could potentially be exposed via a public API. Whether higher-frequency access would be needed for near real-time monitoring has not yet been confirmed and would need to be addressed if required by future system requirements. In terms of CEMS control, Levelise have indicated that its optimisation logic could be disabled or adapted if required to operate alongside a CEMS algorithm and wider SLES control requirements.

6.3.4 Local Data Store and Historian Integrity (P3-R6)

This testing assessed whether the HEMS retains time-series and event data during cloud or external platform outages and can backfill or resynchronise it with the CEMS once the connection is restored. Building on Phase 2, which confirmed asset-to-HEMS retention, this phase focuses on upstream synchronisation, ensuring data completeness, usability, and system-level alignment after reconnection, and identifying any gaps in the community-level dataset after reconnection.

This work does not include development of the HEMS local data store. It assesses the current state of local storage capability within the HEMS and its suitability for integration with an external cloud-based platform, with the aim of de-risking the integration pathway and defining requirements for further development. Further work may be required either within the HEMS data store itself or within the integration layer to support robust synchronisation.

Home Assistant (HA): Lab Testing Result

Testing was conducted on the battery and Mixergy tank by applying state changes immediately prior to a controlled disconnection (battery set to charge mode; Mixergy target temperature and charge percentage increased). The CEMS was disconnected at 13:15 and reconnected at 14:51. Following reconnection, data from the outage period was not fully backfilled from the HEMS historian into the CEMS (See Figure 20). Instead, interpolated trends were displayed rather than discrete event logs (See Figure 21), indicating a break in event-level synchronisation. The local HEMS historian, however, retained all state changes throughout the outage, with full continuity visible in HA. This indicates that no data was lost at the HEMS level, and the gap appears to sit within the dashboard 'CEMS' ingestion layer.

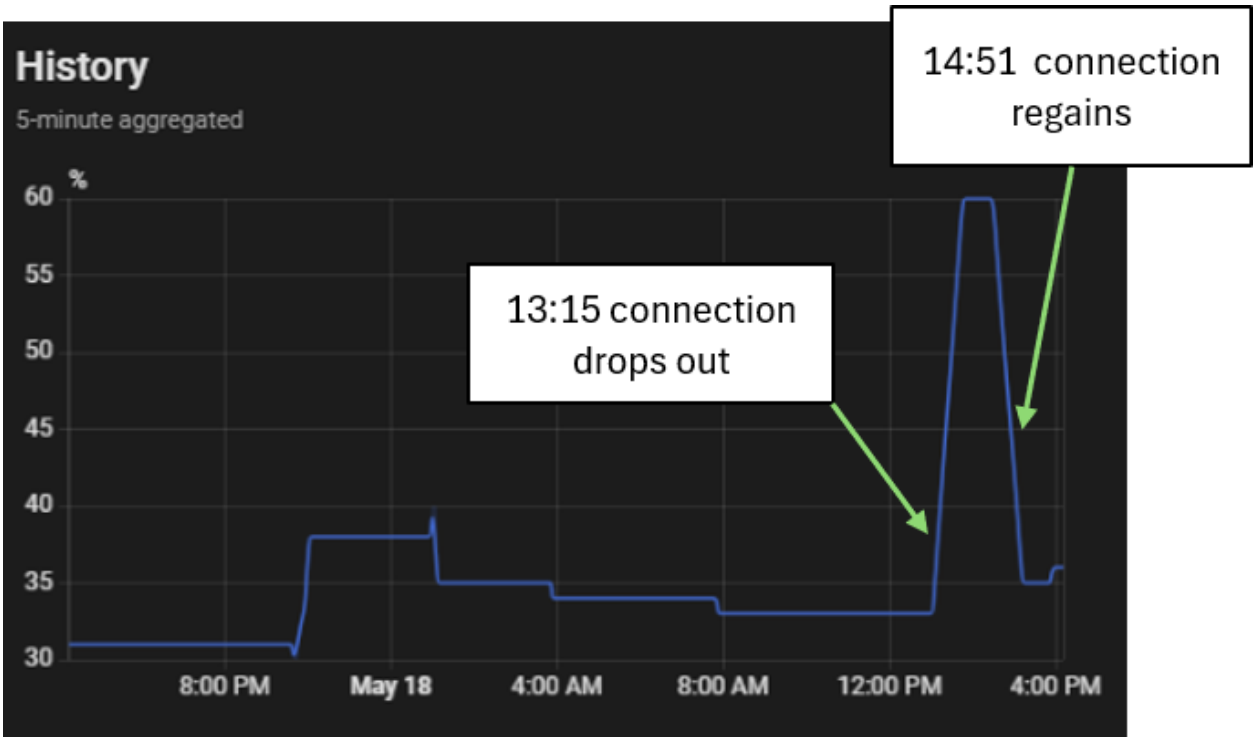


Figure 20 – Home Assistant's data logging of Battery's SoC during connection loss to the CEMS, showing 14:51 connection restored.

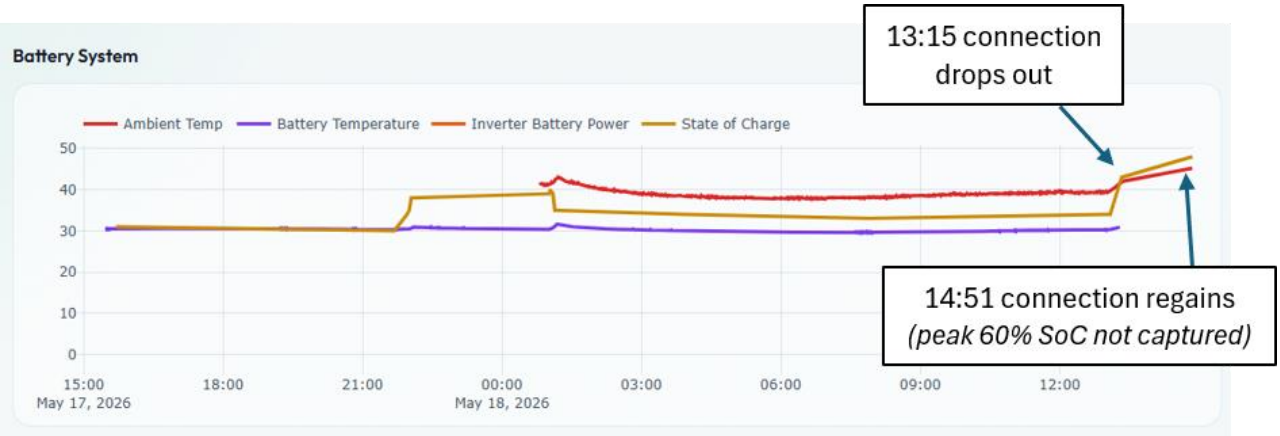


Figure 21 – The CEMS data logging of Battery's SoC during connection loss to Home Assistant, , showing 14:51 connection restored.

The FW platform currently functions as a live state interface, showing the HEMS' current status after reconnection rather than reconstructing historical events. Future work should consider whether FW should include lightweight local data stores or continue relying on a dedicated CEMS data store for historical and analytical purposes.

The CEMS test dashboard already supports data export functionality, providing a potential pathway for structured transfer to external data stores to support downstream applications such as flexibility market settlement and DSO reporting. Planned developments should focus on improving historical data capture and strengthening time-based filtering of historic datasets within the CEMS.

SmartQube: Vendor Discussion Summary

SmartQube stores data on AWS infrastructure with a confirmed retention period of up to ten years, with exports currently provided at 30-minute granularity. QEnergy documentation indicates that

SmartQube continues operating during internet loss, supporting continued optimisation and control, indicating some level of operational continuity during connectivity disruptions.

However, it has not been formally confirmed whether telemetry data is buffered locally during cloud or internet outages and subsequently backfilled to AWS upon reconnection. This remains an open question, particularly for CEMS data integrity requirements where gaps in community-level datasets could impact settlement, reporting, or flexibility market operations.

Passiv/Levelise: Vendor Discussion Summary

The Passiv hub includes local storage, with performance data buffered during Wi-Fi outages and backlogged to the cloud upon reconnection. This addresses some outage resilience concerns and supports continuity of historical data during connectivity loss.

6.3.5 User Overrides Under External Signals (P3-R7)

This testing assessed how the HEMS handles a manual user override, such as a Home Assistant control update, or a boost button press, when an active external schedule or signal from the CEMS or FW is running. This assessed the precedence logic between user intent and community-level signals, and how conflicts are handled and logged.

Home Assistant: Lab Testing Result

Override interaction between the CEMS and HEMS was tested on the Mixergy tank. A 15% target charge command was issued via the CEMS, followed by a competing 9% target command from the HEMS during execution. The asset continued charging beyond the 15% target, indicating that conflicting inputs were not resolved as intended and that command precedence logic between commands was not clearly enforced.

This issue is identified as a key development focus. The logic governing command precedence, conflict resolution, and buffering of competing inputs has not yet been implemented and is expected to require HEMS automation development rather relying on CEMS-layer controls alone. More broadly, this control architecture and system-wide action logging will be key prerequisites for the NZT Fairer Share (FS) algorithm. FS relies on aggregated community-level data from the CEMS to quantify participation in flexibility events and to allocate financial rewards based on measurable contribution, towards flexibility events for instance. This creates a tight coupling between operational control and monitoring in the CEMS and the settlement logic within FS, making accurate, auditable control data essential for fair and transparent reward allocation.

SmartQube: Vendor Discussion Summary

SmartQube does not currently provide user override or boost functionality via the homeowner dashboard. Overrides are only available through the physical asset, associated asset applications, or the installer dashboard. QEnergy indicated that any implemented ‘boost now’ overrides would temporarily take precedence over SmartQube optimisation logic.

Within an external CEMS context, the SmartQube may be expected to respond to tariff or flexibility signals. However, whether a CEMS signal can be given absolute priority (e.g. during grid constraint events) over home-level optimisations, and how conflicting commands are prioritised and logged, remains to be formally implemented and tested.

Passiv/Levelise: Vendor Discussion Summary

In existing flexibility services used alongside Passiv applications, external flexibility signals are understood to be secondary to user overrides, with user comfort taking priority over system or CEMS inputs; consistent with the NZT's intended system requirements. For opt-in flexibility customers, the Passiv optimisation algorithm can adjust operation in advance of flexibility events (e.g. pre-heating the home) while still ensuring that user-defined comfort constraints are met. Clear precedence handling for conflicting control inputs between the HEMS and external systems (e.g. CEMS or FW) has not yet been fully defined and requires further development and testing to confirm behaviour.

6.3.6 Fallback Strategy and Local Control (P3-R8, P3-R9)

This testing assessed whether the HEMS can continue to operate safely and usefully using only local schedules, parameters, and user inputs if the connection to FW or the CEMS is lost, and whether users without app or internet access can still view and control their assets locally. This assessed both system resilience under connectivity loss and accessibility for digitally excluded users.

Home Assistant: Lab Testing Result

Fallback behaviour under CEMS disconnection was partially tested for the battery and Mixergy tank. For the battery, a force-charge command was issued via CEMS and continued to execute after connection was lost, with charging stopping at the configured maximum of 60%, indicating that the HEMS honours commands during outages.

The Mixergy tank partially executed a pre-set charge request (43% to 48.4%), though the target temperature did not update as expected. Calendar-based schedules were expected to persist during outages, but FW schedule retention failed in one test due to a disabled HA automation; this was identified as a configuration issue rather than a platform limitation. When re-trialled, the schedule persisted during an outage, as the calendar event was locally stored. Heat pump fallback was not directly tested, although it may follow a similar pattern because of the shared integration logic.

Lab discussions indicated that the current HA setup could support a locally connected HMI, allowing users to view energy data and control assets via the LAN-based web interface without relying on cloud services or the FW app. While local control and visibility are technically feasible, designing a simple, user-friendly interface for non-technical users has not yet been addressed and should be considered for the next development phase.

SmartQube: Vendor Discussion Summary

QEnergy publicly available information indicates that SmartQube keeps running during internet loss, supporting uninterrupted optimisation and control, suggesting some level of fallback capability. However, the specific behaviour has not been formally confirmed for externally set schedules or CEMS signals, including handling of pre-received schedules, tariff signals, missed events, automatic optimisation resumption, or user notifications during disconnection and reconnection. As SmartQube's optimisation is primarily cloud-based, the extent of local autonomy during extended outages remains uncertain and represents a potential risk for community deployment.

SmartQube does not currently include a local HMI. User override is only possible via the physical assets, the asset vendor apps, or the installer dashboard. While the physical assets retain their own native controls, LAN-only or non-internet access to SmartQube app functions was not verified during testing. Further work would therefore be required to confirm how SmartQube could support residents without reliable internet access, smartphones, or confidence using digital interfaces.

Passiv/Levelise: Vendor Discussion Summary

Pre-set tariff schedules and local heating optimisation are understood to continue uninterrupted during internet outages for Passiv. The Passiv system includes a programmer hub and smart thermostat (HMIs) that remain fully functional without internet, providing local control and visibility independent of the app or cloud services. Vendor discussions indicated that tariff schedules are retained locally, although whether wider CEMS signals would behave in the same way requires confirmation. This suggests a stronger local autonomy than platforms that rely primarily on app or cloud access, and may better support residents without reliable internet access or smartphones.

Levelise's fallback behaviour is not yet confirmed; however, once the FoxESS battery was connected to the Levelise Hub, local control was no longer possible. The HMI, which previously allowed charge/discharge mode control, became locked and unresponsive to manual operation. Further testing is required to determine whether this behaviour is a result of Levelise control logic or a lab-based configuration effect.

6.4 Summary & Conclusions of Phase 3

Table 15 evaluates each HEMS against each phase 3 requirement, defined in Appendix D – Phase 3 Testing Requirements, based on a 1-5 ranking system defined as follows:

1. Not demonstrated during testing, and no evidence indicates the capability currently exists; or testing indicates the capability does not function.
2. Not demonstrated during testing, further vendor documentation or discussions required to confirm, or they have suggested the capability could potentially be developed; but there are no confirmed plans to implement it.
3. Not demonstrated in the laboratory, but vendor evidence, documentation, existing deployments, or product roadmap indicate the capability exists or is planned for development.
4. Capability partially demonstrated in the laboratory, or demonstrated with limitations, configuration changes, vendor intervention, or unresolved issues requiring future development.
5. Capability fully demonstrated in the laboratory and operated reliably without material limitations.

Table 15 - Evaluation table of HEMS providers against Phase 3 requirements defined in

Requirement ID	Requirement Title	Home Assistant	Smart Qube	Passiv / Levelise	
P3-R1	**External Signal Handling**	**5** - Communication pathways with both a Cloud-based Integration test platform, and FW user platform were physically demonstrated with connected assets.	**3** - Vendor discussions indicated external integration is feasible, but implementation routes remain undefined.	**3** - Existing Voltalis integration demonstrates external signal handling, although FW/CEMS integration is not currently implemented and tested.	**2** - External integration capability may exist but insufficient evidence was available during testing.
P3-R2	**External User Platform to Measure Changing Status of Assets**	**5** - Asset telemetry was successfully exposed to FW and synchronised with HEMS data.	**3** - Existing monitoring capability suggests external visibility is feasible, but external access methods remain unconfirmed.	**3** - Vendor discussions indicated asset data could potentially be exposed via a future API.	**2** - External telemetry access routes were not confirmed during testing.
P3-R3	**External Signal Control (User Controls)**	**5** - User schedules and setpoints were successfully transmitted from FW through the HEMS to physical assets.	**3** - Vendor indicated third-party user controls may be possible but is unlikely to be a near-term development priority for them, due to commercial considerations.	**3** - Existing flexibility integrations suggest external control is possible, but no FW/CEMS implementation exists.	**2** - No evidence was provided to confirm user-facing external control capability.
P3-R4	**CEMS Integration Testing (CEMS Controls)**	**5** - Full bidirectional communication and asset control were successfully demonstrated using the Cloud-based Integration test platform.	**3** - Vendor roadmap indicates compatibility with community-level signals, but no integration was demonstrated.	**3** - Existing flexibility services demonstrate external optimisation capability, but no direct CEMS integration was demonstrated.	**3** - Vendor documentation indicated optimisation could operate alongside a CEMS, but this remains unverified.

P3-R5	**Data Synchronisation with CEMS**	**4** – Data synchronisation was demonstrated, although control logging and historian integration require further development.	**2** - Data exports exist, but synchronisation methods, latency and feedback mechanisms remain unconfirmed.	**3** - Confirmed that historical and operational data are available back-end, but external synchronisation mechanisms have not been demonstrated.	**2** - Data synchronisation behaviour with external platforms remains unconfirmed.
P3-R6	**Local Data Store & Historian Integrity**	**4** - Local historian functionality was proven, although full backfilling into the cloud-based platform was not achieved.	**2** - Long-term retention is confirmed but local buffering and outage backfill behaviour remain unverified.	**3** - Vendor confirmed local storage and automatic backlog synchronisation following reconnection.	**2** - Historian and backfill behaviour were not confirmed during testing.
P3-R7	**User Overrides under External Signals**	**4** - Override interactions were demonstrated, although command precedence and conflict resolution require development.	**2** - Override functionality exists, but behaviour under CEMS control remains undefined.	**3** - Existing flexibility services indicate user comfort takes precedence, although conflict handling remains unverified.	**2** - Override behaviour under external signals could not be confirmed.
P3-R8	**Fallback Strategy & Localised Control Evaluation**	**4** - Local schedules and commands continued operating during disconnection, although some recovery behaviours require further validation.	**2** - Operational continuity is claimed by the vendor, but local autonomy and signal recovery remain unconfirmed.	**3** - Local schedules, optimisation and physical HMIs are understood to remain operational during connectivity loss.	**1** - Fallback behaviour could not be confirmed and local control functionality appeared restricted when connected.
P3-R9	**Local Control**	**4** - Local control is technically achievable through the LAN interface, although a user-friendly local interface has not yet been developed.	**2** - No local HMI was identified and local access without cloud services was not demonstrated.	**5** - Dedicated thermostat and programmer interfaces provide proven local visibility and control independent of cloud services.	**1** - Local battery control was unavailable once connected to the Levelise Hub and no alternative local interface was demonstrated.

Home Assistant was the only platform physically integrated and tested against both the Fairer Warmth platform and the Cloud-based Integration test platform during Phase 3. As a result, Home Assistant benefited from direct laboratory validation of external communications, control pathways, data synchronisation and CEMS style integration functionality.

For SmartQube, Passiv and Levelise, Phase 3 findings were derived primarily from vendor discussions, demonstrations, existing commercial deployments, documentation and stated development roadmaps. Consequently, many Phase 3 scores were capped at 3 (See Figure 22) where equivalent laboratory validation was not completed. This should not be interpreted as evidence that a capability does not exist, could not be developed, or would not operate successfully in practice. Rather, it reflects that the capability could not be independently verified within the available operational timeframe.

Passiv was assessed primarily against heat pump, comfort management and local control requirements, whilst Levelise was assessed against battery optimisation and flexibility related functions. Individual scores therefore reflect performance within their respective asset domains and should not be interpreted as representing complete whole-home HEMS capability. Where considered as a combined solution, additional integration and coordination activities would be required to deliver equivalent whole-home functionality.

An exception to the scoring approach exists where capabilities were directly demonstrated and validated. For example, Passiv achieved a score of 5 against P3-R9 Local Control because physical thermostat and programmer interfaces were demonstrated and validated, providing sufficient evidence to confirm compliance with the requirement despite the absence of wider Phase 3 integration testing.

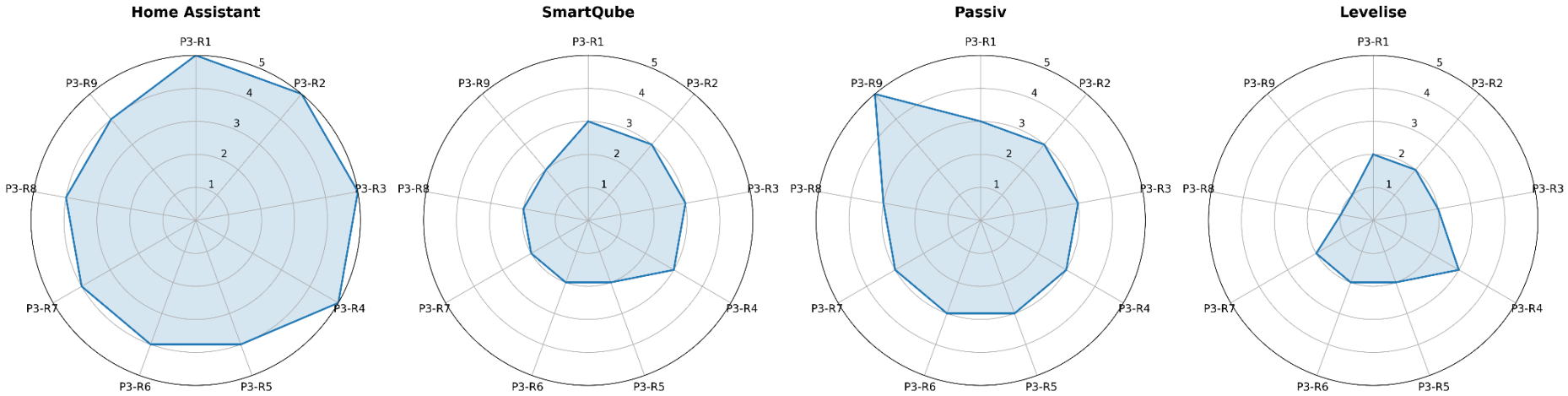


Figure 22 - Radar plots to evaluate each HEMS against Phase 3 key requirements

7. Conclusions & Future HEMS Development

7.1 Summary of Findings

Through structured laboratory testing, vendor engagement and technical review, the capabilities, limitations and interoperability characteristics of each shortlisted HEMS were assessed against the functional and technical requirements defined for the NZT programme.

The results demonstrated that none of the assessed systems could be considered a fully de-risked, deployment-ready solution for the NZT SLES architecture without some degree of additional development, integration or configuration. However, the testing programme provided sufficient evidence to identify the relative strengths, limitations and deployment considerations associated with each system, whilst reducing implementation risk through early validation of key integration, monitoring, control and interoperability requirements.

The findings presented within this report form the evidence base for the subsequent NZT HEMS gap analysis report and the HEMS interoperability development strategy, which define the remaining capability gaps and the development activities required to support deployment of a functioning NZT SLES architecture.

7.2 Further Testing Recommendations

The following areas are recommended for future HEMS development and testing. These will be analysed and developed in greater detail in the interoperability strategy:

- **Persona and user scenario testing:** Assess HEMS performance for different household types (e.g. vulnerable residents, families, low-income households) to ensure comfort, affordability, and usability objectives are met. This should include development of a simple, user-friendly local LAN-based interface for non-technical users who may not have access to a smartphone or reliable internet connection.
- **External event response:** Evaluate how the HEMS responds to dynamic tariffs, grid signals, and weather changes, ensuring assets are optimised without compromising stability or user comfort. An initial proof-of-concept tariff-response automation was successfully demonstrated during Phase 3 testing, switching the heat pump on below a defined price threshold, but further development is required to support more nuanced tariff structures, additional asset types, and more sophisticated control responses across a wider range of operating conditions.
- **Advanced controls and optimisation:** Test interactions between user overrides, schedules, and automated optimisation, particularly where competing priorities such as comfort, cost, and grid constraints exist.
- **Real world resilience testing:** Simulate faults and variability, including device failures, communications outages, tariff changes, and grid events, to further verify effective recovery and fallback operation.
- **User feedback and learning:** Assess the effectiveness of dashboards, alerts, recommendations, and user feedback mechanisms, including the system's ability to adapt to user preferences.
- **Wireless & Wired integration:** Building on the Modbus-based testing completed in Phases 1-3, evaluate wireless connectivity options and assess reliability, latency, coverage, and performance under varied network conditions.
- **Rig Efficiency:** Apply lessons learned from Phases 1-3 to further optimise the test rig architecture, including asset layout, communications infrastructure and integration pathways.

This would improve testing efficiency, repeatability and wireless connectivity performance, whilst supporting a broader range of future SLES interoperability and integration test cases.

- **Mixergy:** Vendor discussions with Mixergy identified an alternative cylinder configuration that may offer improved heat pump compatibility and closer alignment with NZT requirements than the unit evaluated here. Future testing is recommended as, if successful, this configuration could represent a more suitable solution while the knowledge and integration learning gained through the current testing programme can be transferred to streamline test items.
- **Asset fallback and schedule persistence:** Fallback testing focused primarily on the Mixergy tank and battery; heat pump fallback was not tested. Further testing across all assets is recommended to build a complete picture of schedule persistence, partial command execution, and recovery behaviour under disconnection.

7.3 Outstanding Design Decisions

A couple of items were identified during testing as requiring programme-level decisions during further development. These are not technical gaps in the HEMS, but open questions regarding the design and configuration of the wider system.

A decision is required on whether users should be able to **activate holiday mode or asset on/off controls via Fairer Warmth**, given the preference to keep assets available for CEMS optimisation during user absence. Separately, following reconnection, Fairer Warmth will display the current system state rather than reconstructing events that occurred during disconnection. A further decision is required on **whether the Fairer Warmth user application should maintain lightweight local storage for historical data** or rely on the CEMS data store.

7.4 Additional Learnings and Project Development Requirements

The following captures additional findings and development requirements identified during Phase 3 testing that are relevant to the ongoing development of the Fairer Warmth platform, CEMS integration, and wider NZT SLES architecture.

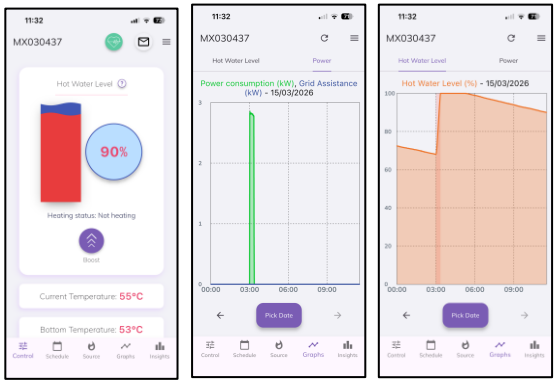
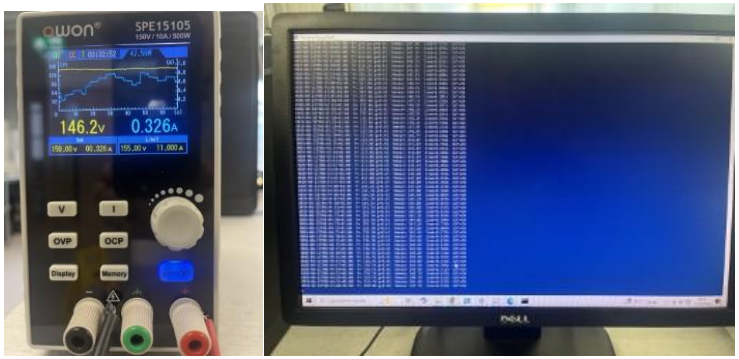
- **TRV-to-heat pump control integration:** Bi-directional CEMS control of the TRV and heat pump was demonstrated, but further Home Assistant automation is required to integrate TRV control within the heat pump optimisation logic to enable autonomous interaction between the two.
- **CEMS data storage, logging and aggregation:** Longer-term storage, event-level control logging and multi-HEMS aggregation are not yet supported by the CEMS test dashboard but are required for auditable record of flexibility participation and the FairerShare algorithm. Data export is currently available – providing a route for downstream settlement and DSO reporting - but planned development should focus on improving historical data capture, time-based filtering, and aggregation of multi-HEMS datasets for community-level analysis.
- **Local HEMS data store synchronisation:** This testing assessed existing local storage capability rather than developing it. Further work may be needed within the HEMS or integration layer to ensure reliable synchronisation between the HEMS local historian and external platforms as the project progresses.
- **Command precedence:** Conflict resolution logic between competing CEMS and HEMS commands has not yet been implemented. A clear command precedence framework will be required, as auditable event-level control logging is a prerequisite for the FairerShare algorithm to allocate community rewards accurately.
- **FW update latency:** A 1-2 minute update latency between HEMS state changes and FW platform updates was observed. This is acceptable for current testing but may require optimisation if future DSO signal response requirements demand faster feedback loops.

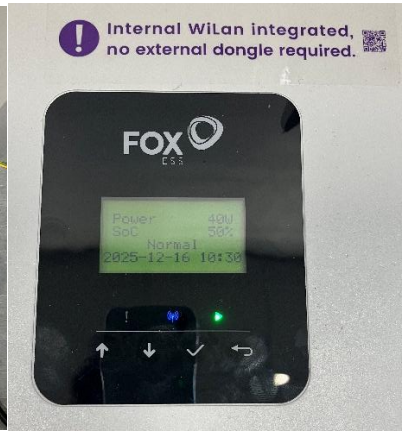
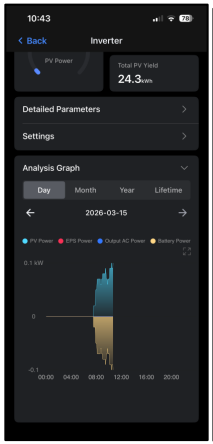
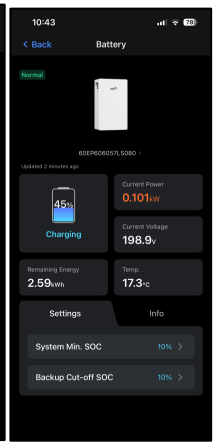
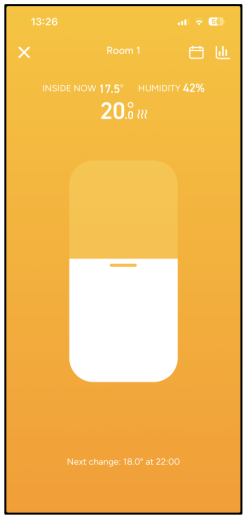
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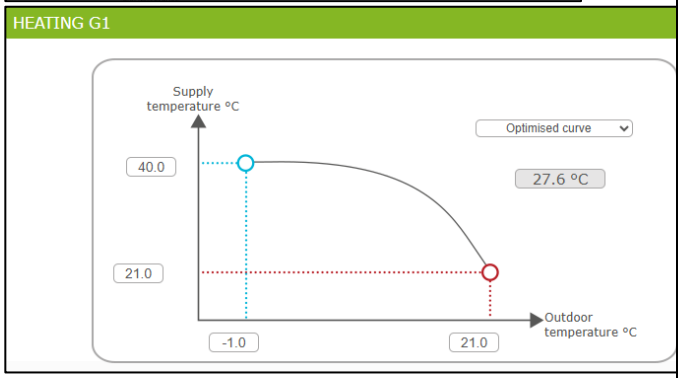
Appendix A – Phase 1 Testing Requirements

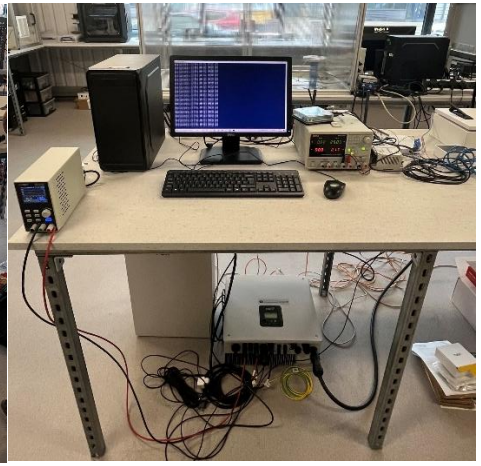
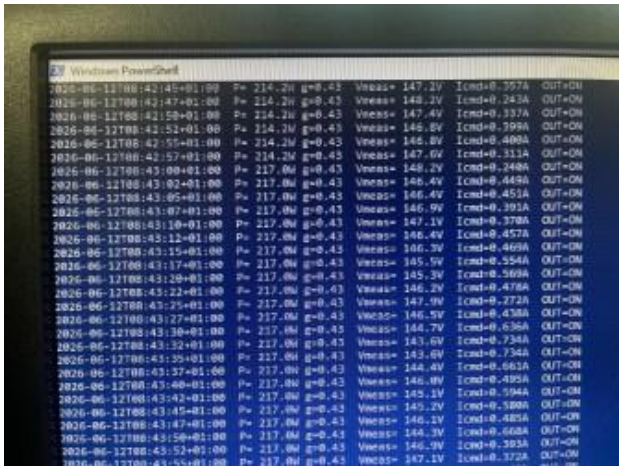
Requirement ID	Requirement Title	Description of Requirement
P1-R1	**Physical Installation and Power Readiness**	Testing establishes whether all assets intended for Phase 1 are installed in the rig, powered, electrically, hydraulically and mechanically safe, and in a known baseline configuration. This requirement exists to confirm that the physical system boundary is present and stable enough to begin system testing. It does not assess behaviour, performance, or integration quality, only whether the hardware baseline exists.
P1-R2	**Communication Interface Configuration**	Testing establishes whether each asset has the defined communication interface in place, including protocol, addressing, and physical or logical connection path to the HEMS. This requirement exists to verify that intended integration routes have been implemented and can be exercised. It does not require the HEMS to successfully communicate with the asset, only that the interface itself exists and is configured for testing.
P1-R3	**Asset Discovery and Identification Capability**	Testing establishes whether the HEMS is able to discover or register each connected asset and uniquely identify it as a distinct device with a defined role. This requirement exists to assess asset visibility from the HEMS perspective. It does not require discovery to succeed, only that discovery has been attempted and the outcome understood and recorded.
P1-R4	**Telemetry Availability from Connected Assets**	Testing establishes whether basic telemetry can be read from each asset by the HEMS, such as temperatures, states of charge, or operational status. This requirement exists to assess observability of the system. It does not require telemetry to be complete, accurate, or usable for optimisation, only that telemetry pathways have been tested and their limitations documented.
P1-R5	**Asset local Autonomy and Constraints Identification**	Any autonomous behaviour, local control logic, or external constraints imposed by individual assets are observed and documented during testing. This requirement captures practical limitations of off-the-shelf systems that may affect later coordination or optimisation. It does not assess whether these behaviours align with project objectives or SLES design intent.
P1-R6	**Phase 1 Evidence Completeness and Traceability**	Sufficient evidence exists to demonstrate that all Phase 1 requirements have been exercised, and outcomes recorded in a traceable manner. This requirement ensures that Phase 1 results are defensible, reviewable, and usable in later phases and assessment. It does not assess system capability, only the completeness and clarity of the testing record.

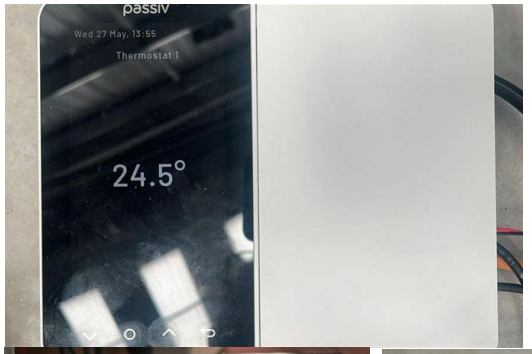
Appendix B – Test Rig Commissioning Evidence

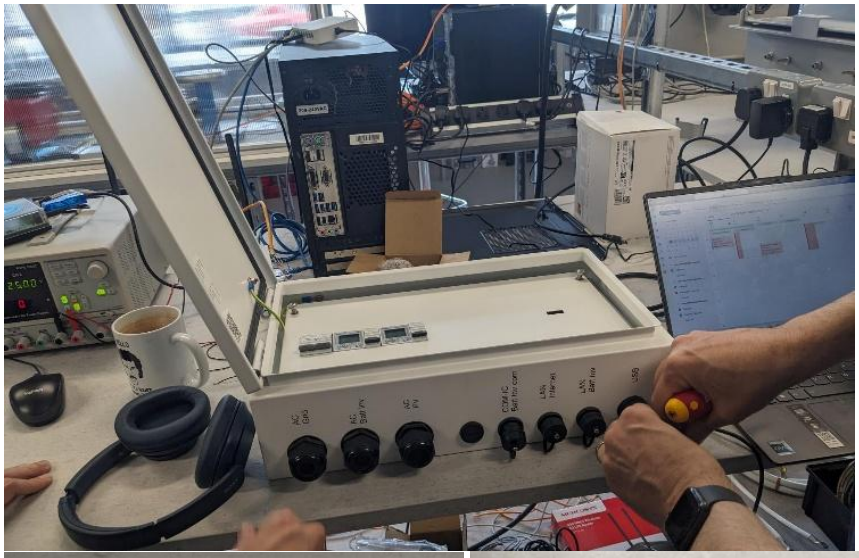
Asset	Lab Evidence	Native App (Where Applicable)
Mixergy		
PV Emulator		N/A

FoxESS	  Internal WiLan integrated, no external dongle required. FOX ESS Power 49W SoC 50% Normal 2025-12-16 10:30	 10:43 Back Inverter PV Power Total PV Yield 24.3kWh Detailed Parameters Settings Analysis Graph Day Month Year Lifetime 2026-03-15  10:43 Back Battery Normal 45% Charging Current Power 0.101kW Current Voltage 198.9V Remaining Energy 2.59kWh Temp. 17.3°C Settings Info System Min. SOC 10% Backup Cut-off SOC 10%
TRV		 13:26 Room 1 INSIDE NOW 17.5° HUMIDITY 42% 20.0° Next change: 18.0° at 22:00

Heat Pump	    Prg Esc ON STAND-BY	 ecoFOREST Settings User Installer ON/OFF Programming Heating Cooling DHW Pool e-Manager Information Alarms Real time Day Current meter Historical meter STATE 13:08 15/03/2026 OPERATION MODE 14.5 °C 15.0 °C 15.5 °C 2.0 bar 0.9 bar 14.9 °C 14.9 °C INSTANTANEOUS ENERGY METER 0 W 0 COP 0 W 0 EER 0 W 0 PF PRODUCTION DEMANDS CONSUMPTION DEMANDS OUTDOOR TEMPERATURE Outdoor temperature 14.5 °C  HEATING G1 Supply temperature °C Optimised curve 40.0 27.6 °C 21.0 -1.0 21.0 Outdoor temperature °C

General	 	
Home Assistant		In main report.

Passiv	   	**In main report.**

Levelise	  	**In main report.**

Appendix C – Phase 2 Testing Requirements

Requirement ID	Requirement Title	Requirement Description
P2-R1	**Capability discovery and documentation**	Testing establishes what built-in capabilities exist across each HEMS and connected devices and records these capabilities and any constraints in a structured catalogue. Testing establishes whether basic control commands can be issued from the HEMS (i.e. on/off) to each asset and whether any response is observable.
P2-R2	**Smart Meter Data Access and Compatibility**	Testing establishes whether the HEMS can access smart meter data via the DCC ecosystem and records supported meter standards, communications hubs, and access methods. This includes identifying meter compatibility, mechanisms to obtain data (direct or via third-party services). The requirement can be met purely through discussions with HEMS providers and understanding their stated connectivity - there is no requirement to verify at this stage.
P2-R3	**Local Available Operational and Telemetry Data Access**	Testing establishes how the HEMS records, stores, and retains operational and telemetry data including control actions and state changes, logs, event histories, energy consumption, or exports. This includes identifying data types, resolution, retention periods, overwrite behaviour, and the extent to which the HEMS provides contextual information or explanations linking control actions to triggers or system state. The requirement is met by observing and recording the full list of data availability and traceability characteristics of each HEMS, regardless of completeness or quality.
P2-R4	**User Schedule Execution**	Testing establishes what device schedule and user preferences can be manually set through the HEMS UI natively. This includes schedule creation, editing, deletion, comfort setpoints, temperature bands, charge windows and any constraint parameters.
P2-R5	**Native Optimisation Logic and Objective Interaction**	Testing identifies whether native optimisation exists, whether it can be enabled or disabled, the objective functions used (e.g. tariff minimisation, self-consumption maximisation, rule-based control), and the inputs influencing optimisation (import/export tariff etc.). Testing confirms how optimisation interacts with user schedules and comfort constraints and whether behaviour changes relative to schedule-only operation.
P2-R6	**Manual Override Handling and Precedence**	Testing establishes how manual user overrides interact with schedules and optimisation logic. This includes override delivery mechanisms (app, UI, physical control), override precedence, duration, expiry behaviour, persistence, and reversion logic. It confirms whether overrides are logged and how they are represented in the interface.
P2-R7	**Single Asset Operational Behaviour Under Defined Use Cases**	Testing establishes that schedules defined in previous requirements operate expectedly (generate correct signals) under typical and constraint scenarios, focusing on single asset operational. Constraint scenarios refer to cases where asset is at its operational limits e.g. the battery is at min/max SOC or disconnected etc. Measure response latency and command acceptance handling.
P2-R8	**Multi-Device Coordination and Prioritisation**	Testing similar to R7 but focusing on multi device operation and confirming prioritisation logic when objectives may compete (e.g. desire to charge battery and heat hot water). Determine whether prioritisation is rule based, optimisation driven or emergent. Confirm operation in constrained cases such as max SOC, approaching user comfort limits etc, including how the system responds when there are time lags between signals and device actions.
P2-R9	**Disconnection and Fallback Behaviour**	Establish how the HEMS and connected assets behave when communication is lost or restored. This includes asset autonomy, persistence of last command, alert generation and storage, default operating state, and data continuity. Confirm whether fallback behaviour is configurable or fixed. Evidence should demonstrate behaviour during comms interruption and full state resynchronisation after recovery.

Appendix D – Phase 3 Testing Requirements

Requirement ID	Requirement Title	Requirement Description
P3-R1	**External Signal Handling**	Testing basic communication integration of the HEMS and connected assets with an external platform (e.g. Fairer Warmth).
P3-R2	**External User Platform to Measure Changing Status of Assets**	Testing if an external user platform can read from the HEMS basic status updates of the assets, e.g. SOC or DHW temperature.
P3-R3	**External Signal Control (User Controls)**	Testing to understand how the assets respond to external control signals sent to the HEMS (i.e. schedules set by Fairer Warmth). Evaluate how these signals are prioritised and integrated into the existing HEMS logic.
P3-R4	**CEMS Integration Testing (CEMS Controls)**	Test the ability of the HEMS to integrate and communicate with a 'Community Energy Management System (CEMS)' signal. This includes evaluating bi-directional data exchange, feedback loops, and how CEMS controls influence individual devices.
P3-R5	**Data Synchronisation with CEMS**	Testing how HEMS synchronises data with CEMS, particularly under varying communication conditions. This includes checking the synchronisation of control actions, usage data, and any optimisation adjustments made.
P3-R6	**Local Data Store & Historian Integrity**	Test the HEMS's native ability to store time-series and event data locally during a loss of 4G/Cloud connectivity to FW/CEMS and Evaluate the data backfilling once connection is restored.
P3-R7	**User Overrides under External Signals**	Testing the interaction between manual user overrides (via HEMS/asset 'boost' buttons) and external optimisation signals (settings made via app/UI). Evaluate how manual overrides are handled when community signals are active, and how the system responds to conflicting inputs.
P3-R8	**Fallback Strategy & Localised Control Evaluation**	Testing the fallback behaviour of the HEMS in the event of a communication failure to FW (e.g. loss of external signal or device communication - simulating a loss of CEMS input & external price signals). Evaluate (i) the persistence of settings and system recovery post-failure, and (ii), the system's ability to function effectively using only local control parameters, schedules, and user inputs.
P3-R9	**Local Control**	Evaluate the functionality of the local HMI (Human-Machine Interface) for asset control and energy visibility. Ensure users can view consumption and manage assets locally without the FW app to prevent digital exclusion.