Backer IoT Smart Temperature Controller & Immersion Heater
HRDi/HRDc

Operating Manual

BACKER

Contents Page

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1. Introducing the HRDc/HRDiController

The HRDc electronic controller is a versatile high performancecontroller with features for industrial heating applications.It is able run/operate three independent PID controllers, which may be configured individually for precise constant temperature control or timed one-shot heating profiles. The HRDc is network enabled to accommodate industrial field-bus protocols and secured Internet (IoT) connectivity for unparalleled process monitoring, configuration, and maintenance.

Once connected to Backer's secure IoT server, users are able to access a wide range of supervisory control and energy management user interfaces, including weekly scheduling and energy state-of-the art thermal modelling and visualisation.Once configured HRDc controller will continue to operate scheduled control.

IP connectivity of the HRDi/HRDc allows for a greatly simplified user interface (UI) to the powerful control, configuration, and safety modes available. An Android application is provided for provisioning your device securely so that only you and your team can access your device.

Digital control includes closed loop PID temperature control of 3 high speed low power SSR outputs to drive external contactors and has one internal 5A/1KW mechanical relay for lower power application. Two PT100 temperature sensor inputs plus an optional thermocouple input are provided in addition to 4-20mA and 0-10v inputs, which can be assigned to any controller for completely flexible multi-input-multi-output control applications.

Relay saving algorithms that optimise the accuracy of the controller whilst minimising switching operations. When connected to the internet, the unit can also time synchronise to support integrated supervisory control features including setpoint and activity scheduling.

The HRDi device can be configured to switch up to 3 internal relays or 3 external Solid State Relays (SSRs) independently for stepped output power operation. The internal PSU has a wide voltage from 110vac to 440vac so that additional supply cables are not required for the controller, which can use the element ac power directly.

2. Getting Started

The HRDc and HRDi controllers default to manual control mode when first powered on. To get the maximum use of the controller's capability the devices should be connected to a network so that they can be securely provisioned to be accessible from mobile UI devices or the Internet-based Devman server. This UI allows all configuration of the device to be accessed.

If you do not have network access initially the devices can be configured to provide basic constant temperature PID control using the front panel buttons:

- The HRDc defaults to using the first PT100 input as the temperature sensor and the mechanical relay output for duty control.
- Once setup the first time the unit is powered it will go through a self-check routine to check internal hardware is fully operational. After 10 seconds the display should settle to show 0.0 for the S.V. and the currently measured temperature in the top display.
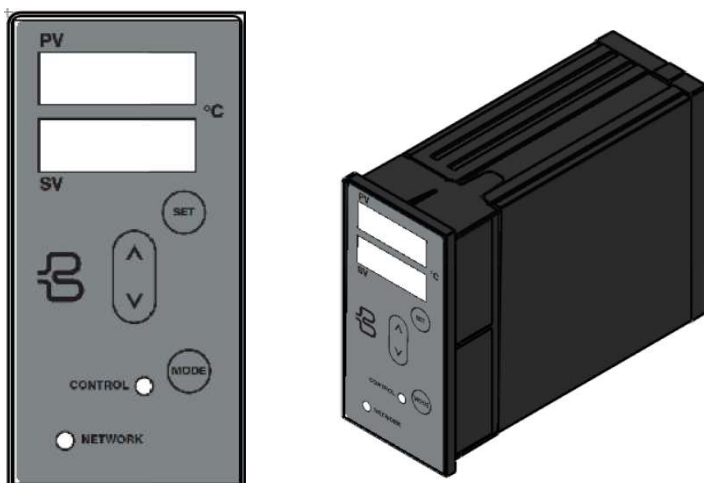

Figure 1: Front panel of the HRDc

- The network light will blink initially because the device has not been provisioned. If connected to an Internet enabled network the LED will blink green. If the network is a private LAN the LED will blink yellow. If there is no IP network connectivity available, the LED will blink red. In any of these states the device can be configured for basic constant temperature control using the front panel buttons as described below.
- To set a desired temperature use the up/down buttons to change the desired setpoint value, which will be displayed on the lower display marked SV. Press the SET button to apply the SV and you should shortly see the control LED switch to red to indicate the relay is closed and heating is active. HRD devices default to a 5 minute relay switching cycle time to avoid rapid relay ware. The operation speed can be increased later via theIP connected UIs.
- Your HRD should now be controlling your processes temperature using PID control.
- There are further control modes available for the HRD, which can be accessed using the Mode button on the HRDc or using a long press on the set button for the HRDi range of controllers. Once pressed the mode will be displayed is "X." where X can be a mode number from 0 to 4:
  - "0." is disabled. The controller will retain itssettings, but no output duty will be applied to any relays or outputs.
  - "1." is the Manual mode the HRD defaulted to when powered on and after a factory reset.

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- o "2." is scheduled mode where the controller's setpoint values will follow a weekly schedule defined in the Devman user portal.
- o "3" is "timer" mode, which asserts a setpoint for a limited period of time each time the set button is pressed on the front panel or the 0-10V input is set to 4V or more*.
- o "4" is a Timer setpoint mode where the duration of heating is triggered when the measured temperature reaches to required SV. Heating duty will stop after the prescribed duration*.

*More details of timed heating modes are in the Settings & Functions section of this manual.

Network Connection

To access all but the most basic features of the controller an Ethernet connection is required for HRD devices. The HRDi/HRDc device will connect to any standard Ethernet router (or via a switch) and will attempt to self-configure using standard DHCP services (see figure 2b). Temporary or independent access to a the HRDi/HRDc from a mobile device can also be achieved using an inexpensive Wi-Fi extender (see figure 2b) such as the Netgear EX2700, which can be configured as a router and access point. It is not mandatory to have internet access if this is not available from the router, however HRD devices need to confirm thetime with a network time service hosted on the Devman server to use any of the scheduling mode (mode #2).
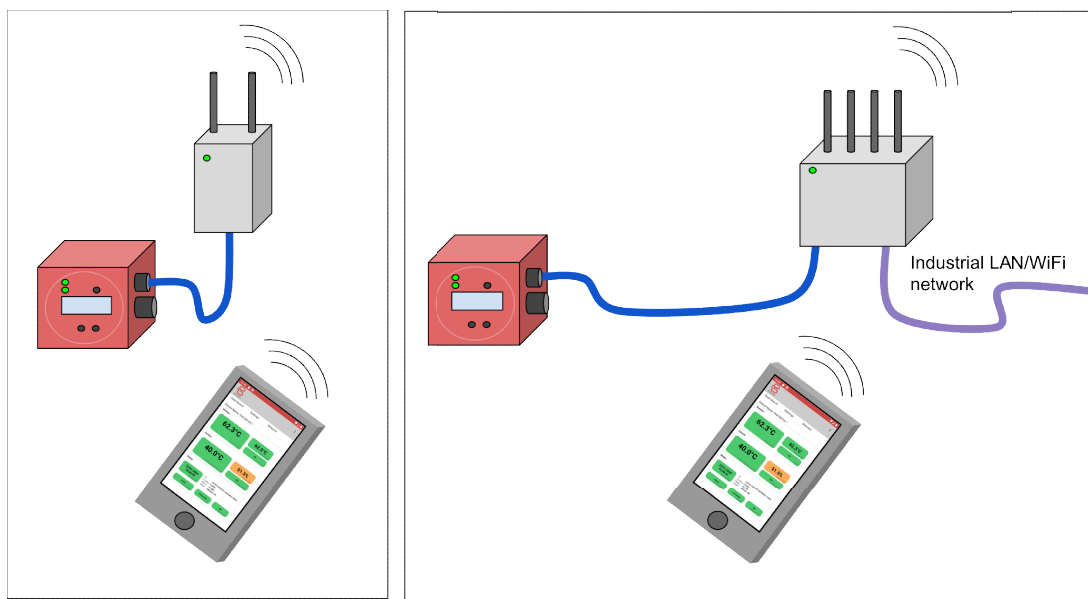

Figure 2a Left: Temporary commissioning or dedicated mini-LAN connection method
Figure 2b Right: Normal Industrial LAN connection

The HRD devices include a network connectivity indicator showing status of the connection:
- ● Red – there is no IP connection available to a local router. This state is reached if there is no Ethernet connection or the device has not been provided with an IP address and gateway via DHCP or manual configuration.
- ● Yellow – There is local network connectivity but a route to the Devman device management server is not available. In this state devices can still be provisioned using the Android mobile application on a private local network.
- ● Green – There is full outbound Internet connectivity for the device.

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Network Requirements & Trouble Shooting

The HRD devices communicate with the Devman server using secured MQTT messaging. Industry standard TLS1.2 authentication and encryptionis used to protect your device and data. This mode of communication is secure at all times from initial bootof the HRD product so that you can benefit from logged data from the moment you access the Devman user portal to check up on your device, process and system performance.

HRD devices use port 8883 to connect (outbound) to the Backer Devman server. Devices will also listen port 80 for mobile application connection requests. This access level can be disabled after provisioning or left enabled for subsequent authenticated LAN-only mobile app access. This allows all the features of the HRD to be accessed directly on the local network from an authenticated mobile device.

HRD products also allow local network access from the Backer IoT mobile application, for a limited period after they are powered on from factory reset state, so that installers can securely "provision" devices and bond them to their accounts. Accounts can be created using the Backer IoT app when there is Internet connectivity available, after which the mobile device can be connected to the LAN on which the HRD is connected to provision the device even if there is no Internet connectivity available on the LAN.

Assuming you are expecting some level of network connectivity for your device and you encounter problems, the network status LED should provide the following guidance for diagnosing the issue:

- If the network light is red: You should first check the RJ45 connection status LEDs normally found on Ethernet switch sockets and also on the HRDc Ethernet socket. If there is no sign of activity on these LEDs, it is most likely there is a cable issue to resolve. Thered flashing status may also occur if the LAN does not support DHCP. IN this case you may initially need to connect you HRD to a network that does support DHCP (e.g. a WiFI + Ethernet router as described above) so that you can provision the device and set it'sIP address in the configuration screen provided.
- If the network light is yellow: this may be normal if you are not intending for the HRD unit to connect to the cloud Devman server and the LAN has no Internet connectivity. If connectivity is expected then it is possible that the connection is being blocked by firewall rules (see port information above).

The next section describes the simple provisioning process that bands devices to user accounts and identifies them for later access in Devman or in the Backer App.

Initial Configuration: Backer IoT App

Once an IP connection to the HRDi/HRDc has been established, you can access it using the Backer IoT mobile application to provision and configure your device:

- Download & install the Backer IoT device application for any Android phone or tablet by accessing the following URL from your mobile device's web browser:
  - https://iotbacker.com/media/hr-iot-app.apk
  - You may be asked for agreement to allow your device's file manager to install applications on your device.
- Start the IoT application (Backer logo branded) and create a new user using the 'register' option (or sign in with an existing account if you already have one). Once you have signed in you will be able to see your HRDi/HRDc or other Backer devices available on the local network.
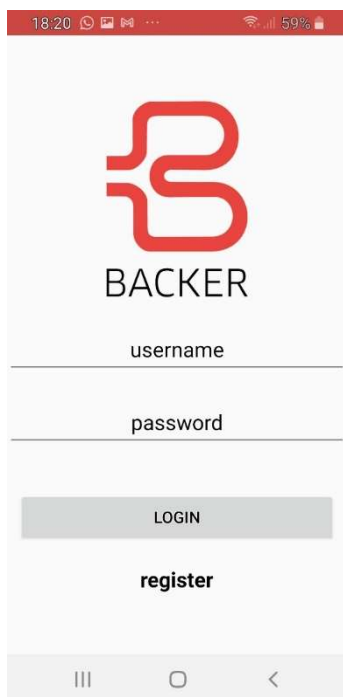
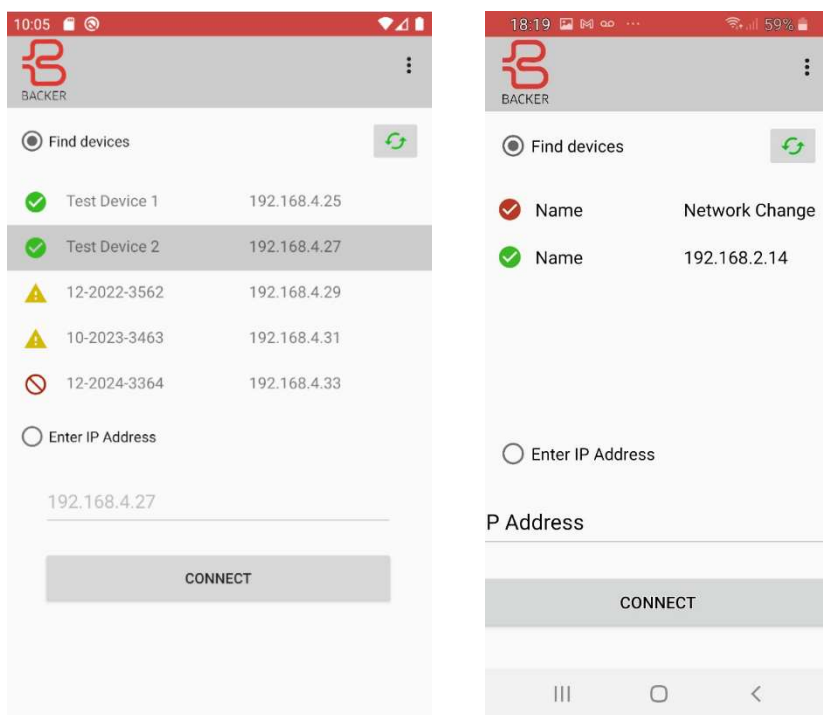**Figure 3a: Signing up and logging into your account**

Figure 3b: Signing up and logging into your account

Devices will be identified on the LAN by the mobile application once you are signed in. If you have already used your account to provision some devices you will see these marked with green ticks indicating you can connect to them immediately and view and modify settings. (to make modifications you will need the PIN number you used when provisioning as an additional level of security).

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If you have devices that you have previously provisioned, but that are shown with a red tick, this means you may now be on a different LAN than the device or the device is offline.

If you see a device with a red no-entry icon next to it that means the device has been provisioned by another user who is not part of your organisation. It is only possible for two accounts to be able to access the same device if an Administrator has enabled this, by adding relevant accounts to the same organization in Devman.

Devices marked with a yellow triangle indicate devices that have not been provisioned and are available to be bound to an account. Devices should not be left on networks in this state to avoid potential access by third parties who may have identified the device's PIN number required to provision a device.

Further information for devices listed can be seen by selecting a device and then the 3 dots in the top right of the app.
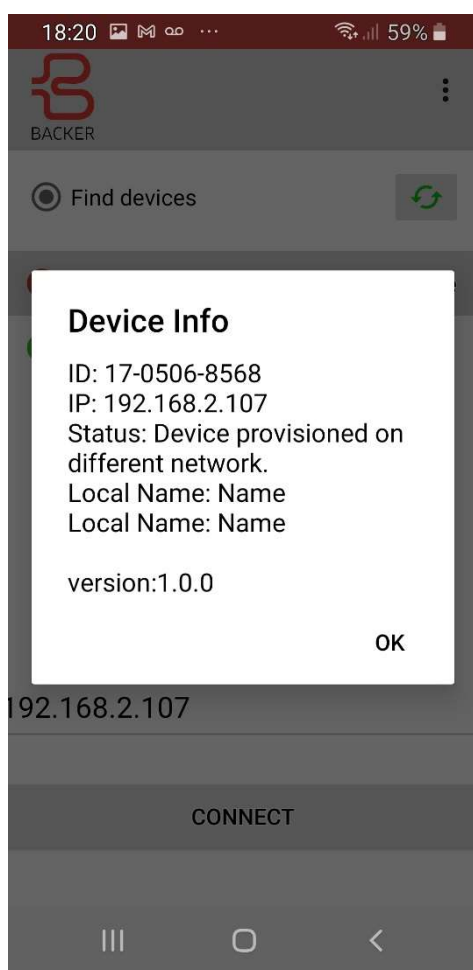
Figure 4: Device information

Initially your device will be "unprovisioned" and is listed with a yellow warning triangle. Your device must be provisioned to secure access its user interfaces via IP. Provisioning will also bind the HRDi/HRDc to you *Devman* account. Provisioning requires the following:

- o The HRDi/HRDc device's 5 digit PIN (this is printed on to a label on the inside of the enclosure)
- o Your Devman account password

- It is often useful initially to know the HRDi/HRDc's device ID to identify it amongst any other Backer IoT devices that may be connected to your LAN (This is 9 digit number provided on your device's paper work)
- **Note:** You must have logged into the Backer IoT Mobile application while your mobile had internal access within the last 5 days to ensure you have a valid provisioning certificate at the time of provisioning a device.
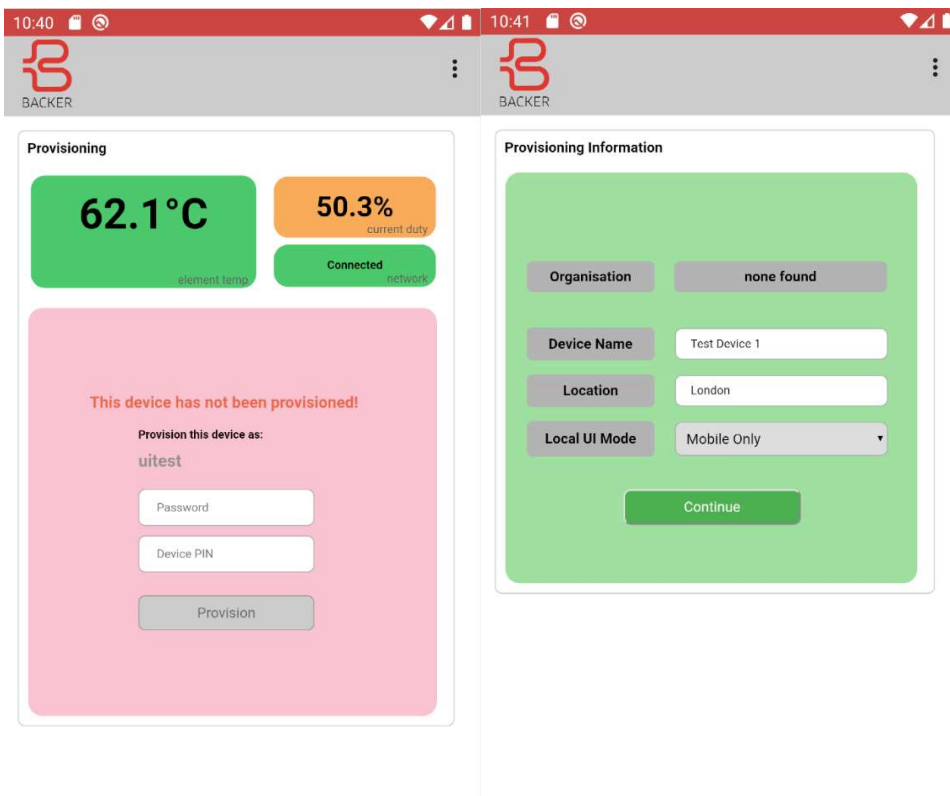

Figure 5. Provisioning your HRDi/HRDc device. A mini dashboard to monitor temperature and duty is provided prior to provisioning to allow validation of initial installation.

- Once your PIN and password has been accepted you can give the device a memorable name and location to identify your devices more easily in the future which is also reflected in the Devman web portal.
- Once provisioned you will be presented with the dashboard screen and access to settings that your account type allows. Self-registered users that do not share devices within an organisation, default to having full access to the device's configuration pages.
    - Demonstrator devices should not require any changes to the preconfigured hardware settings.
- All subsequent connections to the device will go directly to the dashboard page after successful provisioning.
    - To allow other users to access devices you have provisioned with a personal account, you will need to contact the support team to convert your account to a team member account.

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Figure 6: Provisioned Device dashboard

Provisioning Summary

- Provisioning allows local network access to the device's User Interface (UI). It can be carried out using the LAN or by direct Ethernet cable connection to a PC or Wi-Fi dongle & Mobile application.
- Provisioning also binds the device to the specific user's Organisation on Devman when an internet connection is available for the HRDi/HRDc device. This allows others with a team account in the same organisational group (and with sufficient account privileges) to also view and manage the device remotely.
- Devices can only be unprovisioned by physical access to the device or via privileged Devman accounts. Once unprovisioned the device is factory reset to a safe operating mode and all user settings are deleted.
- Devices will close down the local connectivity option if too many false passwords are provided to avoid brute force attacks or spurious network behaviour. Physical access is required to reset the provisioning process.
- Provisioning certificates are time-limited (typically for 5 days) and are validated by HRDi/HRDc devices (and Mobile applications) using multi-factor user and device-specific credentials.

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3. Settings & Configuration

This section will introduce the features and functions of the HRD device via the Backer IoT app Interface. The device settings and dashboards are also available on the cloud-based Devman serverthat can be accessed remotely via a web browser. Devman will be covered in a later section, but will assume familiarity with the HRDs features and functions from reading this section and using the Backer IoT app first.

Before using your HRD you may need to change the hardware settings if you are using your device with multiple outputs, SSRs, or different sensor connections. This section will overview the dashboard which will frequently be used if checking devices via the local network. The Hardware and Network settings tabs of the apps will be used less frequently, but will be dealt with first as correct setup is necessary depending on the installation you are using. The controller settings will be dealt with finally to show how different logical and quantitative parameters can be used configure and optimise the HRD's controllers.

Device Status Dashboard

HRD products have 3 independent PID controllers that can be configured for different sensors and output options. The dashboard shows the sensor values for the first two PID controllers for quick monitoring purposes.

The section at the bottom of the dashboard provides information on the Real Time Clock status, error and warning status and network status.It is also possible to provision devices to show only the minimum dashboard information if this is preferred.To make changes to the device's configuration and see more detailed device information the settings tab must be selected.

Hardware Configuration

HRDi/HRDc devices are supplied with a preset hardware configuration appropriate for its internal element configuration (e.g. 3 wire/4wire 440/340v elements etc.). For re-configured devices the advanced settings section includes further details. The hardware configuration tab is largely concerned with configuring the HRD's safety check systems and also setting limits on the hardware to avoid excessive relay operations for example.
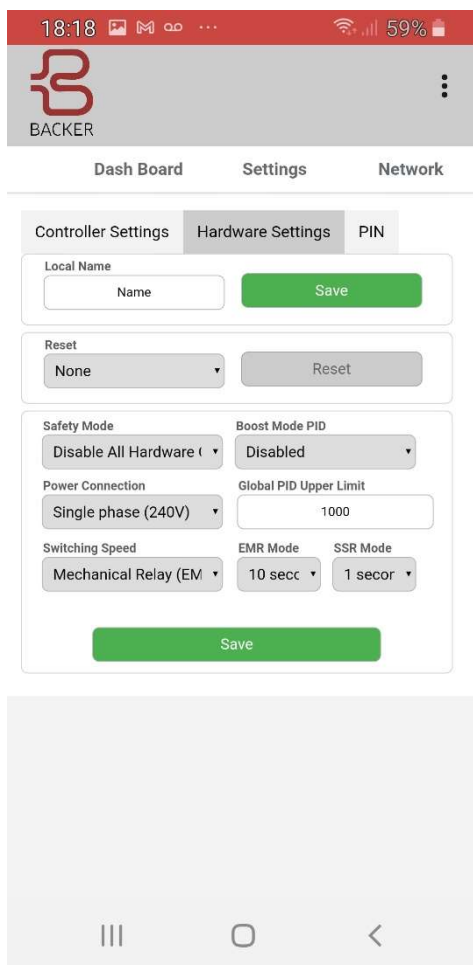
Figure 7: HardwareConfiguration

To change hardware settings the app user requires the device's PIN number as an additional security measure.Once entered the UI will work without re-entering the PIN for up to 1 hour if the UI is kept open.
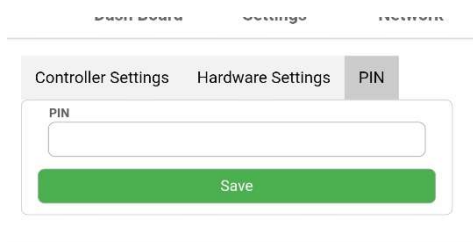

Figure 8: Hardware Configuration

Once a pin is entered the "Enter PIN" button will change to say "Save".

The controller hardware settings include:

- Setting a Local name for the device that will be seen on the LAN and connected IoT app UIs. It is also reported to Devman so that the device can be easily identified later and to remote administrators.
- Reset allows the device to be rebooted in different modes:
  - Restart – simply restarts the device, but does not clear any critical error conditions.
  - Clear Errors and Reset – clears any errors and restarts the device which will recheck for critical errors during restart.

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- ○ Factory Reset – which will remove all configuration the user has provided and will also deprovision the device so that it is again available to be provisioned by other users.
- Safety Mode selection
    - ○ Enable EN60335-1 & EN60730-1 - enables relay status checks on each boot and continuously during operation. These tests require the correct power, element and Thermal cutout configurations to be in place to operate. Even without this mode all EN60730-1 software safety features are maintained and many related to EN60335-1, where these do not depend on specific power connection configurations.
    - ○ Enable Additional Checks - currently does not run any additional self-checks.
    - ○ Disable Slow Start Checks – This disables boot checks that are not required on each boot such as Watchdog timer reset tests, which are not required for SIL-level 2 safety checks.
    - ○ Disable all Hardware Checks - disables the "Slow Start Checks" aboveand also disables
        - ■ Periodic self-checks such as RAM and ROM integrity tests
        - ■ GPIO/Relay output checks.
        - ■ Watchdog timer reset tests
        - ■ Stack corruption tests
        - ■ This option is suitable when high speed control is required, which may otherwise be interrupted for up to 0.5 seconds when periodic self-checks occur during normal operation.
- Power connection (HRD variants only) configure the relay checks to expect specific voltages on each of the three internal mechanical control relays.
- Global PID upper limit is in fact a software limit that applies across all controllers. It provides an upper limit for any controller's sensor which prevents any controller applying heating duty. This value is useful in applications such as multi-element tank heating where temperatures at the top of the tank can be significantly different to the bottom of the tank, where independent heating control is required, but can lead to unsafe temperatures at the top of the tank.
- Switching Speed is a hardware saving feature to limit the operation count that mechanical relays can accumulate under certain circumstances. There are two general modes that all controllers can be switched between:
    - ○ Mechanical Relay (EMR) mode – uses the slower range of switching speeds available from 10 seconds to 20 minutes.
    - ○ Solid State Relay (SSR) mode – can only be set/appliedwhen only external outputs are configured for all controllers. This mode should not be set if the external Relays (driven by the low power SSRs) are mechanical. Switching speeds between 100ms and 10s can be selected for SSR "PWM" output.
- EMR Mode switching speed considerations
    - ○ The default of 5 minutes provides a limit of 288 operations per day, which in the worst-case scenario of a 12kW@415v or 9kW@230v could result in little over 1 year life expectancy of internal or external mechanical relays (typically upper limit electrical life of control relays is 100,000 operations @ 10-15 amps).
    - ○ Worst case switching scenarios are typically only approached when constant temperatures are accurately maintained on systems with little usage. For systems with varying setpoints or frequent usage the duty periods are typically 100% and no switching occurs for the vast majority of the time and life expectancy of the relays dramatically increases to 10+ years with appropriate control period settings.
    - ○ Users should refer to the relays electrical operation endurance specifications to make an assessment of this.
- SSR Mode switching speed considerations:
    - ○ All power contactors must be solid state types.
    - ○ EMC emissions should be adequately dealt with and zero-crossing SSRs or TRIACs used to minimise high frequency harmonics.
    - ○ Element thermal stresses can be improved with faster PWM frequencies.

○ Faster heating responses can be achieved with faster PWM speeds (e.g. for low thermal capacity processes or flow heating applications).

Controller parameters that will typically be adjusted by users can be found on the Controller Settings screen, as detailed below.
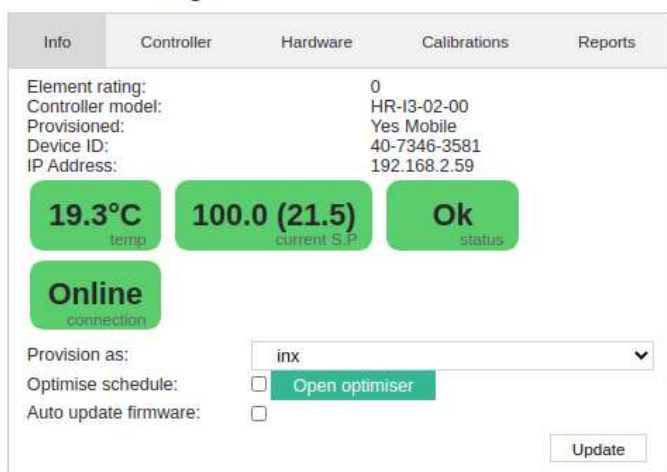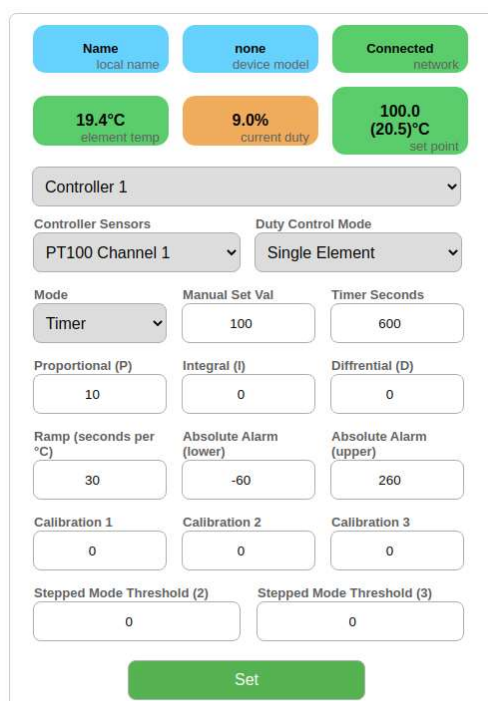
Controller Settings

Figure 9: Main dashboard page

Figure 10: Main configuration settings page

The settings tab of the app shows all three PID controllers sensor temperatures and device information.

- The three controller's parameters are shown depending on the drop-down menu
  ○ If changes have been made to one controller these must be saved before switching to another controller's settings. The drop-down menu should indicate if there are changes and warn you that these will be discarded if a new controller page is selected.
- Each controller can be configured to use any of the PT100, thermocouple (HRDc only), or 0-10v,4-20mA inputs.
  ○ Sensors can be used on more than one controller
  ○ 0-10V and 4-20mA input ranges are mapped to 0-100C. This can be changed for PID1 using the user calibration fields described later.
- Mode can select between
  ○ Disabled – no PID control duty is applied under any circumstances (but auxiliary scheduling is still enabled)
  ○ Manual Set Value – constant setpoint is used for the controller at all times
  ○ Scheduled Set Value – Setpoints are provided by Devman at up to half hourly resolution on a weekly cycle.

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- This mode is only available if the RTC has been set (which initially requires Internet access)
    - Schedules can only be crated in Devman and with a Backer IoT service plan
  - Timer – see previous description of basic use in 'Getting Started'
    - Uses Timer Set Value as the target temperature to heat to.
    - Timer Seconds is the duration the heater will heat for irrespective of the attained temperature.
  - Timer Set Point – see previous description of basic use in Getting Started
    - Uses Timer Set Value as the target temperature to heat to.
    - Timer Seconds is the duration the heater will heat for once the desired Timer Set Value temperature has been first measured.
- Duty Control Modes
  - Single Element – just one relay will be energized during duty
  - Single Element Two Pole – two relays are used to switch a single element (live and neutral) - this is similar to tandem but informs the relay self-check to know only one has live ac connected.
  - Two Element Tandem – switches two element circuits simultaneously.
  - Three Element Tandem – switches three elements simultaneously
  - Two Element stepped – will switch the first selected element on for the initial duty requirement and subsequently switch a second relay when the duty required exceeds the thresholdentered into the field "Stepped Mode Threshold (2)".
  - Three Element stepped – is similar toabove but will use the additional threshold "Stepped Mode Threshold (3) to determine when a third relay would be energised for the highest duty requirements.
- Up to three Outputs for each controller can be selected to support the above tandem and stepped control modes a single PID controller can be configured for.
  - Note – there is no "collision" checking in the UI to prevent more than one controller using the same output, however the controller itself will not energise any output that is being used by another controller (prioritised by increasing Control number).
- PID (Proportional, Integral & Differential) parameters can be entered to minimise error, overshoot, and response for a give process under control.
  - Default values give conservative control without integration to avoid overshoot of delay-heavy sensor locations.
  - Auto PID tune is available in a subsequent firmware release (Q3 2021).
- Ramp (s / C) allows changes in setpoint to be limited to change at rate of 1°C over the given duration in seconds. This parameterapplies to all modes including schedule, manual, timer and Timer Set Point - see following section on Built-in Timer Modes.
- User calibration values
  - PID 1's sensor values can be offset and scaled using the following formula:
    - Temperature = "Calibration 1" + ("calibration 2"+1) x sensor value.
  - The temperature can also be dynamically scaled depending on the heating duty to compensate for flow affects or to include hysteresis-like effects. The temperature will add Calibration 3 to the measure output whenever an output relay is energised for PID1. I.e.
    - Temperature = "Calibration 1" + "calibration 3" + ("calibration 2"+1) x sensor value.
    -

Built-in Timer modes

HRD units can perform accurate relative timed setpoint profiling with or without an internet connection using the internal Real Time Clock (RTC). For date and time of day based scheduling an Internet connection is required to provide a clock source to initialise HRD's RTC, hence this latter type of scheduling is only configurable in the Devman UI.

The relative timer functions can be configured whether on the LAN-Mobile App or Devman and some configuration can also be achieved using only the HRD's front panel buttons and display.

Ramp Function

If the controller isconfigured with a non-zero value for "Ramp seconds per degree"adynamically adjusted setpoint will be used for the relevant PID controller. This will limit any changes in setpoint to the rate of seconds for each degree of change. E.g., a value of 1 would result in the setpoint increasing or decreasing by a value of 1°C every second. This rate of change limit is enforced for any change in setpoint whither it is the manual or scheduled setpoint.

Figure 11: Device settings for ramp function

A ramp value of 0 indicates no ramping will be performed and set point changes will take effect immediately.When in this mode the dynamic set point will be displayed in UIs with brackets next to the final set point.

Hardware displays will be affected by non 0 ramp values in the following ways:
- HRDc - Display 2 will flash the "dynamic set point" as it ramps up to the final set point. Once the final set point is reached it will cease flashing.
- HRDi units will not show the dynamic set point and will show current temperature.

Timer Mode

Mode 3 "Timer" has been added. When this mode is selected on the local UI you will be asked for a set point and then a time. Once these are chosen the devices will behave as follows:
- **HRDi** - Control LED will flash. Time remaining will be displayed. Pressing either - or + will show the current temperature. Pressing either - or + again will show the time remaining. Once finished it will display 00. A short press of set will start the timer again. A long press of set will stop the timer and make the device idle.
- **HRDc** - Control LED will flash. Current temperature will be on display 1. Time remaining will be on display 2. Once finished it will display 00. A short press of set will start the timer again. A long press of set will stop the timer and make the device idle.

Time will be displayed as either 3 digits or 2 digits. 3 digits indicates the number of minutes remaining. Once the time remaining is below a minute then 2 digits will be shown indicating the number of seconds remaining. This is the same for setting the timer.

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The timer duration can be set from Devman and Mobile UIs. However,the timer can only be started by pressing set on the local UI or from an external button connected to the 10v sensor.

Figure 12: Devman configuration for rate of change limited to 30s per degree for 1 10 minute one-shot heating mode

Timed Setpoint Mode

Mode 4 of the HRD device is "Timed set point mode" where the time value defines the duration of heating once a setpoint has been reached. This differs from the basic timer mode where the duration of heating from the moment the timed mode is activated. This mode is also activated either by pressing the set button or applying > 4V to the 0-10V input.

When this mode is selected on the local UI you will be asked for a set point and then a time. Once these are chosen the devices will behave as follows:

- **HRDi** - Control LED will flash. Current temperature will be displayed until set point is reached. At which point the timer will start and the remaining time will be displayed. Pressing either - or + will show the current temperature. Pressing either - or + again will show the time remaining. Once finished it will display 00. A short press of set will start the timer again. A long press of set will stop the timer and make the device idle.
- **HRDc** - Control LED will flash. Current temperature will be on display 1. Display 2 will show time remaining. Once the set point is reached the timer will start and the remaining time will be displayed on display 2. Once finished it will display 00. A short press of set will start the timer again. A long press of set will stop the timer and make the device idle.

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If a ramp value is set, this will be applied from the moment the mode is activated and will reduce the heating only after the duration has been reached, which will mean heating will continue for the additional ramp-down time after the setpoint duration has expired.
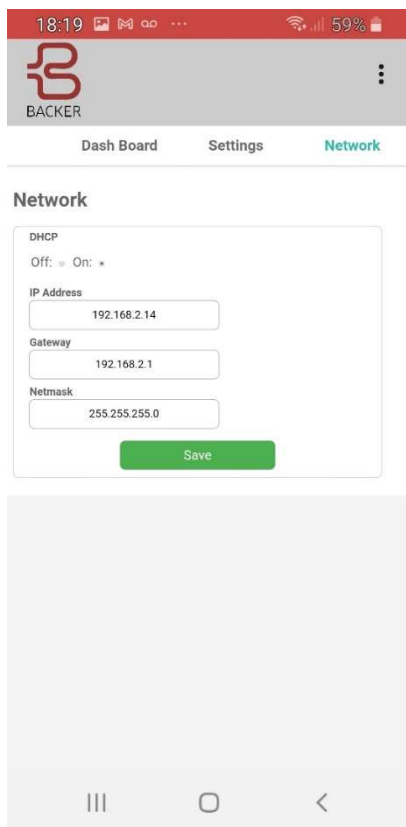
LAN Interface Configuration

Figure 13: Network configuration

Should your host network not support DHCP you will need to configure your device initially with a temporary DHCP enabled access point as described earlier in this manual. From here you can set a static IP address, gateway and Netmask for your device.

Hardware Displays and Buttons

Please see the getting started section for a primer on operating the HRDi units from the front panel buttons. This section provides further details of the user functions available from the front panel display and buttons and also details the error status details that may override the display if errors are detected by the controller.

Mode Setting

The mode button on HRDc performs the same function as a long press of the set button on HRDi. This means the current mode of the HRDc can be controlled by a press of the mode button. Once the mode button has been pressed the current mode is displayed in the third character of the second display. Modes are as follows:

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- 0 - Disabled
- 1 - Manual set point
- 2 - Schedule
- 3 - Timer
- 4 - Timer set point (Timer-SP)

When entering Timer mode 3 or 4 the user is able to enter a time using the up/down buttons to configure the mode's timer settings.

General Button Actions

User Action	Previous State	Subsequent State	FP Buttons
Set Temperature	Manual, Schedule, Timer,Timer-SP Disabled	Display Flashing	Set, Up, or Down
Unfinished actions	Display Flashing	Manual/Schedule/ Timer/Timer-SP/ Disabled	None
Change temperature (fine 0.1 steps)	Display Flashing	Manual Display Flashing	Short Up or Down release
Change temperaturer fast (auto 1°C steps)	Display Flashing	Display Scrolling	Up or Down long press
Apply temperature	Display Flashing	Manual Mode	Set
Change to schedule mode	Manual/Schedule/ Timer/Timer-SP/Disabled	Schedule Mode	Long press set
Reset Device	Manual/Schedule/ Timer/Timer-SP/ Disabled	Manual/Schedule/ Disabled	Long press Down then simultaneous long press Set button
Factory Reset Device	Manual/Schedule/ Timer/Timer-SP/ Disabled	Manual	Long press Down & Up then simultaneous long press Set button

Each time ta unit is powered on and also continuously during operation the HRD runs software and hardware integrity checks. If a unit is powered up without appropriate sensor or power connections, it will immediately set to an error state before any control is carried out.

(HRDi only) Part of boot self-tests will operate the internal relays to check they are switching correctly on boot, which will operate each relay for less than 1 second).

Timer Mode

Mode 3 "Timer" has been added. When this mode is selected on the local UI you will be asked for a set point and then a time. Once these are chosen the devices will behave as follows:

- HRDi - Control LED will flash. Time remaining will be displayed. Pressing either - or + will show the current temperature. Pressing either - or + again will show the time remaining. Once finished it will display 00. A short press of set will start the timer again. A long press of set will stop the timer and make the device idle.
- HRDc - Control LED will flash. Current temperature will be on display 1. Time remaining will be on display 2. Once finished it will display 00. A short press of set will start the timer again. A long press of set will stop the timer and make the device idle.

Time will be displayed as either 3 digits or 2 digits. 3 digits indicates the number of minutes remaining. Once the time remaining is below a minute then 2 digits will be shown indicating the number of seconds remaining. This is the same for setting the timer.

The timer duration can be set from Devman and Mobile UIs. However, timer can only be started by pressing set on the local UI or from an external button connected to the 10v sensor.

Timer Set Point Mode

Mode 4 "Timer set point" has been added. When this mode is selected on the local UI you will be asked for a set point and then a time. Once these are chosen the devices will behave as follows:

- HRDi - Control LED will flash. Current temperature will be displayed until set point is reached. At which point the timer will start and the remaining time will be displayed. Pressing either - or + will show the current temperature. Pressing either - or + again will show the time remaining. Once finished it will display 00. A short press of set will start the timer again. A long press of set will stop the timer and make the device idle.
- HRDc - Control LED will flash. Current temperature will be on display 1. Display 2 will show time remaining. Once the set point is reached the timer will start and the remaining time will be displayed on display 2. Once finished it will display 00. A short press of set will start the timer again. A long press of set will stop the timer and make the device idle.

CriticalError States & Reporting

Error states are reported on the HRDc's front panel display instead of a measured temperature value. If an error state is detected the display will report the error number in the first two digits, with the third blankanda flashing a '0' after the decimal place.

The front panel display reports all error cases in numeric format and display formats that should be easily distinguishable from normal operation display values. Text format error messages are also displayed in both the Mobile App and Devman UIs.

The error number are defined as in table X below and are prioritized from 0 (highest) and 11 (lowest):

Error #	Error State	Notes
0	Relay Stuck On	HRDi Only - Can be caused incorrect element wiring
1	RelayStuck Off	HRDi Only - Can be caused incorrect power wiring
2	Thermal Cutout	HRDi Only – Optional &Can be caused incorrect wiring
3	Sensor unsafe (Perm)	A permanent sensor temperature fault

4	Sensor Unsafe (Temp)	A temporary range error has occurred
5	Watch Dog Error	A software self-check error has occurred.
6	Out of Memory	A software error has occurred
7	RAM Error	A processor hardware error has occurred.
8	Software Error	A software self-check error has occurred.

Error modes will persist between power cycles to avoid actuating relays when permanent hardware errors are known. Once the hardware error has been cleared holding the down button and set button for 10 seconds will reset the device with errors cleared.

Network Status LED

Device Connection State	Network LED	Control LED	4 Digit Display
Normal::No Network	Red	Unchanged	Temperature
Normal::Provisioned-Local Only	Yellow	Unchanged	Temperature
Normal::Provisioned-Local & Devman	Green	Unchanged	Temperature
Normal::Unprovisioned-Local	Flashing yellow	Unchanged	Temperature
Normal::Unprovisioned-Local & Devman	Flashing green	Unchanged	Temperature

Critical hardware fault:
- First two (most significant) digits show the error number, with leading 0 if < 9
- The 3rd digit is left blank
- The 4th digit is rapidly flashed with a 0 to indicate an error condition is being reported.

Critical Software fault:
- No numerical output except a single decimal point will be displayed with the following exception:
  - 888.8 may be left on display in certain circumstances if the device's non-volatile memory is non-functional.
  - The last value will be displayed immediately after the device fails for a short period of time before the device resets into safe mode.
- No LED mode indicators will be illuminated.

Mobile IoT App Error Reporting

The Device dashboard indicates warnings and errors in the relevant status fields. The overall operational state of the device is only available in Normal Operation and Critical Hardware Error modes. As long as the hardware error is not the Network Interface/Ethernet subsystem.

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MODBUS

MODBUS-RT (RS485) is enabled always on HRD devices, however MODBUS-IP is not, as it is not securable with non-secure LANs.

The following MODBUS Registers are mapped to HRD parameters and variables.

REG#	UI Name	Description	Type	Mode
40001	Last known time	Time Year (local Time)	int	Read
40002	Last known time	Time Month (local Time)	int	Read
40003	Last known time	Time Day (local Time)	int	Read
40004	Last known time	Time Hour (24) (local Time)	int	Read
40005	Last known time	Time Minute (local Time)	int	Read
40006	Seconds from 2020	Elapsed seconds from midnight 1/	int	Read/Write
40007 -40009	Not used			
40010	EMR1 contact counts	Internal Mechanical Relay counts	int	Read
40011	EMR2 contact counts	Internal Mechanical Relay counts	int	Read
40012	EMR3 contact counts	Internal Mechanical Relay counts	int	Read
40013	Device Status	**See error States**	int	Read
40014	Device Error parameter	**See error States**	int	Read
40015	Hardware Check Mode	0 - Disabled 1 - Fast Checks Only 2 - All Relay Checks 3 - Additional Checks	int	Read/Write
40016	Power Connection Mode	0- Independent 1 - Single Phase 2 - 3 phase star (4 wire) 3 - 3 phase delta (3 wire)	int	Read/Write
40017	EMR cycle Time	Internal Mechanical Relay switching time (s)	int	Read/Write
40018	SSR cycle Time	External Relay switching time (s)	int	Read/Write
40019	Not used			
40020	Controller 1 Mode	0-Disabled 1-Manual 2-Scheduled 3-Timed 4-Setpoint-timed	int	Read/Write
40021	Sensor Select-1	0- disabled 1 - PT100-1 2 - PT100-2 3 - 0-10V 4- 4-20mA	int	Read/Write

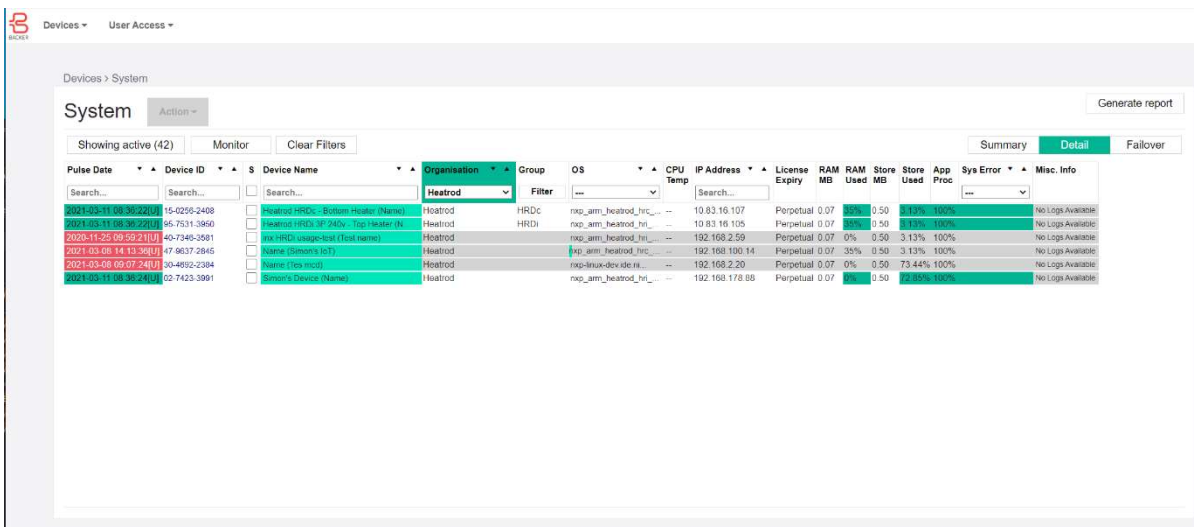| | | 5 - MODBUS | | |
		6 - Thermocouple		
40022	MODBUS MV-1	MODBUS measured value (°C)	int	Read/Write
40023	Temperature-1	Sensor Measured Temperature	int	Read
40024	Current SPV-1	Currently applied SV		Read
40025	Manual SPV-1	Manually set SV (Manual mode)	int	Read/Write
40026	Duty-1	Overall Duty for output type (%)	int	Read
40027	Output-1 Mode	0-Single 1-double stepped 2-double tandem 3-triple stepped 4-triple tandem	int	Read/Write
40028	Output 1-1 config	0 - Disabled 1 - Modbus 2 - Internal1 3- Internal 2 4 - Internal 3 5 - External1 6 - External 2 7 - Internal 3	int	Read/Write
40029	Output 2-1 config	0 - Disabled 1 - Modbus 2 - Internal 1 3- Internal 2 4 - Internal 3 5 - External1 6 - External 2 7 - Internal 3	int	Read/Write
40030	Output 3-1 config	0 - Disabled 1 - Modbus 2 - Internal 1 3- Internal 2 4 - Internal 3 5 - External1 6 - External 2 7 - Internal 3	int	Read/Write
40031- 40039	Not used			
40040	Controller 2 Mode	0-Disabled 1-Manual 2-Scheduled 3-Timed 4-Setpoint-timed	int	Read/Write
40041	Sensor Select-2	0- disabled 1 - PT100-1 2 - PT100-2 3 - 0-10V 4- 4-20mA	int	Read/Write

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		5 - MODBUS		
		6 - Thermocouple		
40042	MODBUS MV-2	MODBUS measured value (°C)	int	Read/Write
40043	Temperature-2	Sensor Measured Temperature	int	Read
40044	Current SPV-2	Currently applied SV		Read
40045	Manual SPV-2	Manually set SV (Manual mode)	int	Read/Write
40046	Duty-2	Overall Duty for output type (%)	int	Read
40047	Output-2 Mode	0- single 1-double stepped 2-double tandem 3-triple stepped 4-triple tandem	int	Read/Write
40048	Output 1-2 config	0 - Disabled 1 - Modbus 2 - Internal 1 3- Internal 2 4 - Internal 3 5 - External1 6 - External 2 7 - Internal 3	int	Read/Write
40049	Output 2-2 config	0 - Disabled 1 - Modbus 2 - Internal 1 3- Internal 2 4 - Internal 3 5 -External1 6 - External 2 7 - Internal 3	int	Read/Write
40050	Output 3-2 config	0 - Disabled 1 - Modbus 2 - Internal 1 3- Internal 2 4 - Internal 3 5 -External1 6 - External 2 7 - Internal 3	int	Read/Write
40051-40059	Not used			
40060	Controller 3 Mode	0-Disabled 1-Manual 2-Scheduled 3-Timed 4-Setpoint-timed	int	Read/Write
40061	Sensor Select-3	0- disabled 1 - PT100-1 2 - PT100-2 3 - 0-10V 4- 4-20mA	int	Read/Write

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		5 - MODBUS 6 - Thermocouple		
40062	MODBUS MV-3	MODBUS measured value (°C)	int	Read/Write
40063	Temperature-3	Sensor Measured Temperature	int	Read
40064	Current SPV-3	Currently applied SV		Read
40065	Manual SPV-3	Manually set SV (Manual mode)	int	Read/Write
40066	Duty-3	Overall Duty for output type (%)	int	Read
40067	Output-3 Mode	0- single 1-double stepped 2-double tandem 3-triple stepped 4-triple tandem	int	Read/Write
40068	Output 1-3 config	0 - Disabled 1 - Modbus 2 - Internal 1 3- Internal 2 4 - Internal 3 5 -External1 6 -External 2 7 -Internal 3	int	Read/Write
40069	Output 2-3 config	0 - Disabled 1 - Modbus 2 - Internal 1 3 - Internal 2 4 - Internal 3 5 -External1 6 -External 2 7 -Internal 3	int	Read/Write
40070	Output 3-3 config	0 - Disabled 1 - Modbus 2 - Internal 1 3- Internal 2 4 - Internal 3 5 -External1 6 -External 2 7 – Internal 3	int	Read/Write

Devman –Web UI

In addition to the local network access using the mobile application you can also access your device from any location using a standard browser (PC, Mac, Tablet or mobile). Your sign-in credentials are valid on the Devman server located at https://iotbacker.com

Your HRDi/HRDc device must be connected to a NAT router network with outgoing Internet access (i.e. a standard LAN). Typically, no specific LAN configuration is required to enable outgoing only communication across the NAT router's firewall, however, if the IT policy of your organisation blocks outgoing port 8883 connections (the standard secure MQTT port), then this will need to be exempted.

Once you have logged into the Devmanportal you should see a list of all devices that have been provisioned to your account or your account's organisation if you have a team enabled account.

Figure 14:Devmandevice listing (Example showing a personal account with a single device available)

In addition to raw data visualisation Devmanroutinely carries out data & system modelling to identify key parameters of the HRDi/HRDc's condition, environment, and energy usage. Input-output dynamic system modelling, and statistical data processing is used to quantify the following system properties:

- Heat capacity of the heated material
- Thermal loss of the heated material container
- Duty - measured temperature delay
- Energy usage trends & patterns

Click on the Device ID to link to your device's dashboard (figure 14 - above)

If you don't see your device listed, then check you have logged in with the same account that the device was provisioned with. If the device is still missing it is likely that the HRDi/HRDc device cannot connect to the internet. You can test this by plugging a laptop into the same network connection the HRDi/HRDc device is using and checking the following URLs in browser:

https://iotbacker.com:8883/ if the network is correctly configured this should return a specific error to a web browser informing the connection was reset rather than not available or any other error. e.g., Google Chrome browser will respond with "The connection was reset.", "ERR_CONNECTION_RESET" if the device connection is enabled. Any other error type indicates the required type of connection to the Devman server has been blocked.

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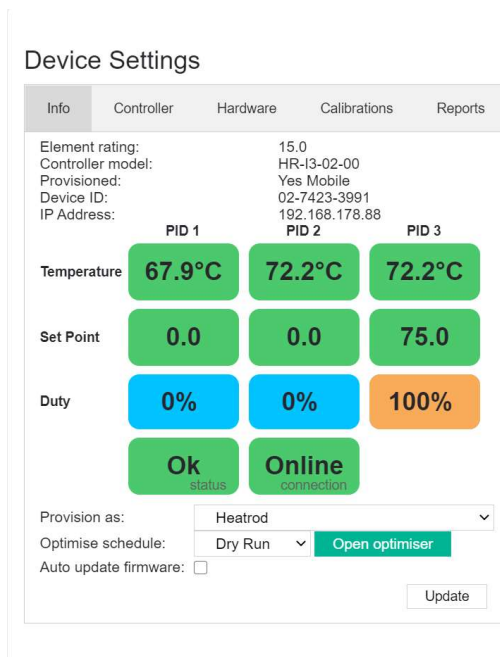
Dashboard UI

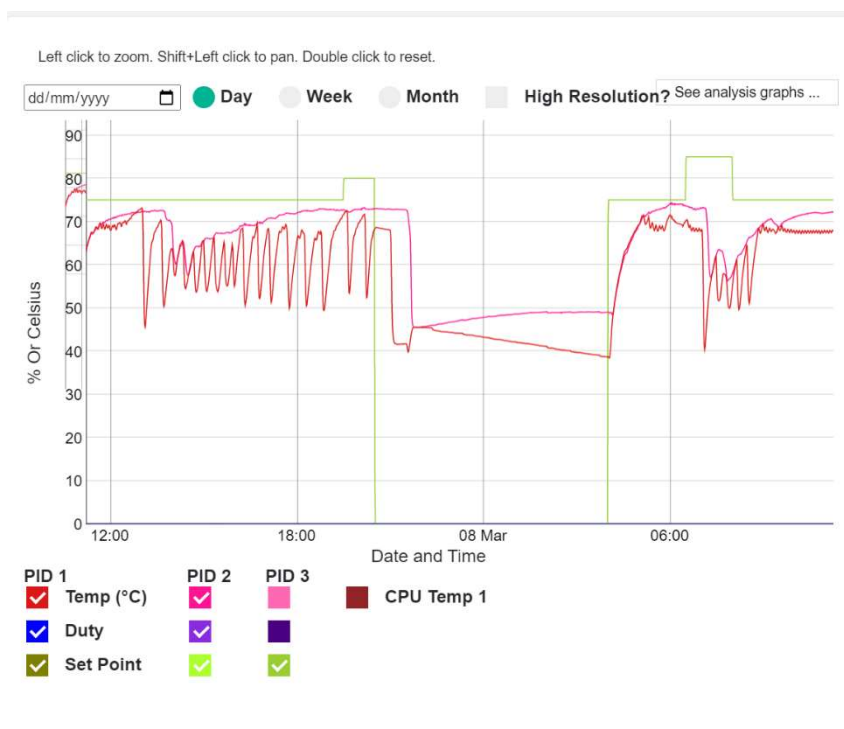**Figure 15:Device Status Dashboard**

Figure 16. Basic Data Visualisation in the Device Dashboard

Temperature, duty and setpoints are logged at up to 1 second resolution to Devman. The raw data can be visualised at daily, weekly or monthly timescales and with enhanced resolution of up to 1 second for a daily time span. Note the graph update speed is dependent on resolution and Internet connection speed.You can also monitor the processors electronics temperature using the CPU temperature monitor.

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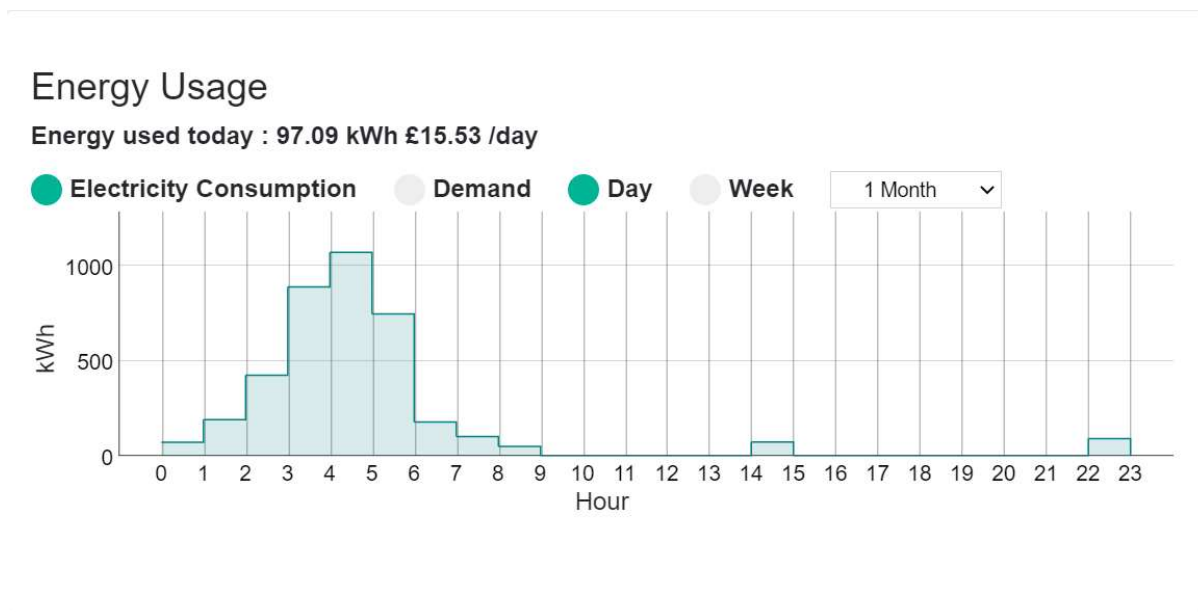
Figure 17: Overview of energy consumption

The device dashboard also gives an overview of Energy consumption trends for the controlled process. If correct element power ratings and energy costs are entered under "OptimiserFlat unit rate"
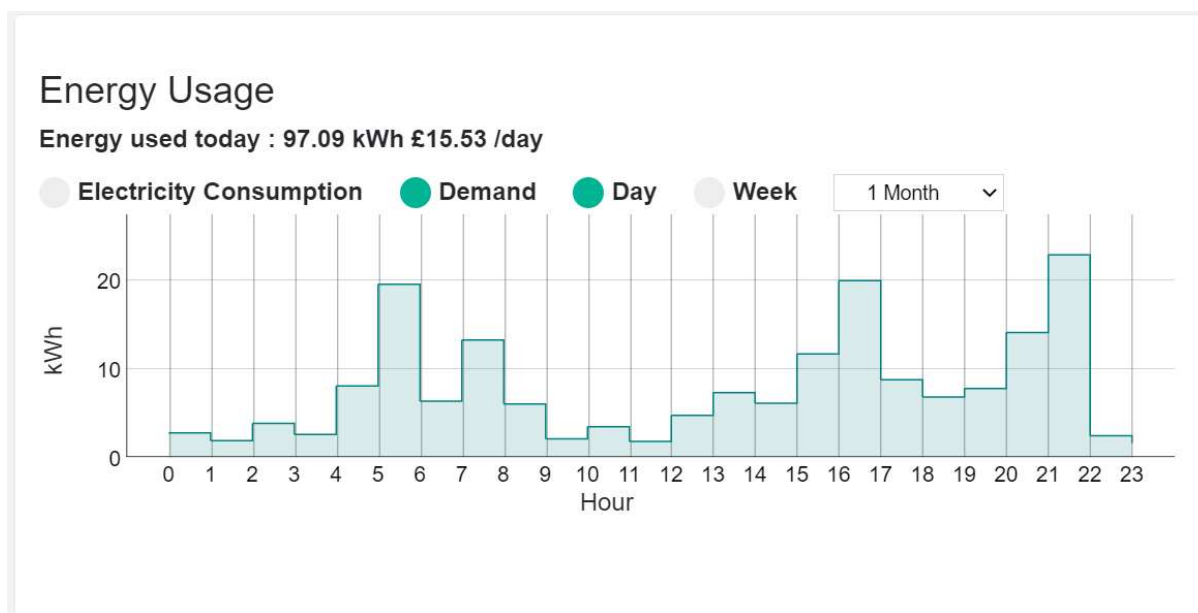
Figure 18:Devman's extended Device dashboard showing recent system activity, supervisory control parameters and summary data analysis.

Devman Device Settings

Devman provides the same access to controller device settings as found in the Mobile app (used for LAN-only access). The Devman UI provides additional tabs for viewing and setting calibration and also for view Event reports from the device to Devman.

To change settings of a device on Devman you must have the device's 5 digit PIN available to make changes to any parameters on the device.

Please see the above Controller Settings section referencing the same configuration fields as available for the Mobile App for details.

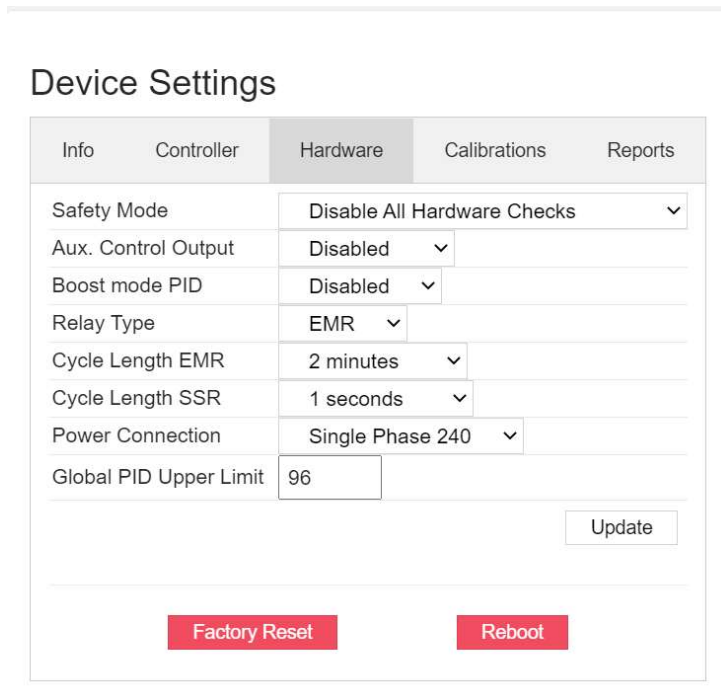**Figure 19: Device settings on Devman UI**

Figure 20: Hardware settings on Devman UI

Scheduling

From the Controller settings page there is an option to set the HRD to scheduled mode. Click on the "Open Scheduler" button to open the weekly schedule editor tool.
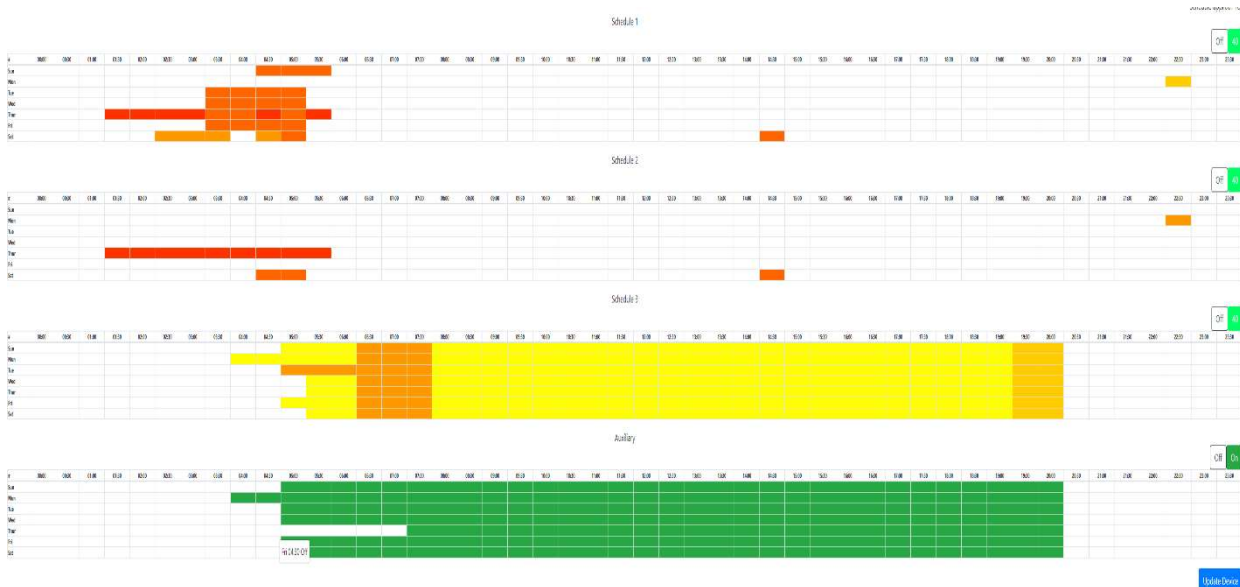

Figure 20. Weekly Heating (top 3 grid plots) and auxiliary control (bottom) scheduler.

Once connected you can see a detailed dashboard of your device's activity by clicking on the Device ID in the table of devices available in your organization or from your personal account.

An additional schedulable on/off control process may also be enabled (for example for independent stirrer control). This provides a digital signal only for external use. To enable this an output must be selected for the auxiliary scheduling in the device settings. The output selected must not conflict with any PID controlled outputs and should not be used to drive heating elements unless there is external temperature control enabled for these.

Drag select operations can be used to quickly create and update weekly heating planners for the weeks ahead. Optimal energy usage suggestions can* be overlaid on to this schedule based on historical data to aid creating economical heating plans that work for you. [* This feature is not currently enabled].

Sensor Control & Data Logging

Selected sensor and system data is securely transmitted to DevmanInternet/Cloud based server using TLS1.2 encryption and authentication. The DevmanServer strictly separates data between different users unless team accounts are required in which case all data and communication with devices is strictly limited to users within the team's organisation.

Sample rates of up to 1 sample per second for each logged value, which by default for HRDi/HRDc devices is:

- o   Internal PT100 sensor
- o   External PT100 sensor
- o   MCU electronics temperature
- o   Temperature set point
- o   PID Controller duty demand

The rate and duration of data maintained on the Devman server is dependent on the user/organisation account type that the HRDi/HRDc device is associated with.

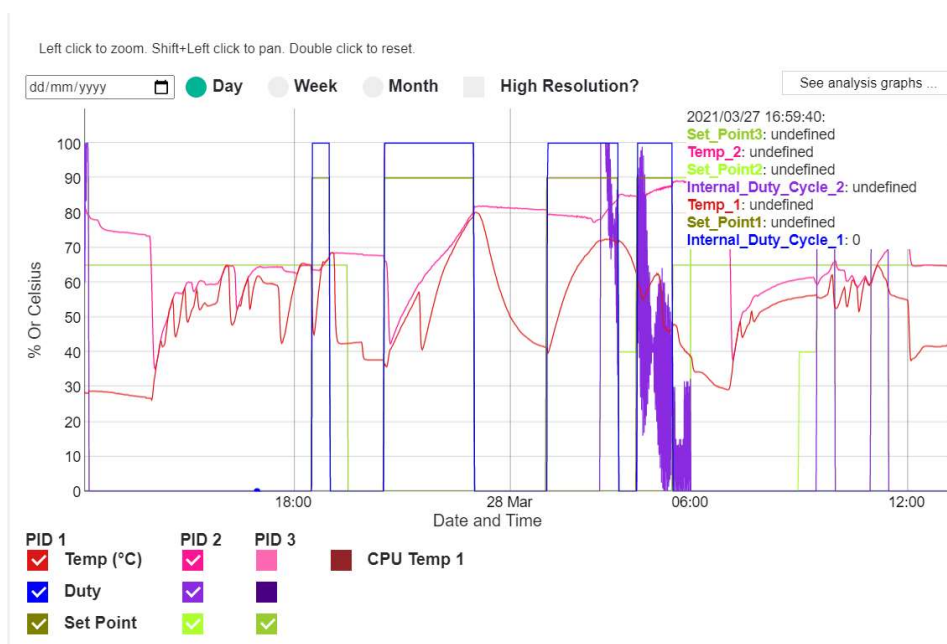Time series databases can be visualised in the Devman Web portal using online graphing features.

Figure 21: Logged data

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Logged data must be from sensors and outputs that are configured to be used for at least one of the Controllers. The three independent controllers available on HRD devices are typically labelled PID*x*, where x denotes the controller number. It is possible for controllers to be given an alternative more descriptive name of their purpose (e.g. "top element", "bottom element"), but currently defaults to PID*x*.

All data associated with sensors, duty and setpoint values that are assigned toa controller are continously logged in Devman. The use can select which traces are displayed using the low tick boxes. The device's internal electronics temperature can also be monitored which is typically most useful for controllers that are integrated into heating element head units.

When daily temperature logging is selected data at 30s resolution is shown to minimise grap load times. For weely and monthly views the resolution is reduced accordingly to minimise load times. The specific resolution may vary between account types. Most account types also support view data at higher resolutions up to 1s for daily duration visualisation.

Drag and drop mouse or touch screen operations can be used to zoom in and out of specific time or value ranges. Double clicking the graph area will return it to the default full data set for the currently active duration.

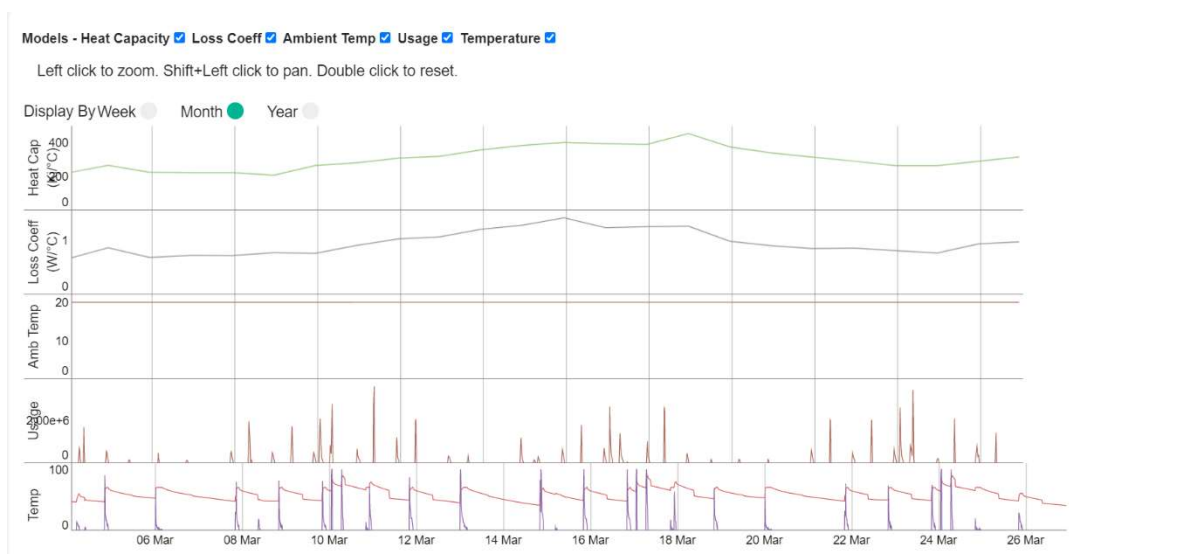## Process Data Modelling Service

Figure 22: Process data modelling service

System models are estimated from high resolution controller data. From this, physical parameters are extracted which can be used to define condition monitoring, closed loop control parameters and supervisory control strategies. Running the model in predictive mode also enables high levels of plant activity to be identified such as water usage and more detailed condition monitoring.

The time series data that is generated from online modelling is also used to direct other parts of the Devman services such as Energy optimisation services.

Though in most cases these systems can be fully self-configuring there are options to configure the process and system analysis more specifically for each application.

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Figure 23: Usage parameters

The parameters above are used as follows:

- Weeks to Average for Usage
  - Defines the number of weeks that are used for usage trend analysis for the dashboard graph and also for the energy optimiser.
- Heat Capacity PID1
  - The heat capacity of the volume heated by controller 1.
  - This is used in the Usage calculation and Energy Optimiser and is typically the set to a known value from the system design or the average estimated value provided in the plots above.
- Ambient Temperature
  - The average ambient temperature expected in the environment surrounding the thermal mass of the system. It is used to help disambiguate parameters estimation where there is insufficient variation in the data for the modelling to robustly estimate it.
- Heat Loss PID1
  - The thermal loss of the system defined by design or estimated by the system in the plots above. Note that in cases where there is no energy extraction or heating of the process it is not possible to estimate these parameters and they may be left blank.
- For cases where there are multiple heating zones in a system and energy is independently added and removed from the process, but there also remains thermal linkage between the zones the Multi PID tank mode can be set and the parameters for the additional heating zone can be set.
  - Up coefficient is the thermal transfer rate from the heating zone controlled by PID2 to PID1's zone.
  - Down coefficient is the rate of transfer from PID1 to PID2's zones.
  - These parameters are specific to different types of thermal storage and are currently estimated by manual experimentation and are therefore typically set for specific OEM products rather than an application-by-application basis. These parameters are non-critical to usage or energy estimation but can help to improve quantitative accuracy of usage events if needed, but it is typically temporal information that is most important.

The usage and thermal properties models can be re-run over historic data using the Re-run modelling button.
This may take some time but can be sped up if the thermal parameter estimation does not need to be re-run.

DevmanError Logging

An event list in the Devmandashboard indicates time stamped warning and error messages in the device dashboard.

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