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1. Introduction

1.1 Scope

This document describes the new ESO electronic cabinet thermal control unit and it includes details about interfaces, installation and operation. It refers to the following versions:

- Hardware: CS-P-2164 Rev.2
  G:\TEC\TEE\PCB Archive\PCBs_2008 ++\CS-P-2164_CCS_Interface\Rev 2
- Software: Version 0.9.5
  http://svnhq19.hq.eso.org/p19/trunk/sandbox/ndilieto/ccs-buildroot @V1739

1.2 Definitions, Acronyms and Abbreviations

This document employs several abbreviations and acronyms to refer concisely to an item, after it has been introduced. The following list is aimed to help the reader in recalling the extended meaning of each short expression:

AC	Alternating Current
DC	Direct Current
LCD	Liquid Crystal Display
LED	Light Emitting Diode
VLT	Very Large Telescope

2. Related Documents

2.1 Applicable Documents

The following documents, of the exact version shown, form part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the content of this document, the content of this document shall be considered as superseding.

AD references shall be specific about which part of the target document is the subject of the reference.

AD1 Base ICS - Field Extension Device Driver WS - PLC Interface Control Document; VLT-ICD-ESO-17530-5660 Issue 1

2.2 Reference Documents

The following documents, of the exact version shown herein, are listed as background references only. They are not to be construed as a binding complement to the present document.

RD1 VLT Electronic Cabinet Thermal 1HE Control Unit User Manual; VLT-MAN-ESO-17130-2027 Issue 1.3

RD2 VLT Electronic Cabinet Cooling System (4HE); VLT_MAN-ESO-17130-1603 Issue 1.0

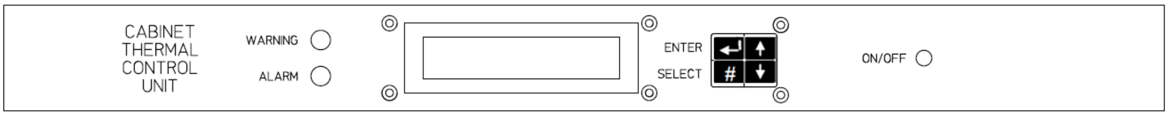
3. System Overview

The temperature of equipment in the telescope area is required to stay close to that of the surrounding environment in order to prevent harmful convective airflows from affecting observations.

Electronic cabinets mounted in proximity to the telescope are fluid cooled. In these cabinets, the cooling system consists of a heat exchanger that transfers the heat generated inside the cabinet to a cooling fluid supplied by the central chilling system.

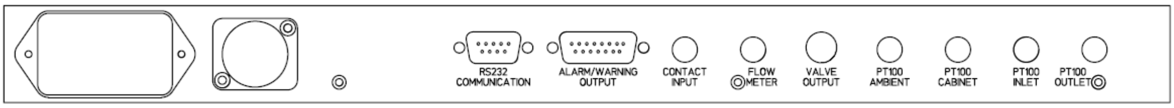
The electronic cabinet thermal control unit monitors the ambient, cabinet and fluid temperatures and regulates the cooling fluid flow in order to keep the difference between the cabinet and ambient temperatures within acceptable limits at all times.

The thermal control unit is housed in a 1HE 19-inch rack mounting chassis. A retro-illuminated liquid crystal display with a 4-button keyboard, two LEDs and an ON/OFF button are found on the front panel.



The LCD shows status information, warning/alarms and in addition a menu based user interface system which is operated through the 4-button keypad.

LEMO connectors for the temperature sensors, the hydraulic valve, the flow meter and the door contact are located on the back panel together with RS232, Ethernet, warning/alarm relay and mains power connectors.



The thermal control unit status can be monitored through either an OPC/UA server communicating over the 100BASE-TX Ethernet interface or, for backwards compatibility, through a simple custom serial protocol over the RS232 interface.

4. Specifications

Operating temperature range	0 … 50°C
Coolant temperature range	-15 … 70°C
AC Supply	230 VAC, 50Hz
AC Power	6 W
Dimensions (DxHxW)	19'' x 1HE x 250mm
Weight	2.5 kg
Liquid crystal display	2 lines x 20 characters
Keypad	4-key
Environmental protection	suitable for installation in electronic cabinet

Table 1

5. Interfaces

5.1 Mechanical Interfaces

The unit is designed to fit in a 19” rack; the height is 1HE.

5.2 Electrical Interfaces

5.2.1 Hydraulic valve actuator (Siemens Acvatix SSP61)

Operating voltage	DC 24V
Maximum current	100 mA
Control voltage	DC 0 … 10 V

5.2.2 Relay outputs

Maximum operating voltage	125 VAC/VDC
Maximum operating current	2A
Maximum switching capacity	62.5 VA, 60 W
Minimum permissible load	10 µA, 10 mVDC

5.2.3 Flow rate sensor (UCC-Dataflow DFC-9000 or compatible)

Power supply	DC 5V isolated, max 100 mA
Output	NPN open collector (pullup built in unit)
Max pulse frequency	1 kHz
Flow constant	default 752 pulses/litre, user changeable

5.2.4 Door contact

Contact	Normally open (door open)
Voltage	DC 12V isolated

5.2.5 Temperature sensors

Type	PT100
Connection	Three wire

5.2.6 Serial interface

Type	RS232, 9600bps, 8 bits, no parity, 1 stop bit
Protocol	See 0

5.2.7 Ethernet interface

Type	RJ45, 100BASE-TX
Protocols	See 5.3.1, 5.3.2

5.3 Software Interfaces

5.3.1 Secure Shell

The unit is powered by a Raspberry Pi B+ running Linux; it is possible to remotely access the system shell through the network using the ssh protocol. Only the root user is available; the password is "pass4u". Network settings such as IP address and netmask can be visualized on the LCD and changed through the local interface on the front panel.

Upon initialization, the root filesystem is loaded from the boot partition and extracted to a RAM disk. Therefore, any changes made to the root filesystem are lost on the next reboot. Permanent changes to the boot partition are possible by first remounting the partition read/write. This is only to allow remote firmware updates and is not necessary during normal operation.

5.3.2 OPC/UA

OPC Unified Architecture (OPC/UA) is an industrial, cross-platform, service-oriented architecture that enables data acquisition and information modelling and communication. It was standardized (IEC 62541 series) in 2010.

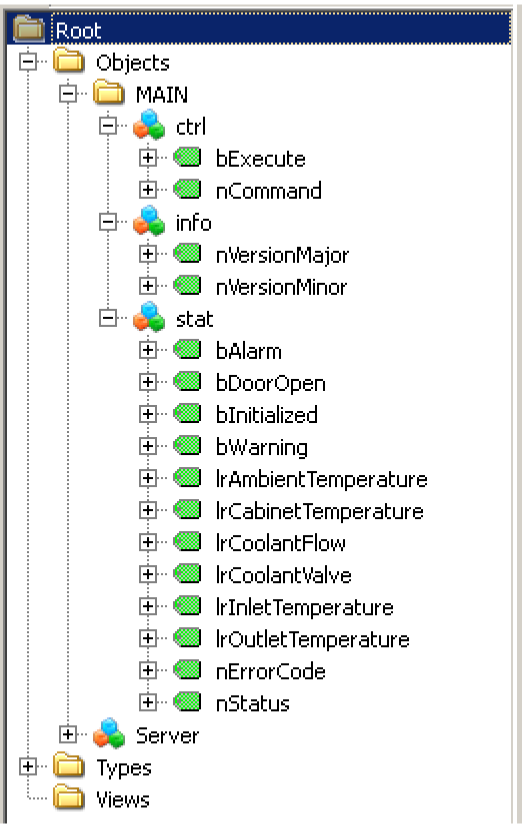


Figure 1

The cabinet thermal control unit implements an OPC/UA server through the opc.tcp:// binary protocol on TCP port 16664. The OPC/UA protocol is based on the open62541 project (see http://open62541.org), an open source C-based library.

Any OPC/UA client compliant to IEC 62541, such as UAExpert from Unified Automation GmbH, can connect to the server through the network, browse the local information model and retrieve attributes and references of particular UA Nodes.

The local information model includes the nodes in Figure 1. The nodes are organized in three categories, according to the categorization described in §2.1 of [AD1]. Note that the "ctrl" nodes are not currently used and are only present because they are mandatory according to the above document.

All significant nodes are in the "stat" category and a brief explanation of their definition and meaning is in Table 2:

Name	Data type	Meaning
bAlarm	BOOL	TRUE when the unit has triggered an Alarm. It corresponds to the state of the Alarm relay and front panel Alarm LED
bDoorOpen	BOOL	TRUE when the door contact switch is open
bInitialized	BOOL	TRUE when the system is up and running
bWarning	BOOL	TRUE when the unit has triggered a Warning. It corresponds to the state of the Warning relay and front panel Warning LED
lrAmbientTemperature	DOUBLE	Last valid ambient temperature in degree Celsius
lrCabinetTemperature	DOUBLE	Last valid cabinet temperature in degree Celsius
lrCoolantFlow	DOUBLE	Last valid coolant flow rate in litre/minute
lrCoolantValve	DOUBLE	Current coolant valve target position in percent
lrInletTemperature	DOUBLE	Last valid inlet coolant temperature in degree Celsius
lrOutletTemperature	DOUBLE	Last valid outlet coolant temperature in degree Celsius

nStatus	INT32	Status code (see also parameters in 7.2)
		• 0 = no errors/warnings
		• 1 = door open
		• 2 = inlet temperature above outlet
		• 3 = any temperature inconsistency:
		  ○ Cabinet – Ambient > `Tcab-Tamb max`
		  ○ Cabinet – Inlet > `Tcab-Tinl max`
		  ○ Outlet – Ambient < `Tout-Tinl min`
		• 4 = Ambient temperature sensor fault
		• 5 = Outlet – Inlet temperature > `Tout-Tinl max`
		• 6 = Outlet temperature sensor fault
		• 7 = Inlet temperature sensor fault
		• 8 = Cabinet temperature too low (< `Tcab min`)
		• 9 = Cabinet temperature too high (> `Tcab max`)
		• 10 = Cabinet temperature sensor fault

nErrorCode	INT32	Error code • 0 = no error • 1 = error (when nStatus > 7)

Table 2

5.3.3 Serial

The serial communication interface is provided for backwards compatibility with the old controller [RD1]. A reduced set of commands is implemented, including only those actually used by the VLT software.

The communication protocol is based on ASCII characters, which allows communicating directly with the controller by using a serial terminal. The host acts as the master of the point-to-point communication, while the controller acts as the slave. Every time the controller receives a message from the host, it sends back an acknowledge message which contains the information required by the host, if any. The controller never sends unsolicited messages to the host; in other words, all messages sent by the controller are acknowledge messages.

Only one message (command ‘C’) causes two acknowledge messages to be sent back. This is for synchronisation purposes, the second message being synchronous with the sampling of the temperatures.

The host shall not send a new message before previous commands have been acknowledged (twice in case of the ‘C’ command). The delay between the reception of a command and the transmission of the acknowledge depends on the specific command but is normally in the order of a few milliseconds.

Some messages contain numeric values. These values are represented as hexadecimal strings.

All temperatures are represented internally by a 15 bit positive number (normalised format). The same format is used to represent the temperatures in the serial messages. To convert a temperature T_n from the normalised format to the corresponding value expressed in °C, the following relationship has to be applied:

$T[°C] = (T_n - 5750)/375$

The normalised format can represent temperatures in the range -15°C to +72 °C with a resolution better than 0.003 °C.

For the hexadecimal representation the protocol can accept both upper and lower case alphabetic characters, although messages sent back by the controller contain always upper case characters.

The character representing the most significant nibble of each byte is transmitted first. Numeric values (16 and 32-bit long) are transferred with the most significant byte first.

5.3.3.1 Serial Message Structure

Messages from the host to the controller are structured in fields as follows:

`<initiator><address><command><parameters><checksum><terminator>`

where:

`<initiator>` is the ‘>’ character, ASCII code 62

`<address>` is two ASCII characters specifying the address in hexadecimal format. This field has been introduced to support multi-drop communication with the RS485 hardware protocol. For RS232 interface the field must be always "00".

`<command>` is a single ASCII alphanumeric character. It is case sensitive: upper and lower case characters correspond to different commands.

`<parameters>` is an ASCII character string representing hexadecimal numbers. The contents and the length depend on the specific command and are described below.

`<checksum>` is the two-character hexadecimal representation of the lowest significant byte of the number obtained by adding up all the bytes of the message except the initiator. If the checksum received does not match with the one computed by the controller, the command is ignored and an error message is sent back (see "error messages"). As a debug shortcut the two characters "??" (ASCII) in place of the checksum disable the checksum check and allow any command to be processed.

`<terminator>` is the Carriage Return character, ASCII code 13

Reply messages from the controller to the host are structured in fields as follows:

`<initiator><reply><checksum><terminator>`

`<reply>` is a reply string. It depends on the command (see below). If the command is not recognized or the checksum does not match, the error message “N00<CR>” is returned.

`<checksum>` and `<terminator>` have the same meaning as above.

Note that if the address characters are not recognised (i.e. they are different from "00", in the default configuration), no answer at all (not even an error message) is sent by the controller.

5.3.3.2 Serial Commands

Command	Description
‘C’	Synchronization command
‘H’	Retrieve the temperature and flow rate measurements
‘f’	Retrieve the flow rate measurement
‘o’	Retrieve the contents of the status register
‘u’	Clear power-up/reset flag
‘V’	Retrieve firmware version

Table 3

5.3.3.3 ‘C’ command

This command causes a dummy message to be sent just after the next acquisition/control cycle has run. Its purpose is to synchronise the host to the controller activity. The ‘C’ command is the only command which causes two messages to be sent by the controller: the acknowledge and the dummy message. The dummy message, being synchronous with the controller activity, can be sent up to 2 seconds (control period) after the command was received.

Command format:

`<‘C’><checksum>` (no parameters)

Acknowledge format :

<'A'><'a'><checksum>

Dummy message format:

<'A'><'d'><checksum>

5.3.3.4 'H' command

This command sends back the temperatures and the flow rate

Command format:

<'H'><checksum> (no parameters)

Acknowledge format:

<'A'>

<flow rate>	2 bytes	(4 Hex chars) unsigned integer
<Outlet temperature>	2 bytes	(4 Hex chars) normalised temperature
<Inlet temperature>	2 bytes	(4 Hex chars) normalised temperature
<Cabinet temperature>	2 bytes	(4 Hex chars) normalised temperature
<Ambient temperature>	2 bytes	(4 Hex chars) normalised temperature
<checksum>	1 byte	(2 Hex chars)

5.3.3.5 'f' command

This command sends back the scaled flow rate. For compatibility with the old controller it returns the same information three times.

Command format:

<'f'><checksum> (no parameters)

Acknowledge format:

<'A'>

<flow rate>	2 bytes	(4 Hex chars) unsigned integer
<flow rate>	2 bytes	(4 Hex chars) unsigned integer
<flow rate>	2 bytes	(4 Hex chars) unsigned integer
<checksum>	1 byte	(2 Hex chars)

5.3.3.6 'o' command

This command sends back the contents of the status bytes.

Command format:

<'o'><checksum> (no parameters)

Acknowledge format:

<'A'>

<CSTAT1>	1 byte (2 Hex chars)
<CSTAT2>	1 byte (2 Hex chars)

`<dummy>`	1 byte (2 Hex chars), always zero
`<dummy>`	1 byte (2 Hex chars), always zero
`<DEBUGR>`	1 byte (2 Hex chars)
`<checksum>`	1 byte (2 Hex chars)

5.3.3.7 'u' command

This command clears the power-up/reset flag (bit 3, value 0x08 of DEBUGR register). This command should be sent by the host at the beginning of the operations. This allows the host to detect if the controller has been reset. Note that the power-up/reset flag cannot be set directly.

Command format:

`<'u'><checksum>` (no parameters)

Acknowledge format:

`<'A'><checksum>`

5.3.3.8 'V' command

Returns the firmware identification string.

Command format:

`<'V'><checksum>` (no parameters)

Acknowledge format:

`<'A'>`

`<version>`	40 character ASCII string
`<checksum>`	1 byte (2 Hex chars)

6. Installation

Install the temperature controller preferably on top of the cabinet. Keep connections to the sensors should as short as practical (within a few meters).

6.1 Electrical Connections

All electrical connections are on the rear panel by means of connectors, each of which is marked with an explanatory label. Not all the electrical connections are necessary to operate the device: the only essential connections are the four temperature sensors (Ambient, Cabinet, Inlet- and Outlet Coolant), the flow rate sensor, the hydraulic valve and the power supply. All other connections optional.

The following table lists the connectors and the recommended cable.

Connector	Type	Recommended Cable
Mains power socket	IEC 60320 – C14	Mains cable
Ethernet (100BASE-TX)	RJ45 socket	Cat5 Ethernet patch cable
Serial (RS-232)	DSUB-9 male	Shielded twisted pair
Alarm/Warning Relays	DSUB-15 male	-
Door Contact	LEMO EPG.0B.302.HLN	2 wires + shield
Flow Meter	LEMO EPG.0B.303.HLN	3 wires + shield
Hydraulic Valve	LEMO EPG.1B.304.HLN	3 wires + shield
Inlet Temperature	LEMO EPG.0B.304.HLN	3 wires + shield
Outlet Temperature	LEMO EPG.0B.304.HLN	3 wires + shield
Ambient Temperature	LEMO EPG.0B.304.HLN	3 wires + shield
Cabinet Temperature	LEMO EPG.0B.304.HLN	3 wires + shield

Table 4

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6.1.1 Connector Pinouts

6.1.1.1 Serial Interface

Pin	Signal
2	RS232-TXD
3	RS232-RXD
5	GND

Table 5

6.1.1.2 Temperature sensors

Pin	Signal	Notes
1	RTD 1	
2	RTD 2	
3	RTD return	
4	AGND	Leave unconnected on RTD side

Table 6

6.1.1.3 Alarm/Warning relays

<table>
<tr><th>Pin</th><th>Signal</th><th>Notes</th></tr>
<tr><td>1</td><td>Alarm common 1</td><td rowspan="6">Alarm 1-2 are two poles of same DPDT relay</td></tr>
<tr><td>2</td><td>Alarm normally close 1</td></tr>
<tr><td>3</td><td>Alarm normally open 1</td></tr>
<tr><td>4</td><td>Alarm common 2</td></tr>
<tr><td>5</td><td>Alarm normally close 2</td></tr>
<tr><td>6</td><td>Alarm normally open 2</td></tr>
<tr><td>7</td><td>Warning common 1</td><td rowspan="6">Warning 1-2 are two poles of same DPDT relay</td></tr>
<tr><td>8</td><td>Warning normally close 1</td></tr>
<tr><td>9</td><td>Warning normally open 1</td></tr>
<tr><td>10</td><td>Warning common 2</td></tr>
<tr><td>11</td><td>Warning normally close 2</td></tr>
<tr><td>12</td><td>Warning normally open 2</td></tr>
</table>

Table 7

6.1.1.4 Hydraulic valve

Pin	Signal	Notes
1	+24V	RED wire on actuator
2	GND	BLACK wire on actuator
3	Control Signal, 0…10V	GREY wire on actuator
4	Control Signal, 10…0V	GREY wire on actuator, use to invert valve

Table 8

6.1.1.5 Flow meter

Pin	Signal	Notes
1	Negative supply	Optoisolated
2	Sensor output	Optoisolated, Open collector
3	Positive supply	Optoisolated, 5V 100 mA max

Table 9

6.1.1.6 Door switch

Pin	Signal	Notes
1	Switch side 1	Optoisolated, Normally Open
2	Switch side 2	Optoisolated, Short to 1 if unused.

Table 10

6.2 Hydraulic connection diagram

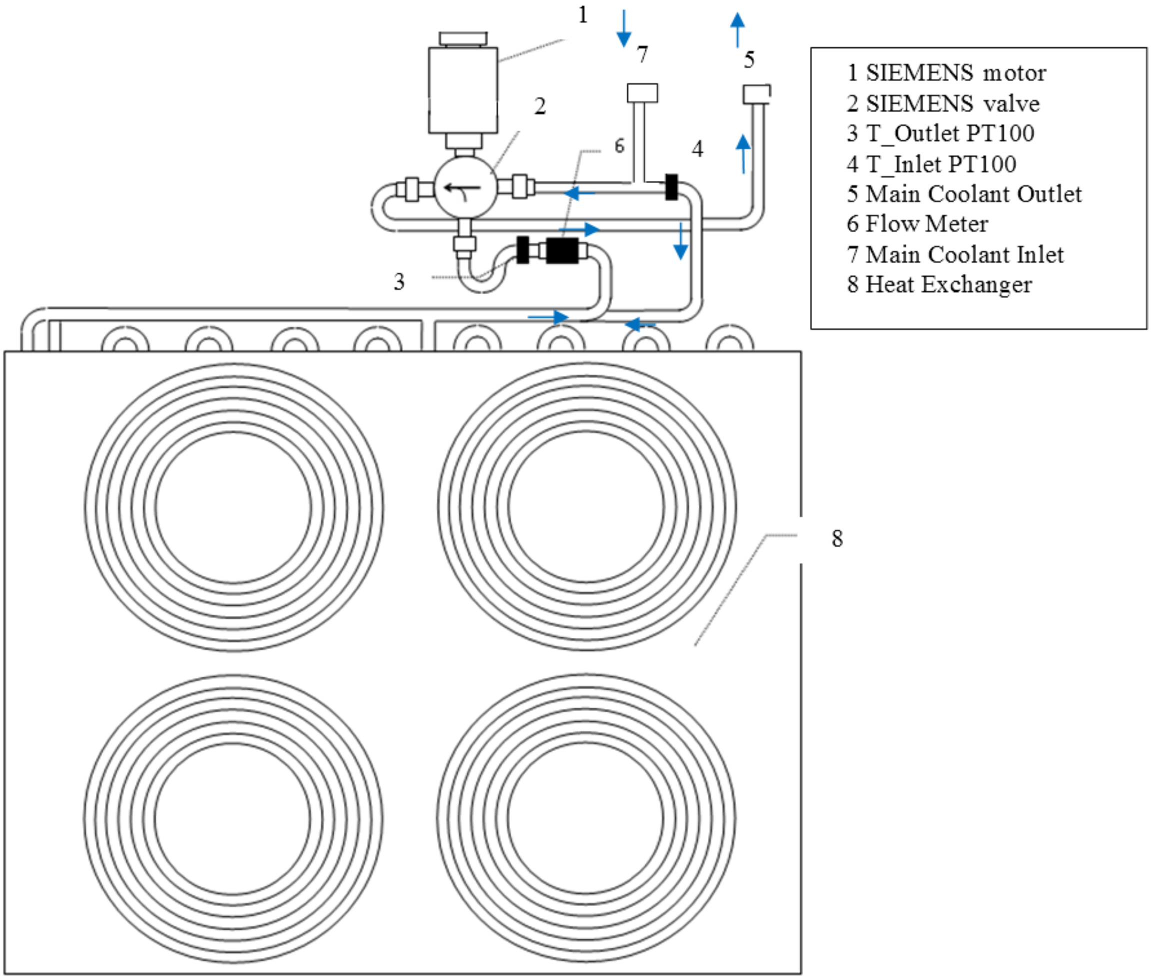

Figure 2

7. Operation

The thermal control unit is supplied ready for installation and operation. Once connected to the sensors and to the valve it starts controlling the cooling flow rate to make the cabinet track the ambient temperature.

7.1 Power on and shutdown

As soon as the unit is connected to mains power, the built-in computer boots the operating system and begins operation. The boot sequence takes approximately 2 seconds. A controlled shutdown can be requested at any time by briefly pressing the power button on the front panel. The unit will then ask confirmation on the LCD and the shutdown will only be carried out if the user confirms by pressing the enter key. The shutdown takes approximately 4 seconds. Alternatively, keeping the power button pressed for more than 5 seconds forces a hard shutdown.

When the unit is shut down but still connected to mains power, a brief press of the power button will restart the operating system and begin operation again.

7.2 Local Interface

A local interface consisting of a liquid crystal display, capable of displaying two lines of 20 alphanumeric characters, and a 4-key keyboard allows interacting with the system.

The display normally shows the current status of the system by automatically cycling through the following three pages of information:

```
Ambient temp:  XX.XX°C
Cabinet temp:  XX.XX°C
```

```
  Inlet temp:  XX.XX°C
 Outlet temp:  XX.XX°C
```

```
 Valve out:  XX.XX%
 Flow rate:  XX.XXlpm
```

The user can manually scroll through the pages at any time by using the arrow up/down keys on the keyboard. Pressing any key on the keyboard activates the display backlight. The backlight turns off automatically after a brief period of inactivity.

Pressing the Enter key activates the user menu interface that allows changing operating parameters. The arrow keys allow scrolling up/down through the menu interface; the Enter key goes down one level (or confirms a change) and the Select key goes back one level (or cancels a change).

Parameter changes are effective immediately after confirming them; after changes are made it is optionally possible to save the current parameters using a menu. Failing this, the previous parameters are restored on reboot. As an exception, changes to network parameters such as the IP address are only effective after a reboot and therefore always need saving.

The menus are according to the following hierarchy, which includes a brief explanation about the function of each item.

- `Parameters` — parameter management
  - `Edit` — edit parameter values
    - `Tcab max` — Max cabinet temperature
    - `Tcab min` — Min cabinet temperature
    - `Tcab-Tamb max` — Max cab-amb temp. difference
    - `Tout-Tinl max` — Max out-inlet temp. difference
    - `Tout-Tinl min` — Min out-inlet temp. difference
    - `Flow sensor K` — Flow sensor [pulses/litre]
    - `Valve min` — Min valve output [%]
    - `Valve max` — Max valve output [%]
    - `Setpoint` — Target Cabinet-Ambient temp [°C]
    - `Deadband` — Regulator deadband [°C]
    - `P gain` — Regulator proportional gain [%/°C]
    - `I gain` — Regulator integral gain [%/(°C s)]
    - `IP Addr X (X=0, 1, 2, 3)` — network IP address
    - `Netmask` — netmask
    - `Gateway X (X=0, 1, 2, 3)` — gateway IP address
  - `Save` — Save parameter values
- `Calibration` — Sensor calibration
  - `Outlet 0°C` — PT100 0°C calibration
  - `Inlet 0°C` — PT100 0°C calibration
  - `Cabinet 0°C` — PT100 0°C calibration
  - `Ambient 0°C` — PT100 0°C calibration
  - `Outlet 80°C` — PT100 80°C calibration
  - `Inlet 80°C` — PT100 80°C calibration
  - `Cabinet 80°C` — PT100 80°C calibration
  - `Ambient 80°C` — PT100 80°C calibration
  - `Save` — Save calibration
- `Valve Override` — Enters manual valve control mode
- `Information` — Displays firmware version on LCD

7.3 Diagnostics

In case of malfunction or fault, the unit sets the nStatus OPC/UA variable to one of the following values (higher codes take priority)

- 0 = no error
- 1 = door open
- 2 = inlet temperature above outlet
- 3 = any temperature inconsistency:
  - Cabinet – Ambient > `Tcab-Tamb max`
  - Cabinet – Inlet > `Tcab-Tinl max`
  - Outlet – Ambient < `Tout-Tinl min`
- 4 = Ambient temperature sensor fault
- 5 = Outlet – Inlet temperature > `Tout-Tinl max`
- 6 = Outlet temperature sensor fault
- 7 = Inlet temperature sensor fault
- 8 = Cabinet temperature too low (< `Tcab min`)
- 9 = Cabinet temperature too high (> `Tcab max`)
- 10 = Cabinet temperature sensor fault

The warning relay is activated whenever nStatus is not zero; the alarm relay is activated if nStatus is greater or equal to 8. In the latter case, the nErrorCode is also set to 1.

Whenever nStatus is not zero, the local display cycles through a fourth page with an appropriate warning or alarm message, for example if the cabinet temperature sensor is faulty:

```
   *** ALARM! ***
 Cabinet RTD faulty
```

7.4 Normal (automatic) operation

In normal operation, the unit regulates the hydraulic valve output through a Proportional + Integral controller to keep the difference between Cabinet and Ambient temperature close to the "`Setpoint`" parameter. Whenever the difference is within +/- "`Deadband`" of "`Setpoint`", the valve output adjustment is frozen. This prevents limiting cycles with small temperature oscillations due to mechanical hysteresis of the valve actuator.

The controller keeps the valve between the "`Valve min`" and "`Valve max`" parameters. The algorithm includes wind-up protection to guarantee stable operation and smooth recovery from saturation of the valve.

7.5 Valve override

The local menu allows activating the valve override mode. In this mode, the automatic controller stops operating the valve and instead the user can manually change the valve output – which is also shown on the display – by using the up/down keys. Exiting the menu with the Select key terminates the override mode and the automatic regulator takes over again.

7.6 Calibration

After assembly, each unit needs calibrating in order to compensate for the systematic errors affecting the measurement chain from the temperature sensor input to the Analog/Digital converter. The calibration parameters are stored in non-volatile memory on the main controller board.

The Calibration menu allows entering calibration mode; every sensor needs two calibrations at 0 and 80 degree Celsius. To perform the calibration, connect a PT100 calibrator to the connector corresponding to the sensor under calibration, input the correct temperature and enter the appropriate Calibration menu option. The unit display will display the current calibrated temperature. When the value settles press the Enter key to update the calibration.

Once all sensors are calibrated, the calibrations must be saved to non-volatile memory by using the Calibration->Save menu.

--- End of document ---