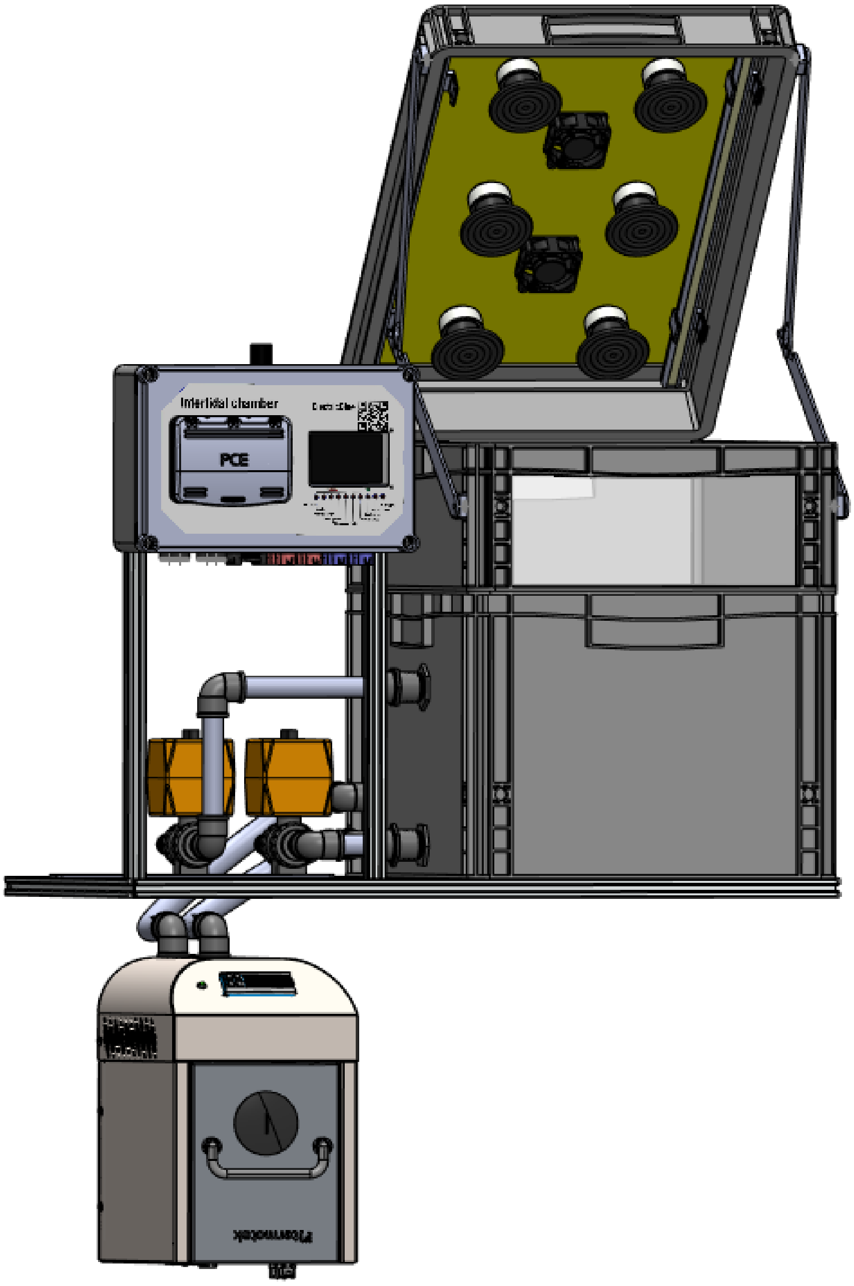
Intertidal Chamber

User's manual, V3.5, updated on 1 October 2024



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AVAILABILITY

This manual refers to supplementary documents, necessary to both use and understanding of the Intertidal chamber operation. These documents are:

- Settings.txt
- Profile_maker.csv
- Chamber_webpage.json
- Chamber_Online_platform_Blynk_setup.mp4
- Chamber_Webpage.mp4
- Blynk_Datastreams.xlsx
- update.bin

1. Overview

The Intertidal Chamber is a self-contained, automatic experimental system that simulates the intertidal environment. Using multiple chambers, researchers can create "virtual common garden experiments" across large geographic spans. The system plugs into a regular mains power outlet and controls other mains power devices (such as pumps and heaters) and 12 V (such as fans, LEDs, and water valves).

This system can be paired with ElectricBlue's autonomous temperature sensors (Envloggers; http://electricblue.eu/envloggers), as it can easily replicate the temperature profiles recorded in the field. It can also be used with our cardiac performance logger (PULSE V2; https://electricblue.eu/pulse), which can monitor the thermal stress of animals inside the experimental unit.

2. Structure & Operation

The Intertidal Chamber can actively control light (visible spectrum), tide level, air and water temperature in the Experiment Tank (**Fig. 1**), as well as water renewal cycles. It can be programmed to undergo months-long experiments with minimal supervision. All data is logged locally in a micro-SD card and online on a remote dashboard. Additionally, experiments can be initiated remotely through an open-source application.

The physical structure of the Intertidal Chamber can be found in **Fig. 1**. It consists of an aluminium profile holding three propylene (PP) tanks, water change valves and a control unit (rated IP65).

The three tanks are: (i) the main Water Storage Tank in the bottom, used for storing water and conditioning its temperature (65 L), (ii) the Experiment Tank (sitting on top of the Water Storage Tank), used to contain organisms and execute the experiment (35 L), and (iii) an upside-down tank, used as a lid structure (15 L).

The lid is connected to the Experiment Tank through a steel hinge that ensures easy access to the experiment and features a steel sheet for additional mechanical and thermal resistance. The lid holds two LED strips that provide visible light, four fans (two for cooling, two for air circulation), and 6 ceramic sockets equipped with Infra-Red (IR) lamps.

Visible light is controlled by adjusting the intensity of the LED strips (defined as percentage of intensity in the experiment profile – 0 to 100%). Low-tide temperature inside the Experiment Tank is controlled through the action of the IR lamps. The LED strips provide light without a significant amount of heat, while the IR lamps emit heat without visible light, effectively decoupling the control of light and temperature profiles. Crucially, for safety reasons, the Intertidal Chamber only allows IR control during low tide (when the Experiment Tank has been fully drained) and with the lid closed. The air-circulating fans inside the lid circulate air inside the Experiment Tank to reduce/eliminate heat spots under the IR lamps and thus contribute to the homogenization of temperature across the Experiment Tank, while the cooling fans pull air out of the Experiment Tank. Note that the cooling fans can only work to cool the Experiment Tank to the same temperature of the room where the Intertidal Chamber is installed. For optimal operation, that room temperature should be lower than the lowest temperature being simulated. All four fans work on 12V and are water and heat resistant (IP69K).

The tide on the Experiment Tank is controlled via a water pump (the Tide Pump) found inside the Water Storage Tank. When the Tide Pump is turned on, water from the Water Storage Tank is pumped into the Experiment Tank. Inside the Experiment Tank, there are two vertical ½'' PVC pipes with a cap filter, limiting the tide height to their length. By default, tide height is set to 11cm, but this can be adjusted up to 14cm by replacing the ½'' pipes with longer ones. These vertical pipes drain the water back to the Water Storage Tank. Since the Tide Pump moves more water than the pipes can drain, when the Tide Pump is working, the water level keeps increasing to the height of the ½'' pipes. While the high tide is maintained by keeping the Tide Pump on, when the Tide Pump is switched off, water gradually drains via the shorter pipe, almost emptying the Experiment Tank (some residual water may remain). The tanks are dimensioned so that even during high tide enough water remains in the Water Storage Tank to keep the Tide Pump always immersed, which is crucial for the functioning of the entire system.

Water temperature is controlled through the combined action of a Water Chiller (Aquamedic Titan 200; 160W) and a Water Heater (Aquamedic Titanium; 500W), while the water homogenization is achieved via another water pump – Chiller Pump. The Water Heater is submerged in the Water Storage Tank (should only be powered when submerged), Water Chiller is a separate device, usually installed next to or beneath the tanks (the arrangement can be modified to optimize space usage in the lab). Water temperature conditioning is achieved by continuously pumping the water (using the Chiller Pump) in the Water Storage Tank through the Water Chiller, which then flows back to the Water Storage Tank. This arrangement ensures that the water inside the Water Storage Tank is continuously circulated and exposed to the temperature-conditioning effect of the cooling and heating elements (preventing thermal stratification).

The water inside the Water Storage Tank can be renewed easily and with minimal user intervention. There are two 12V ¾'' PVC water valves (In Valve and Out Valve) fixed to the outside of the Water Storage Tank. The Out Valve is connected to the bottom of the Water Storage Tank and to its top overflow escape (Safeguard Outlet), which when engaged, removes water from the system. Conversely, the In Valve is connected to the top of the Water Storage Tank and, when engaged, allows new water to enter the system. Alternatively, this valve can be replaced by a water pump (Inlet Pump), allowing a pumped source of water, instead of a pressurized inlet controlled via the In Valve. When the water inlet option is pressurized access, take note that the In Valve can only handle a maximum pressure of 16 Bar. Whereas the water access is via Inlet Pump, this should be submerged in an intermediate tank (not part of the Intertidal Chamber), where new water is stored. Both water valves and Inlet Pump can be operated automatically as part of the experimental profile being run. Additionally, the water valves can be operated manually (even without electricity). For manual operation, the valves must be disconnected from the Control Unit, and a small button beneath the valve must be pressed before turning the black handle (90º counterclockwise to open the valve). The valve will be open when the handle is aligned with the hose, whereas if the handle is perpendicular, it means the valve is closed.

The intake of the Out Valve in the Water Storage Tank is purposedly situated a few cm above the bottom of the tank. As a result, the Water Storage Tank can only be fully emptied by manually removing the water. This safety margin is kept ensuring the water pumps and heater inside the Water Storage Tank are never allowed to operate dry. In this configuration, the Water Storage Tank can only become empty with direct and deliberate human intervention (usually for cleaning up and maintenance). The Intertidal Chamber is also protected from accidental overflow, which could cause catastrophic flooding of the room where it is installed. Overflow is prevented through the presence of a Safeguard Outlet located near the top of the Water Storage Tank. The Safeguard Outlet does not feature any valve and cannot be close. It is advisable to regularly check the Safety Outlet for objects that may clog it, ensuring it is free to discharge to an appropriate reservoir.

The Intertidal Chamber features an array of temperature and water level sensors. Temperature is monitored by 6 sensors, while water presence is monitored by 8 sensors.

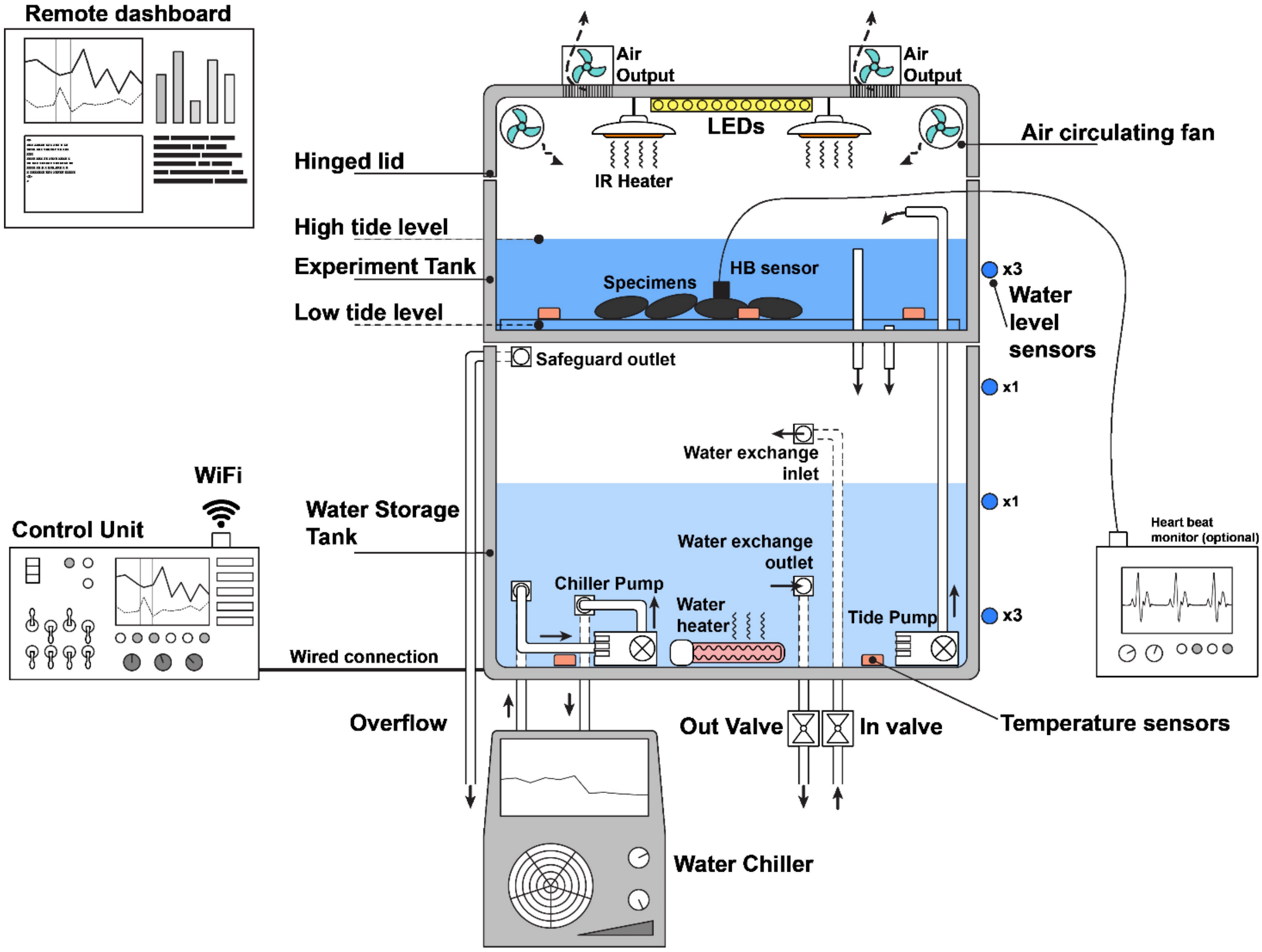

Fig. 1: Layout of the Intertidal Chamber. Experiment Tank on the top, and *Water Storage Tank* on the bottom.

3. System description

3.1. Sensors

3.1.1. Temperature.

Temperature is monitored inside of the Experiment Tank, inside of the Water Storage Tank, and on the outside of the tanks (**Fig.2**). The sensors inside of the Experiment Tank (T1-T3) are used to provide feedback to the Control Unit hence monitoring the effective experimental conditions (which, in some extreme circumstances, may differ from the thermal profile provided – i.e., the target conditions). These sensors are not attached to any part of the Experiment Tank and can/should be placed around the experiment and distributed as evenly as possible inside the tank, as this influences the quality of the temperature readings used as input by the Control Unit. The sensors in the Water Storage Tank (T4-5) are used to monitor water temperature. Both sets of sensors are critical for the operation of the Intertidal Chamber, hence the presence of redundant elements. When all sensors are operational, the Intertidal Chamber uses as input the average of all temperature readings from each of the tanks. In case a sensor malfunctions, averages will be made with the still operational sensors. If all sensors in a tank are malfunctioning, the Intertidal Chamber loses the ability to control the temperature within that tank. The outside sensor (T6) is not used by the Control Unit for any operation and is provided only so that users can check that the room temperature is within an optimal range for the operation of the Intertidal Chamber. All temperature sensors can be disconnected from the Control Unit anytime and individually replaced by new ones. Once a new sensor is plugged in, it is automatically recognized by the Control Unit, and the readings are displayed on the LCD. The temperature sensors are waterproof and operate at 0.1 °C resolution.

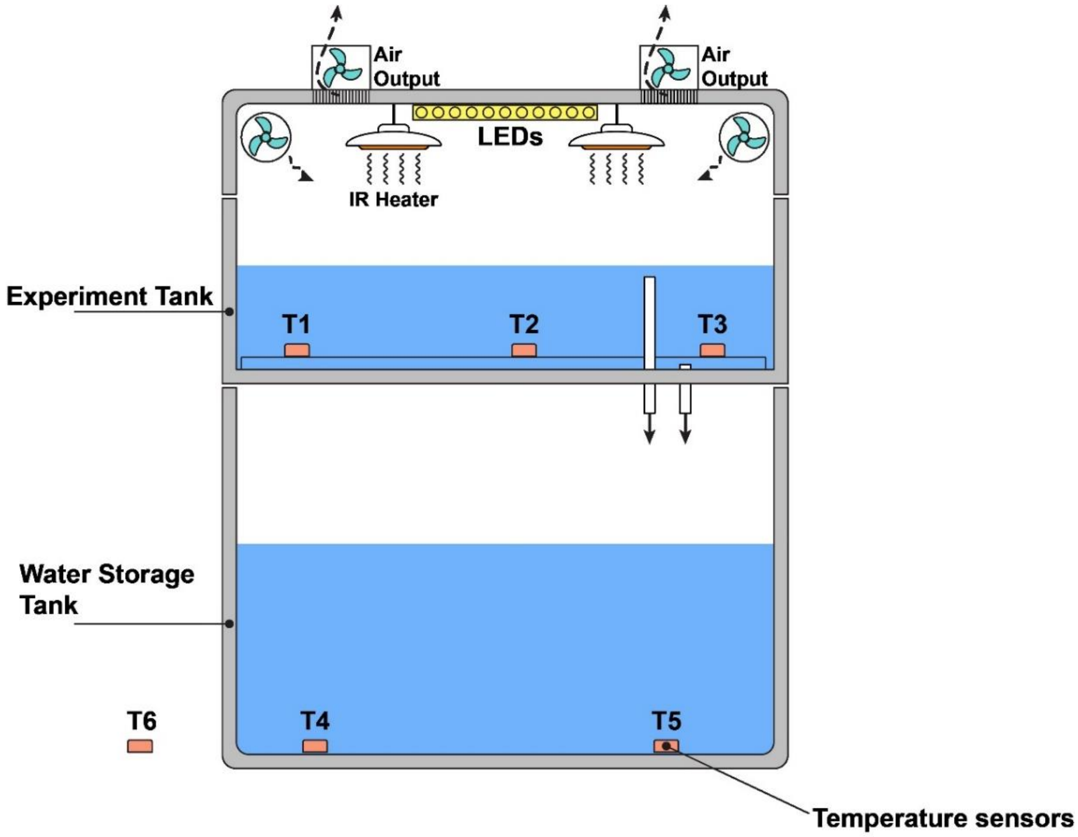

Fig. 2: Layout of the Intertidal Chamber with focus on temperature sensors, here represented as orange rectangles, numbered (T1 to T6).

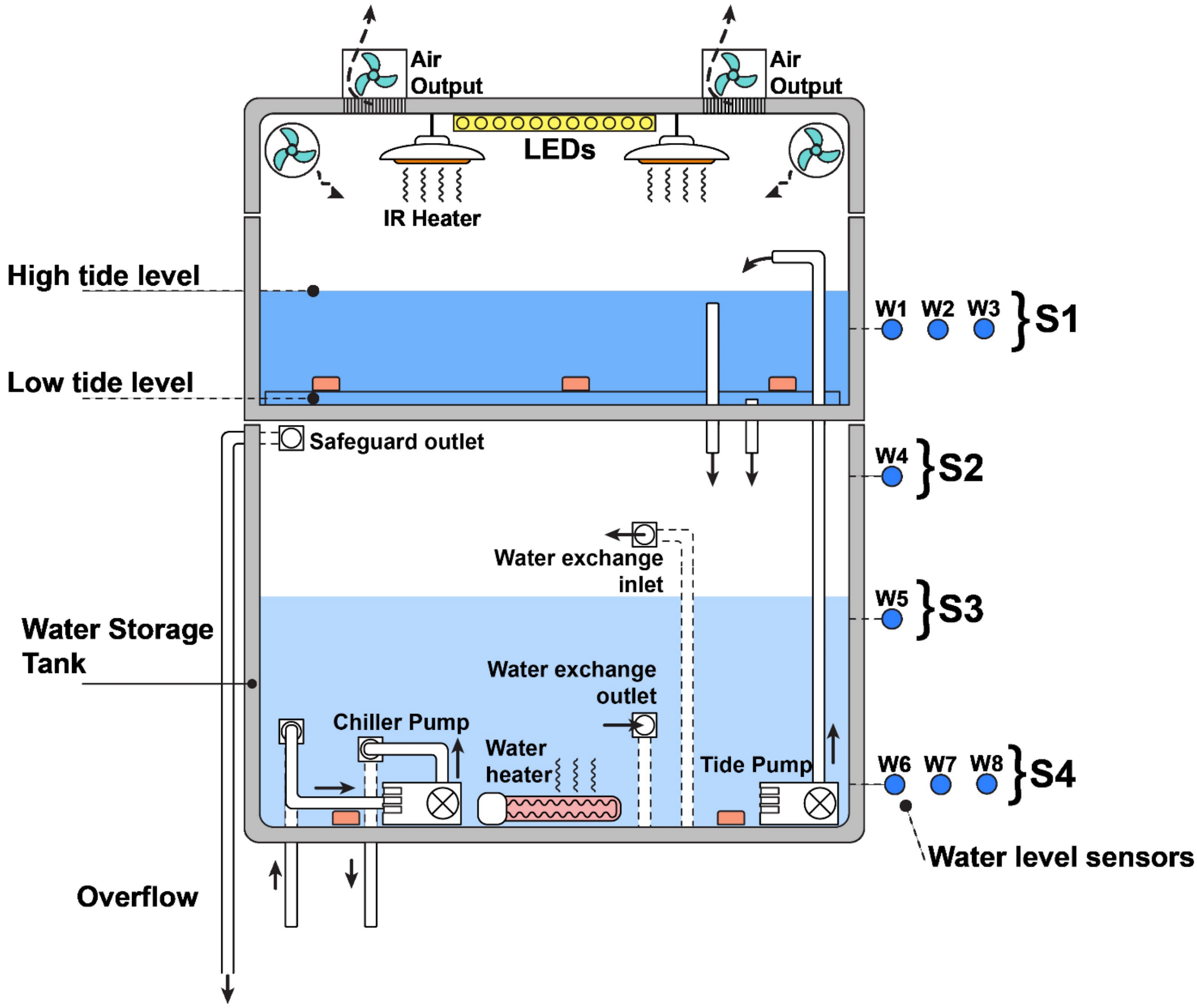

Fig. 3: Layout of the Intertidal Chamber with focus on the water level sensors, here represented as blue circle, numbered (W1 to W8).

3.1.2. Water level

Water level sensors are used to continuously monitor the content of water in the tanks of the Intertidal Chamber (**Fig. 3**). The Control Unit receives the readings of these sensors and determines if it's safe to control temperatures (air or water), tides or water renewal cycles. Sensors are placed in the outer walls of the Experiment Tank (W1-3) and the Water Storage Tank (W4, W5 and W6-8). The Intertidal Chamber features triplicate sensors in critical checkpoints where failure could lead to potentially dangerous situations. The sensors measuring the Experiment Tank (W1-3) are all installed at the same height, close to the low tide level. These sensors are critical to the operation of the Intertidal Chamber because they not only inform the user that the tide regime is being controlled as intended, but also because they are a safeguard to ensure that the IR Lamps do not operate while there's still water inside of the Experiment tank, a situation that could lead to various issues, including their continuous operation and potential overheat of the structure. Additionally, these sensors influence the volume of water exchange in water renewals, as the Experiment Tank water content has to be considered when filling the Water Storage Tank, ensuring this would still have capacity for the Experiment Tank water in case of a low tide occur (as low tide leads to a transfer of water from the Experiment Tank to the Water Storage Tank). Regarding the sensors on the Water storage tank outer wall, one sensor (WS1) is levelled close to the safeguard three are placed just below the level of the Water Exchange

Outlet (W6-8), one is placed just below the level of the Safeguard Outlet (W4), ensuring the maximum water capacity of the Water Storage Tank is not surpassed during the water renewal cycle. At the centre there's another water sensor (W5), which goal is to limit the water intake on the Storage Tank during the water renewal cycle in case water is being detected on the Experiment Tank. This is because the sum of water of the Experiment Tank and the Water Storage tank up to W5, equals the Water Storage Tank volume up to W4. Hence, water renewal cycles will fill the Water Storage Tank up to W4 or W5, depending on the detection of water on the Experiment Tank (W1 to W3). The lower sensors (W6-8) are set to detect the minimum amount of water to keep water pumps, water heater and water chiller working. If these do not detect water, these will be turned off, ensuring nothing workings dry. To simplify the four water levels that are monitored, these are divided in Water sections, where W1 to W3 composed the section 1 (S1), the W4 equal to the S2, W5 to S3 and W6 to S8 to S4. Although S2 and S3 are a direct interpretation of the W4 and W5 states, respectively, the S1 and S4 states are the result of the majority consensus of their sensors.

3.1.3. Water level sensor operation

As explained above, the Intertidal Chamber includes a total of 8 water level sensors (**Fig. 3**). Two of the sensors act individually (W4, W5), while six others are grouped in triplicates at two locations: below the high tide level in the Experiment Tank (W1-3), and just above the Tide and Chiller Pumps in the Water Storage Tank (W6-8). This is because even though these water level sensors are reliable, correctly assessing the presence of water at these two locations has major safety implications. This means that the Control Unit receives multiple readings from each of these two groups of water level sensors, and thus a decision algorithm is required to interpret the water level state. The decision algorithm works as follows: if all three sensors agree If there's water or not, then that's the information the Control Unit will use; whereas if one sensor has the opposite state of the other two, or if is disconnected or malfunctioning, the Control unit will consider the state given by the two agreeing sensors; if two or all sensors are disconnected or malfunctioning, a water level state cannot be provided and a 'Halt!" warning is shown to indicate general malfunction.

The action implications of the final interpreted state for each of the water level detection points is as follows:

Experiment Tank (Water Section 1):

- Water detected:
  - IR lamps cannot be switched ON.
  - Water renewal cycles can only fill the Water Storage Tank up to the level of sensor W5 (because filling the Water Storage Tank beyond this point could lead to an overflow once the tide reverted to Low Tide and the water in the Experiment Tank is drained back to the Water Storage Tank).
- Water not detected:
  - IR lamps can be turned ON.
  - Water renewal cycles can proceed according to schedule and fill all the way to sensor W4.
- Malfunctioning:
  - IR lamps cannot be switched ON.
  - Water renewal cycles are halted.

Water Storage Tank (Water Section 2):

- Water detected:
  - Any ongoing water renewal cycle is finalized.
- Water not detected:

- Any ongoing water renewal cycle keeps going (unless water has been detected in the Experiment Tank by sensors W1-3)

- Malfunctioning or Water detected in W4 but not W5:
  - Water renewal cycles are halted.

Water Storage Tank (Water Section 3):

- Water detected:
  - Any ongoing water renewal cycle is finalized (but only if water is also detected in the Experiment Tank by sensors W1-3).
- Water not detected:
  - Any ongoing water renewal cycle keeps going.
- Malfunctioning or Water not detected in W5 but detected in W4:
  - Water renewal cycles are halted.

Water Storage Tank (Water Section 4):

- Water detected:
  - Water pumps, heater and chiller work normally.
- Water not detected or Malfunctioning:
  - Anomalous situation detected.
  - Tide Pump is switched OFF.
  - Cooler Pump is switched OFF.
  - Water Heater and Water Chiller are switched OFF.
  - Water renewal cycles are halted.

3.2. Water renewal

Water changes can be a source of problems. Removal of water creates a risk of emersion of the Water Pump and Water Heater, and the introduction of water creates an overflow concern. Water changes can be programmed in the experiment profile or manually initiated using the Control Unit switches.

In the Intertidal chamber, two water valves located beside the tanks regulate water changes. Both valves are connected to the Water Storage Tank, with the Outlet valve connecting PVC tube positioned above the required level to ensure the Water Pump and Water Heater remain immersed. The Inlet Valve connection is connected to the upper section of the Water Storage Tank. Both valves are powered at 12V and default to a closed position when powered but not signalled to open. A signal from the Intertidal Chamber can prompt them to open, but they will automatically close once the signal is removed. In case of a power failure, these valves can be manually operated after first disconnecting them from the Chamber to avoid damage to the valve's electric circuit or Control Unit. To manually operate them, press the switch beneath the valve and rotate the black lever on top.

Automatic water changes undergo a series of safety tests. They will not initiate if another water change is already in progress or if any of the water level sensors report errors.

When an automatic water change initiates, it can be cancelled by manually switching off the process in the console board, or via water level sensors. These can cancel an ongoing water change by two ways: (i) if any water level section malfunctions or (ii) if the sequential water detection fails (see previous section).

If not cancelled, water change will go as follows:

1) Outlet valve is flagged to open, allowing water to exit through it.
2) The Outlet valve will be opened until the S4 stops detecting water or the opening duration reaches the seconds indicated on the Water release variable (see **7. Settings**).
3) Immediately after, the Inlet valve will open, allowing water to be let in the Water Storage Tank.
4) The Outlet valve will be opened until the one of three conditions is met: (i) Water is detected by S4, S3 and S2; (ii) Water is detected in S4, S3 and S1 or (ii) The filling duration has reached the seconds indicated on the variable Water_fill variable (see **7. Settings**).

If the water change is cancelled, the Intertidal Chamber will enter the Halt state, exhibiting a “Halt!” red warning in the LCD (see display), inhibiting any water changes and water temperature control. This warning can be surpassed by placing the water change switch on the Control Unit in OFF mode or turning the main Override Switch OFF for a few seconds (**Fig. 2**). In these cases, the experiment will resume with the water left in the system. If the cancellation reason is resolved (for example, by replacing malfunctioning water level sensors), and the user intends to perform a complete water change, this can be done by switching ON the manual Water Change switch on the Control panel (**Fig. 4**).

3.3. Control unit

The Control unit console allows the user to obtain information on the Intertidal Chamber, as well as manually override automatic controls and act on safety features. Within this console there are 4 sections: (i) Control Board, (ii) Status LEDs, (iii) Display, and (iv) connectors (**Fig. 6**).

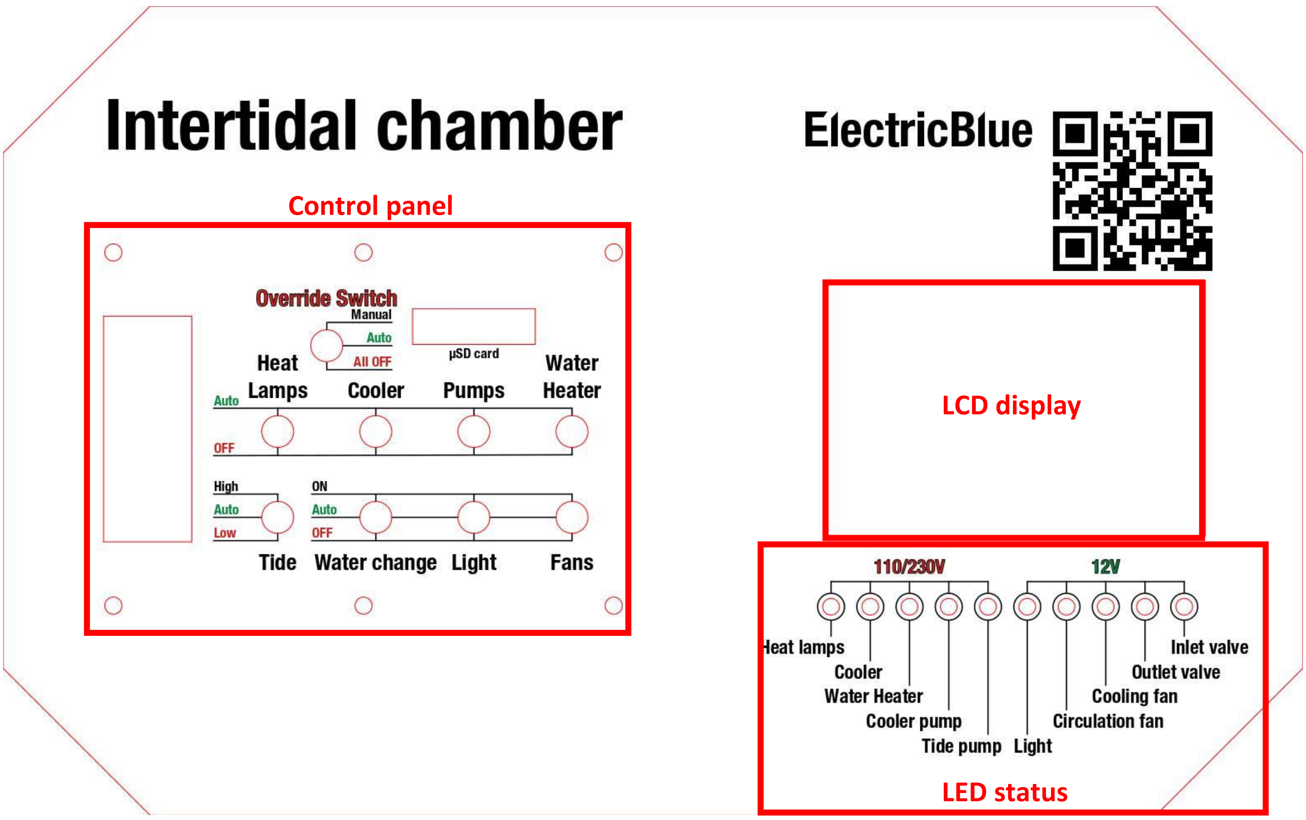

Fig. 4: Layout Control unit, encompassing Control panel, LCD display and LED status areas.

3.3.1. Control panel

The Control unit is splash proof (IP54) and encompasses a Control panel, LCD display and a LED status area (**Fig.** 4). The Control panel section is covered by a transparent lid, covering a circuit breaker that protects and allow the user to cut power to the entire system, there's a micro-SD card socket where the settings and recorded data are stored, and 9 toggle switches that allow manual control over some of the Intertidal Chamber features.

The operation of these switches depends on the state of the **Override Switch**. If this switch is on Auto mode or All OFF, all the remaining switches will be ignored. The distinction between these two states is that in Auto mode, the features controlled by the switches will continue to be automatically controlled by the Control Unit. Whereas in All OFF mode, all features will be off, regardless of everything else. This mode is mainly used for safety purposes. Lastly, if the **Override Switch** is on Manual mode, the status of the 8 switches below will be followed. Their state ("Auto", "ON", "OFF", or "High", "Auto", "Low" in the case of the tide switch) will affect the operation of the correspondent device. For example, if the **Override Switch** is on Manual mode and the Light switch is in ON, this means the LED bars will be turned on, regardless of what's expected in the ongoing experiment. If the Light switch is in OFF, the opposite will happen. Meanwhile, all the switches on Auto mode will keep being activated automatically. This feature is particularly beneficial for users who need to safely make repairs or replace specific devices. For example, if there's a problem with an IR lamp and a replacement is required, this could be done without stopping the ongoing experiment, following these steps: (i) the user sets the **Override Switch** in Manual mode; (ii) then sets the Heat lamps switch on OFF mode, meaning these won't be turning on; (ii) the user replaces the malfunction lamp, and then (iii) sets the Heat lamps switch and the **Override Switch** back on Auto mode.

For safety reasons, some devices do not allow a Manual state ON (Heat lamps, Water cooler, Pumps and Water Heater). It is easy to understand that a forcedly turned-on heat lamp or water heater could have catastrophic consequences. Therefore, such devices can only be either in Auto mode or in OFF mode.

Some manual override switches, such as the Tide switch or the Water Change can have protective functions. This will be later explored in section **3.1.3**. **Water level operation**.

3.3.2. Status LEDs

The intertidal Chamber controls 10 different outputs (five mains power and five 12V outputs). Depending on the system, the mains power could be 110V or 230V. The LEDs present in this section are meant to clarify the state of each device via hardware, meaning that if the device is turned on, the corresponding LED should be on. The mains power devices have red LEDs and the 12V have yellow LEDs, and the labels identify the device. In case a LED is ON but the device is not powered, the most likely explanation is that the protective fuse has blown out and requires replacement. Before turning the device back on, however, ensure it is in proper condition, as a blown fuse may indicate a damaged (and potentially dangerous) component (See **8. Electrical protection**).

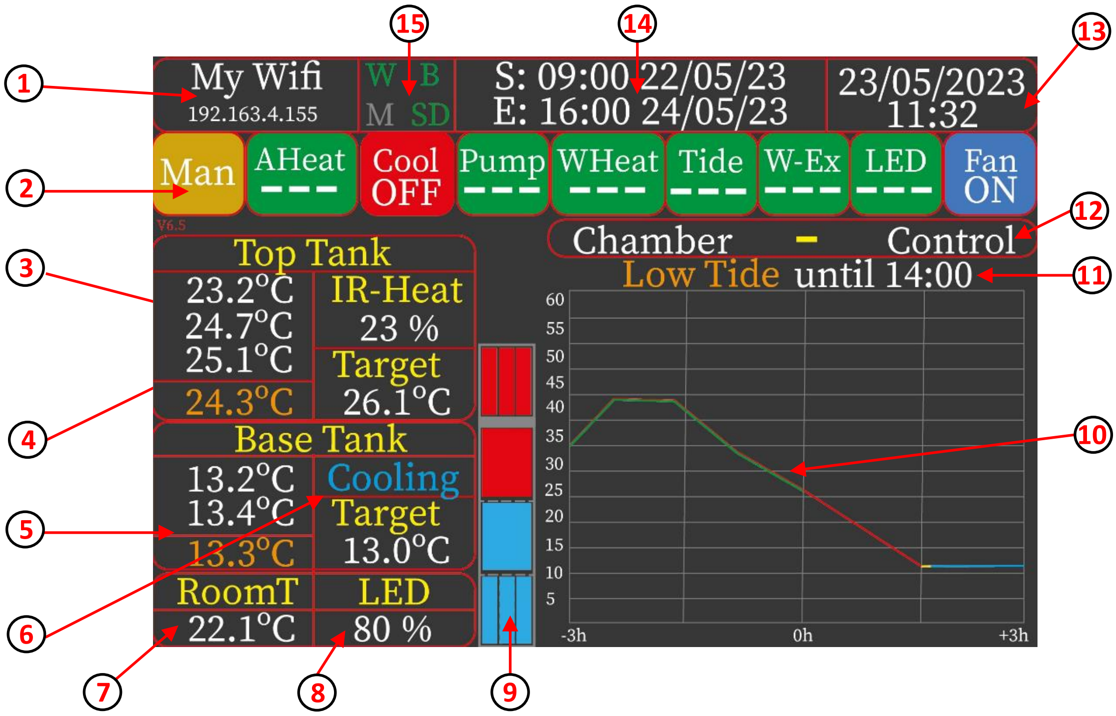

Fig. 5: LCD display sections detailed.

3.3.3. LCD display

The LCD display informs the user about the Intertidal Chamber operation. Here the user can see the state of 15 characteristics about the Intertidal chamber current operation.

The displayed options for each field are as follows:

1) **Wi-Fi connection and IP address:**
The Intertidal Chamber will attempt to connect to the given Wi-Fi credentials (**5. Remote access** and **7. Settings** sections). Until it does, only three dashes will be displayed. If the connection is successful, this section will display the Wi-Fi name and given IP address (relevant for FTP communication). If unsuccessful, it will create its own Wi-Fi network named after the Device name given (see **7. Settings** section) with a fixed IP address (10.10.10.10).

2) **Switch states:**
This section represents the interpretation of the switches (not the state of the devices themselves). If the override switch is set on Auto or All OFF, it will override the state of the remaining switches, setting their functionality to Auto or OFF, accordingly. If in Auto mode, the background will be green, and the switches' states will be ignored (displayed with three dashes"---"). If in All OFF mode, the background will be red, and the switches state ignored as well (displayed with three dashes"---"). The eight controlling switches will only work in Manual mode, which is indicated by the "Man" label with a yellow background. When turned on, the switches will display "ON" with a blue background, and when turned off, they will display "OFF" with a red background.

3) **Experiment tank target temperature and Heat lamps intensity:**
Here the user can see the targeted temperature for the Experiment tank, regardless of which tide is happening. If there's no experiment ongoing, this target will be nulled and a "----ºC" text will show. The percentage value represents the intensity of the IR lamps of each 10 seconds (i.e., 50% means it will be turned on 5 seconds of every 10). Additionally, when the heat lamps are about to start heating after a low tide has just started, a delayed period will appear as a count down before ("0% - 100s"), meaning the intensity is still at 0% (powered off) and will take 100 seconds until it starts heating.

4) **Experiment Tank feedback temperatures:**
There are three temperature sensors on the Experiment tank that work as triplicates (T1, T2 and T3), their values are in white and their average in orange letters. If these are not functional or undetected, the text depicting the sensors' temperature will be replaced four red dashes (----ºC). Average temperature will be made only with working sensors. Malfunctioning sensor can be replaced by operational one at any time.

5) **Water storage Tank feedback temperatures:**
There are two temperature sensors on the Water storage tank that work as duplicates (T5 and T6), their values are in white and their average in orange letters. If these are not functional or undetected, the text depicting the sensors' temperature will be replaced four red dashes (----ºC). Average temperature will be made only with working sensors. Malfunctioning sensor can be replaced by operational one at any time.

6) **Water storage tank target temperature and water state:**
Here the user can see the targeted temperature for the Water storage tank, regardless of which tide is happening. If there's no experiment ongoing, this target will be nulled and a "----ºC" text will show. The water state label can be either 'Cooling', 'Heating', 'Idle' or 'Halt!'. Cooling and Heating means precisely that, the water is being cooled by activation of the water cooler or is heating via water heater. When temperature does not require either temperature changes, it will show and 'Idle' label. However, if water level sensors exhibited any alarming condition (see XX section) an 'Halt!' is shown. This warning can be surpassed by placing the water change switch on the Control Unit in OFF mode or turning the main Override Switch OFF for a few seconds.

7) **Room temperature:**
There is a temperature sensor (T6) that's stays outside the Intertidal chamber, allowing the user to perceive the temperature surrounding the Intertidal chamber. Currently this value is not used in the Intertidal chamber behaviour but could become useful to adjust heating performances in odd room temperatures.

8) **LED intensity:**
The intertidal chamber LED light can be adjusted by intensity (0 to 100%) via experiment profile, the current value will be shown here. The lights can be turned On or OFF manually as well, being ON a 100% intensity and OFF 0%.

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9) Water level sensors:

There are a total of eight water level sensors, three (WS1 to WS3) on the Experiment tank and five (WS4 to WS8) on the Water storage tank. The sensors state is represented by a rectangle. The rectangle's colour can be red for sensor undetected, blue for sensor operational and sensing water, and black for sensor operational and not sensing water. To better understand the role of the water sensors, please read the section **3.1.3. Water level operation**.

10) Experiment tank historic and projected temperatures:

In this graphic area the Experiment tank temperatures for the previous and following three hours are plotted every 90 seconds. The green line represents the average temperature observed in the last three hours, while the red, blue, or yellow line represents the projected temperature and state. If the line is red, it means it's a low tide moment with the represented temperature, whereas if it's blue it's a high tide. The yellow line represents a water exchange instant. For example, in the given example (**Fig. 5**) there will be a water exchange programmed at 14PM immediately before a change from low to high tide.

11) Experiment state:

In this field the user can see if an experiment is ongoing, and in which state it is. There can be 4 states to this message. The first state takes priority over the other, give its alarming feature. If there is no alarming warning to show, the chamber can be any state of the remaining 3 options. The alarming warnings can be:

- If the remote KILL is active, the text "KILL is active" is displayed (see section **5.2. Online cloud (Blynk)).**
- If the SD was not detected on start-up, the text "No SD card detected!" is displayed.
- If the SD card does not have an experiment profile, the text "No experiment" is displayed.

Finally, if all the above conditions failed, and a profile is detected on the SD card, one of the self-explanatory following states will show:

- "Waiting to start"
- "High tide until 18:00"
- "Low tide until 12:00"
- "Experiment finished"

If the user decides to have a manual tide trough the control console switches, the tide information will change to:

- "High tide Manual"
- "Low tide Manual"

On the other hand, if the current tide (automatic or manual) fails to pass the sensors test, the text will change to:

- "High tide halted!"
- "Low tide halted!""

12) Intertidal chamber name and treatment:

Each Intertidal chamber has a name and treatment that are shown in this field. This is important for differentiating each unit, especially if these need to be accessed remotely. Each unit needs to have a treatment attributed to it (i.e., Control, Treatment A, etc). This plays an important role when the user wants to send a experiment profile remotely, as he must decide which treatments will receive that profile (see section **5.3. Node-RED - MQTT**). Additionally, when the Intertidal chamber creates its own Wi-Fi network, it will be named after the units name (see **5. Remote access** section).

13) Intertidal chamber name and treatment:

The current date and time are provided by an internal clock, which keeps running even if there is a power outage. This information will initially be presented in white text, but Wi-Fi connection is working, the internal clock will be synced to international servers and the current date and time will automatically turn green.

14) Current experiment start and end time:

If the micro-SD card contains an experiment profile, its date and time to begin (after letter ‘S’) and end (after letter “E”) will be shown in this field. Otherwise, this info will be filled with dashes (‘S:--:-- --/--/--' and ‘E:--:-- --/--/--').

15) Wi-Fi, Online platform and SD card connection:

In this section the user can see if the Intertidal chamber was successful in connecting to the given Wi-Fi credentials (green “W”) or not (grey “W”). In case the Intertidal chamber is attempting to create its own network, the same will happen but with a letter “A”.

The letter “B” indicates the state of the connection to the online platform (Blynk), this is used to display data remotely, and where users can also turn everything off (via Kill switch). Again, this will be grey until the connection is made, and then turn green if successful (see **5. Remote access** section).

The letter “M” indicates the state of the connection to the MQTT server, a server that establishes the link between the Intertidal Chamber and the Node-red dashboard, where users can upload new experimental profiles to the Intertidal Chamber, remotely.

Finally, “SD” initials depict the status of the connection with the micro-SD card. Again, grey until successful, then green. If the SD card is removed, “SD” will turn grey again until it is re-inserted.

3.4. Connectors panel

All sensors and devices are connected beneath the Control unit (Fig. 6). These are labelled and have distinct connectors to avoid misconnections. The temperature sensors (T1 to T6) and respective panel connectors are red, while the water level sensors are in blue (WS1 to WS8). All the power outlets are in black, but the mains power and 12V connectors cannot be interchanged. Moreover, the mains power connector for the higher power device (heat lamps, water heater and cooler) has larger footprints when compared to the lower power devices (water pumps). Finally, the mains power input has the fitting gender opposite to the power outputs, averting misconnection between mains voltage input and outputs.

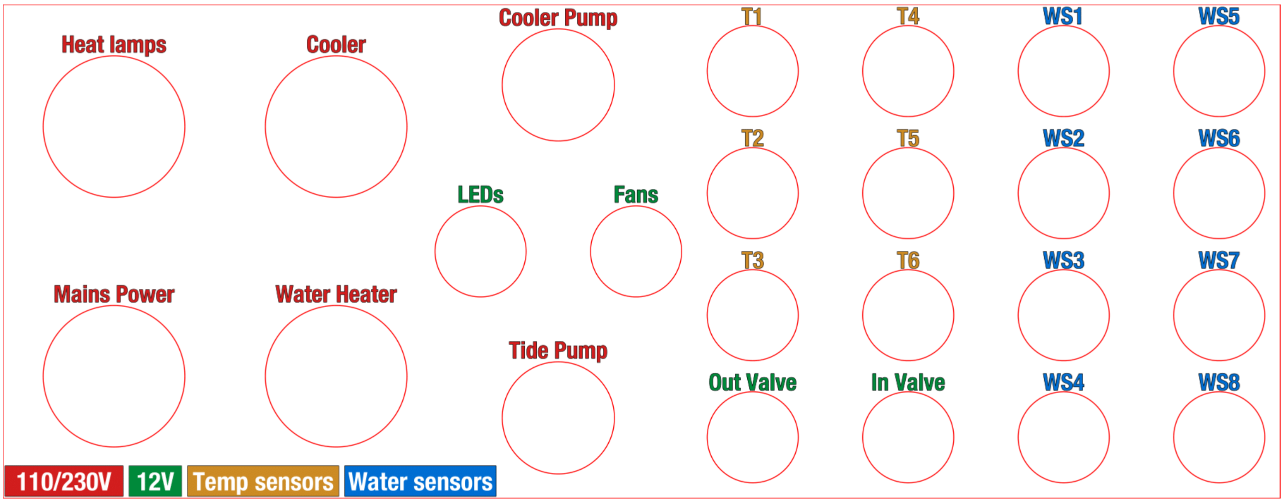

Fig. 6: Connectors panel illustration. Positioned underneath the Control unit.

4. Experiment Profile

To conduct an experiment the SD card must have an experiment profile in the form of a text file, named **Profile.txt**. When the Intertidal Chaber is powered, it will read the Profile.txt present once and determine the start and end of that profile, as well as the current state ("Waiting to start.", "Experiment Finished.", etc). If no experiment profile is found in the micro-SD card, the state displayed on the LCD will be "No experiment". If this case, temperature control will be completely unable, but certain functionalities are still possible through the manual switches in the control board, namely the tide, light, fan, and water changes.

To change the **Profile.txt** in the micro-SD card the user could 1) physical pick the card from the Control unit and edit its content on a computer; 2) use an FTP connection (see **5.1. FTP connection** section) or 3) send the profile remotely trough the Node-RED application (see **5.3.3. Node-RED Operation** section).

The profile text file structure is composed by multiple lines with 18 characters each. These correspond to the setpoints required for the experiment. Each line has a timestamp and a value for each controlled variable, separated by a dash, as follows:

<u>167257440-25010500</u>

Deconstructing this setpoint we have:

- The timestamp in Unix epoch format **167257440** represents the instant **01/01/2023 12:00:00** in a single number.

After the dash we have 4 variables:

- The target temperature we want **250** which mean 25.0 ºC, here we can see that the target temperature is in Celsius and can have 1 decimal point. If the target were 26.7ºC for instance, the variable would be **267** in the setpoint.
- After the temperature setpoint, there's the binary state for tide, seen here as **1**, meaning this moment will be a high tide, if it were a low tide, it would need a **0** here, and no other value is possible in this variable.
- Next, it's the LED intensity in percentage **050**, meaning 50% intensity on the LED bars, this number can go from 0% (**000**) to 100% (**100**), and always needs to have 3 digits, without commas.
- The last number represents a binary state for water change, here we have **0**, meaning the user does not want a water change at this moment, the other option would be a **1**, meaning the user wants a water change at this moment.

To have an experiment ongoing a sequence of setpoints is needed. At every moment an experiment is ongoing, the Intertidal chamber is always finding its position between the two setpoints which timestamp are before and after the current time on the internal clock (the displayed time in the LCD screen). An excel template file is provided to simplify the construction of an experiment profile, but it's important to understand the structure of the setpoints that fulfil the profile.

For clarification, let's suppose a **Profile.txt** with the following content:

```
1672574400-20000800
1672581600-20001000
1672588800-25011000
1672596000-25010600
1672599600-20010400
1672603200-20010300
1672606800-15010100
1672610400-15010001
1672614000-15010000
```

Analysing the first line of the profile (**1672574400-20000800**) as before, it can be perceived that this experiment will start at 01/01/2023 12:00:00, with a low tide, light at 80% intensity and water change inactive. Similarly, we can analyse on the last line (**1672614000-15010000**), that this experiment will end 01/01/2023 23:00:00, on a high tide, light intensity at 0% and water change inactive as well.

Variables like light and tide take effect only after their corresponding setpoint, i.e., the light intensity will be at 80% between the first and the second line timestamp is reached (1672581600-2000**100**0), but after that it will be at 100% because the second line says so. This will only change if one the next setpoints changes this or the experiment ends (not considering possible manual overrides). Similarly, the tide will remain low until the timestamp of the third line is reached (1672588800-25011000) because only here does the binary digit for tide changes to **1**.

The water change variable is similar in the sense that it only occurs when the corresponding setpoint is reached, but its duration is dependent of the time taken for the water to be released and recovered, not necessarily lasting until the next setpoint. The timings for the water change however are manly set by the water level sensors (see **3.2. Water change**).

Lastly, the targeted temperature, this variable is perceived as the value the Intertidal Chamber will attempt to reach at the corresponding timestamp, creating a linear regression between the previous setpoint and the next. For example, between the second and the third line of this profile, target temperature changes from 20.0 ºC to 25.0 ºC and the timestamp difference is 2 hours. Between these two points the target temperature will follow the linear regression, i.e., the target temperature at 1 hour after the second timestamp will be 22.5 ºC, and at 1h:30 minutes after will be 23.75 ºC, and so on, culminating on the target temperature of 25.0 ºC at the third setpoint timelapse.

For clarification, and assuming the internal clock on the Intertidal Chamber at 01/01/2023 15:00:00, the chart for the predicted experiment would be:

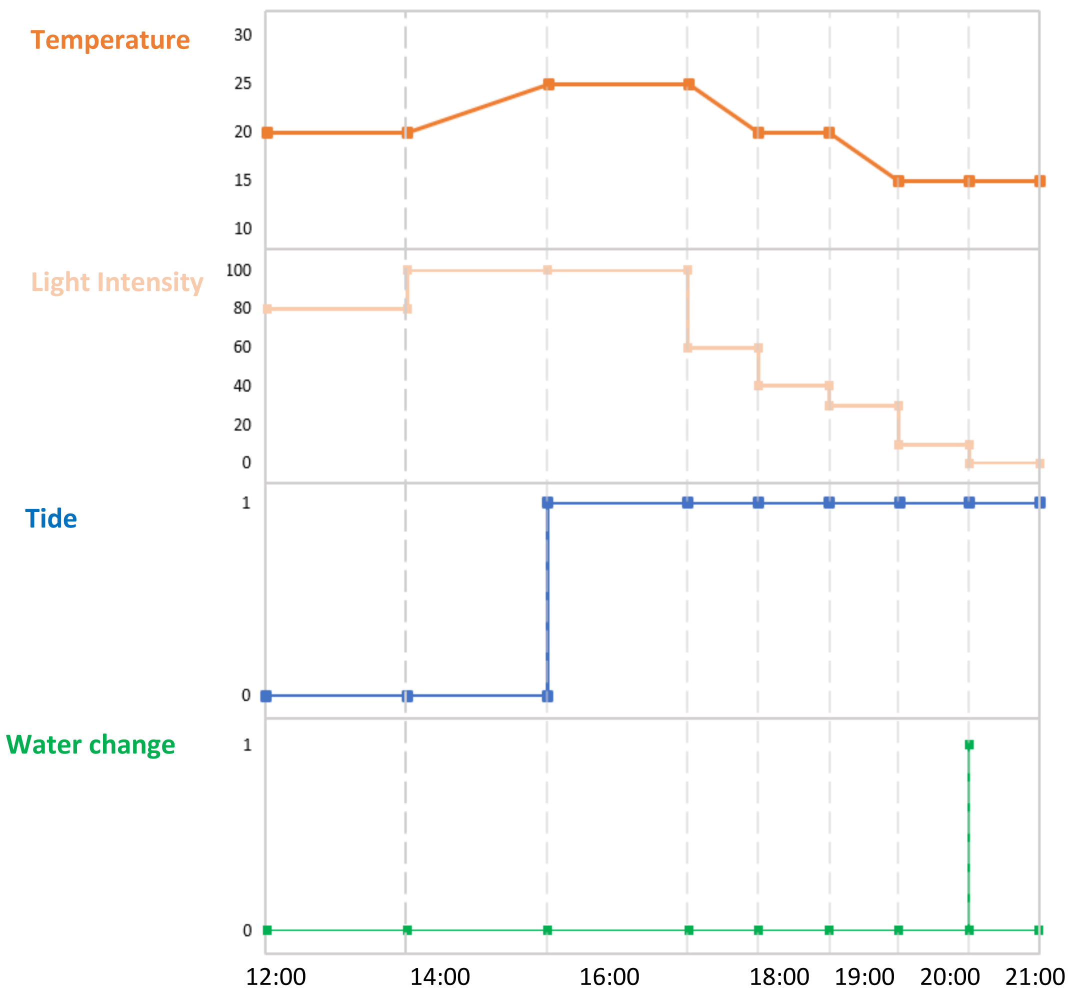

Fig. 7: Chart detailing the Experiment profile setpoints.

5. Remote access

The Intertidal chamber can be remotely accessed via Wi-Fi by 3 different methods: 1) File transfer protocol (FTP), allowing insight to the interior of its micro-SD card, 2) Online cloud platform (Blynk) and 3) Node-RED application (via MQTT server).

5.1. FTP connection

Once the Intertidal chamber has acquired an IP address, this is shown in the display, together with the current network and immediately it starts acting as an FTP server, accepting the connection of an FTP client (a computer with an FTP program installed) to allow the user access over the content of the micro-SD card. This is a remote way to retrieve the log files but also to edit the files **settings.txt** and **Profile.txt** files without having to remove the micro-SD card physically.

To create an FTP connection with your Intertidal chamber, follow these steps:

1. On your computer, install an FTP client of your preference. We recommend the freely available software **FileZilla**, from https://filezilla-project.org/download.php?type=client#close. There are versions for Linux, Windows and Mac. The following instructions apply to FileZilla but shouldn't be too different for other software packages.
2. Once FileZilla is installed, you must connect the computer to the same Wi-Fi as the Intertidal chamber.
3. On FileZilla, click on the "**Open the Site Manager**" button on the top left (**Fig. 4**).
4. On the site manager window, click "**New site**".
5. On the site's hierarchy tree displayed, the new entry is initially called "New site", but you can edit its name to something more informative of your choosing.
6. Still within the site manager window, in the **Host** field of the **General** tab, you must insert the **IP address** displayed in the Intertidal chamber screen (**Fig. 3**).
7. In the **Encryption** drop down menu, you must choose "**Only use plain FTP (insecure)**". This is because the microcontroller in charge of the Intertidal chamber functioning does not work with encryption data. This will not expose your computer to any harm, as it only pretrains to the connection between the computer and PULSE V2.
8. Type in "**Chamber_EB**" in both **User** and **Password** fields. These credentials are hardcoded in the Intertidal chamber firmware and cannot be changed unless you decide to edit the C++ code.
9. In the "**Transfer settings**" tab, select the "**Limit number of simultaneous connections**" box.
10. You can now click "**Connect**". Once the connection is established, you'll be presented with the file storage tree held in your Intertidal chamber's micro-SD card memory (**Fig. 5**).
11. You can now right click on any file and choose to download or edit. Pay attention to the "**Local site**" window, as it shows where your downloaded files are being saved to (i.e., on your computer side). You can change this simply by selecting any folder on your computer in the file hierarchy tree below this field.
12. The log data files are inside the Data folder and are named **YYYY_mm_dd__XXh.csv**, for example 2023_02_01_13h.csv.
13. To edit the settings (Settings.txt) or the profile (Profile.txt) files, you can drag and drop a new file, or right click on it and select "**View/Edit**" and save it after editing. You can see an example of a settings file at the end of this manual. For clarification on the role of these files, please see **4. Experiment Profile** and **7. Settings** sections.

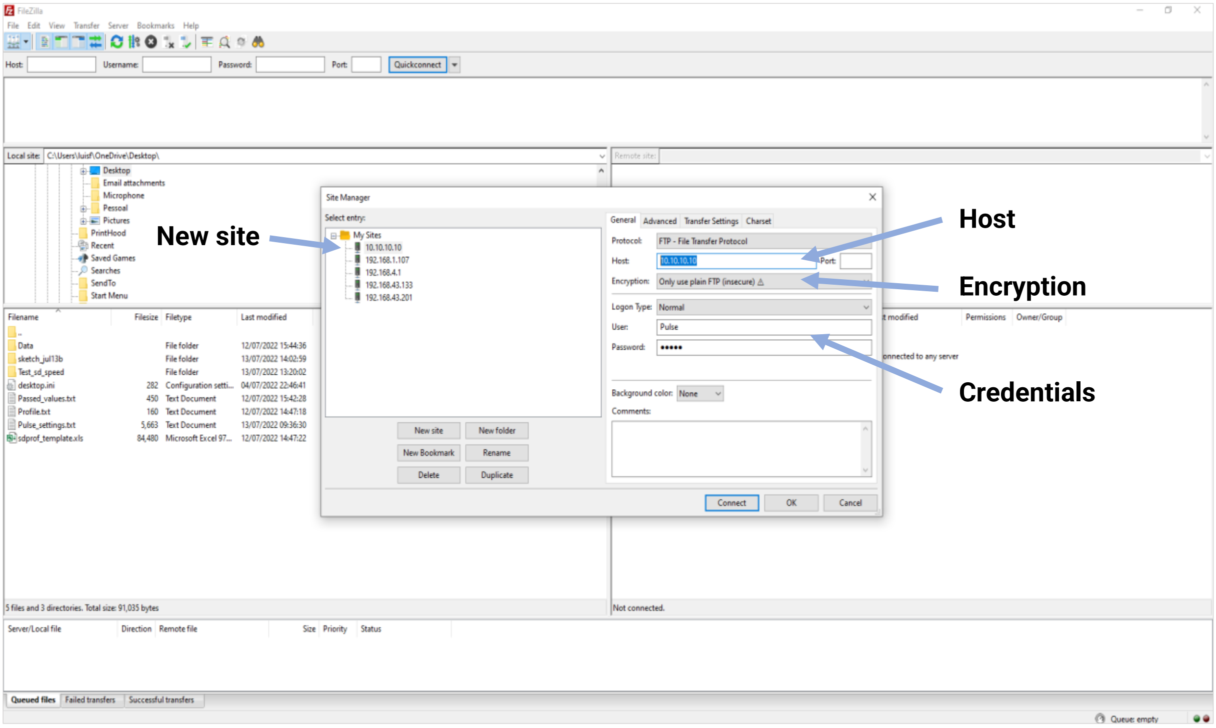

Fig. 8: Creating a new connection in FileZilla interface.

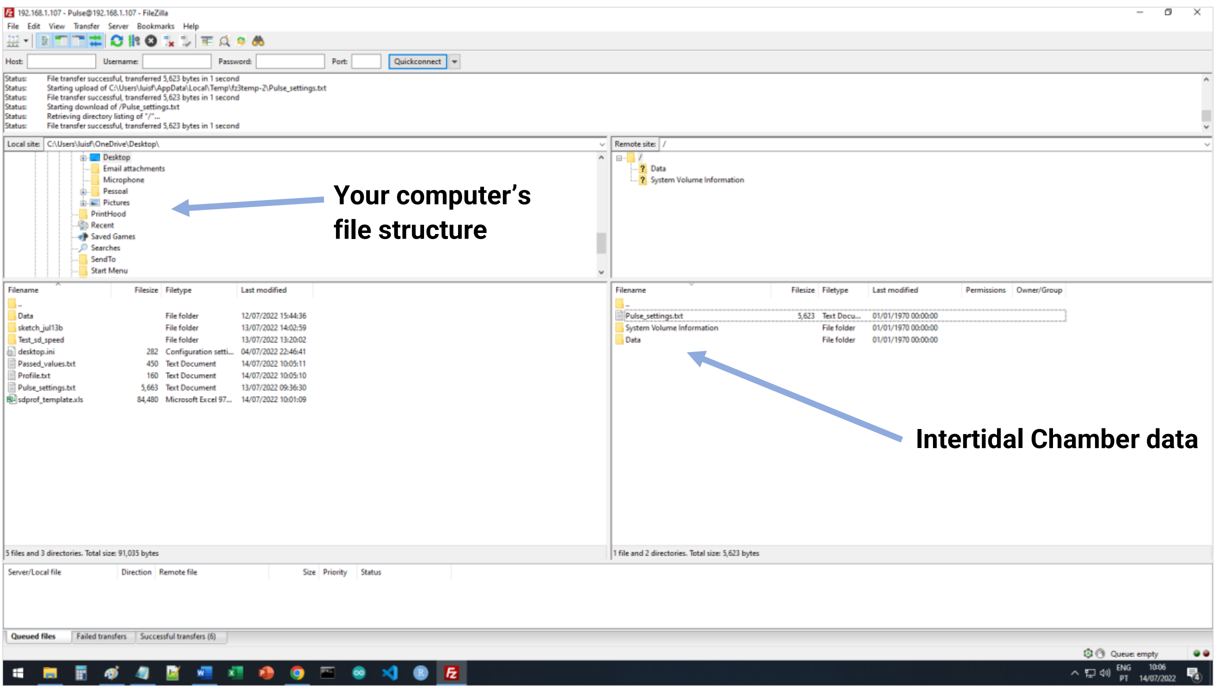

Fig. 9: Accessing the Intertidal chamber data in FileZilla interface.

5.2. Online cloud (Blynk)

Blynk is cloud platform which allows the user to store and send data remotely to virtually any microcontroller. There are 5 main features achieved with this platform:

1. Remote monitor of all sensors and device states.
2. Ability to turn off all devices via a **KILL** switch accessible on dashboard.
3. Historical data report downloads for all variables.
4. Remote calibration of heat lamps PID constants.
5. Remote firmware updates.

To use the Blynk platform, the user needs to create an account at https://blynk.io/, this can be completely free, but there are paid versions that the user may consider, for example, at the moment (February/2024) the free option only allows your data to be stored for 1 week an only access to 5 (out of 48) variables the Intertidal Chamber sends online, while the paid version (Maker plan) stored your data for 1 month enables the access to 20 variables. A simple setup allows the user can have a dashboard such as **Fig.10**.

The setup for this online platform will be explained by the following steps and trough a **tutorial video** provided.

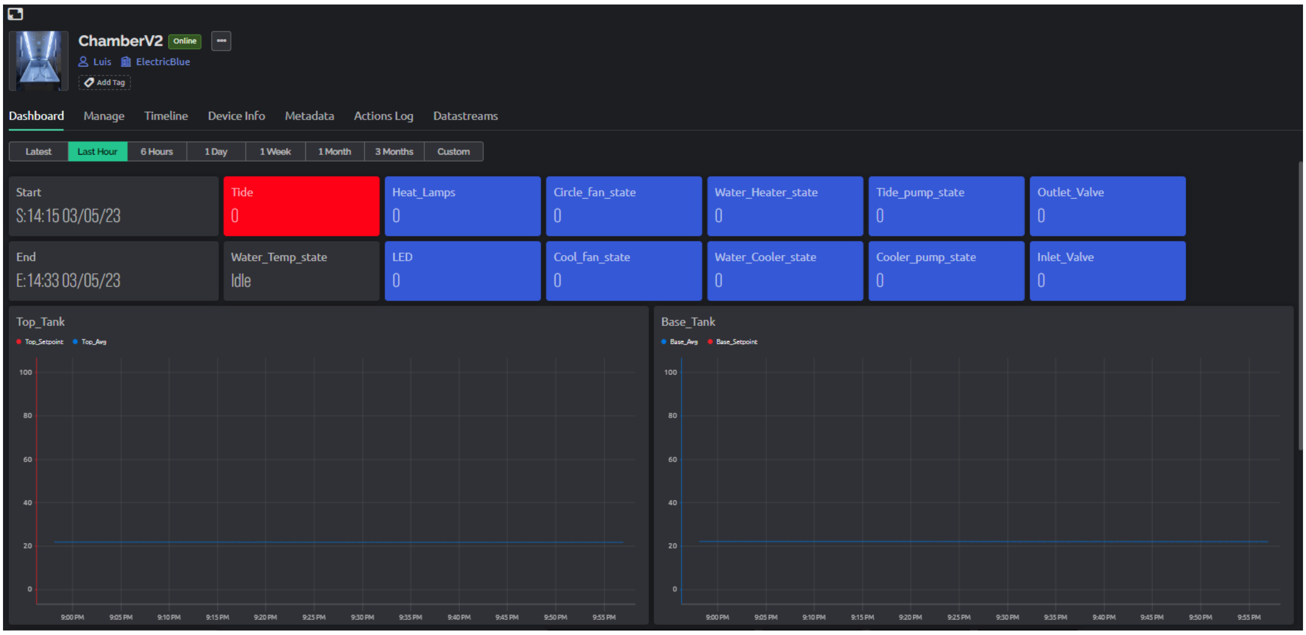

Fig. 10: Online platform exemplification (Blynk).

Simply follow these steps:

1. Create an account on Blynk website.
2. Create a template and leave if empty for now.
3. Create a device (choose ESP32 module) and associate to the template you just created.
4. On the **Device Info** tab copy the **BLYNK_TEMPLATE_ID** and **BLYNK_AUTH_TOKEN** and place if the settings.txt file present the Intertidal Chamber micro-SD card (see **7. Settings** section).
5. If your chamber has Wi-Fi connection you should see the "B" character turning green after a few seconds, symbolizing it has been able to connect to you Blynk platform.

- Now you can configure your dashboard to you linking, on Blynk website there are various explanatory tutorials and videos to help understand this procedure, the list of variables the Intertidal Chamber sends to Blynk platform is in **Blynk_Datastreams.xlsx**. Nonetheless, we present a video (**Chamber_Online_platform_Blynk_setup.mp4**) explaining how to build a dashboard appropriate to the Intertidal chamber use.

The **KILL** switch when toggled on, informs the Intertidal Chamber to turn all devices off and stores a text file in the micro-SD card named KILL.txt, which content becomes KILL=1. If the user toggles off this switch the Intertidal Chamber will go back to its automatic behaviour and edit the content of the KILL.txt file to KILL=0. This local file is a way for the Intertidal chamber to know that it was ordered to having everything unpowered (KILL toggled on) even if the electronics reboots and no longer has access to Wi-Fi. When Wi-Fi is recovered, the local file will check the online state of the KILL switch and update its local file accordingly.

Although the current firmware for the Intertidal chamber makes use of this service, this project has no connection whatsoever to Blynk company, in fact, previous versions of the Intertidal Chamber firmware used other sort of cloud-dashboard platforms, such as AdafruitIO, Grafana and Losant. The Blynk option is currently the choice for this remote monitoring service due its simplicity, cost, and features.

5.3. Node-RED - MQTT

Node-RED is a free development tool written in Node.js and JavaScript that allows the construction of interactive applications, with dashboards and device-to-device communication. Due to its simplicity and strong community, it is a perfect tool for small applications that can be passed between peers and easily editable by any beginner. In the Intertidal chamber, a Node-RED application is used to send new profile experiments remotely. Ideally, this would be made through the Blynk platform, and so minimizing the applications required to communicate with the Intertidal chamber, but Blynk features do not allow the transfer or files between their platform and a device. On the other hand, to develop a Node-RED application that would contain all the features an accessible on the Blynk platform, would be quite and endeavour, although possible.

The Node-RED application can be hosted in virtually any 32 bits device capable of hosting an operative system (Windows, Linux or Mac). This could be a personal computer, a server, a raspberry Pi or an online hosting service. To make this application attainable to anyone, this manual is going to focus on the procedure of creating a Node-RED application hosted on a free cloud service (Oracle corporation).

In this application, the communications between the Node-RED and the Intertidal Chamber are made by MQTT (Message Queuing Telemetry Transport), which is a protocol similar to HTPP but with a smaller package load and so, more efficient on unstable Wi-Fi and less demanding on the microcontrollers processing. To have MQTT messages traffic means, we need a MQTT server, which could be hosted in the same cloud service (Oracle), but these require long configurations in bash code, and often change the commands required to achieve our goal. Therefore, the most reliable and replicable method found was to have Node-RED hosted in a free cloud service (https://www.oracle.com/cloud/free/) and have the MQTT server that forwards messages between the Node-RED application and the Intertidal chamber on another free service (https://www.hivemq.com/) – **Fig.11**. The process involves the creation on a cloud instance, which works like a virtual computer hosted by Oracle Cloud, where the user can install Node-RED and configure this to its liking. This approach has many advantages compared to having your own server or application running on a local machine, namely the security involved. The remote access to your local server would require special interfaces and port forwarding features which can represent a vulnerability to unknown internet access. With an online cloud service, this concern is now on Oracle services, a software giant next to IBM or Amazon.

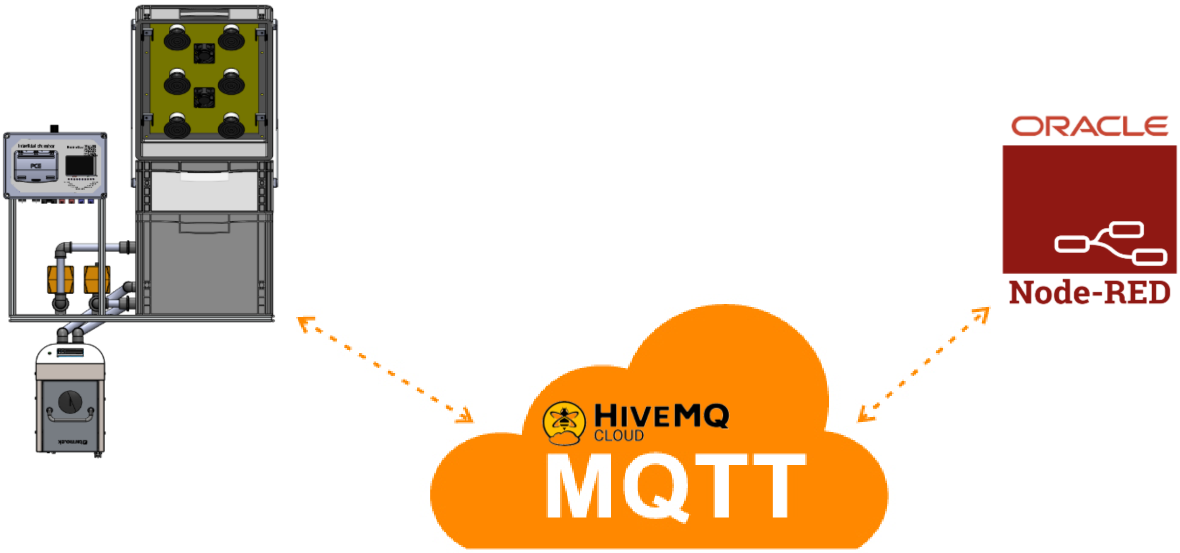

Fig. 11: Illustration of communication between Intertidal chamber, MQTT server and Node-RED webpage.

The setup for this MQTT cloud platform will be explained by the following steps and trough a **tutorial video** provided.

5.3.1. MQTT server in HiveMQ

To create the free MQTT server the user must follow these steps:

1. Create a HiveMQ account at https://www.hivemq.com/hivemq/mqtt-broker/ .
2. Provide a **Username** and a **password** of your choice.
3. Save your given **Cluster URL**, together with the **Username** and **password** you just provided for Publish&Subscribe, these will be required for both settings file in the Intertidal Chamber and the Node-RED application.

5.3.2. Node-RED application at Oracle

To establish a free Node-RED application in the Oracle online cloud, there are various tutorials online prepared by Oracle company (https://blogs.oracle.com/developers/post/installing-node-red-in-an-always-free-vm-on-oracle-cloud). Initially we"ll have to create a virtual computer instance on Oracle Cloud and establish an Secure Shell (SSH) connection to it. After this, we"ll be able to access this instance as it was a computer and install Node-RED. Nevertheless, here are the steps required:

Creating an Oracle instance and establish SSH connection:

1. Sing up for a free account at Oracle Cloud (https://www.oracle.com/cloud/free/).
2. Although the instance suggested here is completely free, a credit card association might be required.
3. Once you are logged in into your Oracle Cloud account, go to Instances -> Create instance.
4. Choose Oracle Linux 8 version operative system.
5. On the SSH keys field, download both private and public keys generated by Oracle, or add your own.

6. On Networking field, make sure “Assign a public IPv4 address” option is enabled and select “Create new virtual cloud network”, you can leave all information as default.
7. Press “Create” and after it completes instance startup, you”ll taken to you “Instance details”, where you can see your “Public IP address” and here you should press Start.
8. In out instance details, we need to add access from outside this network to our future Node-RED application. Go to your Subnet -> Click on your default security list and add the ingress rule with source 0.0.0.0/0 and port range 1880 (Node-RED by default uses port 1880). Repeat this process for the port range 8883 (required for HiveMQ server).
9. From now on, your Oracle instance works as a virtual computer you can access from your own computer via SSH communication. For that we can use a free software called PuTTy (https://www.putty.org/).
10. To establish a connection to your instance public IP there is a security layer for which you’ll need the private key you downloaded in step 4 converted into a format acceptable to Putty (.ppk). Luckly, Oracle explains this procedure quite well (https://docs.oracle.com/en/cloud/paas/goldengate-cloud/tutorial-change-private-key-format/). You” ll need another small program called Puttygen , also available at https://www.putty.org/.
11. Once you have your private key in .ppk format connect to your instance by setting your .ppk key on Connection -> SSH -> Auth -> Authentication parameters, use the file browser here to select your private key (Figure XX)..
12. Finally add your instance public IP address and your key Putty and press Open (Figure XX).

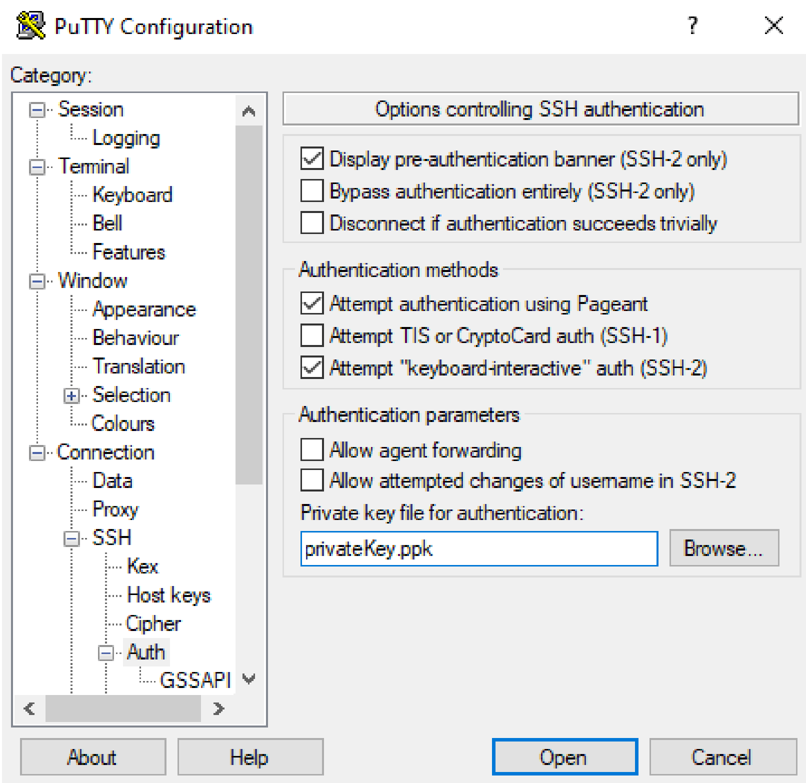

Fig. 12: PuTTY program – focus in SSH authentication key field.

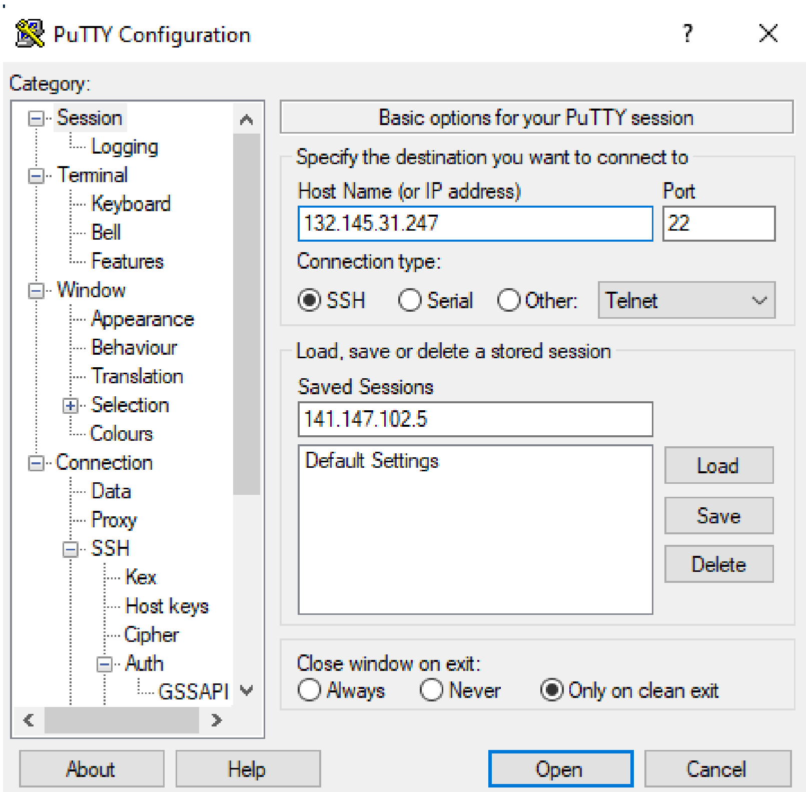

Fig. 13: PuTTY program – focus in SSH IP connection.

Installing Node-RED in Oracle cloud instance:

1. Once we have established a SSH connection, a black background terminal will open and prompt the login username, by default, on Oracle this is **“opc**”.
2. Copy paste and run the following command lines, one-by-one to install Node-RED and its pre-requisites:
   sudo dnf module enable nodejs:18
   sudo dnf install nodejs
   bash <(curl -sL https://raw.githubusercontent.com/node-red/linux-installers/master/rpm/update-nodejs-and-nodered)
   node-red-start
   sudo systemctl enable nodered.service
   You”ll prompted with questions regarding the installation, just press y and enter.

3. You can know access the Node-RED application background on the port 1880 on your instance public IP address, for example, if your instance public IP is 144.147.102.18, then your Node-RED application background is accessible in any browser via the link:
   http: //144.147.102.18:1880
4. Now all the user needs to do is install the required packages on Node-RED and import the application. To install the required packages, on Node-RED application got to the top right corner and press on settings icon (the 3 horizontal lines) and go to Manage palette.
   Then go to the Install tab and one by one, search and install the following packages:
   - node-red-dashboard (v 3.4.0)
   - node-red-contrib-ui-upload (v 0.7.0)
   - node-red-node-ui-list (v 0.3.6)
5. Once all packages are installed, restart the Node-RED application, by entering the command in the SSH terminal connection:
   node-red-restart

- Now we can import the application, go to same settings icon as before, press Import and in the empty clipboard that appears copy paste the text from the provided file: **Chamber_webpage.json** .

6. Once you have imported the Node-RED application, you”ll be looking at the “nodes” that constitute the app, and the last detail required, is to give it access to the HiveMQ server created earlier. To do that simply double click on the node called HiveMQ_MQTT inside the green box.
7. In the prompt “Edit mqtt out node” press on the pencil icon to edit your MQTT server.

8. In the Connection tab, insert in the Server filed HiveMQ URL from your account, leave "Connect automatically" and "Use TLS" enabled. In the Security tab insert the username and password for your HiveMQ server. Press the red button Update -> Done and at the right top corner press Deploy.
   Your application dashboard should now be visible at **/ui** extension of the Node-RED link.

http: //144.147.102.18:1880/ui

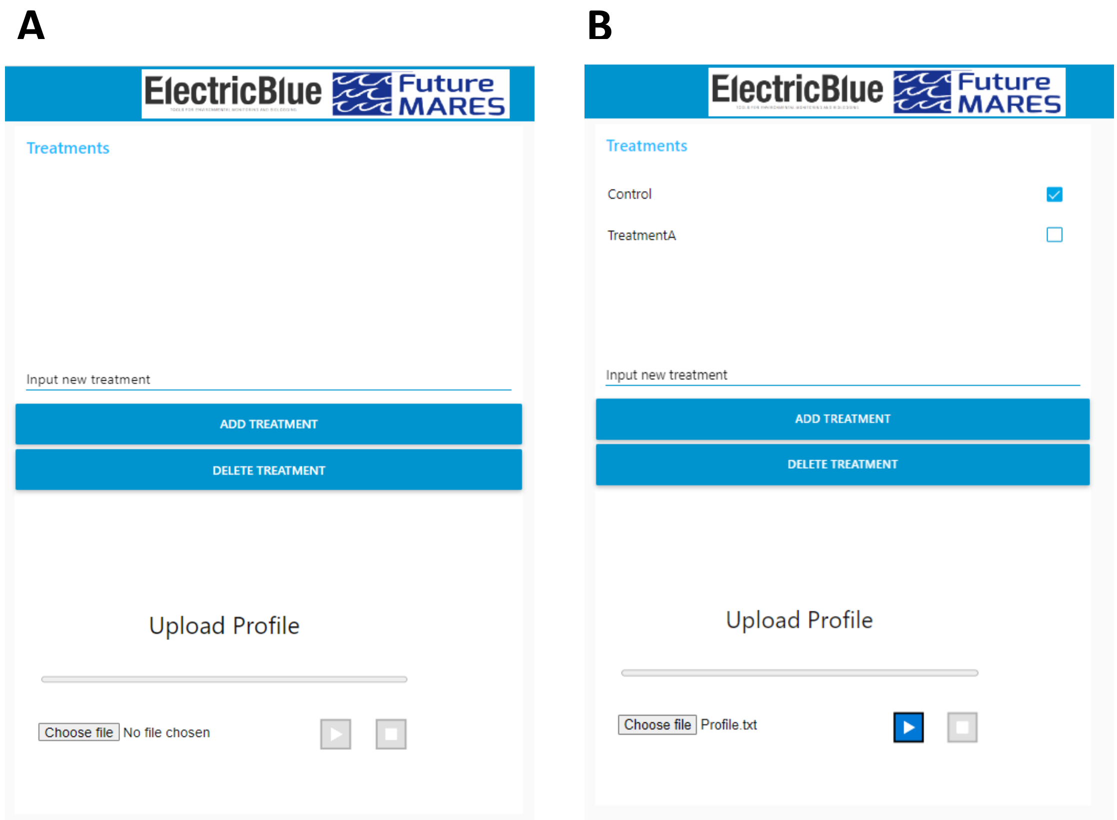

Fig. 14: Webpage illustration – A stands for initial interface and B for treatments added example.

Now you're ready to send experiment profiles to any chambers that share the same HiveMQ server credentials in their settings.txt file.

5.3.3. Node-RED Operation

To send a profile experiment to any Intertidal chamber from Node-RED application, both need to share access to the HiveMQ server (note the **Fig.11** architecture). Once you can access to the application (**Fig.14**), you are able to add "Treatments" by typing the desired treatment and pressing the "ADD TREATMENT".

After inserting a new treatment, this should show in the vertical list above. To send a profile you must 1) select which treatment is supposed to receive this, 2) upload the profile.txt file on the file browser under "Upload Profile", 3) Press the play icon to send it.

The way this application works, profile experiments are sent to the Intertidal chamber connected to the same MQTT server that have the selected treatment on their settings file. Therefore, multiple Intertidal chambers could receive the same profile at once. To send different profiles to different treatments just repeat the process for each treatment.

5.3.4. Node-RED security

Initially, the Node-RED application dashboard and background can be accessed by anyone, but this doesn't have to be so, credentials can be configured to limit this. To add credentials the user needs to edit the file settings.js inside the Node-RED instance. To do so, follow these steps:

1. Establish an SSH connection trough PuTTy as described in the **5.3.2. Node-RED application at Oracle** section.
2. Generate an encrypted password with the command below.
   A password will be requested, and the encrypted version will be returned, save this.
   node-red admin hash-pw
3. Move to the Node-RED directory:
   cd .node-red
4. Open the the settings.js to edit the credentials:
   sudo nano settings.js
5. To add credentials to your Node-RED application background uncomment (remove double slash "//" from each line start) to the **adminAuth** section and add your username and encrypted password.
   To paste text in bash simple press mouse right-click.
   Should look like this:

```
adminAuth: {
    type: "credentials",
    users: [{
      username: "Username",
       password: "$2b$08$YJGyasOxBvWHFm.wasS3hOqYcfFPt/5asQUqYG3yGlijimyqed.7q”
       permissions: "*"
    }]
 },
```

6. Still within settings.js file edition, the user can add credentials to your Node-RED application dashboard. For this, uncomment (remove double slash "//" from each line start) to the **httpNodeAuth** section (about 40 lines below the **adminAuth** section). Add your desires username and encrypted password as before.
   Should look like this:

```
httpNodeAuth: {user:" Username ",pass:"
"$2b$08$YJGyasOxBvWHFm.wasS3hOqYcfFPt/5asQUqYG3yGlijimyqed.7q "},
```

7. To save and exit press **Ctrl+X** , press Y an enter.
8. Restart Node-RED app to apply these changes:

node-red-restart

Campus Agrário de Vairão, Rua Padre Armando Quintas n.º 7, 4485-661 Vairão, Portugal • mail@electricblue.eu • www.electricblue.eu

9. From now on, every attempt to access the Node_RED app dashboard or background will be propted with a credentials request (Fig XX).

5.4. Firmware update

The firmware for the Intertidal chamber can suffer updates and these will be made available as a single file with .bin extension. To update the Intertidal chamber firmware, there are 3 options:

1) The user can place the firmware file in the micro-SD root content under the name “update.bin” and the Intertidal chamber will auto-detect this file upon reboot. An informative message will fill the LCD display: “Detected new Firmware. Updating…” .

Fig. 15: Firmware update via webpage interface.

2) The user can access the same Wi-Fi as the Intertidal chamber and use a browser to open the update webpage hosted by the intertidal chamber under its IP address followed by /update, i.e., if the chamber IP address seen in the display is 192.163.10.10, then the update webpage is at http:// 192.163.10.10/update (**Fig.15**). Here the user only needs to select the firmware .bin file and press “Update”.

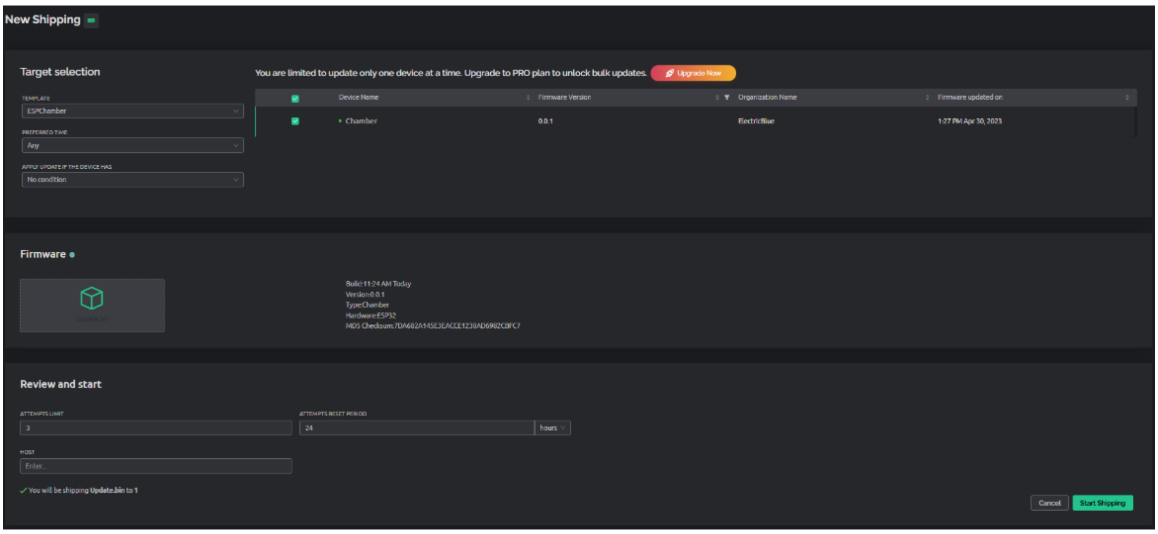

Fig. 15: Firmware update via Blynk online platform.

3) The user can also update the firmware from a remote network via the Blynk platform. On the left icons, the “Firmware OTA Updates” leads to a menu where the user can initiate a “New Shipping” of

firmware to the chosen device. Here make sure the correct .bin file is selected and there's no version condition to the update and press "Start Shipping" (**Fig. 15**).

6. Log files

Although all information is being sent to Blynk platform, it stored in the SD card, via CSV files. The files name will be an assembly of their time of creation timestamp: **YYYY_mm_dd__XXh.csv** (e.g. 2024_01_17_08h for a file created at 8AM of the 17th of January 2024). These will files created hourly.

Their content will have an initial header with:

- Firmware version (e.g. **V6.5**);
- Device name;
- Treatment;
- UTC (e.g. +1 for Paris time, or 0 for London);
- Daylight saving time (e.g. 'Yes' or No);
- Heat_wait seconds;
- Chiller_wait seconds;
- Water_release seconds;
- Water_fill seconds;
- Experiment_Start (e.g. 'S:17:00 15/01/2024');
- Experiment_End (e.g. 'E:10:25 19/02/2024');

Following these, a set of variables will be added every 10 seconds in individual columns, containing the following:

- Date (e.g. '17/01/2024');
- Time (e.g. '08:00:00');
- Temperature sensors (T1 to T6);
- Temperature average for the Experiment tank in Celsius (Top_avg);
- Temperature setpoint for the Experiment tank in Celsius (Top_setpoint);
- Temperature average for the Water storage tank in Celsius (Base_avg);
- Temperature setpoint for the Water storage tank in Celsius (Base_setpoint);
- Tide state ('0' for low, '1' for high tide);
- Water sensors state (WS1 to WS8, '0' for no water detection and '1' for water detection);
- Heat lamps intensity in percentage ('Heat_Lamps_%');
- Water cooler state ('0' for OFF, '1' for ON);
- Water heater state ('0' for OFF, '1' for ON);
- Cooler pump state ('0' for OFF, '1' for ON);
- Tide pump state ('0' for OFF, '1' for ON);
- LED intensity in percentage ('LED_intensity_%');
- Circle fan state, representing the interior homogenization fans ('0' for OFF, '1' for ON);
- Cool fan state, representing the cooling fans that pull air outwards of the Experiment tank ('0' for OFF, '1' for ON);
- State of the outlet valve ('0' for OFF, '1' for ON);
- State of the inlet valve or Pump ('0' for OFF, '1' for ON);
- PID algorithm constants (Kp, Ki and Kd, by default this will be set to Kp=10 , Ki=0.096 and Kd=0);

7. Settings

The Intertidal chamber operation settings are configured by the Settings.txt file present in the SD card. To edit this, either access it physical by removing the card from the console board or via FTP connection (see **5.1. FTP connection** section). The settings file is composed by 15 lines, each one configuring a feature of the Intertidal chamber, the content and interpretation are as follows:

Device_name=Chamber

This field defines the name given to this device. The name will be shown in the LCD display, will be used to name the network access point in case there's not and Wi-Fi connection, will be sent to Blynk dashboard for identification and will be added to the data CSV header of the log files. This field is limited to a length of 10 characters.

Treatment=Control

This field defines the treatment given to this device. The treatment will be shown in the LCD display, sent to Blynk dashboard for identification and will be added to the data CSV header of the log files. More importantly, this treatment is the required to receive profile experiments from the Node-RED application. This field is limited to a length of 10 characters.

Wifi=My_wifi

The Wi-Fi field sets the name of a known Wi-Fi network to which Intertidal chamber will connect to. This field is limited to a length of 14 characters and its display in the LCD is limited to 8 characters. In case you don't provide a Wi-Fi name here, Intertidal Chamber will not attempt to connect to any Wi-Fi network and will instead create its own Wi-Fi network, named after the provided **Device_name**. An attempt to search and connect to the given Wi-Fi network will be made every 20 seconds.

Wifi_pass=Wifi_password

The **Wifi_pass** field provides the password required for the Wi-Fi network defined in the **Wifi** field. Password is limited to a length of 30 characters. If no password is given, the system will assume that the Wi-Fi network provided has no password. An attempt to search and connect to the given Wi-Fi network will be made every 20 seconds.

AP_pass=Chamber12345

This filed is the password required to connect to the Intertidal Chamber own Wi-Fi network. In case there's not a successful connection to Wi-Fi network, the Intertidal Chamber will create its own Wi-Fi network to which the user can access via FTP connection and edit the micro-SD files content, namely the Settings.txt file or the Profile.txt. This network will be named after the provided **Device_name** and will have the provided **AP_pass** as password, by default this will be **"**Chamber12345". This field is limited to a length of 20 characters.

Local_time_zone=0

This value represents the deviation (positive or negative) from UTC (UTC means Universal Time Coordinated). When connected to the internet, Intertidal chamber will sync its clock and use this value to adjust itself to local time. It accepts values from -12 to 12 with half unit increases. For example, someone in the UK should use '0', in Germany should use “1', in Brazil should use '-3', and in South Australia '9.5'. If the given value is outside these limits, local time will be set to UTC+0. The time shown in the display and the logged files stored in the internal memory will use local time. Because this information is printed in the header of the CSV file, any future analysis will know under which time zone data were collected.

DST=Yes

DST means Daylight Saving Time. This can be set to 'Yes', 'yes', 'Y', or 'y' to consider DST adjustment (+1 hour). Any other text will be interpreted as a negative choice, meaning that no extra hour will be added. For clarity it is recommended typing 'Yes' or 'No'. The time shown in the display and in the logged data files will incorporate the DST setting. It will also be printed in the header of the CSV data files, and thus that information will be available for posterior data verification and processing. **This option will not adjust itself automatically at the end of Summer**. Rather, you must edit again when appropriate to turn it off.

Heat_wait=120

This field represents the wait period in seconds before the IR heat lamps start heating after the water level sensors at the top tank stop sensing water. The moment the water level section 1 stops detecting water does not mean the top tank is completely empty. Due to the sensor size and placement, there will still be water evacuating to the base tank when after these sensors stop sensing water. Although the wait required to empty the tank completely without obstructions would be less than 120 seconds (default value), the ability to edit this variable is relevant due custom variations the top tank might have, i.e., in the presence of substrate or some sort of degree can prolong this wait.

Water_release=600

This field represents a timeout limit in seconds for the water release stage in a water change. This is a preventive measure in case something went wrong with the water evacuation, avoiding the experiment interruption because water changes are not being possible. By default, this variable is set to 600 seconds (10 minutes), meaning that in the filling stage of a water change, in the release stage, if the water level section 4 has not stop detecting water after 10 minutes, then the Outlet valve closes and initiates the water fill stage. This variable has a minimum limit of 5 seconds.

Water_fill=30

This field represents a timeout limit in seconds for the water filling stage in a water change. This is a preventive measure in case something went wrong with the water inlet, avoiding the experiment interruption because water changes are not being possible. By default, this variable is set to 300 seconds (5 minutes), meaning that in the filling stage of a water change, if the conditions to stop filling have not been met (see Water change) after 5 minutes, then the Inlet valve closes and finishes the water change cycle. This variable has a minimum limit of 5 seconds.

MQTT_Host=ea8c728d98195426a43f3ab3f42fd0ac.s2.eu.hivemq.cloud

This field represents the URL for your MQTT server if the user followed the HiveMQ server creation tutorial (**5.3.1. MQTT server in HiveMQ** section), this will be URL visible in the https://console.hivemq.cloud/ of your account. This variable has no default, if it’s not present, or incorrect, no connection will be made to your MQTT server, and the Node-RED application functionality will not work. The state of your Intertidal chamber connection to the MQTT server will be perceptible by the colour of the “M” character (see **3.3.3. LCD display** section). An attempt to connect to the MQTT server will be made every 90 seconds.

MQTT_ID=Your_Username

This field represents the Username for your MQTT server, if the user followed the HiveMQ server creation tutorial (**5.3.1. MQTT server in HiveMQ** section), this will be Username given to your account. This variable has no default, if it’s not present, or incorrect, no connection will be made to your MQTT server, and the Node-RED application functionality will not work. The state of your Intertidal chamber connection to the MQTT server will be perceptible by the colour of the “M” character (see **3.3.3. LCD display** section). An attempt to connect to the MQTT server will be made every 90 seconds.

MQTT_pass=Your_Password

This field represents the password for your MQTT server, if the user followed the HiveMQ server creation tutorial (**5.3.1. MQTT server in HiveMQ** section), this will be Password given to your account. This variable has no default, if it’s not present, or incorrect, no connection will be made to your MQTT server, and the Node-RED application functionality will not work. The state of your Intertidal chamber connection to the MQTT server will be perceptible by the colour of the “M” character (see **3.3.3. LCD display** section). An attempt to connect to the MQTT server will be made every 90 seconds.

BLYNK_TEMPLATE_ID=TXPLJLS4pvY9

This field represents the BLYNK_TEMPLATE_ID attributed to your Blynk dashboard see (**5.2. Online cloud (Blynk)** section). This will be a different value for each dashboard and its present in your Blynk account, namely in the “Info” section of your dashboard template and the “Device Info” section of your device. The state of your Intertidal chamber connection to the MQTT server will be perceptible by the colour of the “B” character (see **3.3.3. LCD display** section). An attempt to connect to the Blynk account will be made every 30 seconds.

BLYNK_AUTH_TOKEN =e9HjaqMDKICV_QexflnGtW9yaEvXfdc5

This field represents the BLYNK_AUTH_TOKEN attributed to your Blynk device see (**5.2. Online cloud (Blynk)** section). This will be a different value for each device and its present in your Blynk account, namely in the “Device Info” section of your device. The state of your Intertidal chamber connection to the MQTT server will be perceptible by the colour of the “B” character. An attempt to connect to the Blynk account will be made every 30 seconds.

Fig. 16: Control panel detail – focus on circuit braker protection.

8. Electrical protection

The Intertidal chamber has a series of safety features to ensure the combination of water, electricity and heating devices operates safely. Electrical protection starts on the main breaker in the Control unit, rated at 30mA runaway current and 16 amperes peak, this breaker reacts to overcurrent or short-circuit and cuts power to all Intertidal chamber (**Fig.16**).

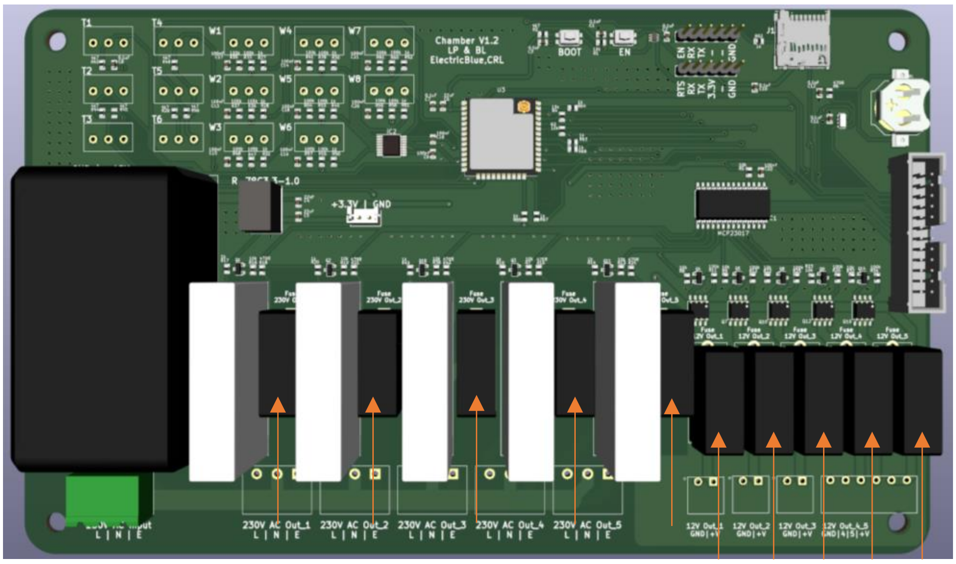

Fig. 17: Main electric board, orange arrows indicate protective fuse's location.

Inside the Control unit, in the main electric board, there are individual glass fuses for each device, both for mains powered or 12V DC powered. These are 20x5mm glass fuses rated for 5A, which protect each component individually in case of overcurrent. The glass fuses are inside their plastic sockets (**Fig.17**) and are labelled accordingly:

- Ceramic heat lamps fuse is labelled as "230V AC Out_1".
- Water cooler fuse is labelled as "230V AC Out_2".
- Water Heater fuse is labelled as "230V AC Out_3".
- Cooler circulation pump fuse is labelled as "230V AC Out_4".
- Tide control pump heat fuse is labelled as "230V AC Out_5".
- LED bars fuse is labelled as "12V Out_1".
- Circulation fans fuse is labelled as "12V Out_2".
- Cooling fans fuse is labelled as "12V Out_3".
- Water exit valve fuse is labelled as "12V Out_4".
- Water inlet valve fuse is labelled as "12V Out_5".