

Table of Contents

A.1 : Onset HOBO Motor On/Off Data Logger (UX90-004).....	4
A.1.1 : Onset HOBO Motor On/Off Data Logger Connection to Computer	4
A.1.2 : Configuring the Onset HOBO Motor On/Off Data Logger	5
A.1.3 : Deploying the Onset HOBO Motor On/Off Data Logger	7
A.1.4 : Onset HOBO Motor On/Off Data Logger Field Setup	9
A.1.5 : Onset HOBO Motor On/Off Data Logger Field Calibration	10
A.1.6 : Verification of Data Collection for the Onset HOBO Motor On/Off Data Logger.....	12
A.1.7 : Exporting Data from the Onset HOBO Motor On/Off Data Logger to a .csv File	15
A.2 : Fluke 345 Power Quality Clamp Meter.....	17
A.2.1 : Fluke 345 Clamp Meter Field Setup.....	17
A.2.2 : Taking Screenshots of the Fluke 345 Clamp Meter Readings	22
A.3 : DENT ELITEproXC Portable Power Data Logger	23
A.3.1 : Dent ELITEproXC Power Meter Initial Setup	23
Logging Interval Section.....	26
Data Logging Section.....	27
Quick Setups Section	27
Physical Power Channels Section	29
Calculated Power Channels Section	30
A.3.2 : Dent ELITEproXC Power Meter Field Setup.....	31
A.3.3 : CT (Current Transformer) and Alligator Clip Installation	31
A.3.4 : Dent ELITEproXC Power Meter Field Site Removal	35
A.3.5 : Dent ELITEproXC Power Meter Data Extraction	35
A.3.6 : Exporting Data from the Dent ELITEpro Power Meter to a .csv File.....	38
A.4 : Onset HOBO 4-Channel Analog Logger (UX120-006M) with Onset HOBO Split-Core Current Sensor	38
A.4.1 : Onset HOBO 4-Channel Analog Logger Connection to Computer.....	39
A.4.2 : Configuring the Onset HOBO 4-Channel Analog Logger with Onset HOBO Split-Core Current Sensor	41
A.4.3 : Deploying the Onset HOBO 4-Channel Analog Logger with Onset HOBO Split-Core Current Sensor	44
A.4.4 : Onset HOBO 4-Channel Analog Logger with Onset Split Core-Current Sensor Field Setup.....	47
A.4.5 : Verification of Data Collection for the Onset HOBO 4-Channel Analog Logger with Onset HOBO Split-Core Current Sensor	51
A.4.6 : Exporting Data from the Onset HOBO 4-Channel Analog Logger to a .csv File.....	54

A.5 : Onset HOBO Light On/Off Data Logger (UX90-002)	56
A.5.1 : Onset HOBO Light On/Off Data Logger Connection to Computer	56
A.5.2 : Configuring the Onset HOBO Light On/Off Data Logger	57
A.5.3 : Deploying the Onset HOBO Light On/Off Data Logger	59
A.5.4 : Onset HOBO Light On/Off Data Logger Field Setup.....	61
A.5.5 : Onset HOBO Light On/Off Data Logger Field Calibration.....	62
A.5.6 : Verification of Data Collection for the Onset HOBO Light On/Off Data Logger	64
A.5.7 : Exporting Data from the Onset HOBO Light On/Off Data Logger to a .csv File.....	67
A.6 : Onset HOBO Temperature/Relative Humidity Data Logger (MX1101)	69
A.6.1 : MX1101 Data Logger Connection to iOS or Android Device	69
A.6.2 : Logging Setup for the MX1101 Data Logger.....	70
A.6.3 : Setting the Advanced Features and Deployment of the MX1101 Data Logger	75
A.6.4 : MX1101 Data Logger Field Setup	78
A.6.5 : Verification of Data Collection for the MX1101 Data Logger.....	80
A.6.6 : Exporting Data from the MX1101 Data Logger to a .csv File	82
A.7 : Onset HOBO Temperature/Relative Humidity Weatherproof Data Logger (MX2301)	89
A.7.1 : MX2301 Data Logger Connection to iOS or Android Device	90
A.7.2 : Logging Setup for the MX2301 Data Logger.....	91
A.7.3 : Setting the Advanced Features and Deployment of the MX2301 Data Logger	97
A.7.4 : MX2301 Data Logger Field Setup	100
A.7.5 : Verification of Data Collection for the MX2301 Data Logger.....	100
A.7.6 : Exporting Data from the MX2301 Data Logger to a .csv File	102
A.8 : Onset HOBO Temperature Data Logger (UX100-001)	109
A.8.1 : UX100 Data Logger Connection to Computer	110
A.8.2 : Configuring the UX100 Data Logger	111
A.8.3 : Deploying the UX100 Data Logger.....	113
A.8.4 : UX100 Data Logger Field Setup	116
A.8.5 : Verification of Data for the UX100 Data Logger.....	118
A.8.6 : Exporting Data from the UX100 Data Logger to a .csv File	121
A.9 : Onset HOBO 4-Channel Analog Logger (UX120-006M) with Onset HOBO Gauge Pressure Sensor (T-ASH-G2-500).....	123
A.9.1 : Onset HOBO 4-Channel Analog Logger Connection to Computer.....	123
A.9.2 : Configuring the Onset HOBO 4-Channel Analog Logger with Onset HOBO Gauge Pressure Sensor	125
A.9.3 : Deploying the Onset HOBO 4-Channel Analog Logger with Onset HOBO Gauge Pressure Sensor	127

A.9.4 : Onset HOBO 4-Channel Analog Logger with Onset HOBO Gauge Pressure Sensor Field Setup	130
A.9.5 : Verification of Data Collection for the Onset HOBO 4-Channel Analog Logger with Onset HOBO Gauge Pressure Sensor	135
A.9.6 : Exporting Data from the Onset HOBO 4-Channel Analog Logger to a .csv File.....	138
A.10 : TSI-9545 Velocicalc Air Velocity Meter /TSI AVM430 Hot Wire Anemometer	140
A.10.1 : TSI-9545 Velocicalc Air Velocity Meter Initial Setup.....	140
A.10.2 : Setting the “Data Logging” Options/Initial Setup Completion for the TSI 9545 Velocicalc Air Velocity Meter.....	144
A.10.3 : TSI 9545 Velocicalc Air Velocity Meter Field Setup	148
For a Ductless Airflow	149
For Airflow in a Duct	149
A.10.4 : Viewing the Measurements on the TSI 9545 Velocicalc Air Velocity Meter	151
A.11 : Brinno TLC200 Pro Time Lapse Camera	153
A.11.1 : Brinno TLC200 Pro Time Lapse Camera Initial Setup.....	153
A.11.2 : Brinno TLC200 Pro Time Lapse Camera Field Setup	159
A.11.3 : Verification of Data Collection for the Brinno TLC200 Pro Time Lapse Camera	163
A.11.4 : Viewing and exporting the .AVI videos from the SD card to your Computer	164
A.12 : Onset HOBO 4-Channel Thermocouple Logger (UX120-014M)	167
A.12.1 : Onset HOBO 4-Channel Thermocouple Logger Connection to Computer	167
A.12.2 : Configuring the Onset HOBO 4-Channel Thermocouple Logger	169
A.12.3 : Deploying the Onset HOBO 4-Channel Thermocouple Logger.....	171
A.12.4 : Onset HOBO 4-Channel Thermocouple Logger Field Setup	175
A.12.5 : Verification of Data Collection for the Onset HOBO 4-Channel Thermocouple Logger	177
A.12.6 : Exporting Data from the Onset HOBO 4-Channel Thermocouple Logger to a .csv File.....	179
A.13 : AHU Fan Calculations.....	181
A.14 : Boiler Calculations	187
A.15 : Cooling Tower Fan Calculations	189
A.16 : DCV Calculations.....	192
A.17 : Air-Cooled Chiller Calculations.....	206
A.18 : Secondary Chilled Water Pump Calculations	210
A.19 : Lighting on Dedicated Panelboards Without Automatic Controls Calculations.....	214
A.20 : Lighting on Dedicated Panelboards With Automatic Controls Calculations.....	224
A.21 : Lighting on Mixed Panelboards Without Automatic Controls Calculations.....	233
A.22 : Lighting on Mixed Panelboards With Automatic Controls Calculations.....	242
A.23 : Additional Resources	253

A.1: Onset HOBOWare Motor On/Off Data Logger (UX90-004)

Sections A.1.1, A.1.2, A.1.3, A.1.6, and A.1.7 will require the use of the HOBOWare software. The HOBOWare software will be provided through a mini USB drive. Alternatively, HOBOWare Free can be downloaded from the following website: <https://www.onsetcomp.com/hoboware-free-download>.

A.1.1: Onset HOBOWare Motor On/Off Data Logger Connection to Computer

This section provides steps on how to connect the Onset HOBOWare Motor On/Off Data Logger to the computer. This is necessary in order to perform an initial setup of the logger prior to being deployed on the site.

1. Open the HOBOWare software and connect the logger to computer using a mini-USB cable.
2. Confirm that the logger name is displayed on the bottom left of the screen and that “1 device connected” is displayed on the bottom right, as shown on Figure A.1.2. If both messages are present, click the “Launch” button, boxed in on the top left. This will open the “Launch Logger” pop-up window as shown on where you select the parameters for collecting data.



Figure A.1.1: The logger connected to laptop computer via USB.

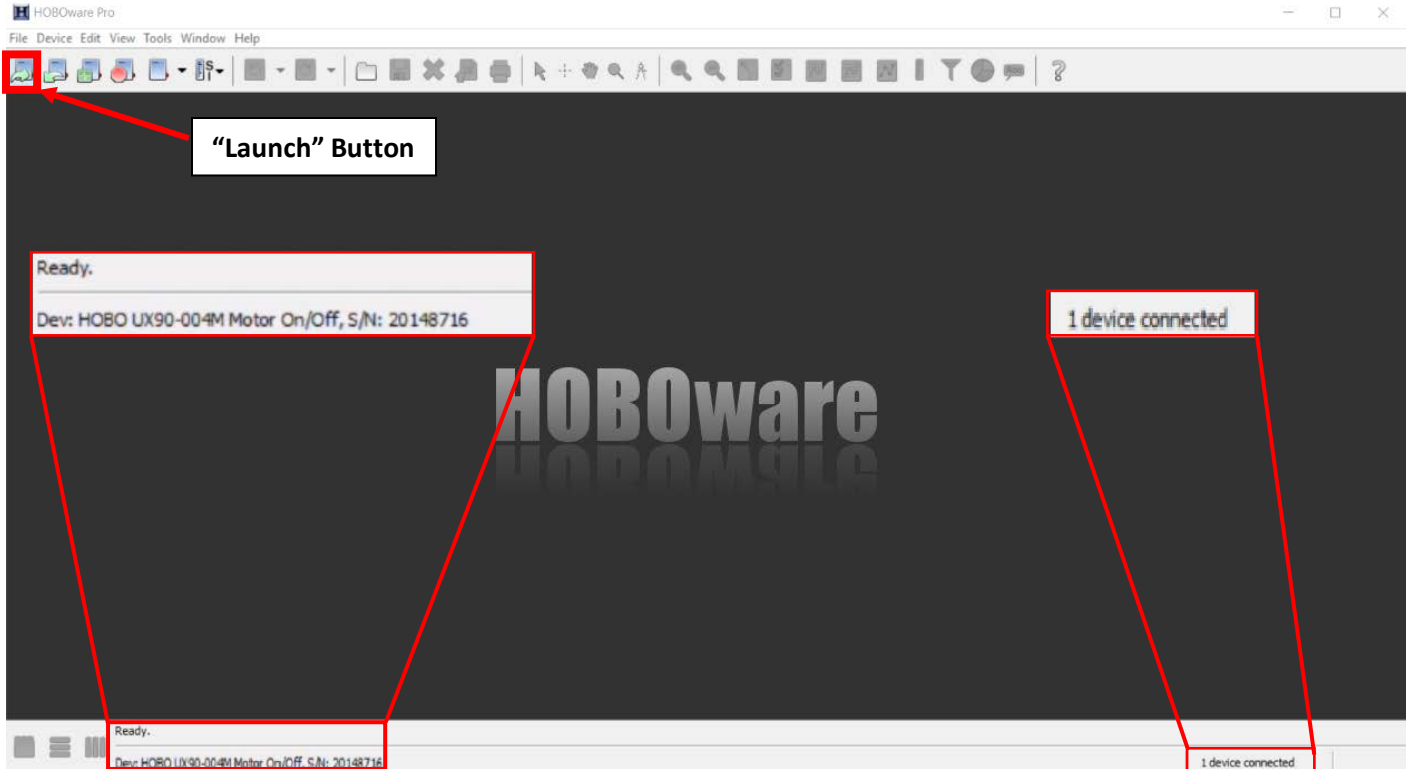


Figure A.1.2: HOBOWare launch menu

A.1.2: Configuring the Onset HOBO Motor On/Off Data Logger

In the “Launch Logger” window shown on Figure A.1.3:

1. In the “Name” field, enter a meaningful label. Ideally, the “Name” field should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - a. For example, for an AHU system, we can set a name with the facility’s name, the AHU number, and whether it’s a supply or return fan in this format:
facilityname_ahunumber_supply OR *facilityname_ahunumber_return*.
2. Check the battery level to confirm that the Onset HOBO Motor On/Off Data Logger is sufficiently powered and doesn’t require a battery replacement.
3. Within the “Launch Logger” window, the “Sensors” table allows you to configure each input port of the Onset HOBO Motor On/Off Data Logger.
4. Figure A.1.4 shows what settings to enable in the “Sensors” table:
 - a. Select the internal sensor by clicking the circle to the left of the word “Internal” in the “Sensors” table.
 - b. Click the dropdown menu and select “Runtime” to indicate that the logger will measure the total amount of time that the motor is on.
 - c. Label the sensor in a similar fashion to that of Step 1.
 - d. Set the “State Description” to “off/on”.

5. Click the “Filters...” button (Figure A.1.4). A window called “Filter Series” will appear.

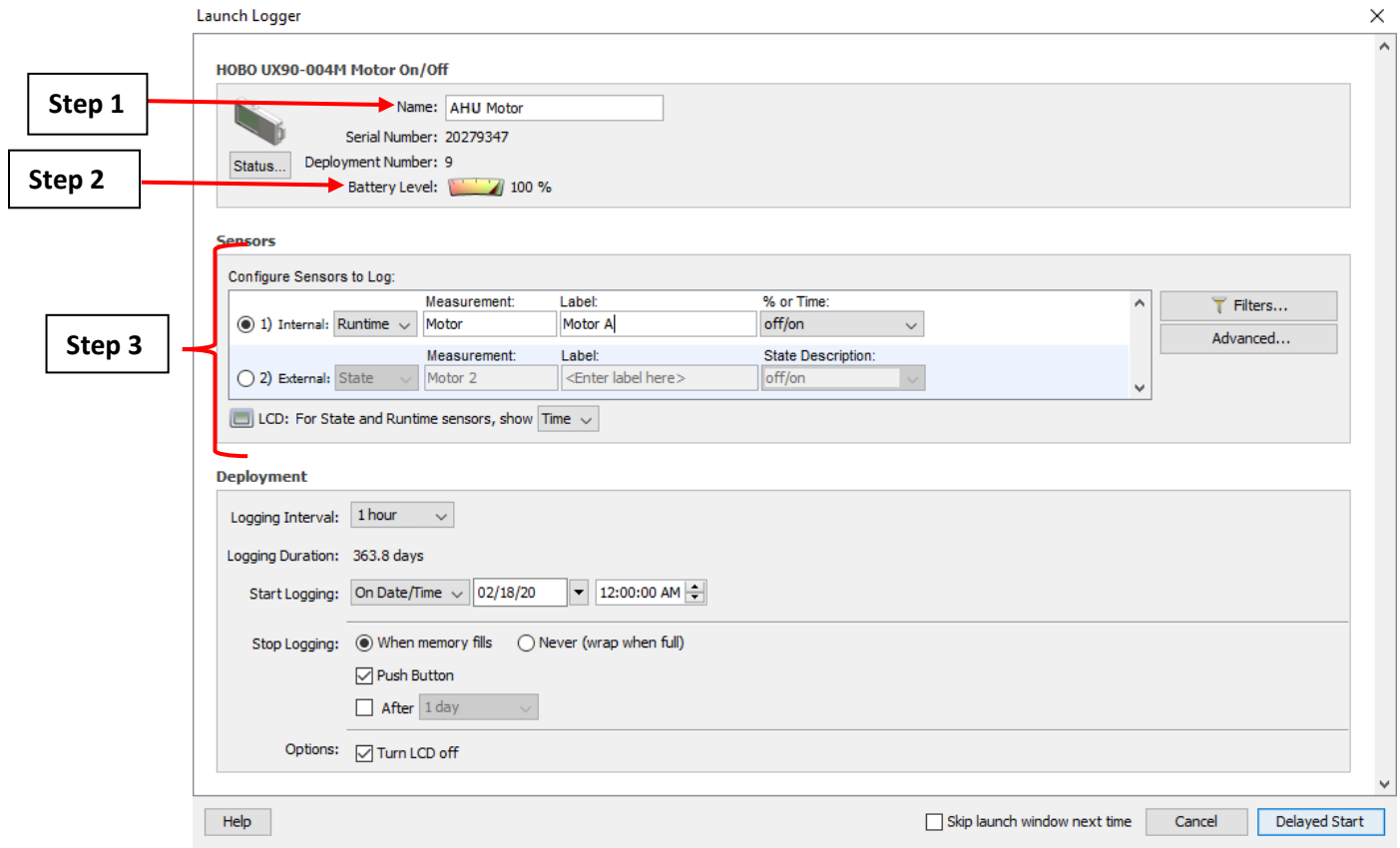


Figure A.1.3: The “Launch Logger” window with the necessary configuration steps.

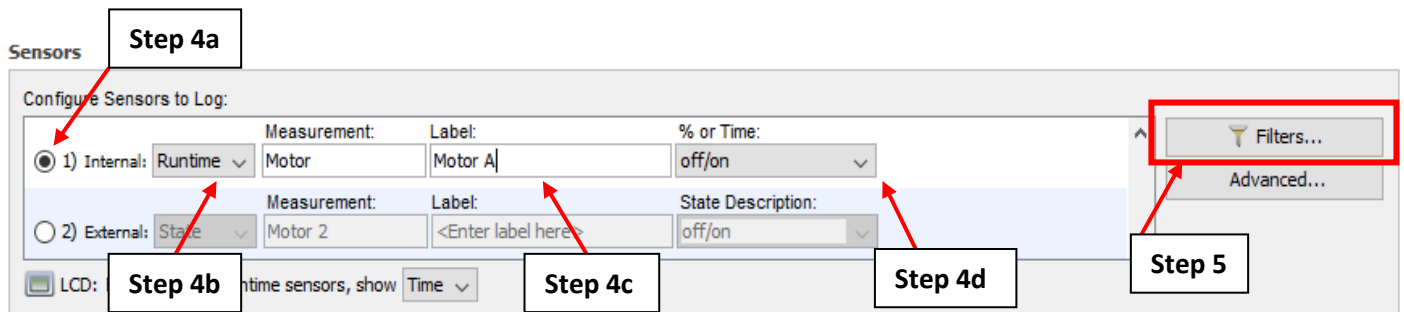


Figure A.1.4: The “Sensors” table with the necessary configuration steps.

6. To configure the “Filter Series” pop-up window shown on Figure A.1.5:
 - a. In the “Show the” dropdown menu, select the “Total Motor on” option. This configures the logger to show the total motor operational time.
 - b. Set the interval to “1 Hour”. This indicates that the logger will trend how many seconds the motor is running for each hour.
 - c. Click “Create New Series.”
 - d. Click “Done” on the bottom right corner of the window.

The screenshot shows the 'Filter Series' configuration window. At the top, there is a dropdown menu for 'Select channel to filter:' with '1) Motor on' selected. Below it, there are fields for 'Show the' (set to 'Total Motor on'), 'in each' (set to '1'), 'interval' (set to 'Hour'), and 'Start day' (set to 'First data point'). A text field for 'Resultant Series Name:' contains 'Total: Motor on'. A 'Create New Series' button is on the right. Below this is a table area with 'Filter Series' as a header, an empty table, and 'Edit' and 'Delete' buttons. At the bottom, there are 'Help', 'Step 6d', and 'Done' buttons. Red arrows and boxes highlight specific elements: 'Step 6a' points to the 'Resultant Series Name' field; 'Step 6b' points to the 'Hour' interval dropdown; 'Step 6c' points to the 'Create New Series' button; and 'Step 6d' points to the 'Done' button.

Figure A.1.5: “Filter Series” Configuration Steps

A.1.3: Deploying the Onset HOBO Motor On/Off Data Logger

Below the “Sensors” table you will see the “Deployment” table as shown in Figure A.1.6. This allows you to specify your logger deployment with details such as when to start and stop logging.

1. Click on the dropdown menu next to “Logging Interval” and select “1 hour”.
2. Click on the “Start Logging” dropdown menu and select “On Date/Time”.
3. Edit the values in the date and time boxes to specify the date and time that the logger will begin to collect measurements. If multiple loggers are being deployed, all loggers should be set to begin at the same date and time.
4. Set the “Stop Logging” option When memory fills”. This specifies that the data logger will stop collecting measurements when the internal memory of the logger is filled.
5. Identify if the LCD screen should remain on. If the logger will be deployed for more than one month, turn off the screen to conserve battery life.
6. Click “Delayed Start” to complete the configuration process. Do not unplug the logger from the computer until deployment is complete as shown in Figure A.1.7.

If the logger needs to be reconfigured, click the “Launch” button as shown in Figure A.1.2 and repeat the steps in sections A.1.2 and A.1.3.

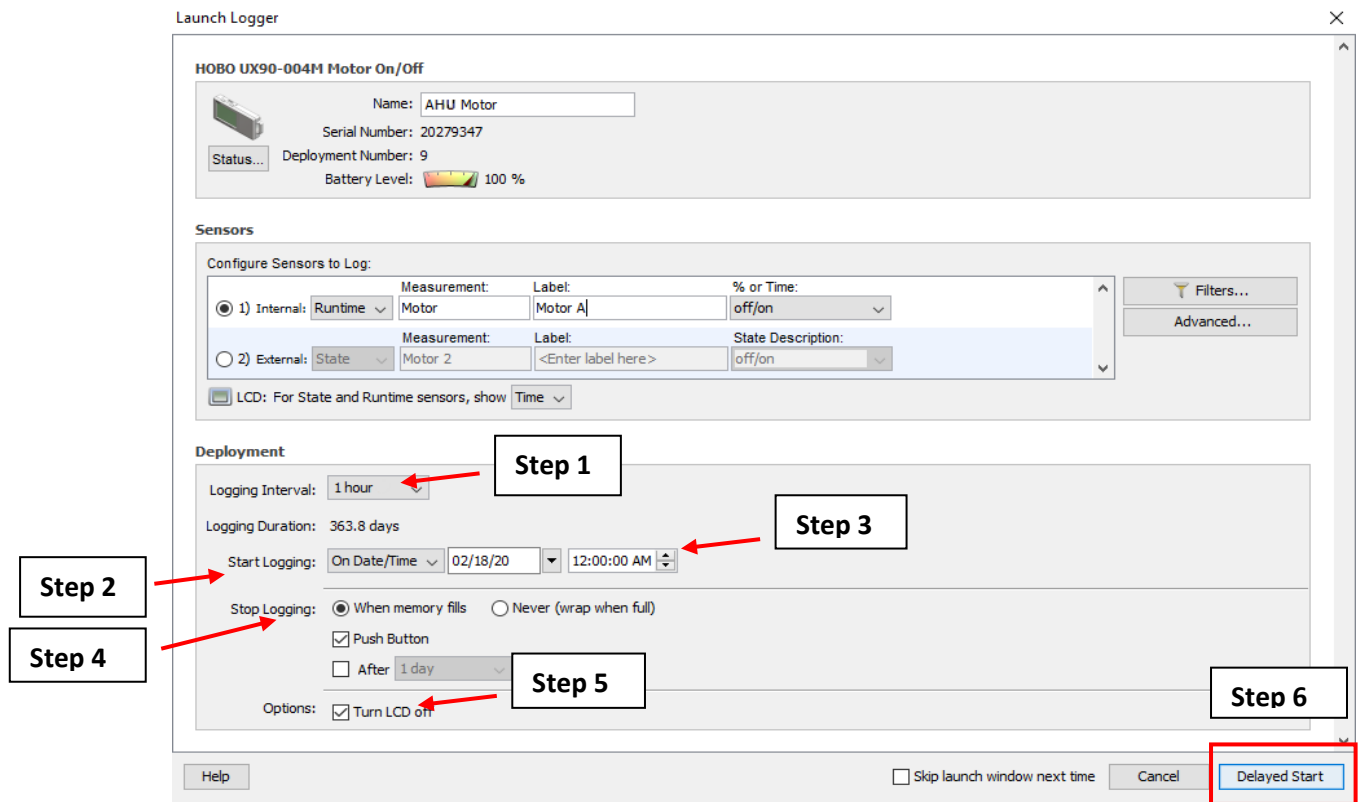


Figure A.1.6: The “Launch Logger” Window with the necessary deployment steps.

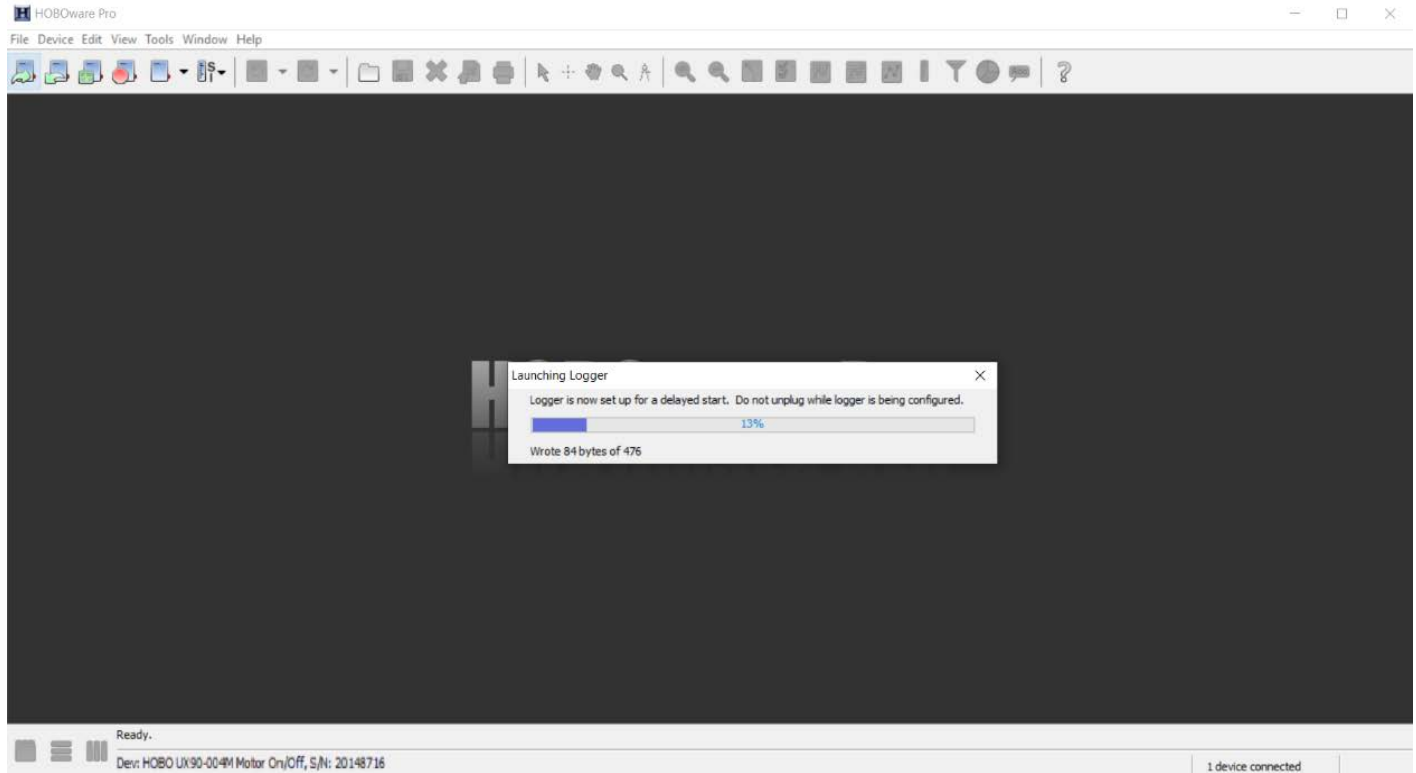


Figure A.1.7: Launching the logger using the HOBOWare software.

A.1.4: Onset HOBO Motor On/Off Data Logger Field Setup

This section will guide you through the field setup of the Onset HOBO Motor On/Off Data Logger. Please exercise the appropriate safety precautions while performing the field setup.

1. Someone familiar with the building's system should identify the motor(s) for the system(s). This will probably be one of the building's designated electricians.
2. Have the electrician turn off the motor.
3. Place the logger on the motor. Note that the back of the logger is magnetic, and the logger should be placed on the motor as shown in Figure A.1.8.



Figure A.1.8: Motor on/off Logger Placement on a 3-Phase Induction Motor.

A.1.5: Onset HOBO Motor On/Off Data Logger Field Calibration

Because of the possibility of interfering magnetic fields or vibrations near the motor being measured (e.g. logging a small motor located near a larger motor with a much larger magnetic field), calibration may be required. Please follow section A.1.4 before proceeding to this section. The logger should be attached to the motor for the entirety of this section.

1. Ensure that the LCD screen displays what is shown on Figure A.1.9.

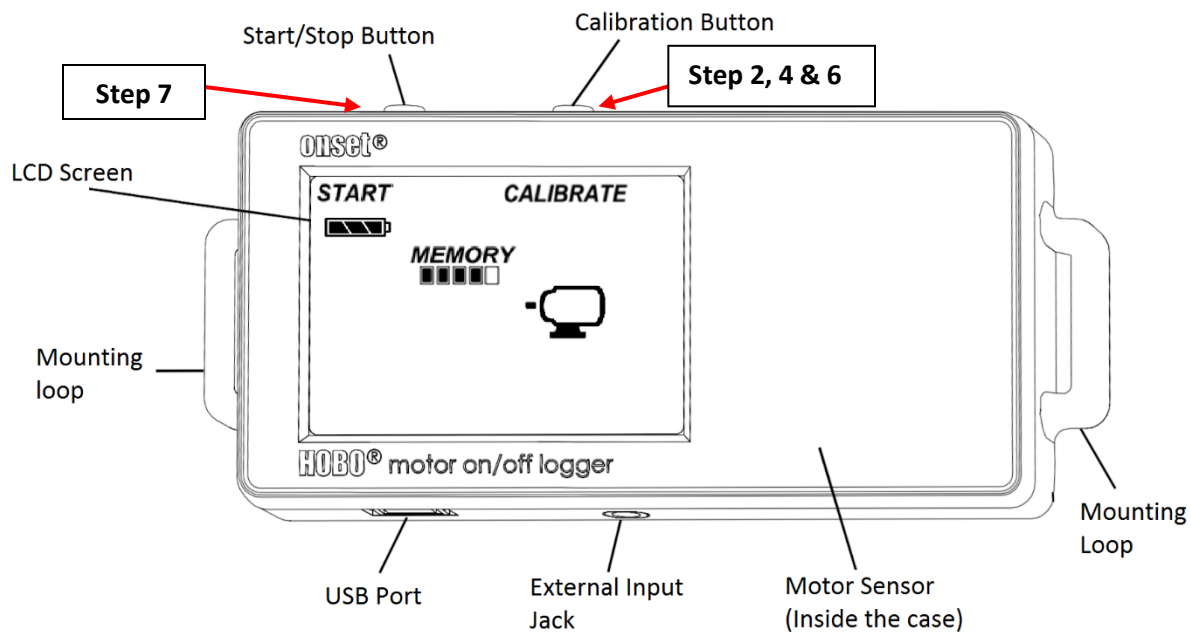


Figure A.1.9: A labeled diagram of the onset HOBO motor on/off data logger with initial startup screen.

2. Press and hold the Calibration Button (Figure A.1.9) until “MEMORY” and the five bars underneath as shown on Figure A.1.9 are replaced with “SIGNAL” and 5 empty bars right under as shown in Figure A.1.10. The bars right under the word “SIGNAL” should be empty because the motor is off. The empty motor icon shown on the same figure also indicates that the motor is off.

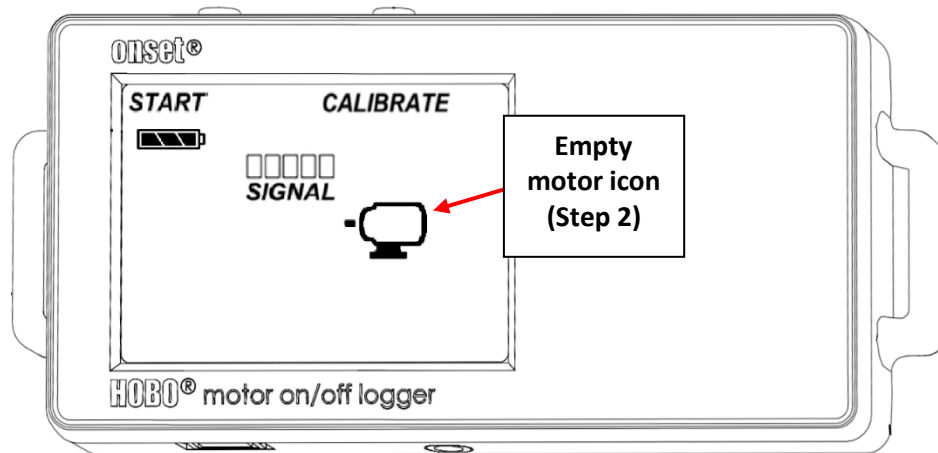


Figure A.1.10: The HOBO motor on/off data logger with LCD screen displaying the word “SIGNAL” and its corresponding signal strength bars.

3. Turn on the motor. At least 3 bars right under the word “SIGNAL” should be filled. Figure A.1.11 shows all 5 bars filled which indicates full signal strength between the logger’s internal sensor and the motor the logger is attached to. If not, reposition the logger until at least 3 bars are filled. The motor icon on the LCD screen should be filled after the motor has been turned on as shown on

the same figure.

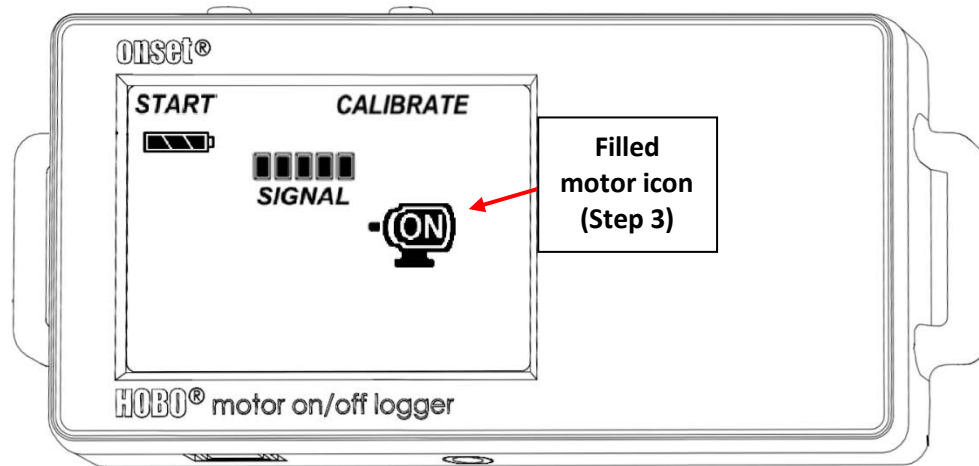


Figure A.1.11: HOBOb motor on/off data logger with full signal strength.

4. Press and hold the Calibration Button. The word “HOLD” will appear on the LCD screen. The logger will then initiate a second 4 count down. After this countdown begins, you can let go of the button. The LCD screen will then display either “AUTO CAL PASS” or “AUTO CAL FAIL”.
5. If the words “AUTO CAL PASS” appear, calibration is complete. If the words “AUTO CAL FAIL” appear, reposition the logger and repeat steps 3 and 4.
6. The LCD screen will revert to what is shown on Figure A.1.9 (with the motor icon filled instead of empty) after following step 5. Press the Calibration Button again and ensure that the signal strength is still the same as it was on Step 3.
7. Calibration is complete. The Onset HOBOb Motor On/Off Data Logger will automatically begin data collection based on the date and time that was set on step 3 of section A.1.3.

A.1.6: Verification of Data Collection for the Onset HOBOb Motor On/Off Data Logger

It is important to verify the Onset HOBOb Motor On/Off Data Logger is collecting accurate data while installed on the motor. HOBObware offers an easy way to check collected data without interfering with the initial setup from the previous sections.

1. Open the HOBObware software on your computer.
2. Connect the USB-mini cable to the logger (See Figure A.1.1). **Do not remove the logger from the motor.**
3. Click the “Readout” button on the top left corner of the screen (Figure A.1.12).
4. The “Stop Logger” pop-up will appear (Figure A.1.13) asking if you want to stop logging. Click “Don’t Stop”.

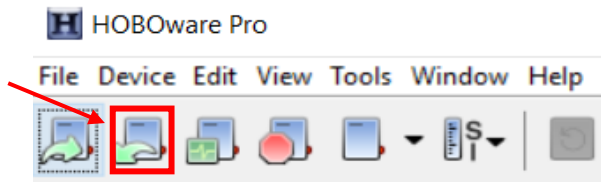


Figure A.1.12: HOBOWare “Readout” button.

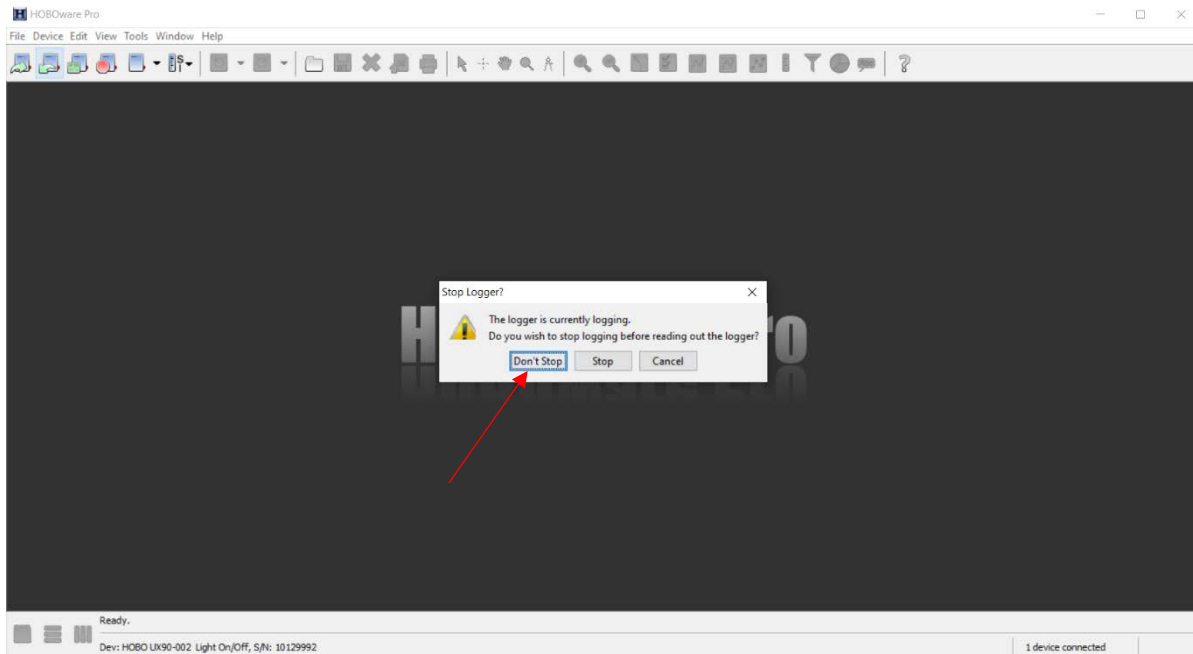


Figure A.1.13: “Stop Logger?” pop-up window.

5. The Plot Setup window open as shown in Figure A.1.14. To set up the data series:
 - a. Name your data in the same way as in step 1 of section A.1.2.
 - b. Select the “off/on” measurement (Unit: “Time On”) to plot. Deselect all other series.
 - c. Deselect the three “Event Types” at the bottom of the menu.
 - d. Click “Plot” to display your graph.

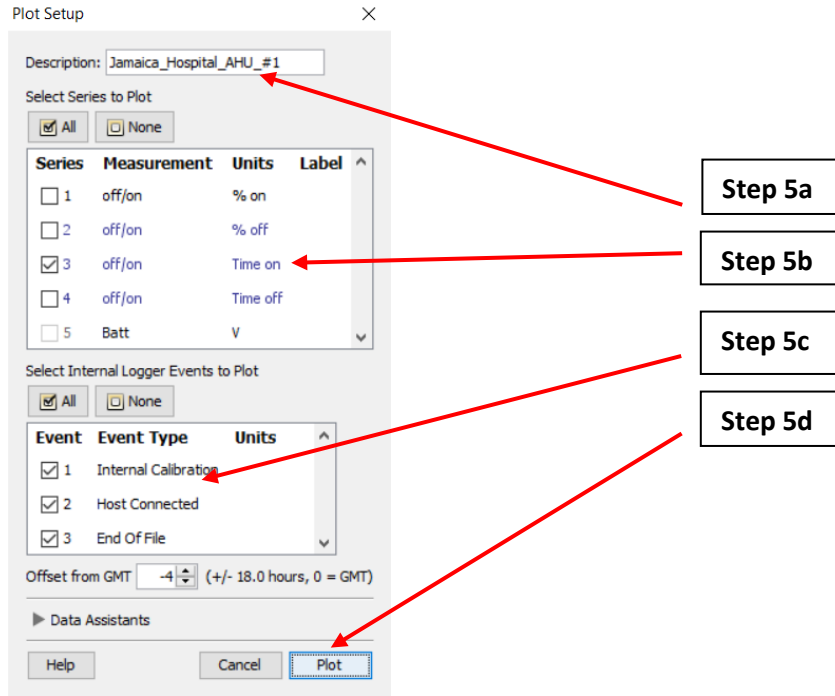


Figure A.1.14: “Plot Setup” pop-up window with the corresponding steps.

6. After following step 5, HOBOWare will open a new tab with data from the logger. Focus your attention on the “Data Table” pane at the top of the window. Here you will see:
 - a. The date and time of the logged data stored in the first column.
 - b. The amount of time the motor was detected to be on each hour, stored the second column.

#	Time, GMT-04:00	off/on, Time on (hh:mm:ss)	Internal Calibration	Host Connected	End Of File
1	03/10/20 10:00:00 PM		Logged		
2	03/10/20 11:00:00 PM	00:06:56			
3	03/11/20 12:00:00 AM	00:00:00			
4	03/11/20 01:00:00 AM	00:00:00			
5	03/11/20 02:00:00 AM	00:00:00			
6	03/11/20 03:00:00 AM	00:00:00			

Figure A.1.15: HOBOWare Data Table pane.

7. Scroll through the table and assess the collected data to ensure that the measured operational time corresponds to expected AHU fan motor operation.
 - a. For example, the motor in Figure A.1.15 was detected to be on for 6 minutes and 56 seconds between the hours of 11 PM and 12 AM. The motor was off for remaining hours.
8. If the measured data is unusual or inaccurate based on your understanding of the system, then the Onset HOBOWare Motor On/Off Data Logger may need to be recalibrated.

A.1.7: Exporting Data from the Onset HOBO Motor On/Off Data Logger to a .csv File

After the allotted measurement period (based on the measurement guide) the entire dataset can be extracted and used to calculate the annual electricity consumption of the fan motor.

1. At the end of the measurement period, follow the procedure in section A.1.6 to verify that the collected data is accurate.
2. If satisfied with the accuracy of the measurements, click the “Stop Logging” button on the top left corner of the screen (Figure A.1.16).

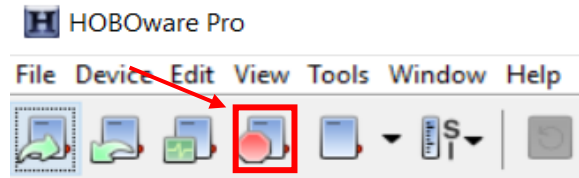


Figure A.1.16: HOBOWare “Stop Logging” Button.

3. Click “File” > “Export Table Data” (Figure A.1.17).

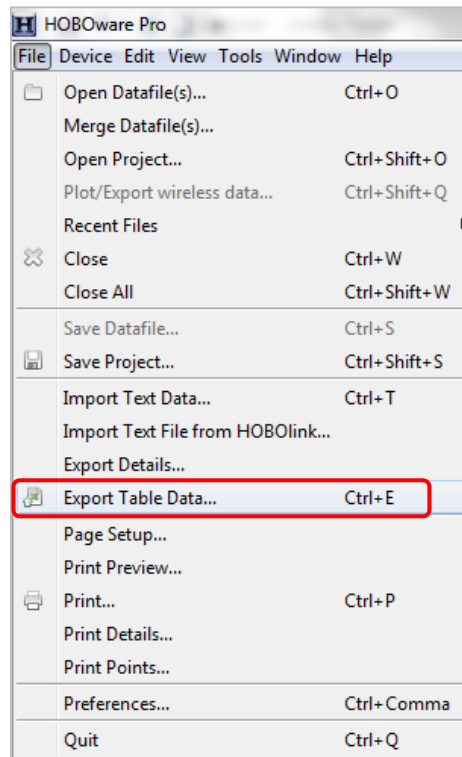


Figure A.1.17: File menu options.

4. The “Export” window will open and display the data available to export (Figure A.1.18).
5. Select “off/on” and uncheck all other boxes.

6. Click “Export...” to export the data.

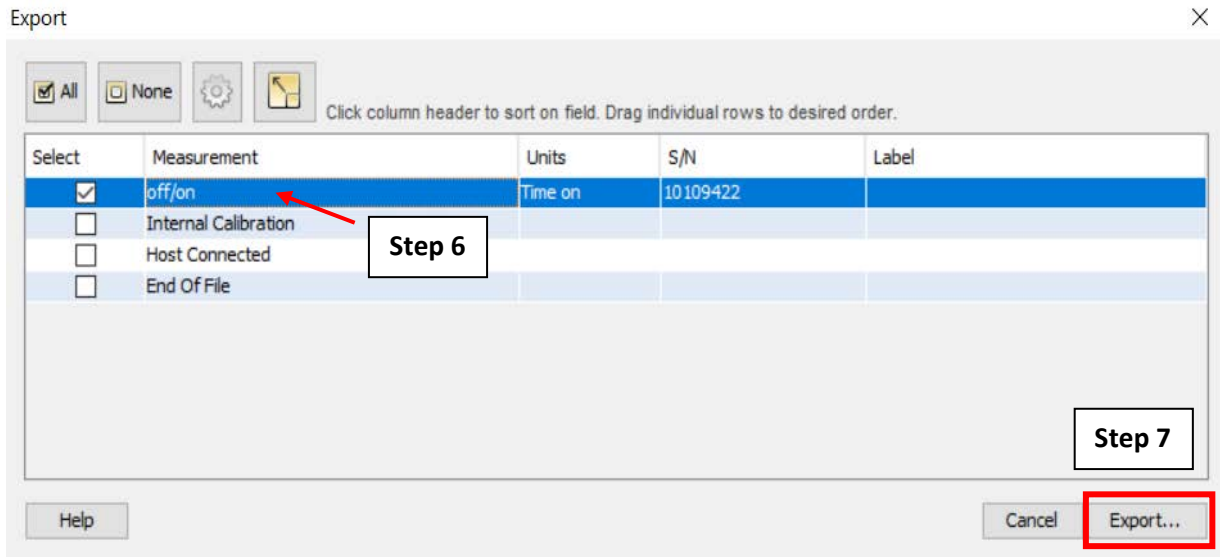


Figure A.1.18: The “Export” pop-up window and corresponding steps.

7. Choose a location to save the file.
8. Name the file the same way as step 1 of section A.1.2.
9. Click “Save” to complete the .csv exporting process.

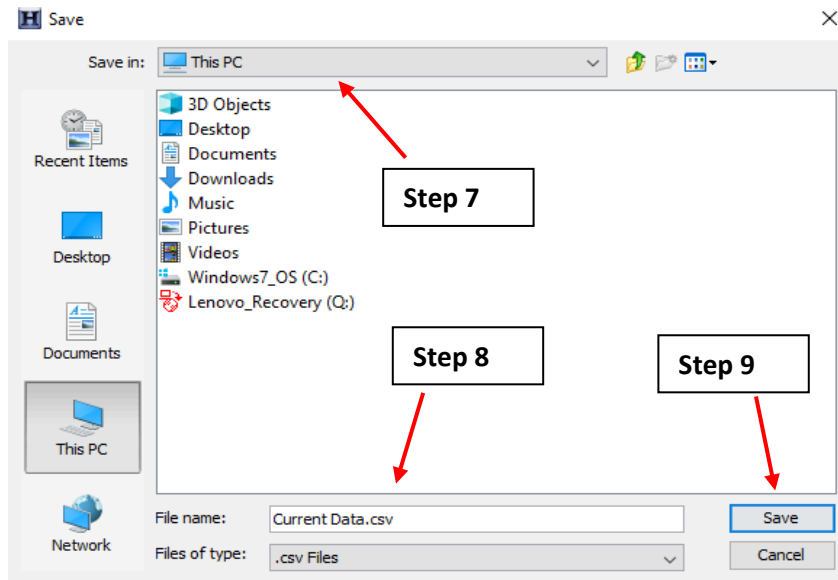


Figure A.1.19: “Save” pop-up window.

A.2: Fluke 345 Power Quality Clamp Meter

When obtaining the Fluke 345 Clamp Meter from the CUNY BPL FELL, ensure that alligator clips are connected to the “COM” and “V” ports located on the bottom of the Fluke 345 Clamp Meter. The alligator clips are required in order to make the necessary connections between the clamp meter and the metal contacts in the panelboard.

A.2.1: Fluke 345 Clamp Meter Field Setup

This section will guide you through the field setup of the Fluke 345 Clamp Meter. Please exercise the appropriate safety precautions during installation. Please ensure that the appropriate building electrician is present to guide you through the components necessary for data collection.

1. Please ensure that the building electrician shuts off the current before installing any of the equipment. **Failure to do so could result in electrocution.**
2. Have the building electrician identify connections necessary to collect measurements from the panelboard.
3. Turn the clamp meter on and set it to measure voltage, current, and power factor on the True Power setting of the meter by turning the dial to “W”.
4. Identify the wire to be measured based on the leg which the current meter is attached to. The clamp meter should always be used to measure the true power for the same leg on which current is being trended. There are a set of 3 wires present in the panelboard that must be identified:
 - a. If there is no VFD present, the clamp arm should be wrapped around one of the wires going directly to the system component from which power is being measured.
 - b. If a VFD is present, the clamp arm should be wrapped around one of the wires going into the VFD.
5. The alligator clips (attached to the clamp meter at the “COM” and “V” ports on the bottom of the Fluke 345 Clamp meter) should be attached to each of the other two legs of the circuit at metal contacts. Attach one alligator clip to one metal contact and the other clip to the other contact. It does not matter which alligator clip is attached to which contact. Please view Figures Figure A.2.3 and Figure A.2.4 to see how the clamp meter was installed on a typical AHU panelboard at Woodhull Hospital.
 - a. Note that additional probes are available to replace the alligator clips for panels which don't have easily accessible metal contacts.



Figure A.2.1: Fluke 345 Clamp Meter

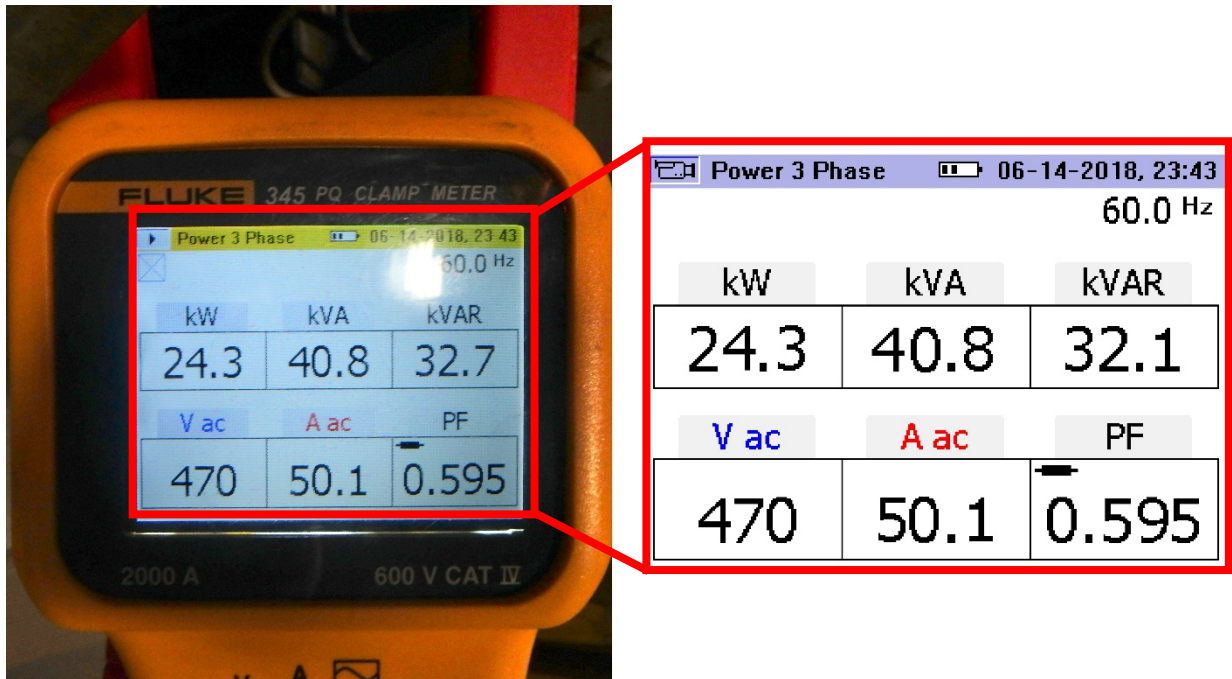


Figure A.2.2: Fluke 345 clamp meter screen with dial set to "W".



Figure A.2.3: Placement of probes onto panelboard (Woodhull Hospital)



Figure A.2.4: Clamp arms around wire (Woodhull Hospital).

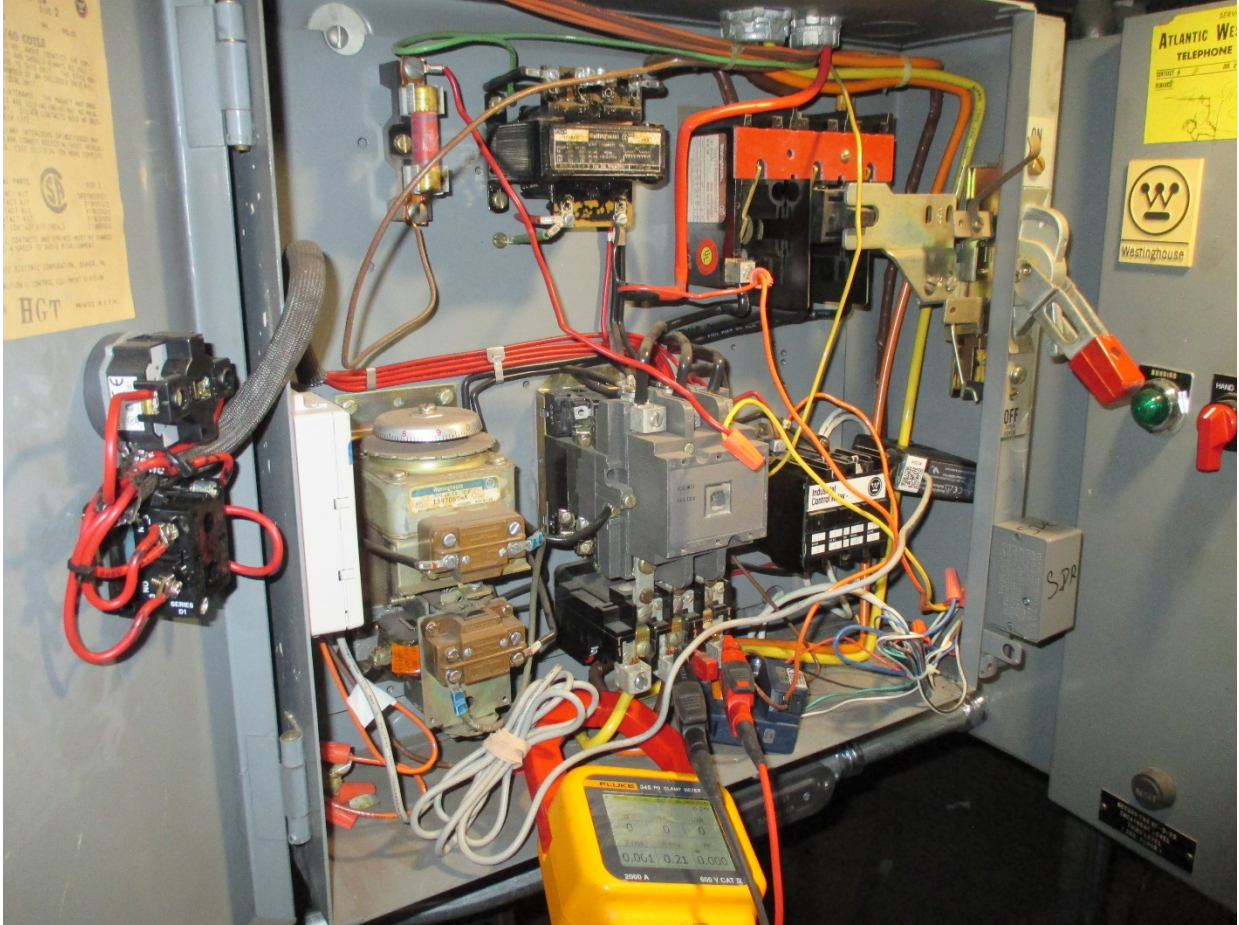


Figure A.2.5: Panelboard with Fluke 345 clamp meter installed obtaining measurements (Woodhull Hospital).

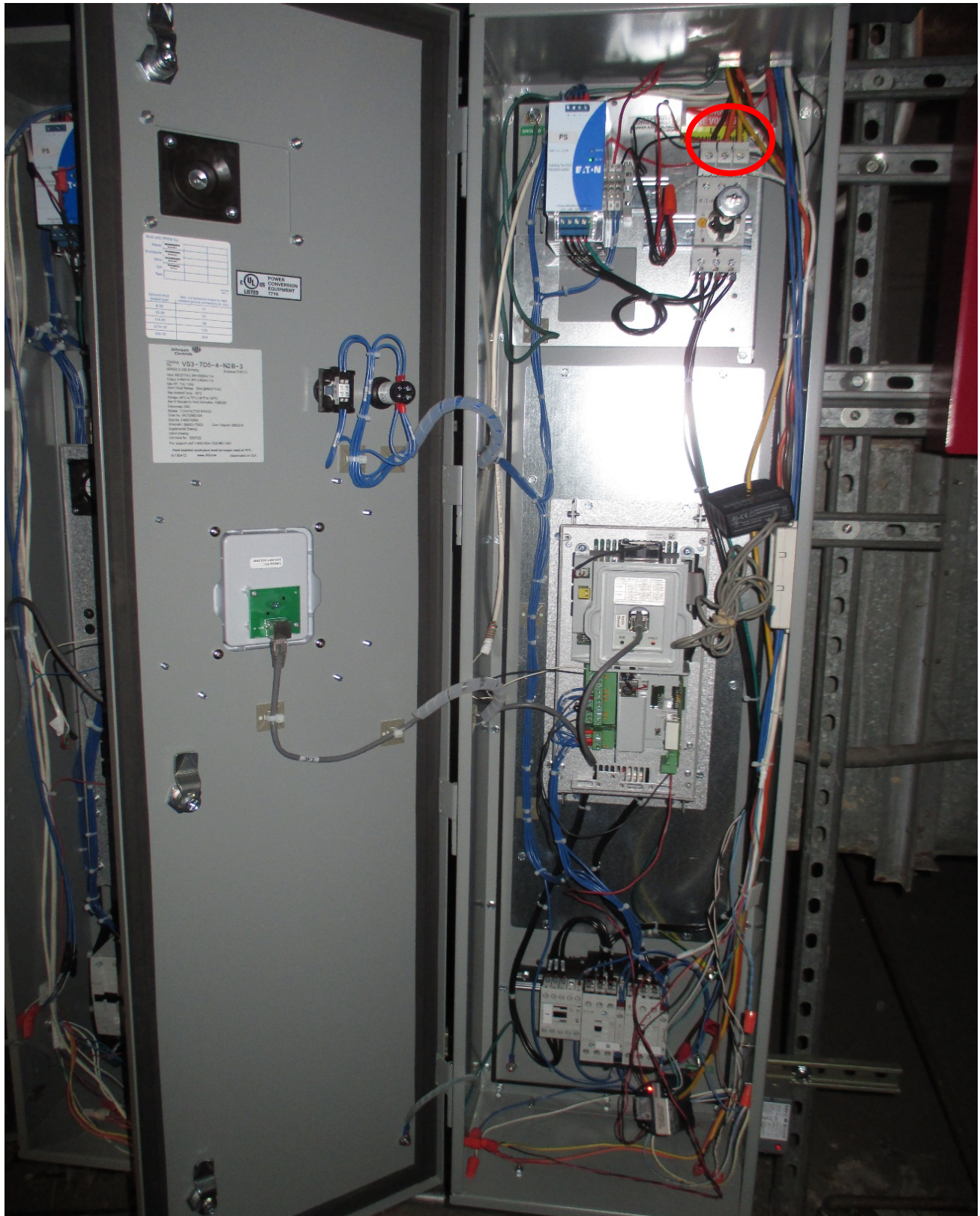


Figure A.2.6: VFD Panelboard. Measurement points are circled in red (Woodhull Hospital).

A.2.2: Taking Screenshots of the Fluke 345 Clamp Meter Readings

After installation of the Fluke 345 clamp meter by following section A.2.1, it is now possible to take true RMS power readings of the panelboard. The Fluke 345 Clamp Meter can take screenshots of these measurement readings. This section provides steps on how to obtain these screenshots. Please exercise extreme caution when obtaining screenshots while the Fluke 345 clamp meter is installed onto the panelboard.

1. Make sure to follow section A.2.1 before proceeding. At this point, the Fluke 345 Clamp Meter should be installed, and the system should have been turned off by the building electrician.
2. Make sure the parameters (kW, kVA, kVAR, V ac, A ac, PF) that are displayed on the clamp meter screen are the same parameters that are displayed in Figure A.2.2.
3. Have the building electrician switch on the system. Wait until the numbers on the screen have reached steady state before proceeding to Step 3.
4. Press the “ENTER/SAVE” button, which is boxed out in Figure A.2.1, to initiate the screen saving which will display a screen similar to what is shown in Figure A.2.7.

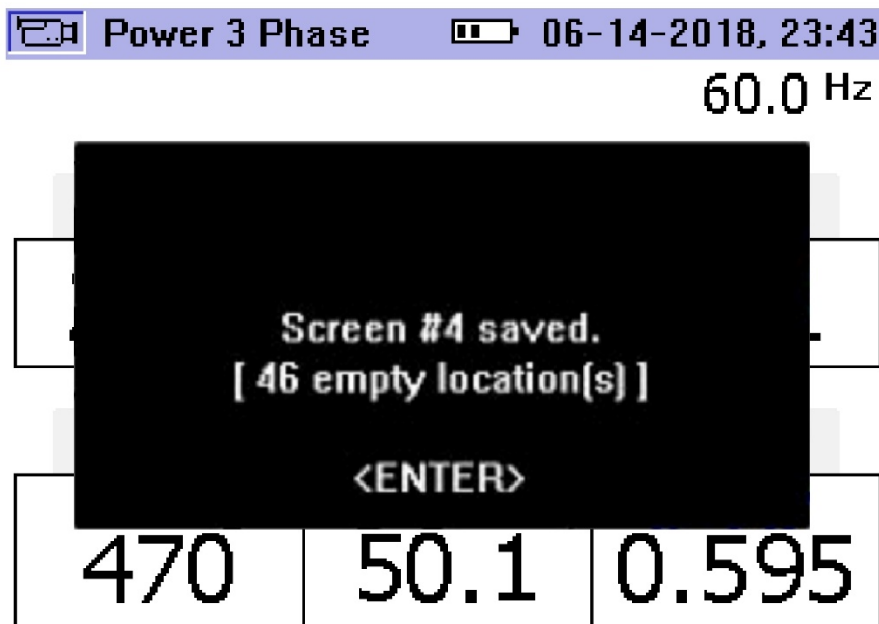


Figure A.2.7: Fluke 345 Screenshot saved screen.

5. Press the “ENTER/SAVE” button again to accept the screen displayed. There is a maximum of 50 screenshots that can be saved at a time. Once the number of screenshots has exceeded 50, the previous initial screenshots are replaced with new screenshots.
6. Once the screenshot has been saved onto the clamp meter, repeat steps 2, 3, and 4 if multiple screenshots must be taken.

- The saved screens can be viewed by pressing the “MENU/ESC” button right next to the “ENTER/SAVE” button, then highlighting the “View/Delete Screens” option and pressing the “ENTER/SAVE” button again, which will take you to the “View/Delete” screen shown in figure A.2.8.

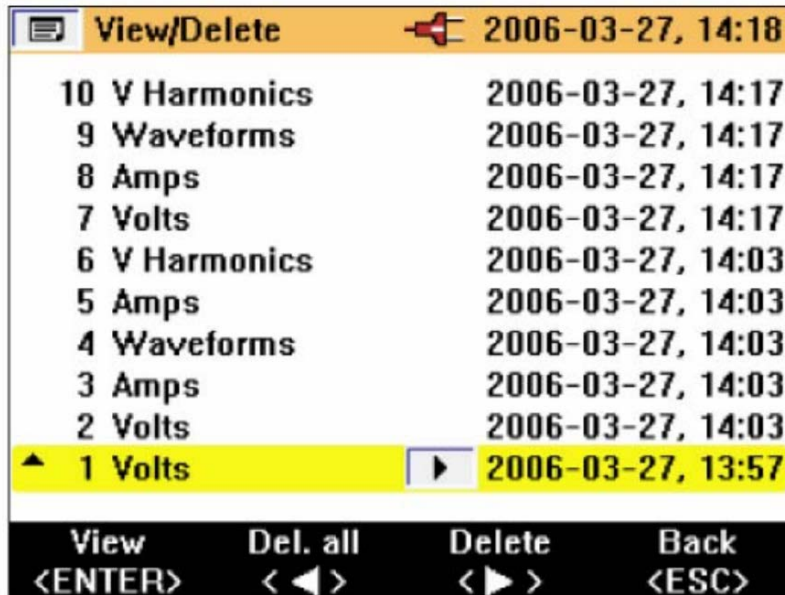


Figure A.2.8: Saved screenshots menu.

- Use the up and down arrow keys located below the “ENTER/SAVE” button to select the required screen for viewing. When the required screen is highlighted, press the “ENTER/SAVE” button again to view the screenshot.

A.3: DENT ELITEproXC Portable Power Data Logger

Sections A.3.1, A.3.3, A.3.4, A.3.5, and A.3.6 will require the use of the ELOG19 software. The ELOG19 software will be provided through a mini USB drive provided by the CUNY BPL FELL.

Please ensure that the CTs and alligator clips are connected to the DENT ELITEproXC Portable Power Data Logger when retrieving them from the CUNY BPL FELL. If not, please ask the CUNY BPL FELL personnel to make the connections for you.

A.3.1: Dent ELITEproXC Power Meter Initial Setup

This section provides steps on how to perform an initial setup of the Dent ELITEproXC power meter. This section will set up the meter to record measurements with the 16” Flexible CTs which are preconnected to the Dent power meter. This section including subsequent sections starting with “A.3” will require the use of the ELOG19 software, which can be downloaded from a mini USB drive provided by the CUNY BPL FELL.

- Open the ELOG19 software, which will cause the initial startup screen to appear as shown in Figure A.3.1. After opening the software, connect the Dent ELITEproXC Power Meter to the computer with the supplied USB cable.



Figure A.3.1: ELOG19 Initial startup screen.

2. At the top of the window select the “Logger” tab (Figure A.3.2).
3. Select “Create New Logger Setup Table.” (Figure A.3.2).

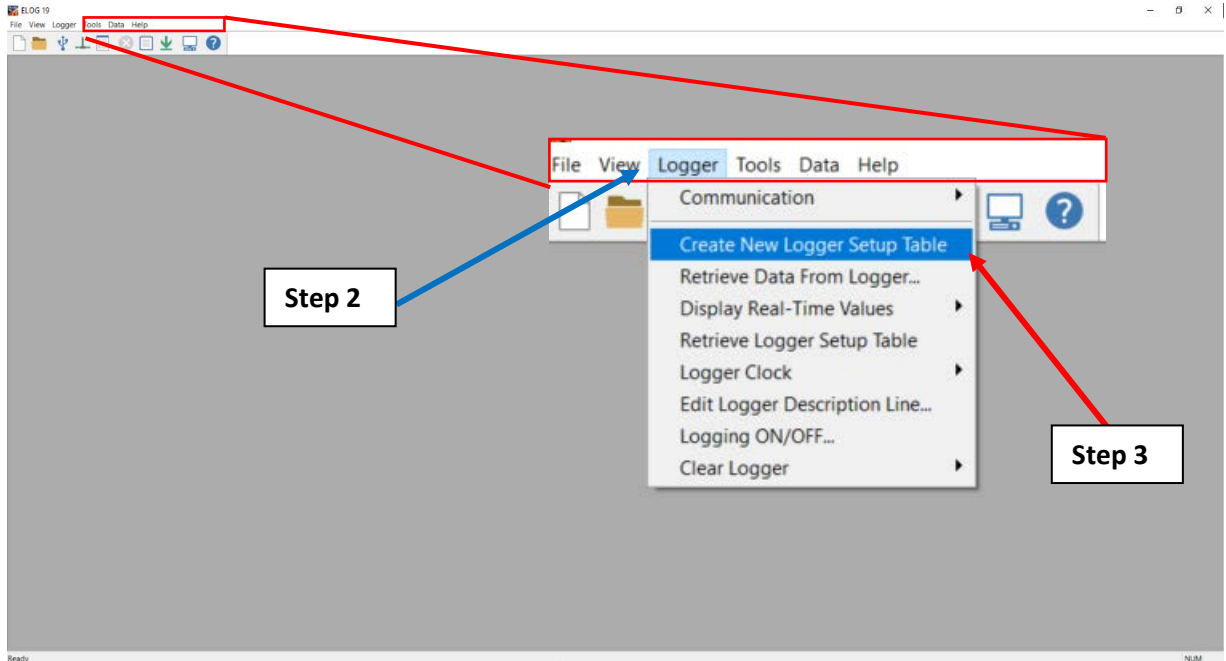


Figure A.3.2: Creation of New Logger Setup Table.

4. The “Select A Setup Table Type” pop-up window will appear (Figure A.3.3) after completing step 3. Select the “ELITEproXC” option (Figure A.3.3) from the dropdown menu.

5. Click "OK" (Figure A.3.3).

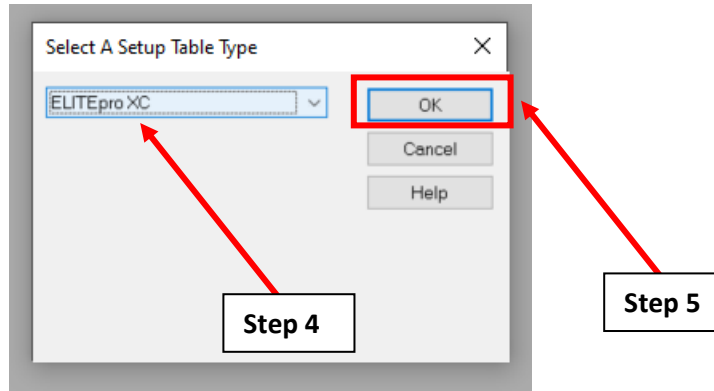


Figure A.3.3: Selection of a setup table type for the ELOG19 software.

6. The "Setup" table will open and appear as shown in Figure A.3.4. The sections boxed in red are relevant for this Dent ELITEproXC Power Meter setup. This guide will describe each section separately.

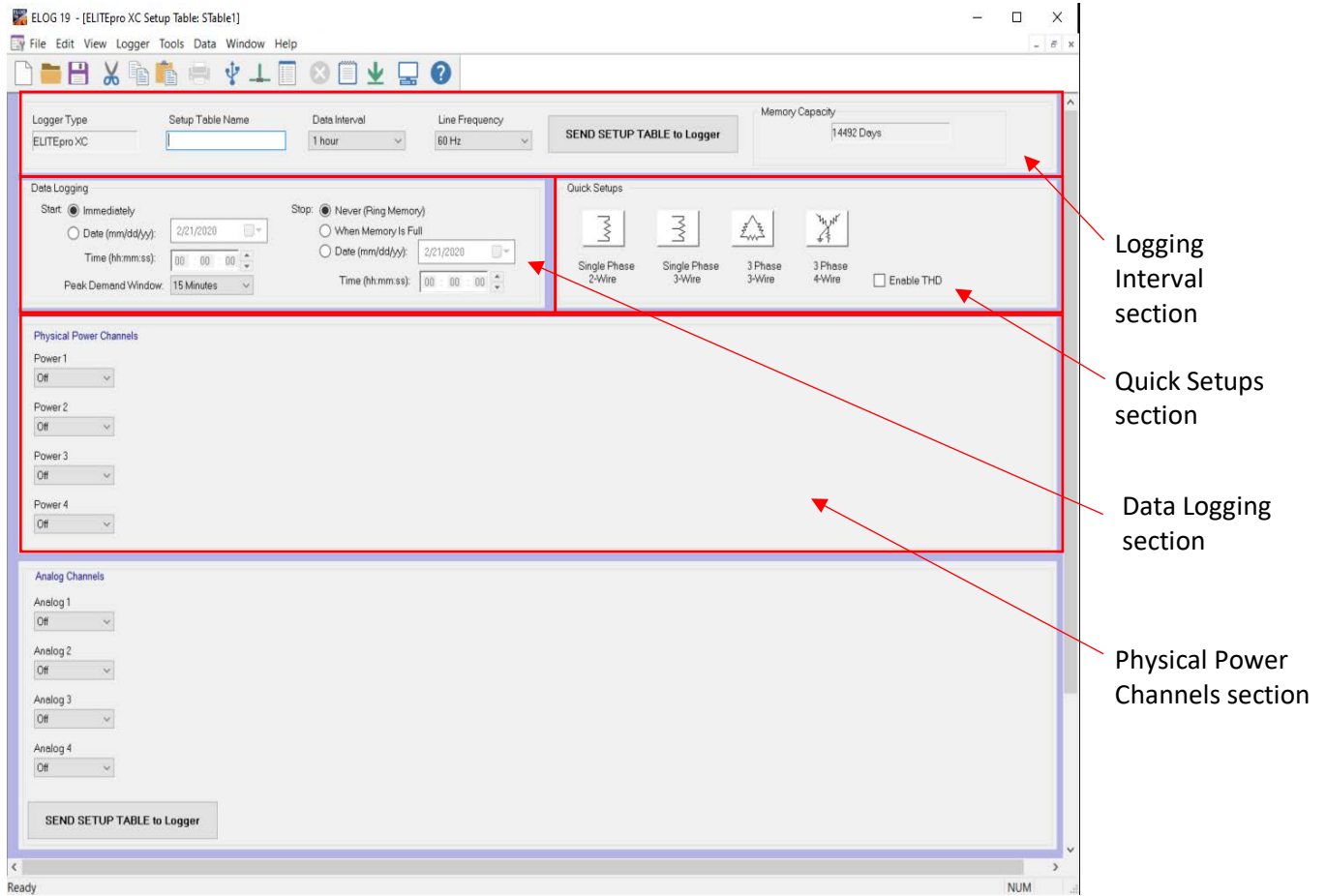


Figure A.3.4: ELITEproXC “Setup” table.

The following 4 subsections show which options to set for each of the red boxes in Figure A.3.4.

Logging Interval Section

The Logging Interval section allows for naming the table of data the Dent ELITEproXC Power Meter will collect as shown on Figure A.3.5.

1. Leave the “Setup Table Name” box alone as shown in Figure A.3.4. We will assign a name to the data collected after setting up the Quick Setups section.
2. In the “Data Interval” dropdown menu, select “1 hour”.



Figure A.3.5: What to fill in for the top box of the ELITEproXC “Setup” table.

Data Logging Section

This section configures the start and stop time for collecting data as shown on Figure A.3.6.

1. On the left side labelled “Start”, click “Date” and set a date and time to **begin** collecting data with the Dent meter.
2. On the right side labelled “Stop” set the date to **four weeks after** the start date and time. The Dent meter is now set to collect four weeks maximum of data.

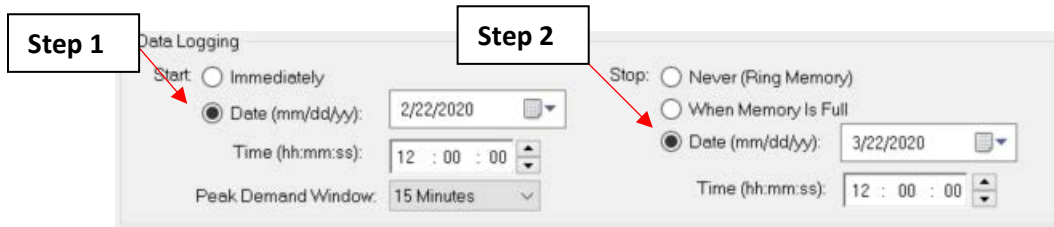


Figure A.3.6: Data Logging configuration.

Quick Setups Section

In this section, you select the configuration of the electric panel that feeds the motor. Typically, panels are 3 phase - 3 wire or 3 phase - 4 wire but the setup process will be the same.

1. Select the configuration in the Quick Setups section that best matches your panelboard configuration. In Figure A.3.7, “3 Phase 3-Wire” selected as an example.
2. A new window will pop up called “CT Selection”. In this pop-up window, select “RoCoil (Rogowski)”.
3. Click “Ok” which completes the setting up of the Quick Setups section.

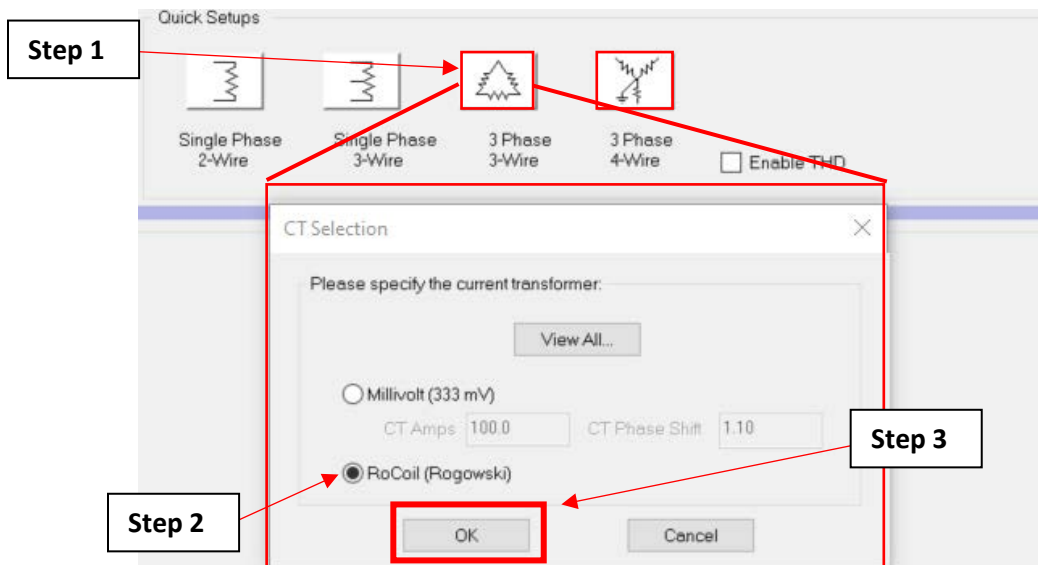


Figure A.3.7: CT Selection popup window.

4. Take note of the changes that have occurred in “Setup” table:

Change 1: The “Physical Power Channels” section shown in Figure A.3.4 along with the rest of the underlying sections has changed to what is shown in Figure A.3.8. The “Physical Power Channels” section has expanded to allow the configuration of each sensor connected to the Dent ELITEproXC Power Meter.

Change 2: An additional section will have appeared labelled “Calculated Power Channels”, located right under the updated “Physical Power Channels” section.

The Dent ELITEproXC Power Meter will come equipped with three sensors that are automatically labelled “L1 Phase”, “L2 Phase”, and “L3 Phase” in the “Name” boxes of the “Physical Power Channels” section. **Leave these names as is.**

5. In the “Name” field, enter a meaningful label. Ideally, the “Name” field should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - a. For example, for an AHU system, we can set a name with the facility’s name, the AHU number, and whether it’s a supply or return fan in this format:
facilityname_ahunumber_supply OR *facilityname_ahunumber_return*.

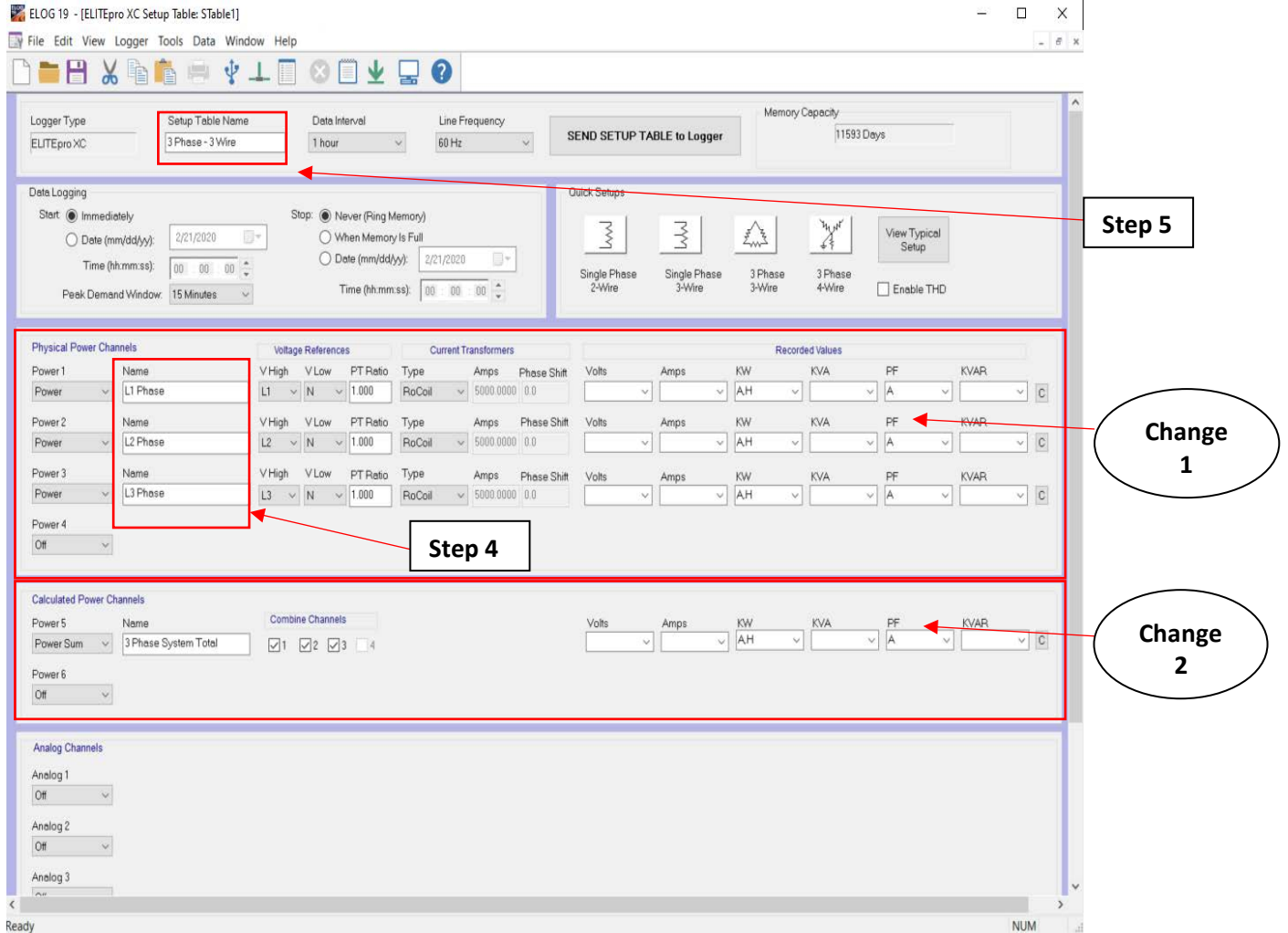


Figure A.3.8: ELITEproXC Setup Table with a different Physical Power Channels section.

Physical Power Channels Section

This section is where you configure what type of data to collect. the CUNY BPL FELL provides 3 Dent RoCoil Flexible CTs (Current Transformers) (Model # CT-R16-A4-U) already attached to the Dent ELITEproXC Power Meter. As a result, the ELOG19 software will recognize them and set a default name for each of the sensors; "L1 Phase", "L2 Phase", and "L3 Phase" as shown on Figure A.3.9.

1. Click the dropdown menu for "KW" for all three physical power channels and select the "Average" and "KWh" checkboxes.
2. Uncheck all boxes for the remaining variables for all three physical power channels (Volts, Amps, KVA, PF and KVAR).

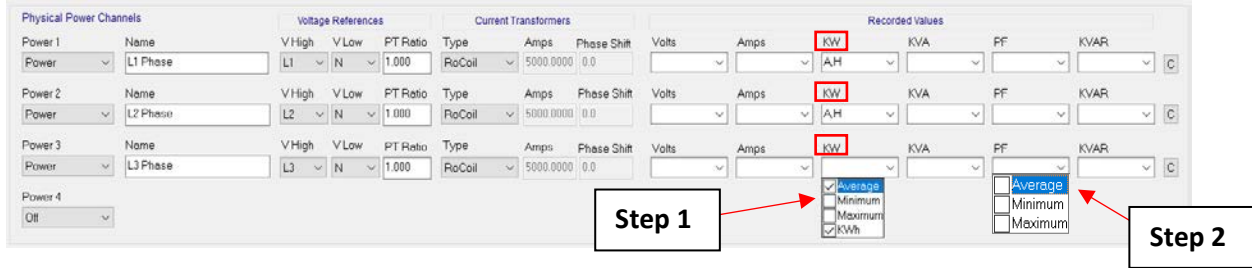


Figure A.3.9: The Physical Power Channels section.

Calculated Power Channels Section

The Dent ELITEproXC Power Meter can sum the measured values collected by each of the sensors. After extracting data, you can view the power acquired by each sensor as well as the total sum.

1. Click on the “KW” dropdown menu in the Calculated Power Channels section and click on the “Average” and “kWh” checkboxes. Once this is done, the letters “AH” should appear in the “KW” dropdown menu. Leave all other variables blank.
2. Ensure the first 3 boxes are checked in the “Combine Channels” option. The 4th box should be greyed out.



Figure A.3.10: The Calculated Power Channels section.

All 4 sections outlined in Figure A.3.4 have now been properly set to record power measurements. These parameters are ready to be sent to the Dent ELITEproXC Power Meter.

1. Click on “SEND SETUP TABLE to Logger.”
2. A new window will appear, click “Send SUT and Delete Data”.

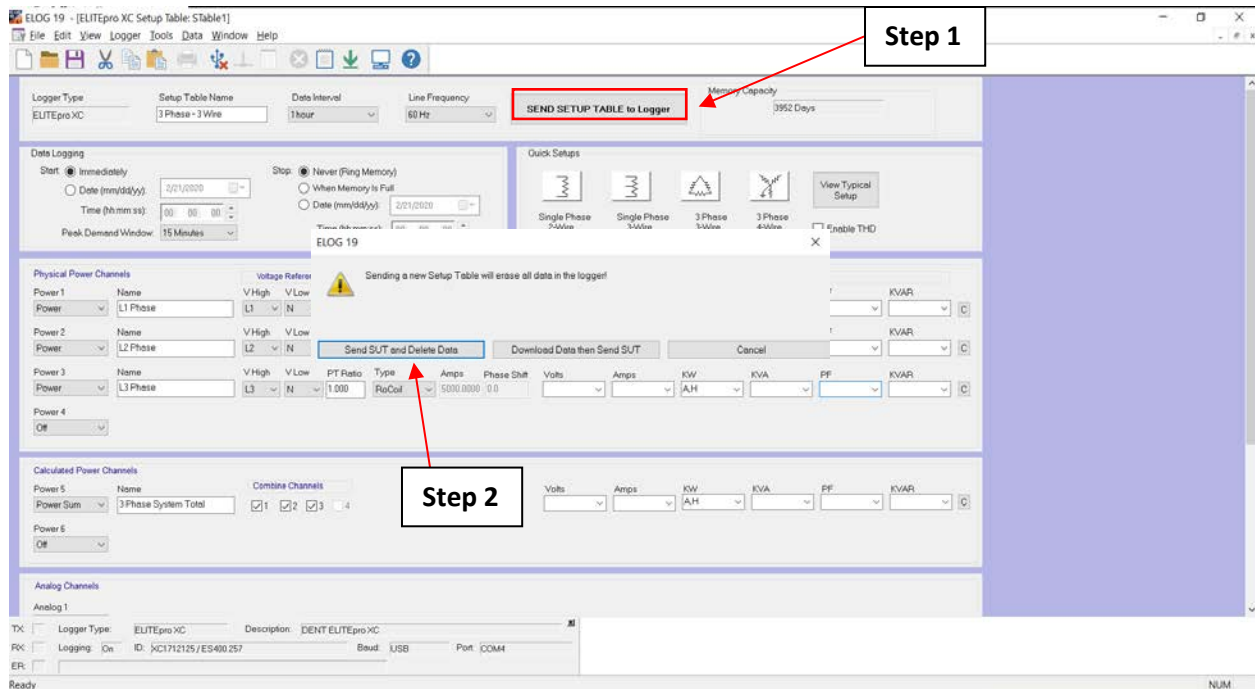


Figure A.3.11: Completion of initial sensor setup.

The Dent ELITEproXC Power Meter setup process is complete. You may now follow along section A.3.2 to setup the logger at the field site after disconnecting the device from your computer.

For more information on how to setup the Dent ELITEproXC refer to the video “Launching Elite pro meter” on the CUNY BPL YouTube channel:

https://www.youtube.com/watch?time_continue=312&v=DuklsskdK9k&feature=emb_title

A.3.2: Dent ELITEproXC Power Meter Field Setup

This section and section A.3.3 will guide you through the field setup of the Dent ELITEproXC Power Meter. Please exercise the appropriate safety precautions while performing the field setup.

1. Someone familiar with the building’s system should identify the control panel(s) for the target AHU(s).
2. At the panel, ensure that the components have been checked to make sure that **no current** is flowing once the AHU has been turned off. **Failure to do so could result in death.**
3. Since the back of the power meter has 4 magnets, the meter can be placed onto any magnetic surface. Place the Dent meter onto the side inner walls of the panelboard. Alternatively, if the side inter walls of the panelboard are too narrow, place the Dent ELITEproXC Power Meter on the panelboard door. Ensure that the panelboard door can be closed fully with the Dent ELITEproXC power meter either attached to the door, as shown on Figure A.3.13, or placed on the side inner wall of the panelboard.

A.3.3: CT (Current Transformer) and Alligator Clip Installation

In the Quick Setups Section of section A.3.1, the configuration of the electric panel was chosen to be 3 phase – 3 wire. The Dent meter provided by the CUNY BPL FELL comes with 3 CTs and 4 alligator clips pre-connected to the Dent meter. 3 CTs needed to be pre-connected to the Dent meter in accordance with the 3 phase – 3 wire selection.

1. Open the CT with the **black tape** (shown on the bottom left of Figure A.3.14) by squeezing the connector latch and pulling the CT apart.
2. Look at the arrow on the CT as shown on Figure A.3.12. The direction of the arrow should align with the direction of current flow, if this is known. If the arrow pointed opposite the direction of the load, the collected power measurements would have a negative sign, which can be disregarded.

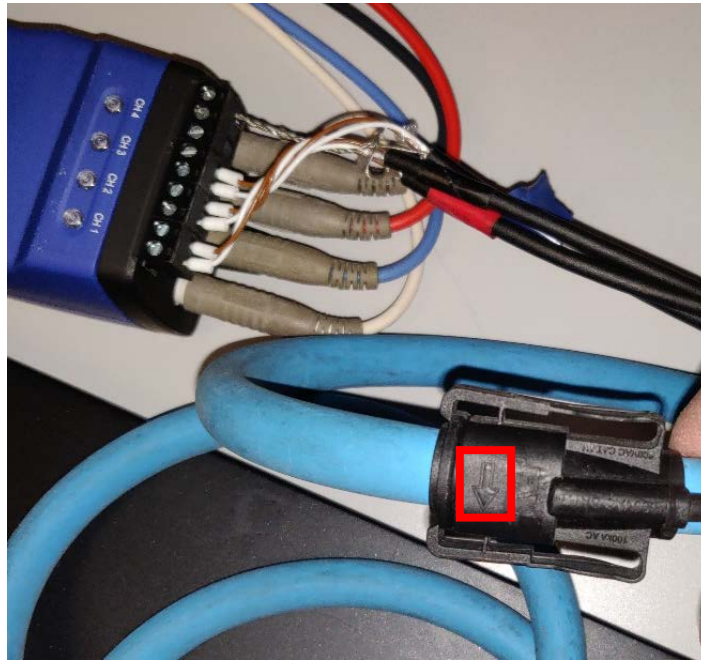
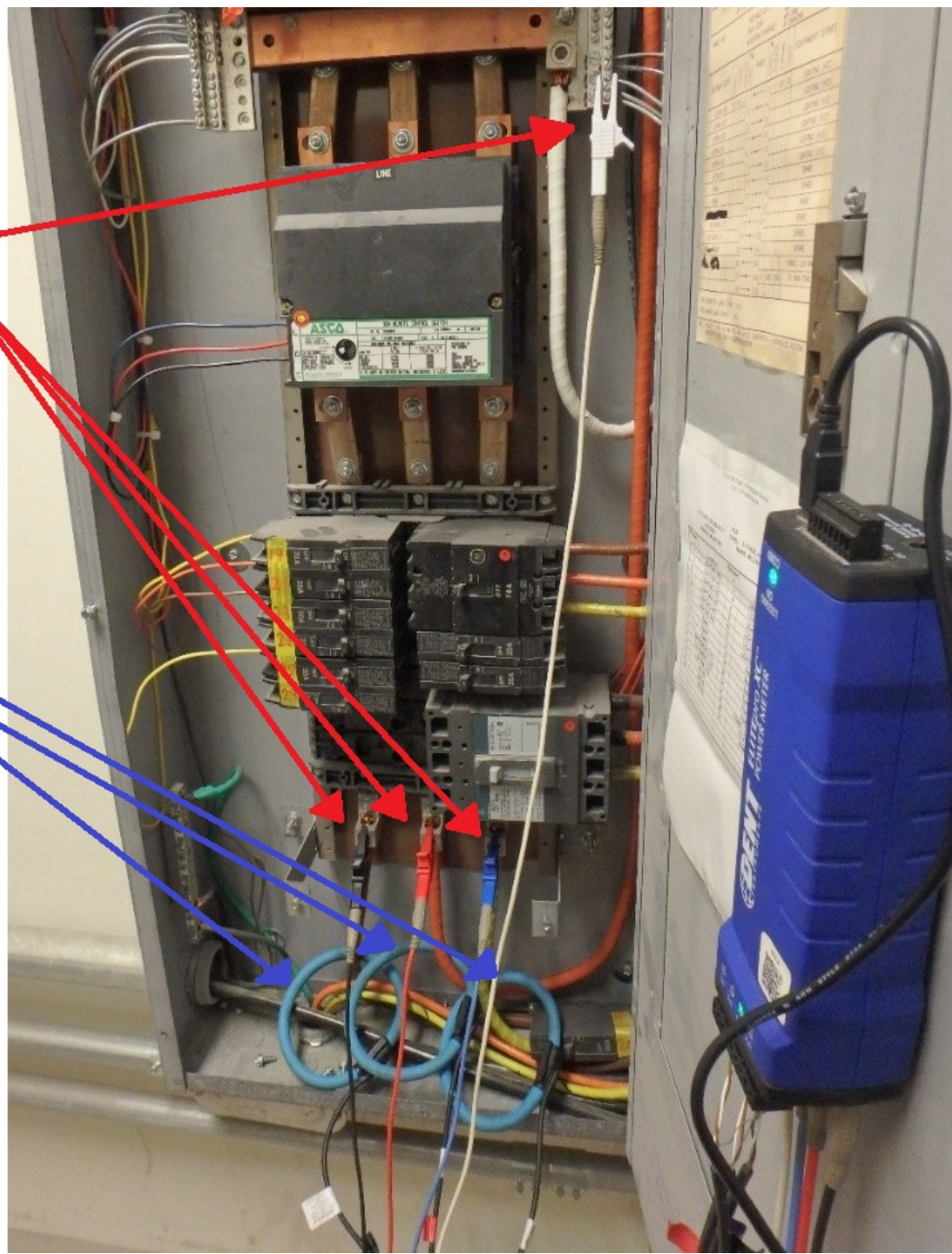


Figure A.3.12: Flexible CT.

3. Place the open CT around the brown wire¹ as shown on Figure A.3.13 and push the connector back together, making sure that the brown wire is around the CT loop as shown on Figure A.3.14. Figures Figure A.3.13 and Figure A.3.14 depict a Dent meter field setup for a typical panelboard.
4. Repeat steps 1 to 3 for the other two CTs, installing the CT with the **red tape** to the orange wire on the panelboard, and the CT with the **blue tape** to the yellow wire on the panelboard as shown on Figure A.3.14.

¹ Wire colors may differ between panelboards. It is commonplace to see black, red, and blue wires in the panelboard in place of brown, orange, and yellow wires. This guide follows the US AC power circuit wiring color codes (<https://www.allaboutcircuits.com/textbook/reference/chpt-2/wiring-color-codes/>).

5. There are a set of 4 alligator clips which come pre-connected to the Dent meter. It is imperative that the neutral wire, represented by the white clip, is attached to earth ground, shown on Figure A.3.13.
6. For the rest of the alligator clips: similar to how the CT with the black tape was connected around the brown wire, the **black alligator clip** should be connected to the voltage source denoted by the brown wire, the **red alligator clip** to the orange wire, and the **blue alligator clip** to the yellow wire. The alligator clip connections for a typical panelboard are depicted in Figure A.3.14.



Alligator clips

Flexible CTs

Dent meter

Figure A.3.13: Completed Dent meter field setup.

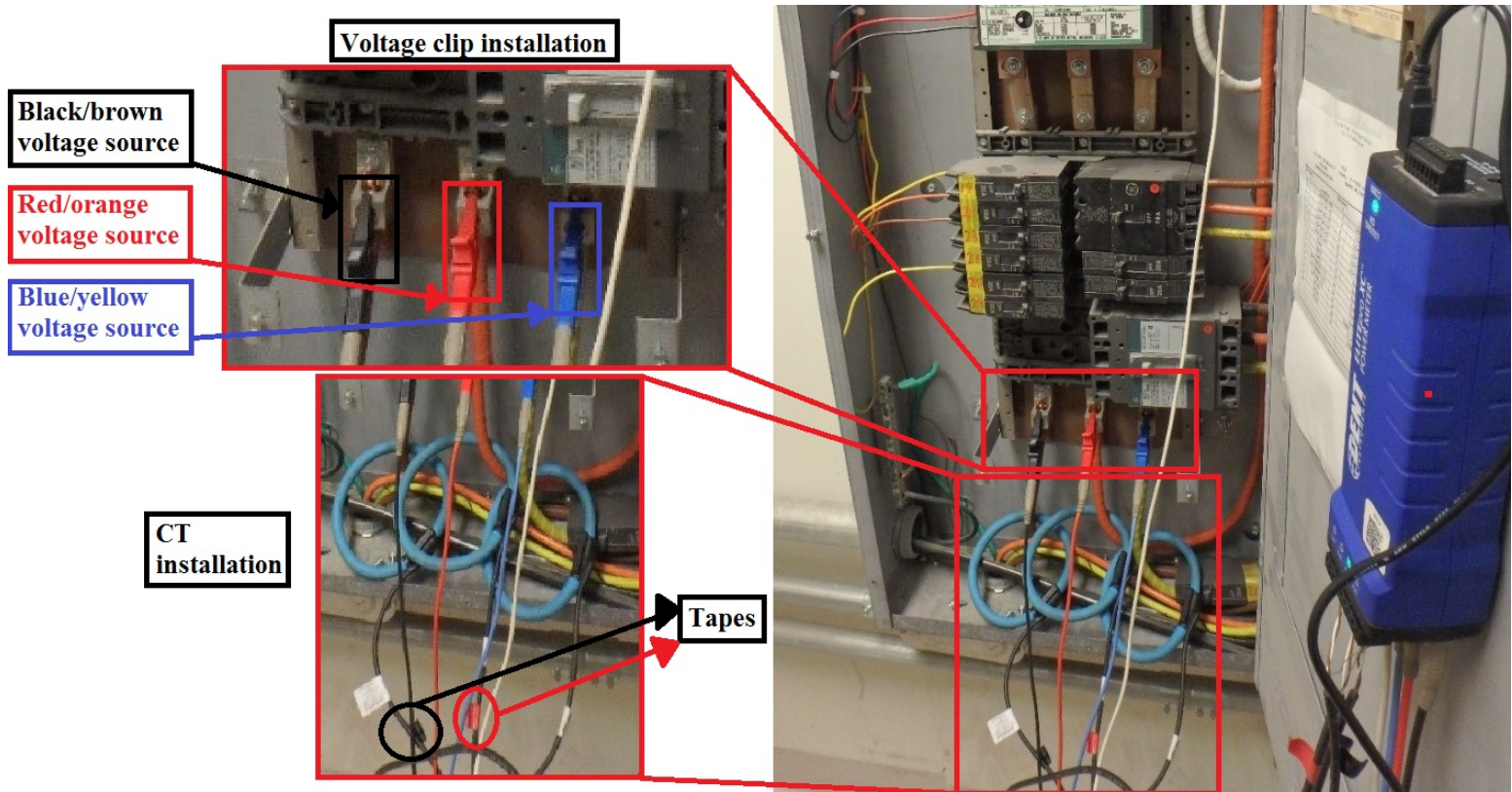


Figure A.3.14: Voltage clip and CT installation on a typical panelboard.

7. Turn the power to the system back on. Field setup is complete.

A.3.4: Dent ELITEproXC Power Meter Field Site Removal

This section will guide you on how to extract the Dent ELITEproXC Power Meter from the panelboard after the measurement period has elapsed or for recalibration if after following section A.3.5 the data is inconsistent with your expectations.

1. Have the accompanying electrician turn off the AHU system to which the Dent ELITEproXC Power Meter is attached.
2. At the panel, ensure that the components have been checked to make sure that **no current** is flowing once the AHU has been turned off. **Failure to do so could result in death. Do NOT remove the Dent meter if current is present.**
3. Once it has been verified that no current flows through the AHU, the Dent meter can then be extracted from the panelboard for data verification and extraction.
4. Reinstallation of the motor once the data has been verified can be done by refollowing section A.3.3.

A.3.5: Dent ELITEproXC Power Meter Data Extraction

This section will guide you on how to extract the recorded values from the Dent ELITEproXC power meter which can be analyzed for data integrity and accuracy. **Exercise extreme caution when analyzing the data while the Dent ELITEproXC Power Meter is installed onto the panelboard. Have the building electrician assist you for this section.**

1. In the ELOG19 software click on “Logger”.
2. In the small window that pops up, click on “Retrieve Data From Logger...”

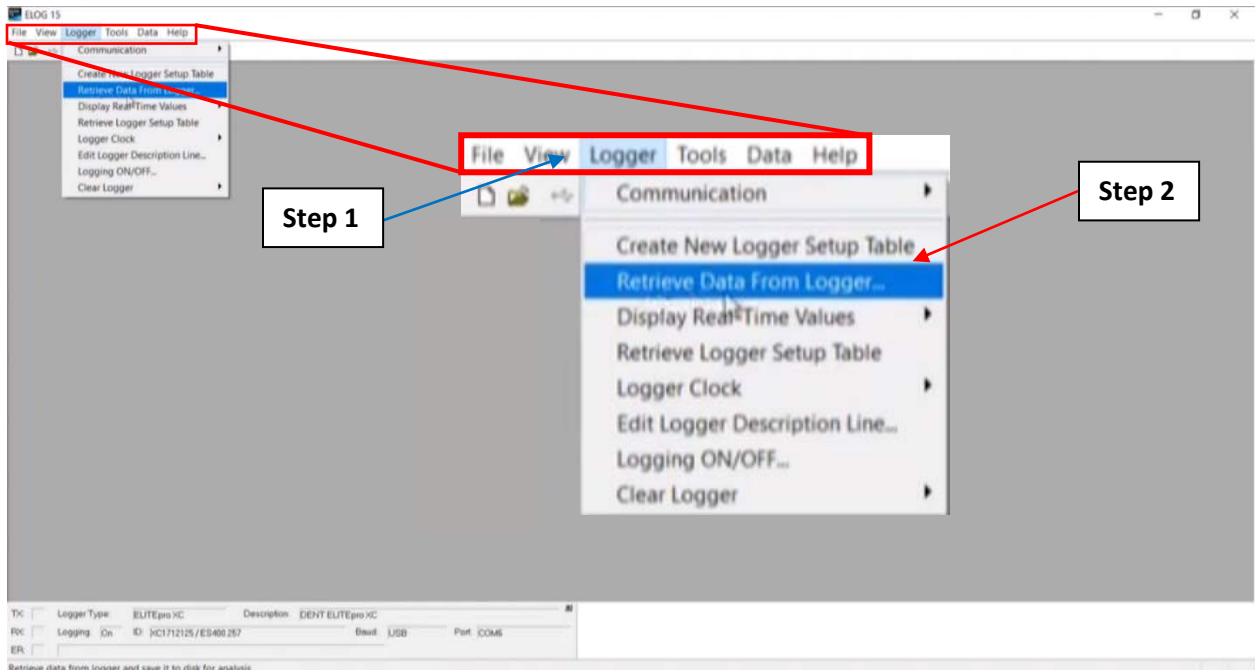


Figure A.3.15: Selecting the “Retrieve Data from Logger...” option from the ELOG19 software.

3. A new window will open that will prompt you to save the .ELOG file on your system as shown on Figure A.3.16. Name the file with the same format that was used in step 5 of the Quick Setups Section.
4. Find an appropriate file destination then click “Save” (Figure A.3.16).

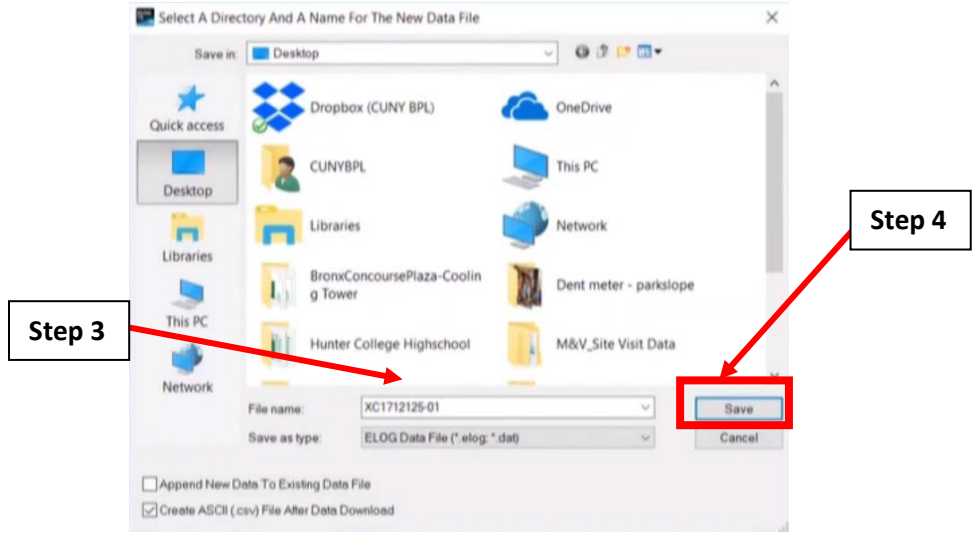


Figure A.3.16: The "Save As" window.

	Record Date	Record End Time	Power 1 Min. Volt L1 Phase	Power 1 Min. Time L1 Phase	Power 1 Max. Volt L1 Phase	Power 1 Max. Time L1 Phase	Power 1 Avg. Volt L1 Phase	Power 1 Min. Amp L1 Phase	Power 1 Min. Time L1 Phase	Power 1 Max. Amp L1 Phase	Power 1 Max. Time L1 Phase	Power 1 Avg. Amp L1 Phase
1	01/16/20	17:00:00	121.513	16:54:47	124.832	16:59:29	123.653	0.000	16:48:23	95.538	16:48:20	17.903
2	01/16/20	17:15:00	121.903	17:01:21	124.442	17:03:59	123.590	0.000	17:00:00	0.000	17:00:00	0.000
3	01/16/20	17:30:00	121.383	17:26:54	124.572	17:15:54	123.222	0.000	17:15:00	0.000	17:15:00	0.000
4	01/16/20	17:45:00	122.359	17:30:58	125.223	17:38:02	124.063	0.000	17:30:00	0.000	17:30:00	0.000
5	01/16/20	18:00:00	121.578	17:53:48	125.418	17:48:41	123.768	0.000	17:45:00	0.000	17:45:00	0.000
6	01/16/20	18:15:00	121.057	18:02:35	124.051	18:14:13	122.946	0.000	18:00:00	0.000	18:00:00	0.000
7	01/16/20	18:30:00	121.513	18:18:00	124.376	18:18:49	123.451	0.000	18:15:00	0.000	18:15:00	0.000
8	01/16/20	18:45:00	121.643	18:32:22	124.376	18:35:30	123.578	0.000	18:30:00	0.000	18:30:00	0.000
9	01/16/20	19:00:00	120.992	18:51:54	124.442	18:46:43	123.187	0.000	18:45:00	0.000	18:45:00	0.000
10	01/16/20	19:15:00	121.578	19:13:32	124.116	19:02:01	123.368	0.000	19:00:00	0.000	19:00:00	0.000
11	01/16/20	19:30:00	121.513	19:25:05	124.246	19:28:17	123.536	0.000	19:15:00	0.000	19:15:00	0.000
12	01/16/20	19:45:00	121.122	19:33:47	124.376	19:40:19	123.361	0.000	19:30:00	0.000	19:30:00	0.000
13	01/16/20	20:00:00	121.122	19:54:58	123.986	19:46:38	122.835	0.000	19:45:00	0.000	19:45:00	0.000
14	01/16/20	20:15:00	121.057	20:13:30	123.595	20:00:02	122.992	0.000	20:00:00	0.000	20:00:00	0.000
15	01/16/20	20:30:00	121.057	20:19:18	123.270	20:24:20	122.650	0.000	20:15:00	0.000	20:15:00	0.000

Figure A.3.17: Extracted data displayed as a table in ELOG19.

A new window will pop up in the ELOG19 software after following step 4. You will see a table with values as shown on Figure A.3.17. The table on Figure A.3.17 shows data the Dent Logger has collected over the measurement period. The top row lists the names of the measured quantities. The table is an example depiction of the different measured quantities arranged in a table. These measured quantities include, voltage, current, average voltage, average current, etc.. Your data will not be as dense and will include less columns.

- Columns with the name “Power 1” indicate the first channel or RoCoil that was taking measurements. Only “Power 1” is shown on Figure A.3.17.
- “Power 2” and “Power 3” are the other two RoCoil data measurements which are not shown in Figure A.3.17 but can be accessed in the table.
- “Power 5” is the sum of the measured data among all three RoCoils, this is the data that will be exported to Excel. This is also not shown in Figure A.3.17 but can be accessed on the table.

Take note of the second and third column to the left of the data table, they specify the date and time of the collected data. Examine the kWh and Average kW for Power 1, 2 and 3 for each time stamp and notice the trend. **Make sure that the data is consistent with your expectations.**

A.3.6: Exporting Data from the Dent ELITEpro Power Meter to a .csv File

- Click “File” > “Export Data to Excel Format (CSV)” as shown on Figure A.3.18.
- Find and click on the .ELOG file that was saved in step 4 of section A.3.5. Then, click “Open.”
- A “Save” pop-up window will be shown on your screen. Name the .csv file (it should be the same exact name as the .ELOG file), select a file destination, and click “Save.” (in a similar fashion to Figure A.3.16).

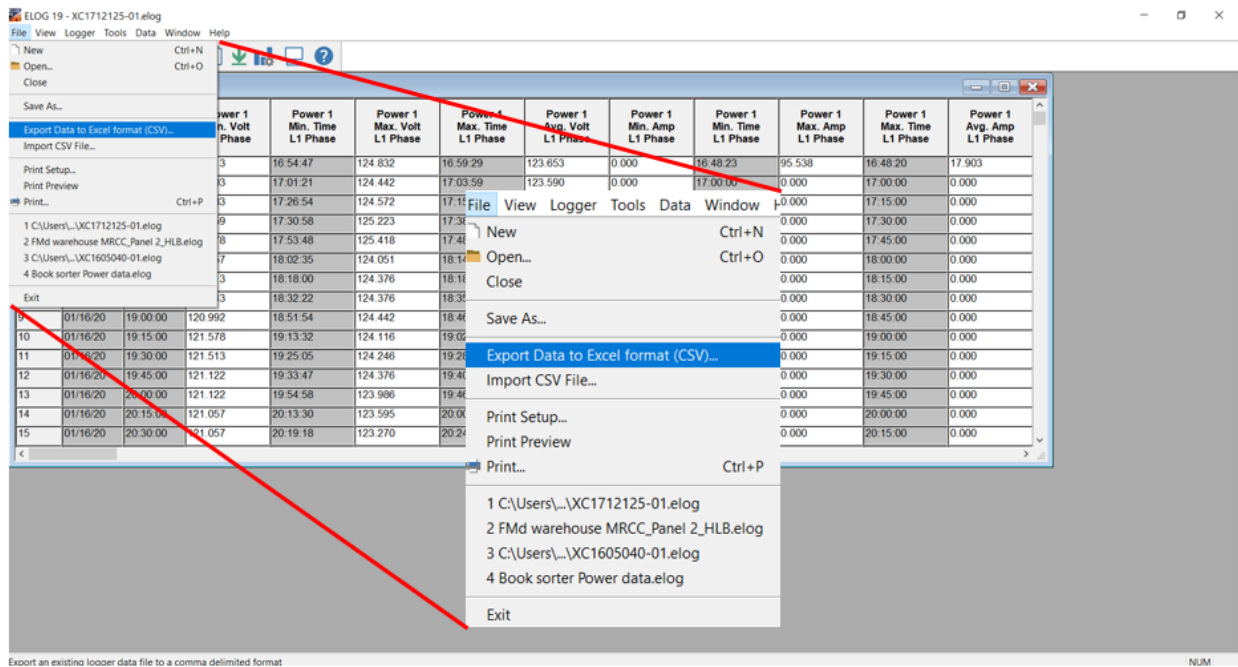


Figure A.3.18: Export data to .csv format in ELOG19.

A.4: Onset HOBO 4-Channel Analog Logger (UX120-006M) with Onset HOBO Split-Core Current Sensor

Sections A.4.1, A.4.2, A.4.3, A.4.5, and A.4.6 will require the use of the HOBOWare software. The HOBOWare software will be provided through a mini USB drive from the CUNY BPL FELL. Alternatively,

HOBOWare Free can be downloaded from the following website:

<https://www.onsetcomp.com/hoboware-free-download>.

When picking up the Onset HOBOWare 4-Channel Analog Logger from the CUNY BPL FELL, ensure that the sensor that is required to log the measurements for the M&V guide that you are following is connected to the logger. If not, please ask the CUNY BPL FELL personnel to assist you in making those connections.

A.4.1: Onset HOBOWare 4-Channel Analog Logger Connection to Computer

This section provides steps on how to connect the Onset HOBOWare 4-Channel Analog Logger to the computer. This is necessary in order to perform an initial setup of the logger prior to being deployed on the site.

1. **Open** the HOBOWare software and **connect** the logger to computer using a mini-USB cable as shown on Figure A.4.1.
2. Confirm that the logger name is displayed on the bottom left of the screen and that “1 device connected” is displayed on the bottom right, as shown in Figure A.4.2. If both messages are present, click the “Launch” button, boxed in on the top left. This will open the “Launch Logger” pop-up window as shown on where you select the parameters for collecting data.



Figure A.4.1: Onset HOBO 4-Channel Analog Logger connected to computer via USB.

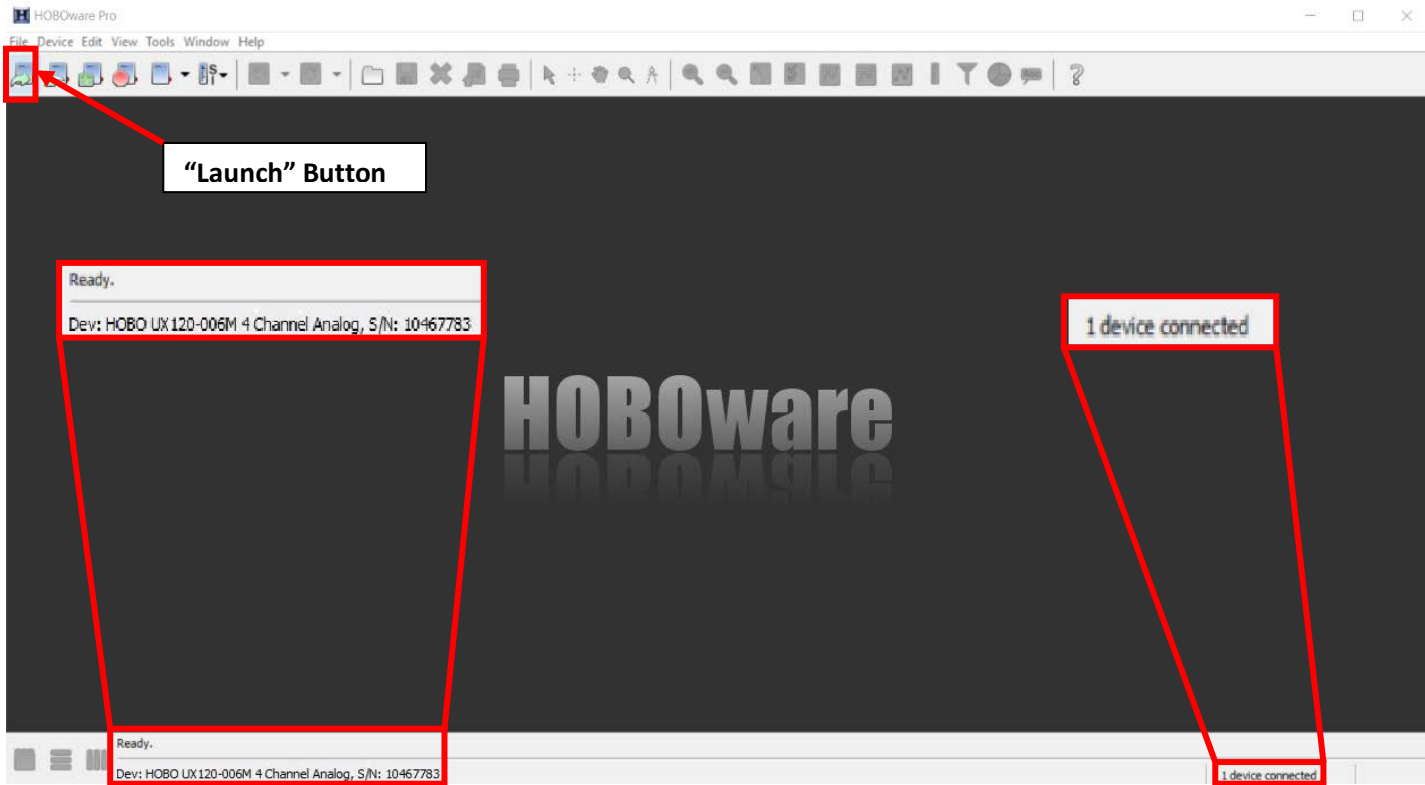


Figure A.4.2: HOBOWare launch menu.

A.4.2: Configuring the Onset HOBO 4-Channel Analog Logger with Onset HOBO Split-Core Current Sensor

1. In the “Name” field, enter a meaningful label. Ideally, the “Name” field should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - a. For example, for an AHU system, we can set a name with the facility’s name, the AHU number, and whether it’s a supply or return fan in this format:
facilityname_ahunumber_supply OR *facilityname_ahunumber_return*.
2. Check the battery level to confirm that the logger is sufficiently powered and doesn’t require a battery replacement (Figure A.4.4).
3. Within the “Launch Logger” window, the “Sensors” table allows you to configure each input port of the data logger (labeled as “Step 3” in Figure A.4.4).
4. Figure A.4.5 shows what setting to enable in the “Sensors” table.
 - a. There are 4 checkboxes which represent the different channels that can be configured on the Onset HOBO 4-Channel Analog Logger. Check the appropriate number of checkboxes which correspond to the number of sensors that will be used to collect measurements.
 - i. Some systems, like the AHU fan system, only require 1 Onset HOBO Split-Core Current Sensor, which means only one checkbox should be checked in. Other systems, like lighting, may require the use of all 4 channels, and as such, all 4 checkboxes should be checked.
 - b. Click the grey box to the right of the logger port number. This box will be used to specify the type of sensor connected to the port. Select the sensor that you will be using at the field site from the dropdown menu.
 - i. Recommended settings for the any of the Onset HOBO Split-Core Current Sensors: After clicking on the grey box, move your cursor to AC Current, then select the current range of Onset HOBO Split-Core Current Sensor (displayed on the body of the Onset HOBO Split-Core Current Sensor as shown on Figure A.4.3).
 - c. Ensure the units for current are labelled correctly.
 - i. For example, since the Onset HOBO Split-Core Current Sensor, which measures current in amps, was selected in the previous step, the LCD units box has the word “AMP” in it as shown on Figure A.4.5, which is the correct label for Amps.
 - d. Label the port descriptively in the “<Enter label here>” box (e.g., AHU #3 Supply Fan, AHU #7 Return Fan).
 - e. Perform steps 4b to 4e for all sensors if more than one will be used.



Figure A.4.3: The Onset HOBOTV-B 50A CT. One of several current sensors offered at FELL for current measurements.

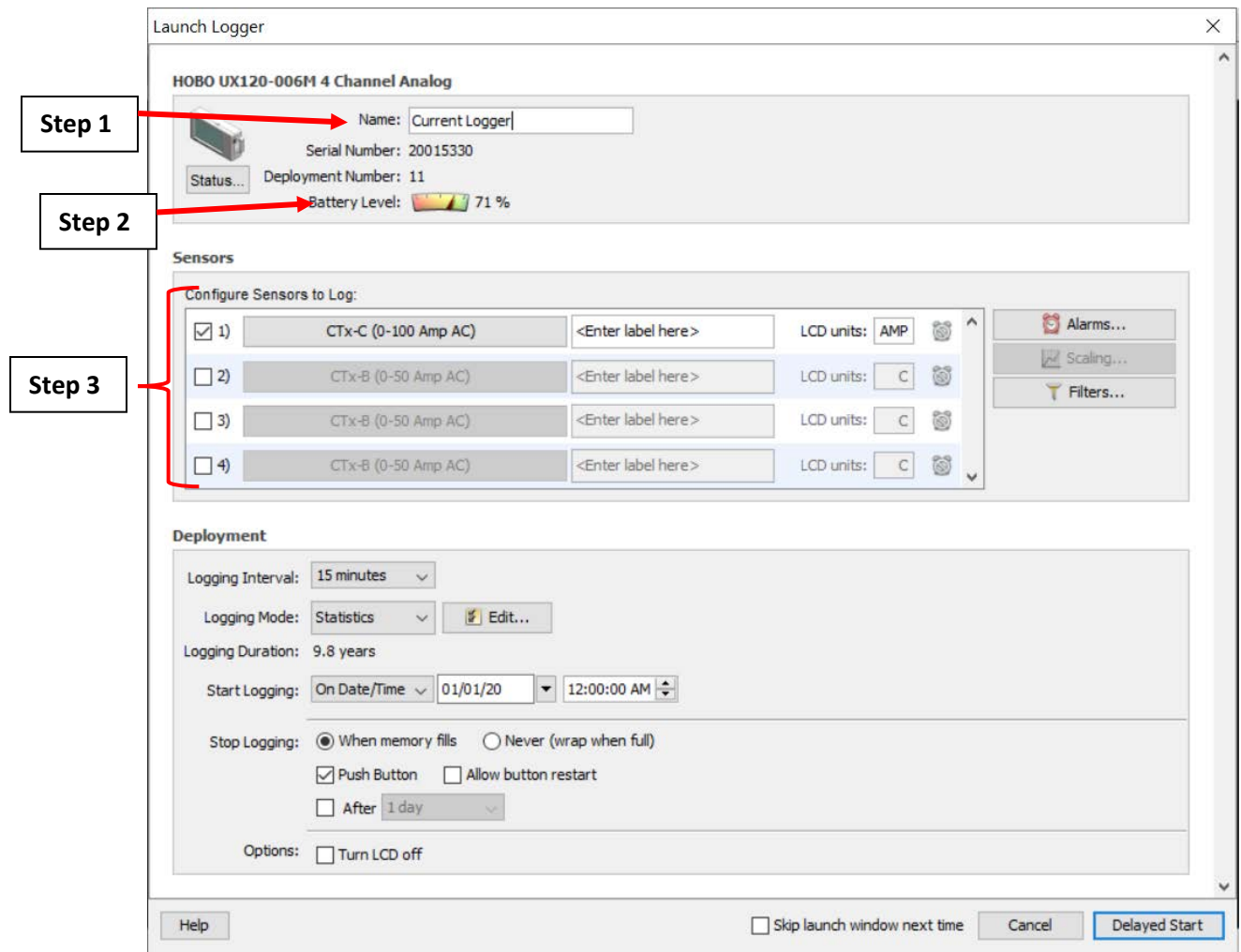


Figure A.4.4: The “Launch Logger” pop-up window for the Onset HOB0 4-Channel Analog Logger.

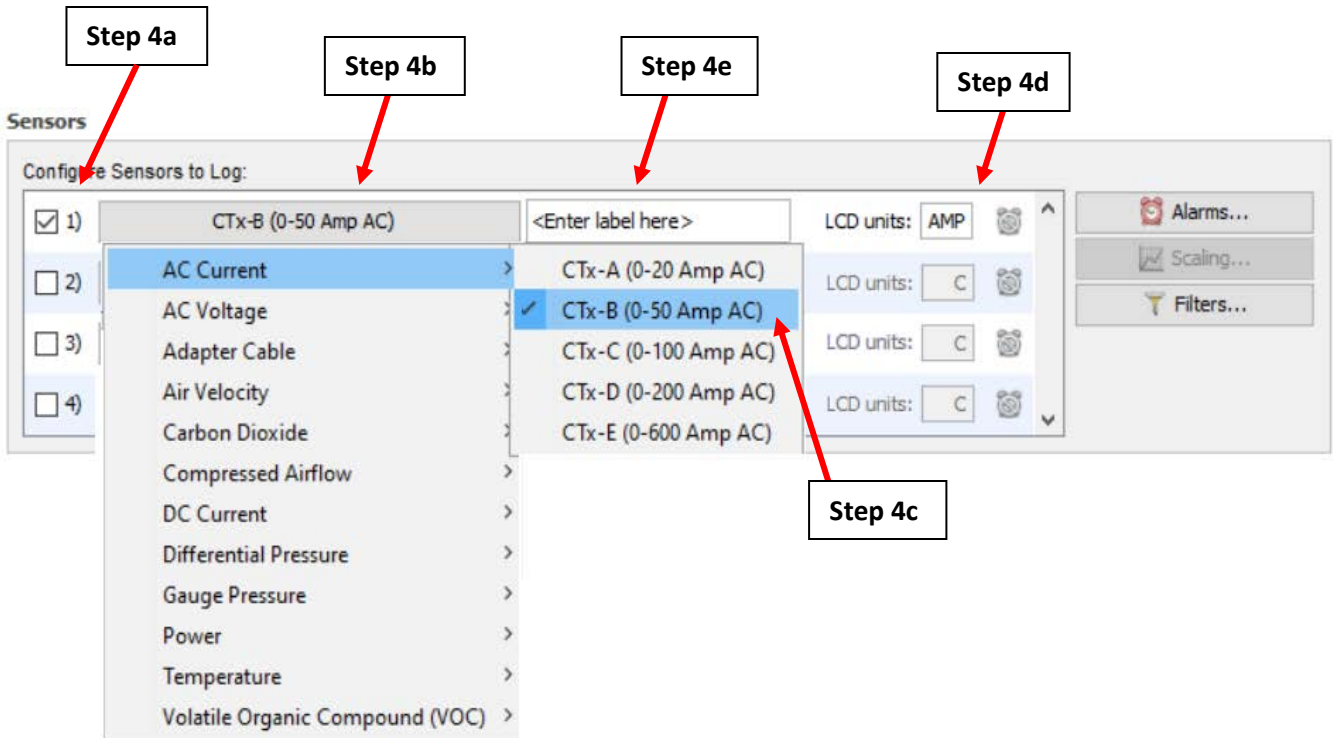


Figure A.4.5: Configuring the Onset HOBO Split-Core AC Current Transformer in the “Sensors” table. Select the options that match the sensors that will be used for the M&V guide that is being followed.

A.4.3: Deploying the Onset HOBO 4-Channel Analog Logger with Onset HOBO Split-Core Current Sensor

Below the “Sensors” table you will see the “Deployment” table as shown on Figure A.4.6. This allows you to specify your logger deployment with details such as when to start and stop logging.

To deploy the logger:

1. Click the arrow in the “Logging Interval” dropdown menu and select 1 hour as the logging interval.
2. Set the logging mode to “Statistics”.
3. Click the “Edit” button to make the Statistics window appear.

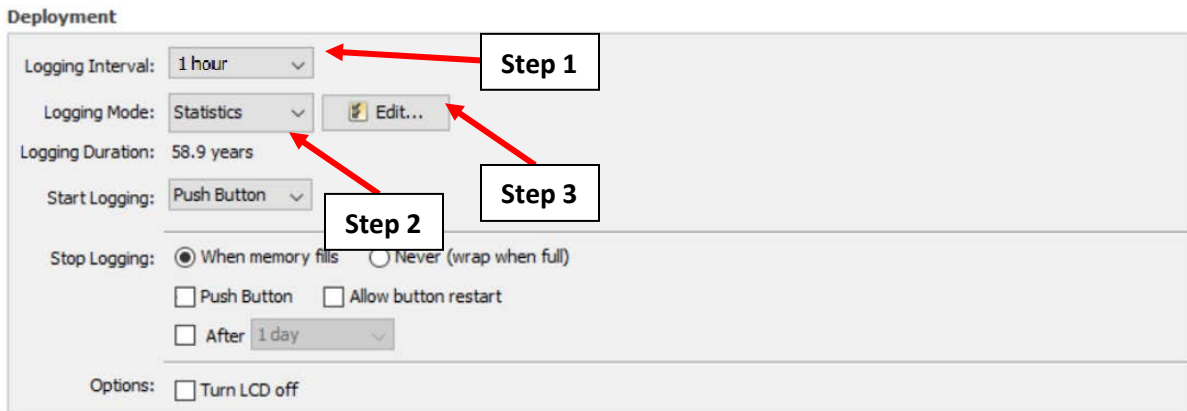


Figure A.4.6: Setting the Logging Interval and the Logging Mode in the Deployment table.

4. Following Figure A.4.7, select the checkbox labeled “Average” and uncheck the other boxes.
5. Click on the drop-down menu for “Sampling every:” and select 1 second (as shown above). This stipulates that the Onset HOBO 4-Channel Analog Logger will record the 1-hour average draw for the sensor being used based on 1 second measurements.
6. Click “OK” to close the Statistics window.

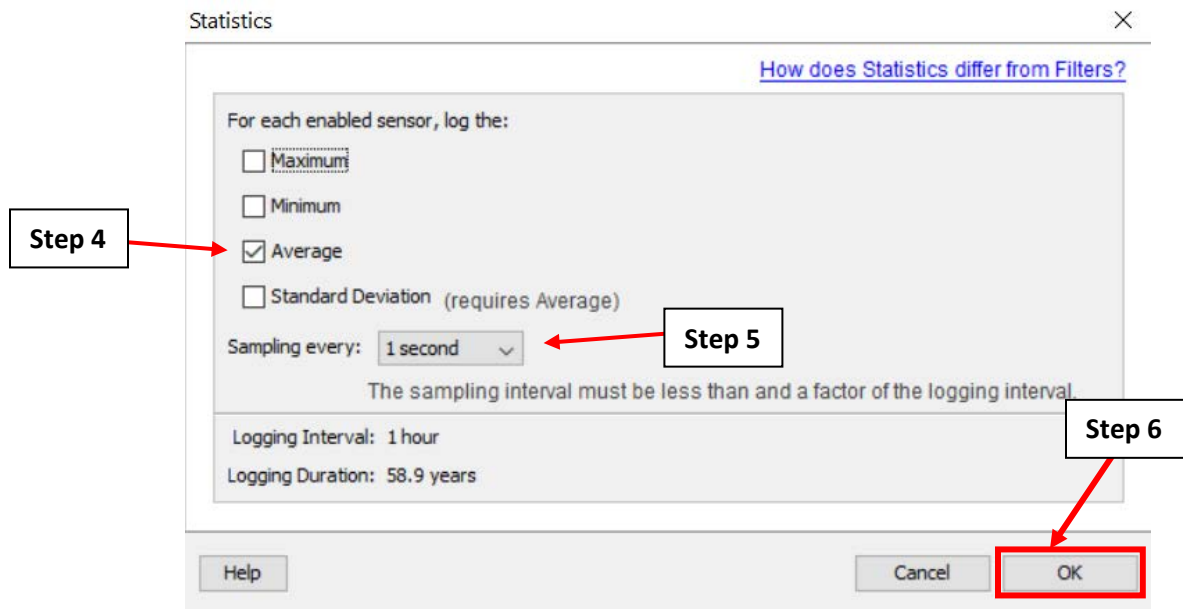


Figure A.4.7: Setting the sampling rate in the Statistics pop-up window.

7. Back on the “Launch Logger” screen (Figure A.4.8), go to the “Deployment” table. Click on the “Start Logging” dropdown menu. Select “On Date/Time” to specify the date and time that the logger will begin to collect measurements.
8. Set the date and time for the logger to begin taking measurements in the two new boxes that appear on the right.
 - a. Note that if you have multiple loggers being deployed on your site, all loggers should be set to begin at the same date and time.

9. Set the “Stop Logging” option to “When memory fills”. This specifies that the data logger will stop collecting measurements when the internal memory of the logger is filled. Ensure that the “Push Button”, “Allow button restart” and “After” checkboxes are unchecked.
10. Identify if the LCD screen should remain on. If the logger will be deployed for more than one month, turn off the screen to conserve battery life.
11. Click “Delayed Start” to complete the configuration process. Do not unplug the logger from the computer until deployment is complete (shown in Figure A.4.9).
12. If the logger needs to be reconfigured, click the “Launch” button shown in Figure A.4.2 and repeat the steps in sections A.4.2 and A.4.3.

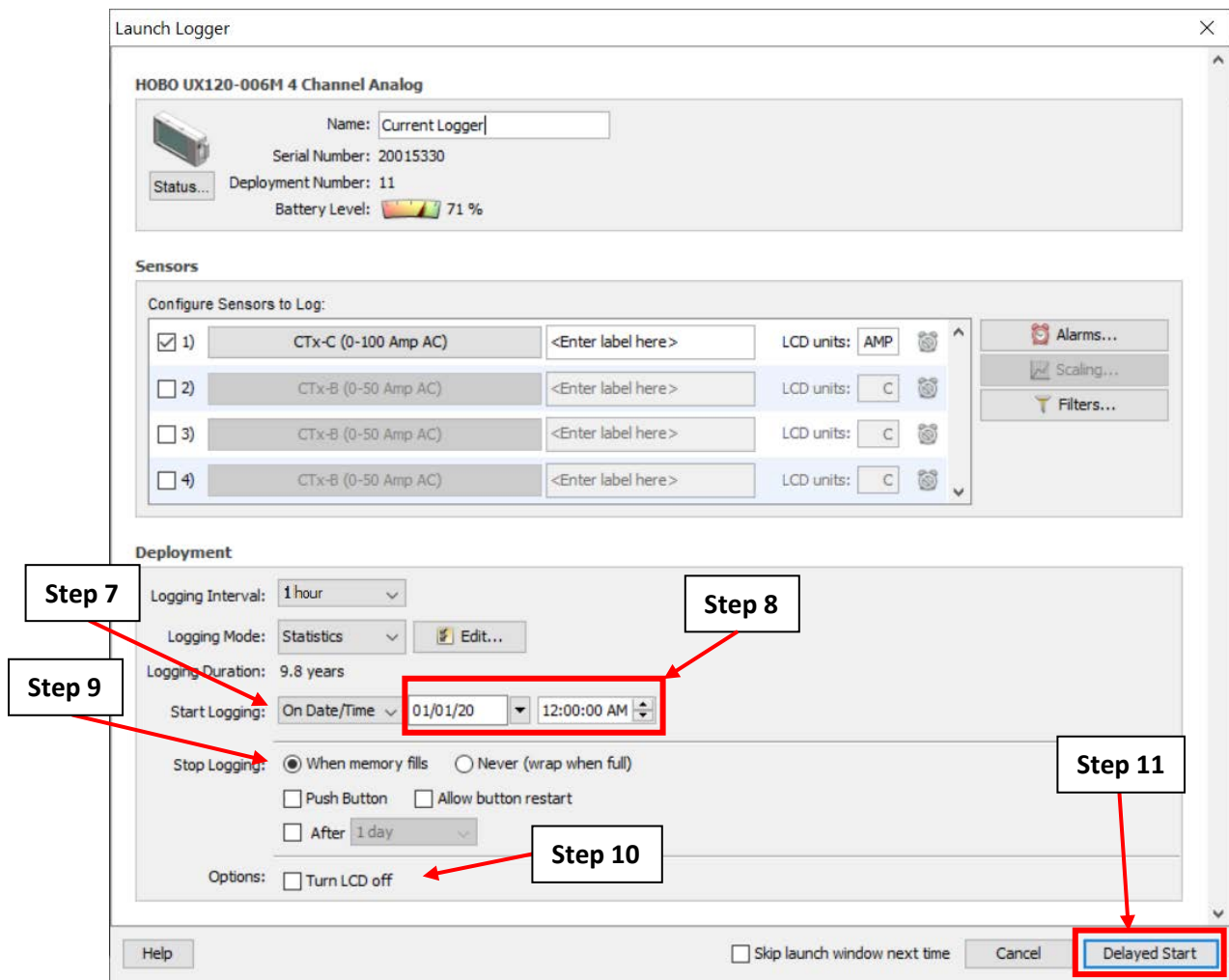


Figure A.4.8: The “Launch Logger” window with the deployment steps.

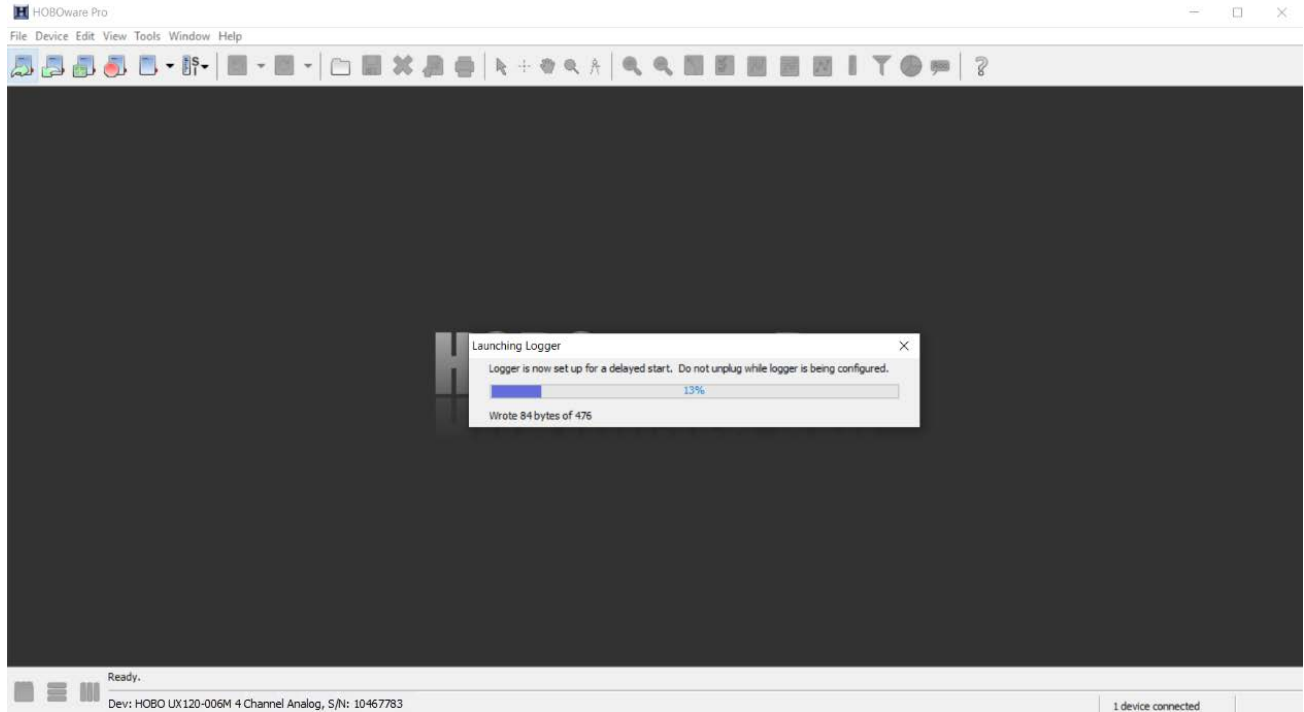


Figure A.4.9: Launching the logger using the HOBOWare software.

A.4.4: Onset HOBOWare 4-Channel Analog Logger with Onset Split Core-Current Sensor Field Setup

Please ensure that the sensor that will be used to collect measurements is connected to the Onset HOBOWare 4-Channel Analog Logger before continuing. If not, please consult with the CUNY BPL FELL personnel to make the necessary connections.

1. Someone familiar with the building's system should identify the panelboard(s) for the target system(s).
2. At the panel, ensure that the components have been checked to make sure that **no current** is flowing once the system has been turned off. **Failure to do so could result in death.**
3. Connect the Onset HOBOWare Split-Core Current Sensors to the Onset HOBOWare 4-channel Analog Logger by plugging in the CT's cables to their respective channels that were set on step 4 of section A.4.2 as shown on Figure A.4.10.

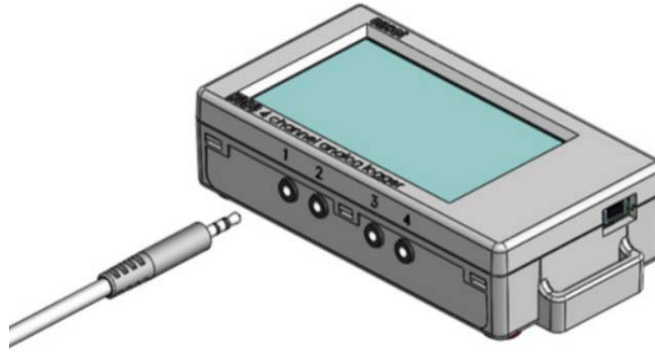


Figure A.4.10: Connecting the Onset HOB0 Split-core AC Current Transformer to the Onset HOB0 4-Channel Analog Logger.

4. There are a set of 3 wires present in the panelboard that must be identified:
 - a. If there is no VFD present, the Onset HOB0 Split-Core Current Sensor should be connected to one of the wires going directly to the system component from which the current is being measured (e.g. a motor) from the panel.
 - b. If a VFD is present, the Onset HOB0 Split-Core Current Sensor should be connected to one of the wires going into the VFD.
5. Open the Onset HOB0 Split-Core Current Sensor clamp and insert one of the wires into the opening as shown on Figure A.4.11.



Figure A.4.11: Insertion of wire into the Onset HOB0 Split-core AC Current Transformer.

6. Make sure that the wire is securely held in the Onset HOB0 Split-Core Current Sensor to ensure the wire stays in place as shown on Figure A.4.11, Figure A.4.12, and Figure A.4.13.

7. Close the sensor and attach the 4-channel logger (connected to the sensor) against the wall of the control panel using the magnet on the back of the logger as shown on Figure A.4.12.
8. If multiple Onset HOBO Split-Core Current Sensors are needed (see Figure A.4.13), repeat steps 4 to 7.
9. Field set up is now complete and the logger will automatically start collecting data at the date and time that was set on step 7 of section A.4.3.



Placement of wire

Figure A.4.12: Installation of the current sensor into the panelboard for an AHU fan motor with VFD installed. Note that only one Onset HOBO Split-Core AC Current Transformer is installed.

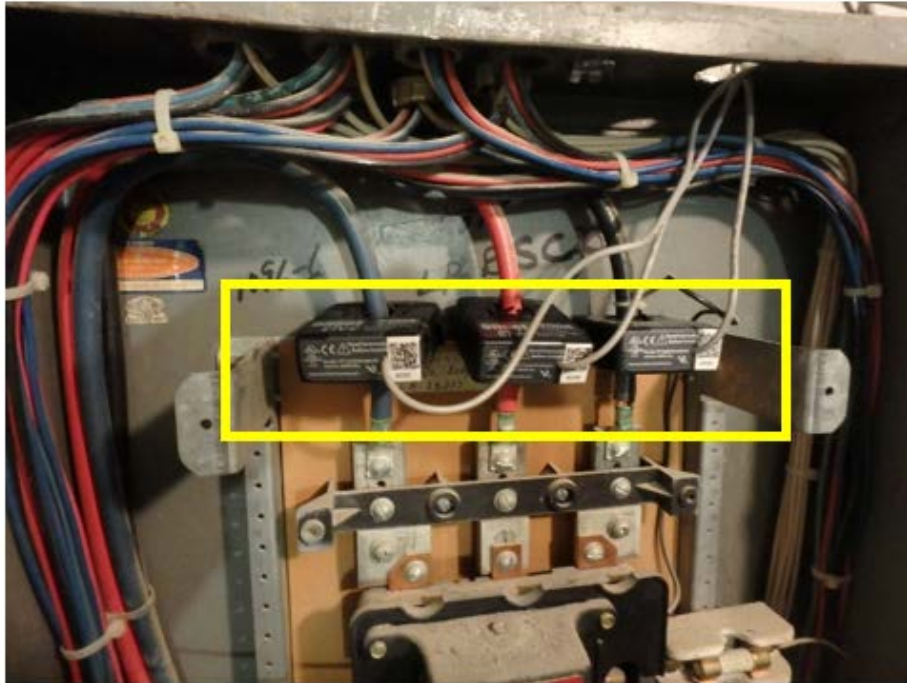


Figure A.4.13: Three Onset HOBOSplit-Core AC Current Transformers installed onto the main feed of a panelboard for a lighting system.

A.4.5: Verification of Data Collection for the Onset HOBOSplit-Core AC Current Transformer with Onset HOBOSplit-Core Current Sensor

It is important to verify the Onset HOBOSplit-Core AC Current Transformer is collecting accurate data. HOBOWare offers an easy way to check collected data without interfering with the initial setup from the previous sections.

1. Open the HOBOWare software on your computer.
2. Connect the USB-mini cable to the logger. **Do not move the logger or sensors.**
3. Click the readout button on the top menu as shown on Figure A.4.14.
4. The “Stop Logger?” pop-up window will appear asking if you want to stop logging as shown on Figure A.4.15, click **“Don’t Stop”**.

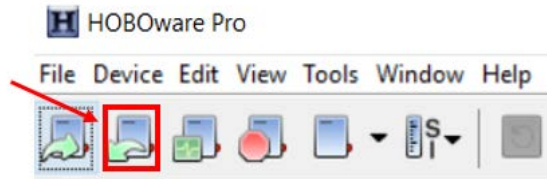


Figure A.4.14: The HOBOWare readout button.

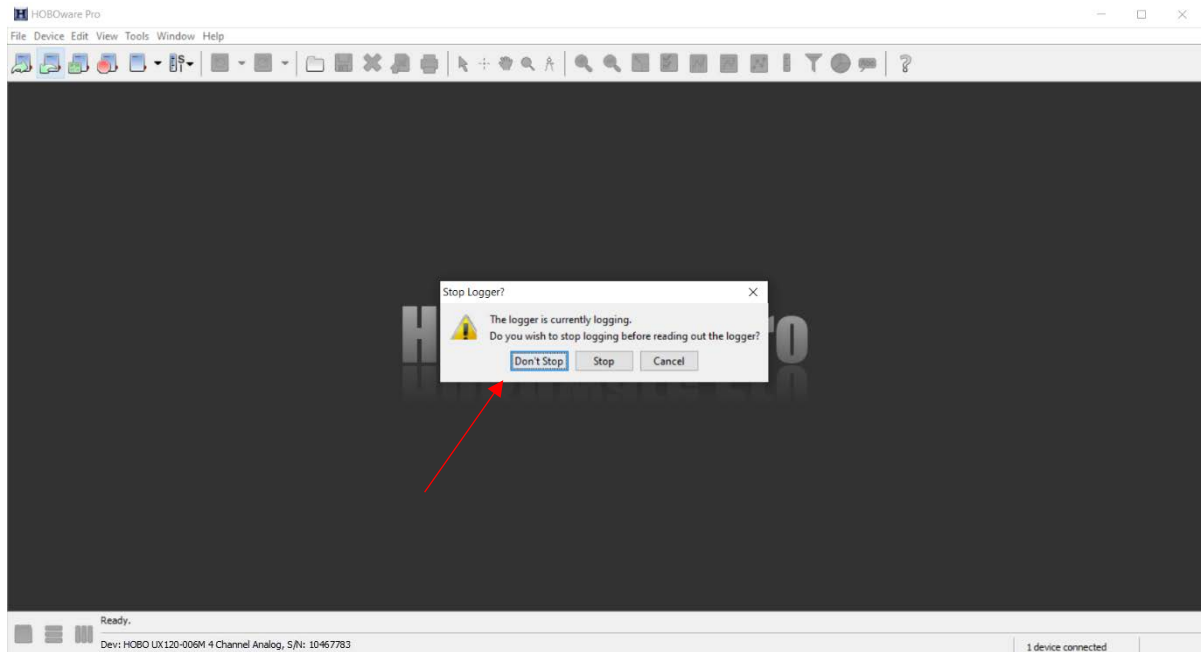


Figure A.4.15: The “Stop Logger?” pop-up window.

5. The “Plot Setup” window will open (see Figure A.4.16).
 - a. Name your data in the same way as in step 1 of section A.4.2.
 - b. Select the measurements that are required for the M&V guide that is being followed. Deselect all other series.
 - i. For example, for the Onset HOBOWare Split-Core Current Sensor, the “AC Curr – Avg” measurements (Unit: “Amps”) were selected as shown Figure A.4.16.
 - c. Deselect the three “Event Types” at the bottom of the menu.
 - d. Click “Plot” to display your graph.

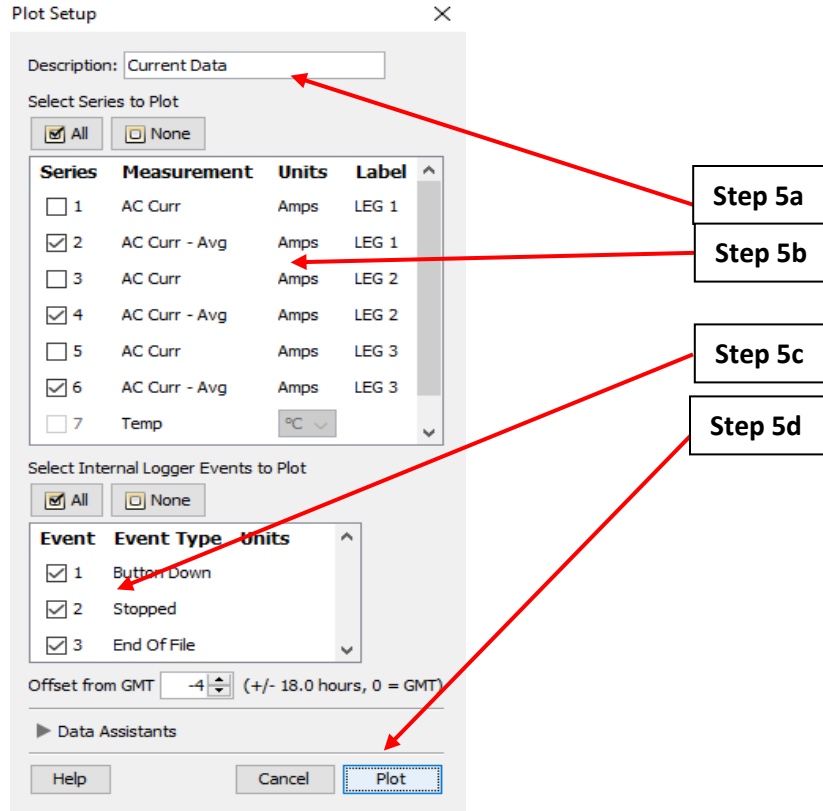


Figure A.4.16: The “Plot Setup” pop-up window with the corresponding steps.

9. After following step 5, HOBOWare will open a new tab with data from the logger. Focus your attention on the “Data Table” pane at the top of the window as shown on Figure A.4.17. Here you will see:
 - a. The date and time of the logged data stored in the first column.
 - b. The columns after the date and time column will vary based on which types of sensors were used.
 - i. For example, the data shown on Figure A.4.17 is with respect to the Onset HOBO Split-Core Current Sensor. The amount of current in Amps measured by each Onset HOBO Split-Core Current Sensor is shown for each of the time stamps.

#	Time, GMT-04:00	off/on, Time on (hh:mm:ss)	Internal Calibration	Host Connected	End Of File
1	03/10/20 10:00:00 PM		Logged		
2	03/10/20 11:00:00 PM	00:06:56			
3	03/11/20 12:00:00 AM	00:00:00			
4	03/11/20 01:00:00 AM	00:00:00			
5	03/11/20 02:00:00 AM	00:00:00			
6	03/11/20 03:00:00 AM	00:00:00			

Figure A.4.17: HOBOWare data table pane.

10. Scroll through the table and assess the collected data to ensure that the measured operational time corresponds to expected motor operation.

11. If the measured data is unusual or inaccurate based on your understanding of the system, then the Onset HOBOWare 4-Channel Analog Logger may need to be recalibrated.

A.4.6: Exporting Data from the Onset HOBOWare 4-Channel Analog Logger to a .csv File

After the allotted measurement period, the entire dataset can be extracted and used to calculate other parameters with respect to the M&V guide being followed.

1. At the end of the measurement period, follow the procedure in section A.4.5 to verify that the collected data is accurate.
2. If satisfied with the accuracy of the measurements, click the “Stop Logging” button on the top left corner of the screen (Figure A.4.18).

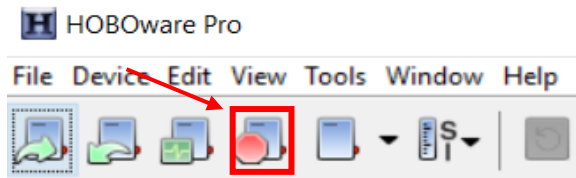


Figure A.4.18: HOBOWare “Stop Logging” Button

3. Click “File” > “Export Table Data” (Figure A.4.19).

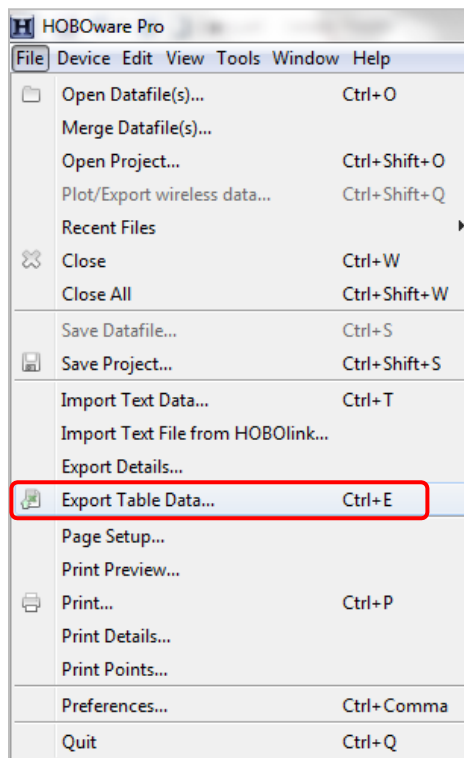


Figure A.4.19: File menu options.

4. The “Export” window will open and display the data available to export (Figure A.4.20).
5. Select “off/on” and uncheck all other boxes.
6. Click “Export...” to export the data.

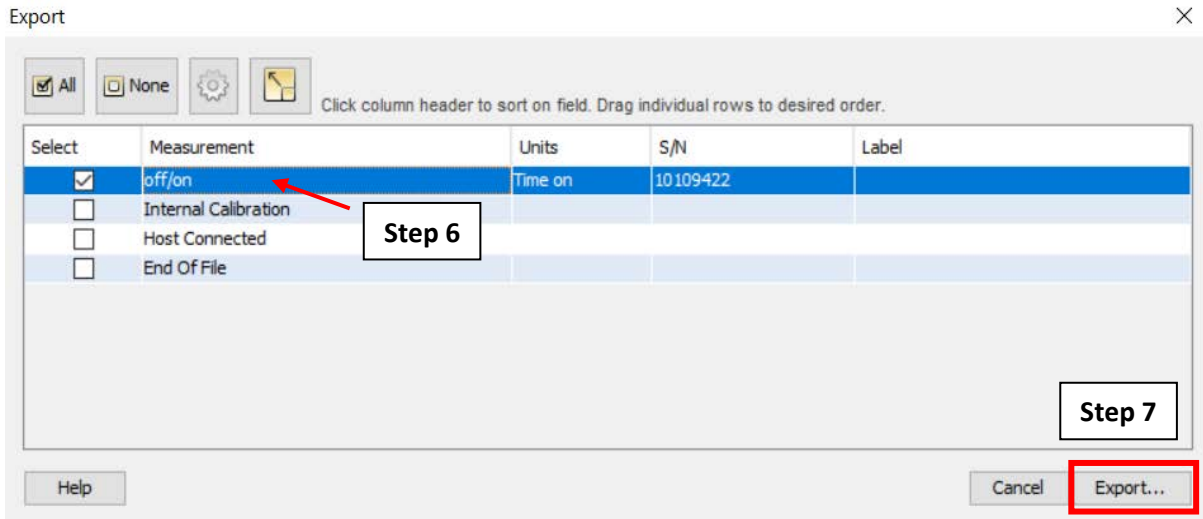


Figure A.4.20: The “Export” Window and corresponding steps.

7. Choose a location to save the file.
8. Name the file the same way as step 1 of section A.4.2.
9. Click “Save” to complete the .csv exporting process.

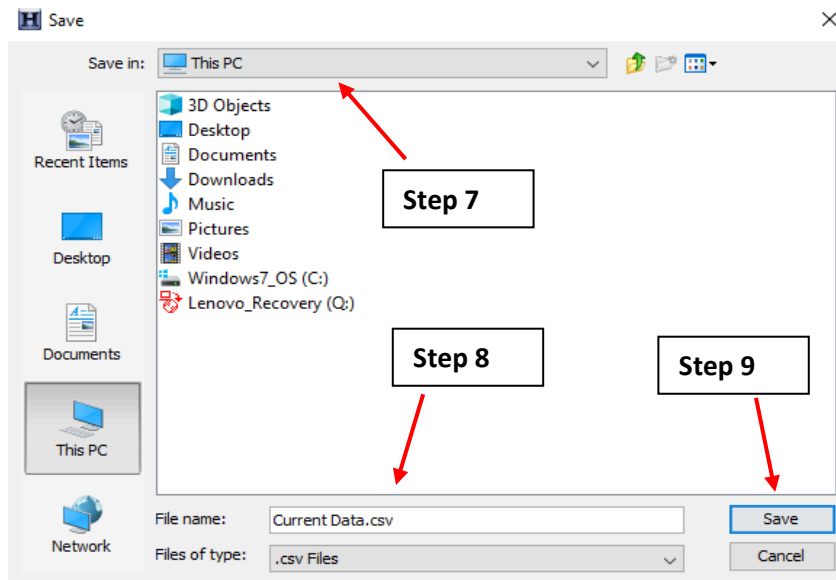


Figure A.4.21: “Save” pop-up window.

A.5: Onset HOBO Light On/Off Data Logger (UX90-002)

Sections A.5.1, A.5.2, A.5.3, A.5.6, and A.5.7 will require the use of the HOBOWare software. The HOBOWare software will be provided through a mini USB drive from the CUNY BPL FELL. Alternatively, HOBOWare Free can be downloaded from the following website:

<https://www.onsetcomp.com/hoboware-free-download>.

A.5.1: Onset HOBO Light On/Off Data Logger Connection to Computer

This section provides steps on how to connect the Onset HOBO Light On/Off Data Logger to the computer. This is necessary in order to perform an initial setup of the logger prior to being deployed on the site.

1. Open the HOBOWare software and connect the logger to computer using a mini-USB cable.
2. Confirm that the logger name is displayed on the bottom left of the screen and that “1 device connected” is displayed on the bottom right, as shown in Figure A.5.2. If both messages are present, click the “Launch” button, boxed in on the top left. This will open the “Launch Logger” pop-up window as shown on where you select the parameters for collecting data.



Figure A.5.1: The logger connected to laptop computer via USB.

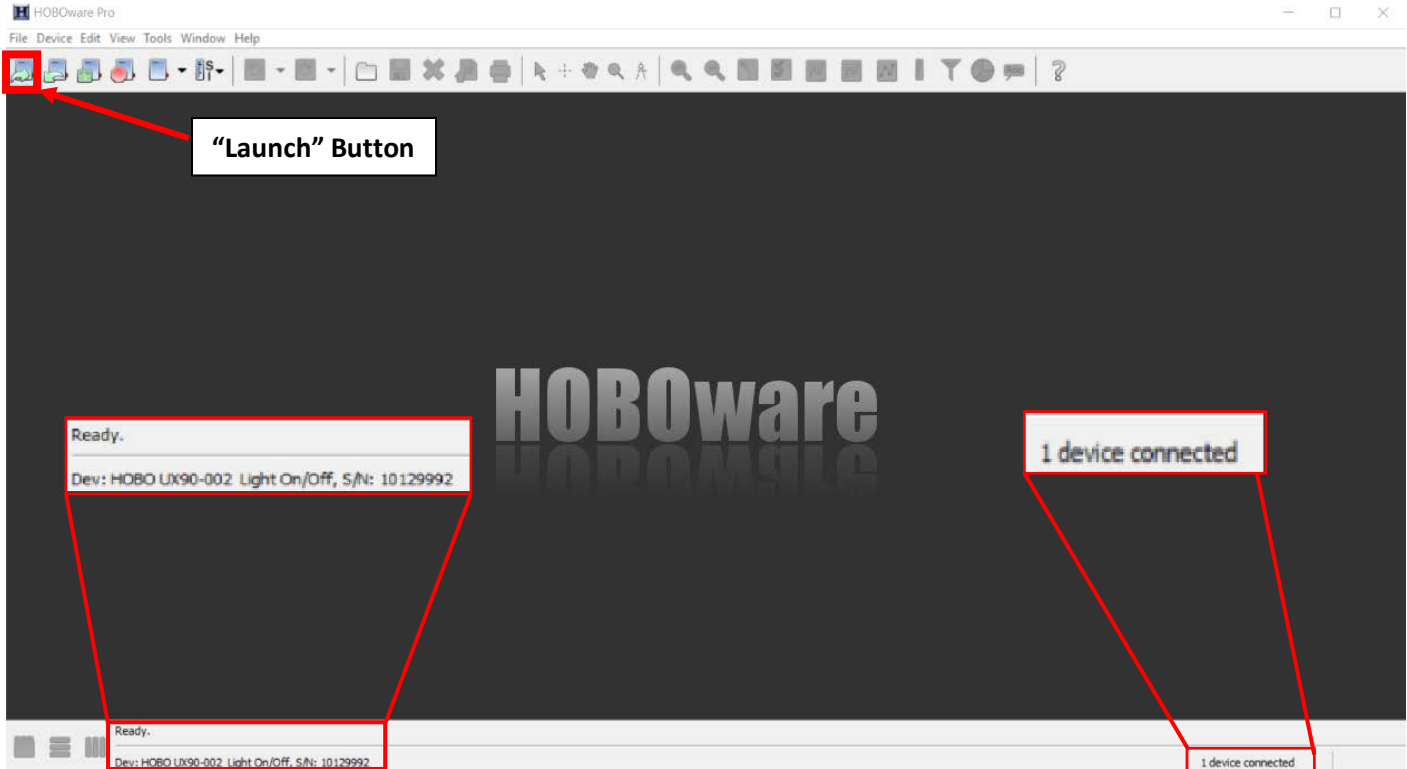


Figure A.5.2: HOBOWare launch menu

A.5.2: Configuring the Onset HOBO Light On/Off Data Logger

In the “Launch Logger” window shown on Figure A.5.3:

1. In the “Name” field, enter a meaningful label. Ideally, the “Name” field should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - a. For example, for an AHU system, we can set a name with the facility’s name, the AHU number, and whether it’s a supply or return fan in this format:
facilityname_ahunumber_supply OR *facilityname_ahunumber_return*.
2. Check the battery level to confirm that the logger is sufficiently powered and doesn’t require a battery replacement.
3. Within the “Launch Logger” window, the “Sensors” table allows you to configure the internal sensor of the data logger.
4. Figure A.5.4 shows what settings to enable in the “Sensors” table:
 - a. Make sure the checkbox to the far left is checked in. If not, click on the checkbox to check it in.
 - b. Click the dropdown menu and select “Runtime” to indicate that the logger will measure the total amount of time that the motor is on.
 - c. Label the sensor in a similar fashion to that of Step 1.
 - d. Set the “State Description” to “off/on”.

5. Click the “Filters...” button (Figure A.5.4). A window called “Filter Series” will appear.

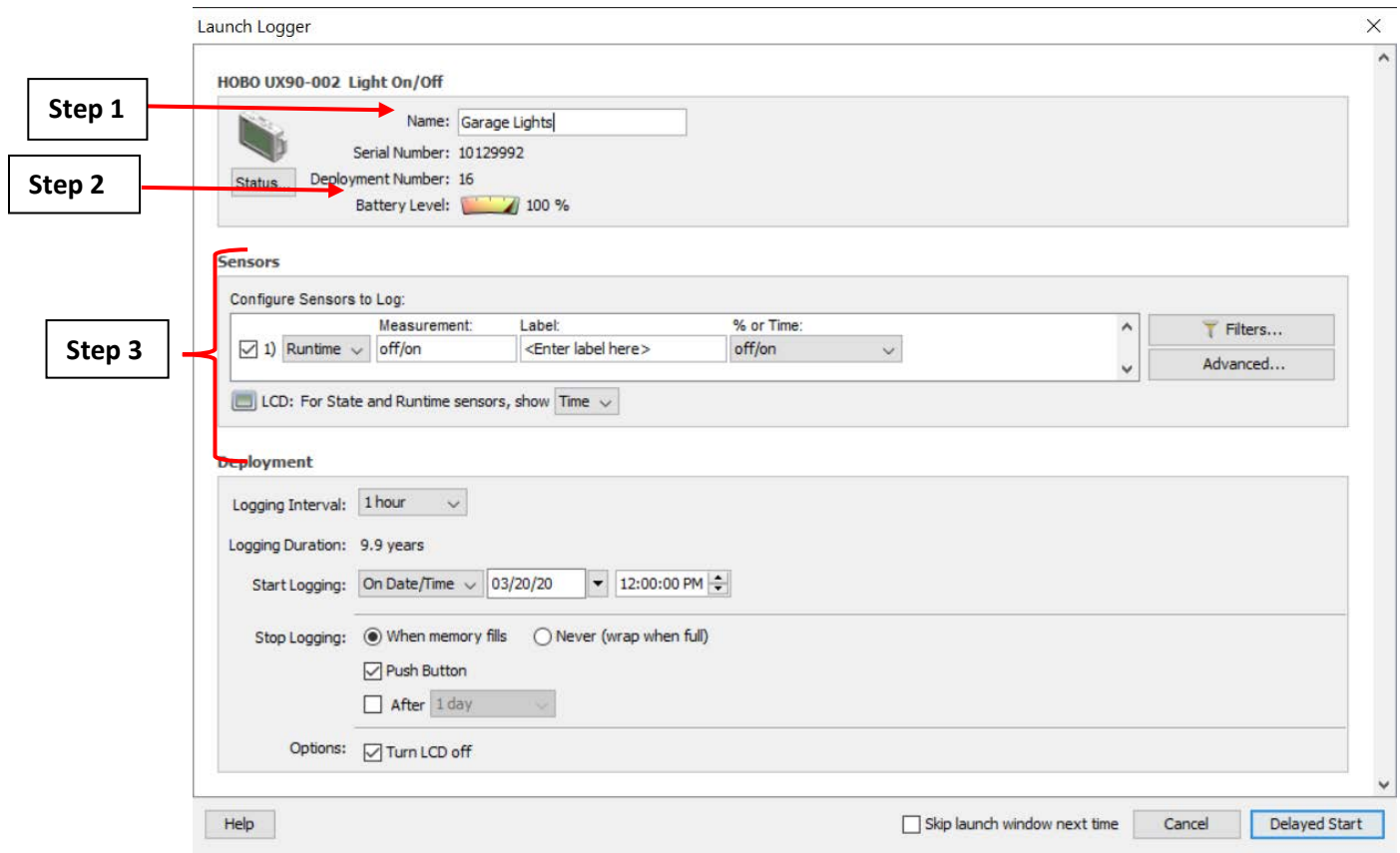


Figure A.5.3: “Launch Logger” Window with Configuration Steps

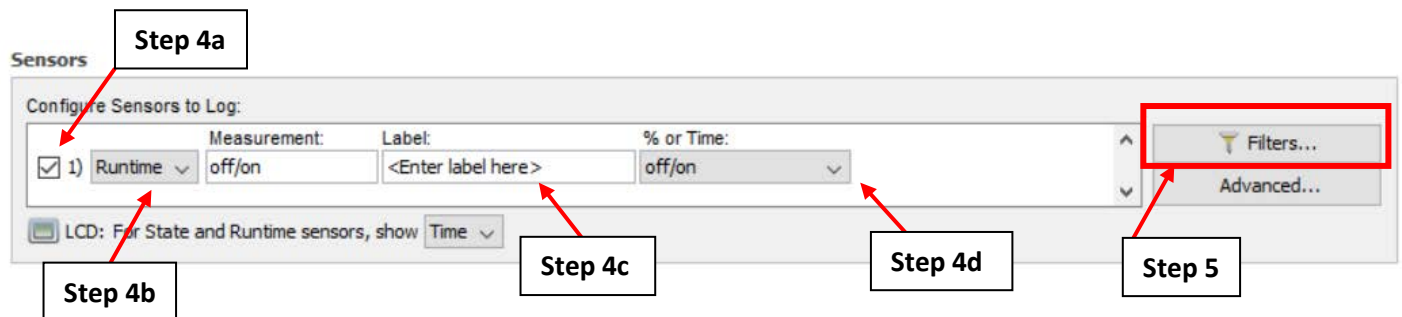


Figure A.5.4: “Sensors” Table Configuration Steps

6. To configure the “Filter Series” pop-up window shown on Figure A.5.5:
 - a. In the “Show the” dropdown menu, select the “Total off/on on” option. This configures the logger to show the total lighting operational time.
 - b. Set the interval to “1 Hour”. This indicates that the logger will trend how many seconds the motor is running for each hour.
 - c. Click “Create New Series.”
 - d. Click “Done” on the bottom right corner of the window.

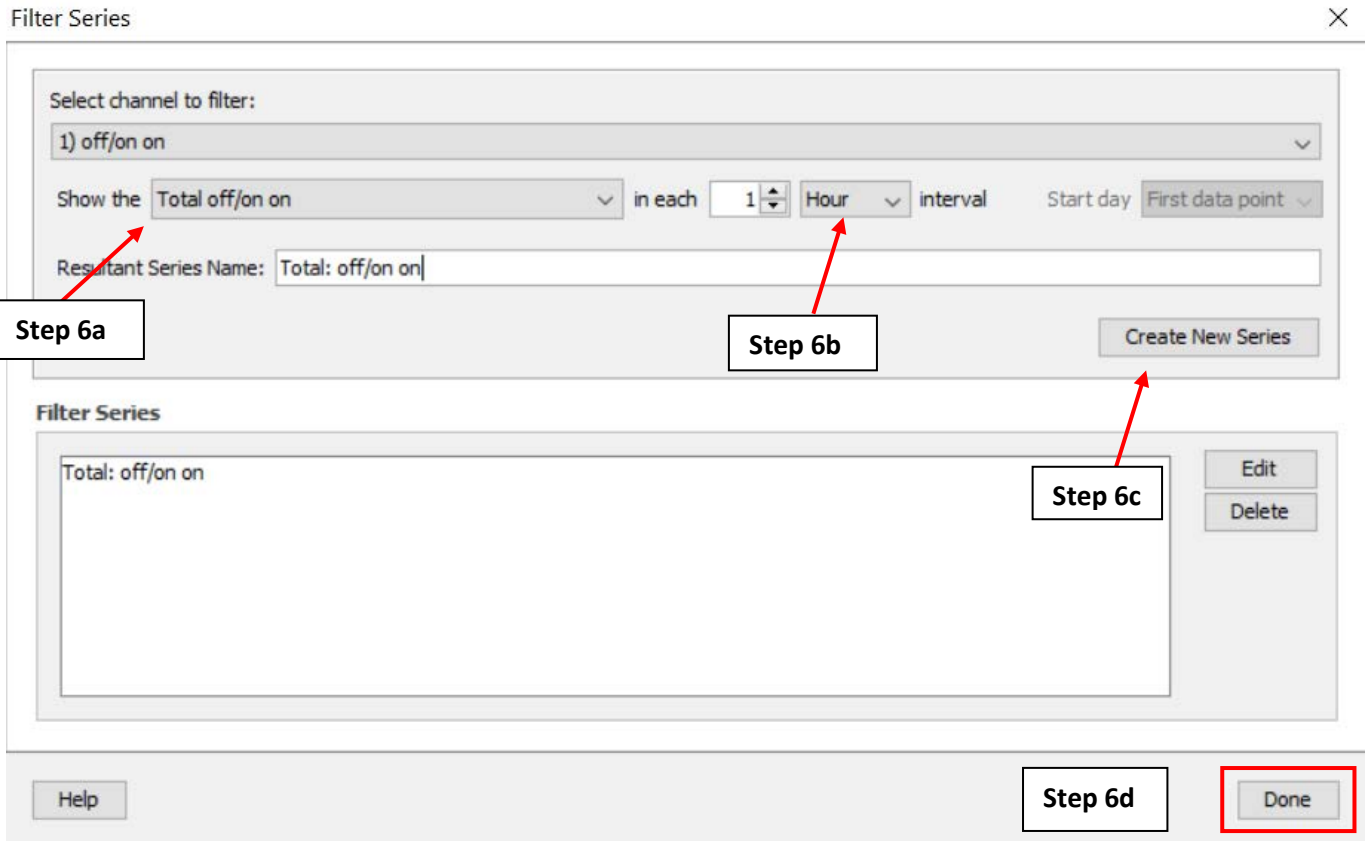


Figure A.5.5: "Filter Series" Configuration Steps

A.5.3: Deploying the Onset HOBO Light On/Off Data Logger

Below the "Sensors" table you will see the "Deployment" table as shown in Figure A.5.6. This allows you to specify your logger deployment with details such as when to start and stop logging.

1. Click on the dropdown menu next to "Logging Interval" and select "1 hour".
2. Click on the "Start Logging" dropdown menu and select "On Date/Time".
3. Edit the values in the date and time boxes to specify the date and time that the logger will begin to collect measurements. If multiple loggers are being deployed, all loggers should be set to begin at the same date and time.
4. Set the "Stop Logging" option When memory fills". This specifies that the data logger will stop collecting measurements when the internal memory of the logger is filled.
5. Identify if the LCD screen should remain on. If the logger will be deployed for more than one month, turn off the screen to conserve battery life.
6. Click "Delayed Start" to complete the configuration process. Do not unplug the logger from the computer until deployment is complete as shown in Figure A.5.7.

If the logger needs to be reconfigured, click the “Launch” button as shown in Figure A.5.2 and repeat the steps in sections A.5.2 and A.5.3.

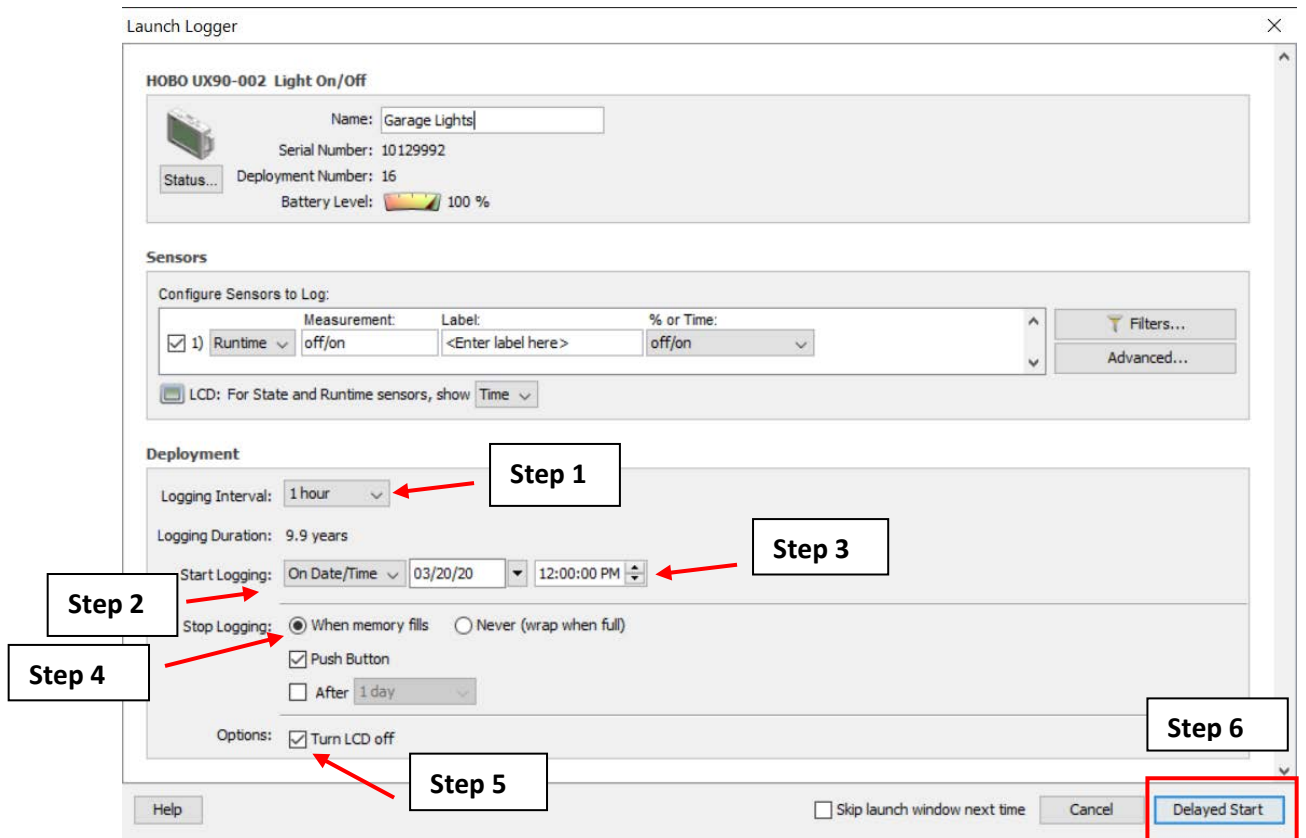


Figure A.5.6: “Launch Logger” Window with Deployment Steps

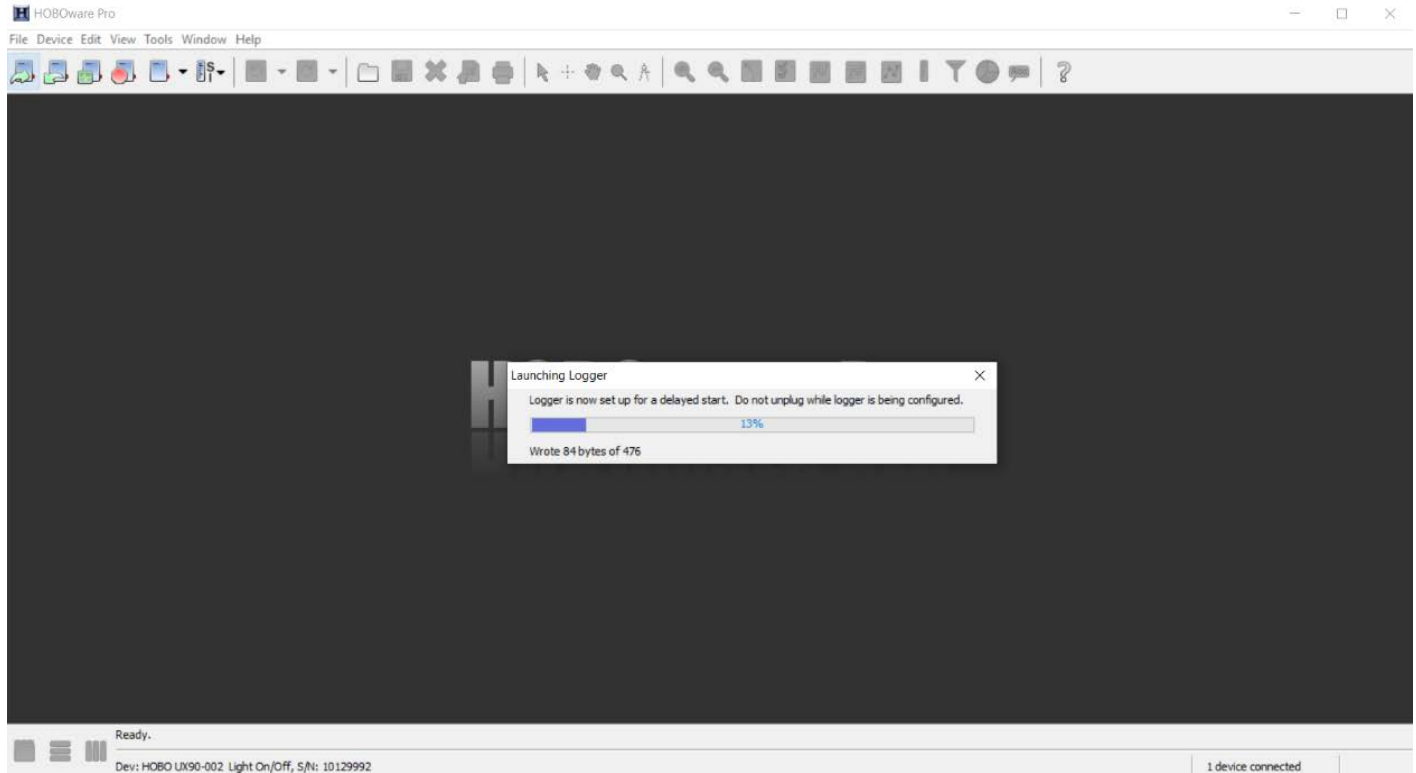


Figure A.5.7: Logger Launching from HOBOWare

A.5.4: Onset HOBO Light On/Off Data Logger Field Setup

1. Someone familiar with the lighting retrofit fixtures should identify the spaces that need to be measured for hours of operation using the light loggers.
2. Place the logger on a metal surface as close as possible to a light fixture. The actual light sensor itself is located on the top of the logger. Ensure the light source is directly above the sensor for accurate data acquisition as shown on Figure A.5.8.



Figure A.5.8: Onset HOBO Light On/Off Data Logger attached to metal surface.

A.5.5: Onset HOBO Light On/Off Data Logger Field Calibration

The light logger should be calibrated to measure the on/off time of a single light fixture. This prevents other light sources unrelated to the retrofit to contribute to the data collection. The logger should be installed as shown on Figure A.5.8 and the light should be on.

1. Ensure that the LCD screen displays what is shown on Figure A.5.9. The light off icon may be displayed as shown on this figure instead of the light on icon. Ignore whatever icon is there for now.

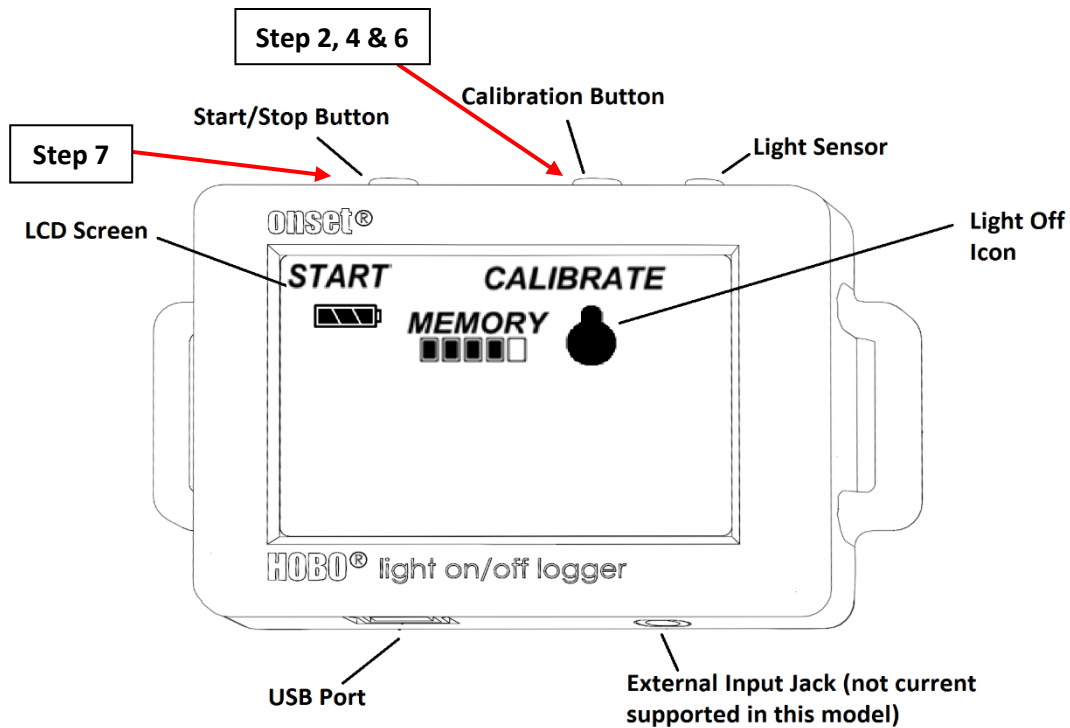


Figure A.5.9: A labeled diagram of the onset HOBO motor on/off data logger with initial startup screen.

2. Press and hold the Calibration Button (Figure A.5.9) until “MEMORY” and the five bars underneath as shown on Figure A.5.9 are replaced with “SIGNAL” and 5 bars right under as shown in Figure A.5.10. Some or all of the bars right under the word “SIGNAL” should be filled.
3. In Figure A.5.8 and Figure A.5.10, all of the bars right under the word “SIGNAL” are filled, which indicate full/optimal signal strength. All bars right under the word “SIGNAL” should be filled. If not, reposition the logger until all 5 signal bars are filled. The light on icon should also be displayed on the LCD screen as shown on Figure A.5.10.

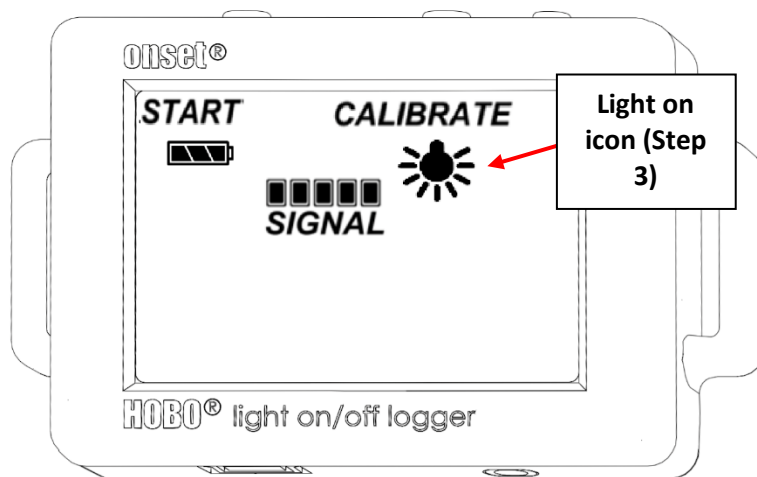


Figure A.5.10: HOBO motor on/off data logger with full signal strength.

4. Press and hold the Calibration Button. The word “HOLD” will appear on the LCD screen. The logger will then initiate a 4 second count down. After this countdown begins, you can let go of the button. The LCD screen will then display either “AUTO CAL PASS” or “AUTO CAL FAIL”.
5. If the words “AUTO CAL PASS” appear, calibration is complete. If the words “AUTO CAL FAIL” appear, reposition the logger and repeat steps 3 and 4.
6. The LCD screen will revert to what is shown on Figure A.5.9 (with the light on icon instead of the light off icon) after following step 5. Press the Calibration Button again and ensure that the signal strength is still the same as it was on Step 3.
7. Calibration is complete. The Onset HOBO Light On/Off Data Logger will automatically begin data collection based on the date and time that was set on step 3 of section A.5.3.

A.5.6: Verification of Data Collection for the Onset HOBO Light On/Off Data Logger

It is important to verify the Onset HOBO Light On/Off Data Logger is collecting accurate data while installed near the light source. HOBOWare offers an easy way to check collected data without interfering with the initial setup from the previous sections.

1. Open the HOBOWare software on your computer.
2. Connect the USB-mini cable to the logger (See Figure A.5.1). Do not remove the logger from the motor.
3. Click the “Readout” button on the top left corner of the screen (Figure A.5.11).

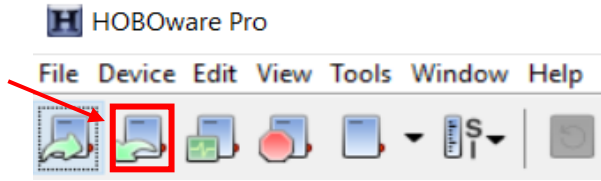


Figure A.5.11: HOBOWare “Readout” button.

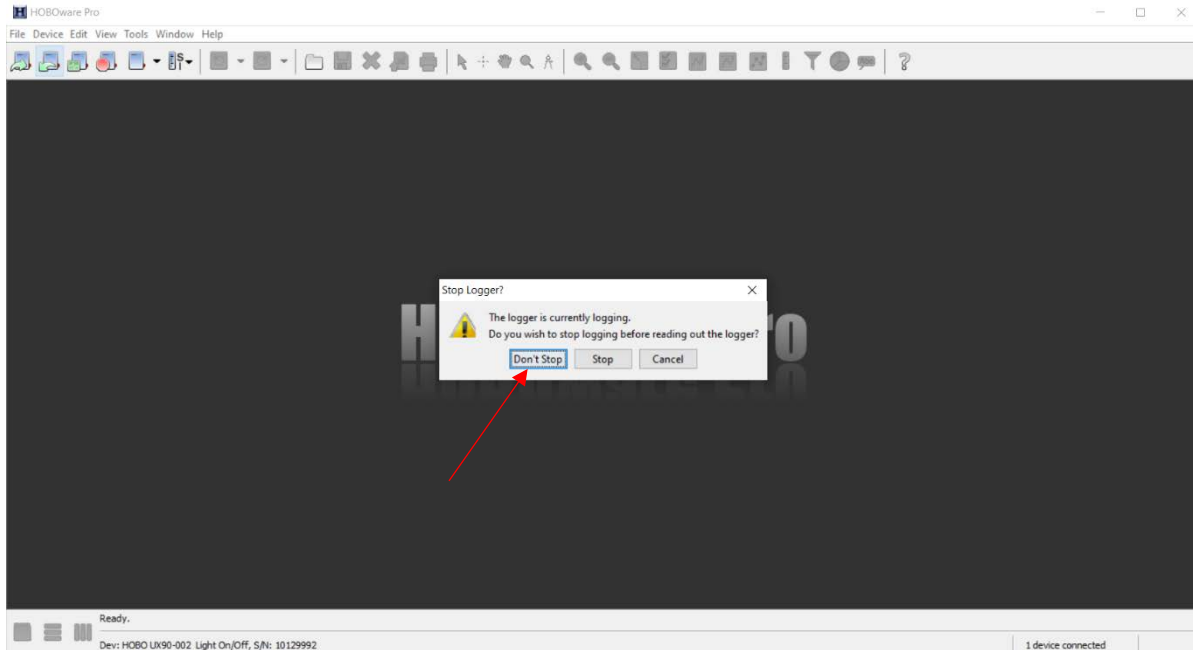


Figure A.5.12: “Stop Logger?” pop-up window.

4. A pop-up will appear asking if you want to stop logging. Click “Don’t Stop”.
5. The Plot Setup window open as shown in . To set up the data series:
 - a. Name your data in the same way as in step 1 of section A.5.2.
 - b. Select the “off/on” measurement (Unit: “Time On”) to plot. Deselect all other series.
 - c. Deselect the three “Event Types” at the bottom of the menu.
 - d. Click “Plot” to display your graph.

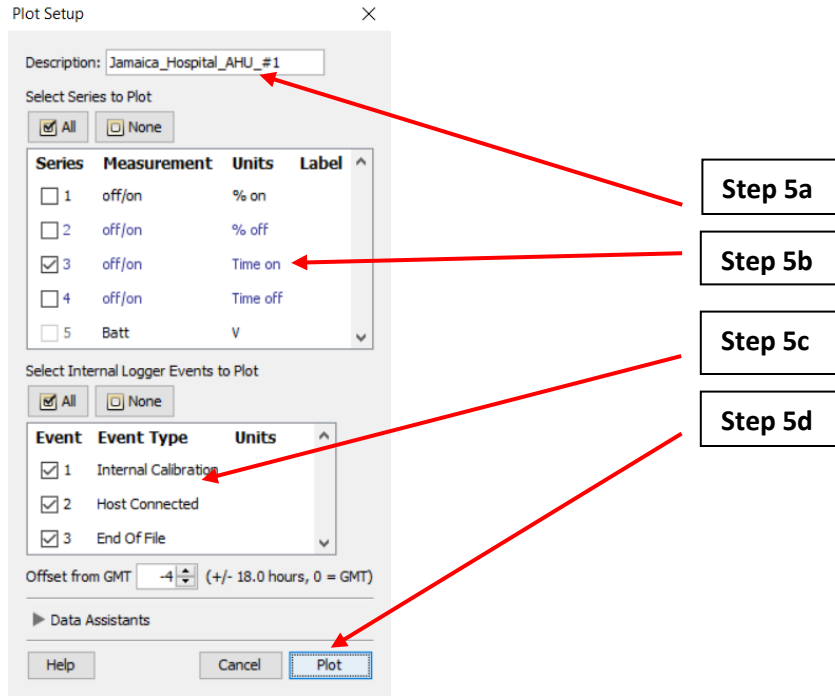


Figure A.5.13: “Plot Setup” pop-up window with the corresponding steps.

6. After following step 5, HOBOWare will open a new tab with data from the logger. Focus your attention on the “Data Table” pane at the top of the window. Here you will see:
 - a. The date and time of the logged data stored in the first column.
 - b. The amount of time the motor was detected to be on each hour, stored the second column.

#	Time, GMT-04:00	off/on, Time on (hh:mm:ss)	Internal Calibration	Host Connected	End Of File
1	03/10/20 10:00:00 PM		Logged		
2	03/10/20 11:00:00 PM	00:06:56			
3	03/11/20 12:00:00 AM	00:00:00			
4	03/11/20 01:00:00 AM	00:00:00			
5	03/11/20 02:00:00 AM	00:00:00			
6	03/11/20 03:00:00 AM	00:00:00			

Figure A.5.14: HOBOWare Data Table pane.

7. Scroll through the table and assess the collected data to ensure that the measured operational time corresponds to expected lighting operation.
 - a. For example, the light source in Figure A.5.14 was detected to be on for 6 minutes and 56 seconds between the hours of 11PM and 12AM. The light source was off for remaining hours.
8. If the measured data is unusual or inaccurate based on your understanding of the system, then the logger may need to be recalibrated.

A.5.7: Exporting Data from the Onset HOBO Light On/Off Data Logger to a .csv File

After the allotted measurement period (based on the measurement guide) the entire dataset can be extracted and used to calculate the annual electricity consumption of the light source.

1. At the end of the measurement period, follow the procedure in section A.5.5 to verify that the collected data is accurate.
2. If satisfied with the accuracy of the measurements, click the “Stop Logging” button on the top left corner of the screen (Figure A.5.15).

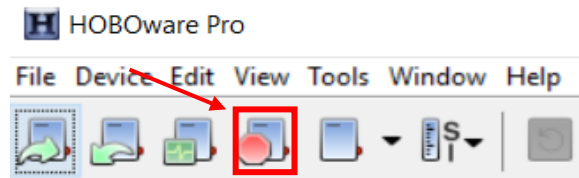


Figure A.5.15: HOBOWare “Stop Logging” Button.

3. Click “File” > “Export Table Data” (Figure A.5.16).

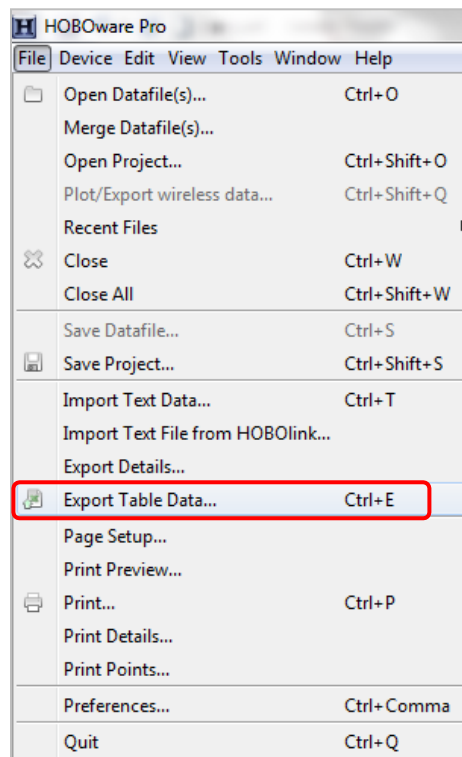


Figure A.5.16: File menu options.

4. The “Export” window will open and display the data available to export (Figure A.5.17).
5. Select “off/on” and uncheck all other boxes.

6. Click “Export...” to export the data.

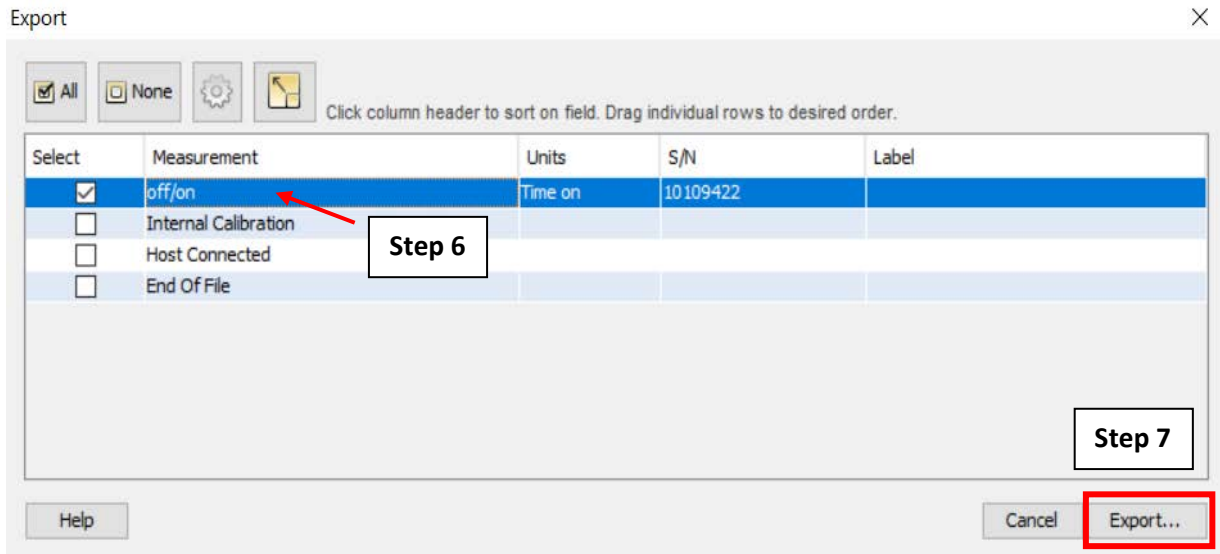


Figure A.5.17: The “Export” pop-up window and corresponding steps.

7. Choose a location to save the file.
8. Name the file the same way as step 1 of section A.5.2.
9. Click “Save” to complete the .csv exporting process.

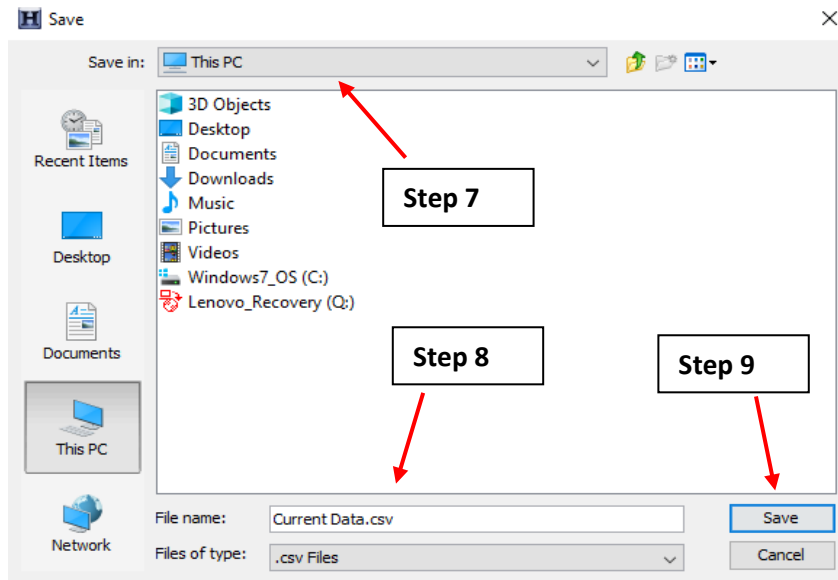


Figure A.5.18: “Save” pop-up window.

A.6: Onset HOBO Temperature/Relative Humidity Data Logger (MX1101)

Sections A.6.1, A.6.2, A.6.3, A.6.5, and A.6.6 require the use of the HOBOMobile app. For iOS devices, this app can be downloaded from the App Store for free. For Android devices, this app can be downloaded from the Google Play Store. For this guide, the Onset HOBO Temperature/Relative Humidity Data Logger will be referred to as the MX1101 Data Logger.

A.6.1: MX1101 Data Logger Connection to iOS or Android Device

Please follow this section to connect the MX1101 Data Logger to the HOBOMobile app on your iOS or Android device.

1. Make sure that the screen on the MX1101 Data Logger displays what is shown on Figure A.6.1.

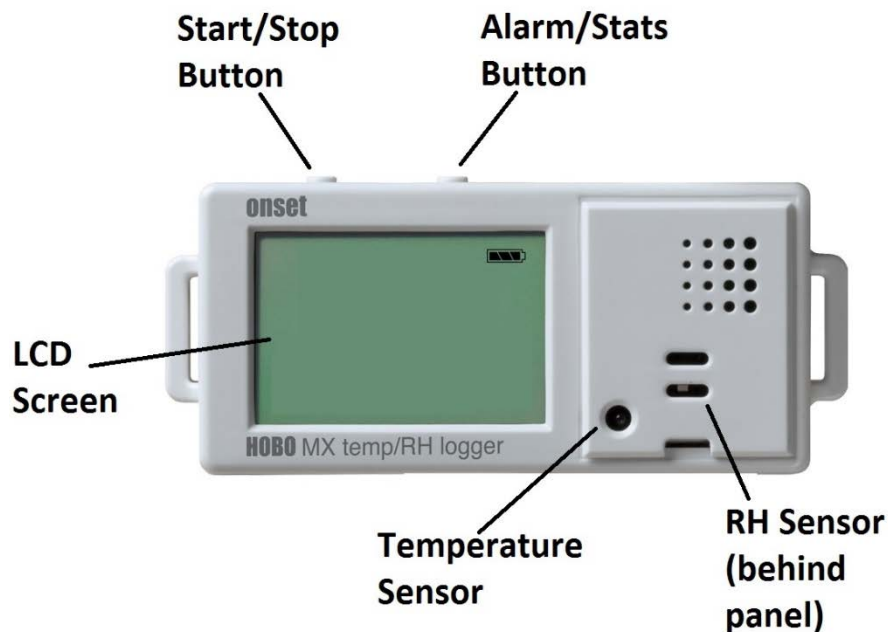


Figure A.6.1: MX1101 Data Logger Diagram

2. Enable Bluetooth on your iOS or Android device. This varies between different devices, but most devices allow you to configure Bluetooth in the “Settings” option.
3. On the HOBOMobile app, tap the “HOBOS” button on the bottom of the screen to go to the “HOBOS” screen.
4. The MX1101 Data Logger should be displayed in the “Recently Seen/In Range” list starting with the letters “SN”, and then continuing with the serial number. This is the default name for the MX1101 Data Logger.
5. Check the battery level to confirm that the MX1101 Data Logger is sufficiently powered and doesn’t require a battery replacement.

6. Tap the row in the “In Range” list to connect to the MX1101 Data Logger.

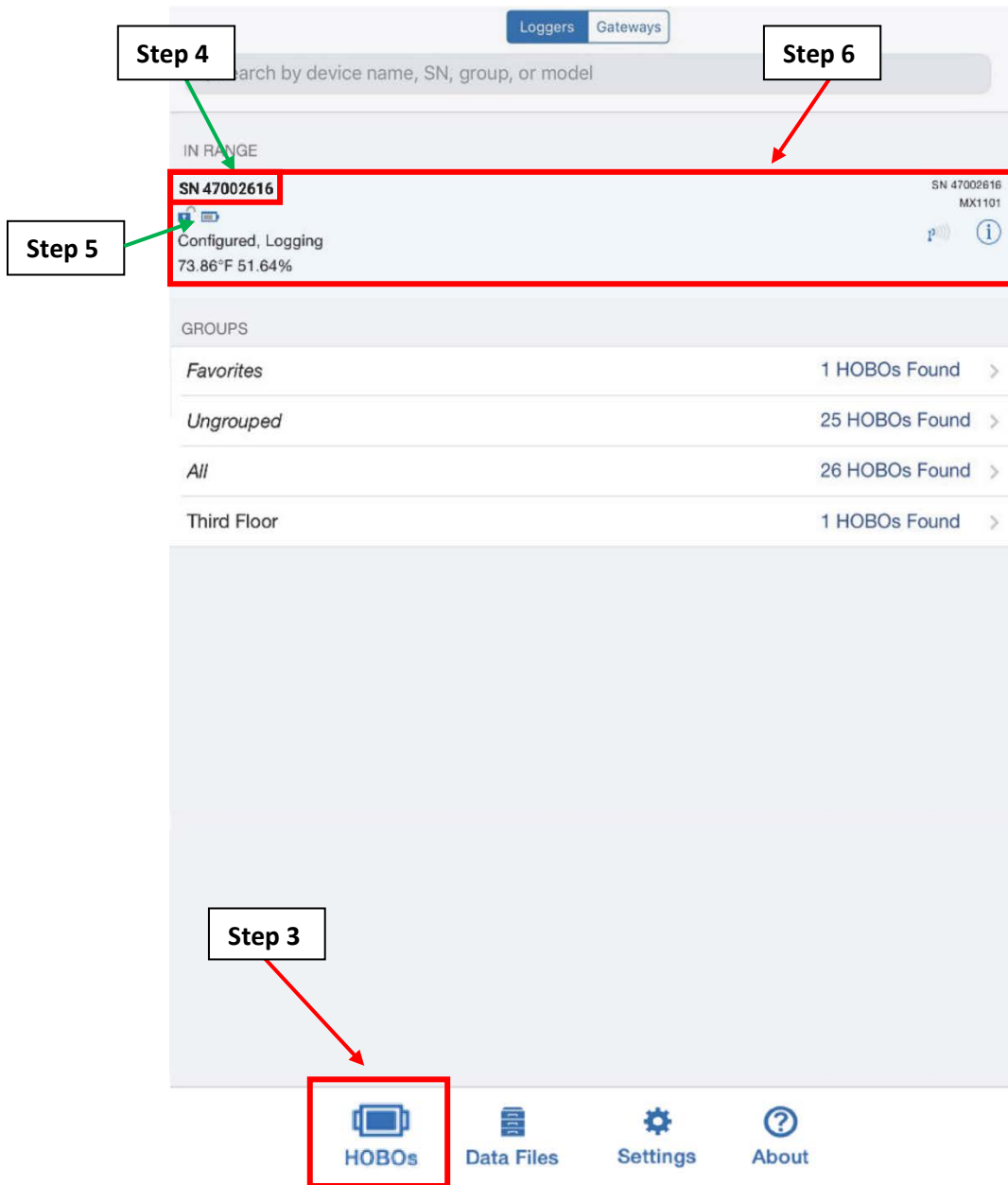


Figure A.6.2: “HOBOS” screen on HOBOMobile app.

A.6.2: Logging Setup for the MX1101 Data Logger

1. After connecting to the MX1101 Data Logger by following section A.6.1, tap the “Configure” option (Figure A.6.3).

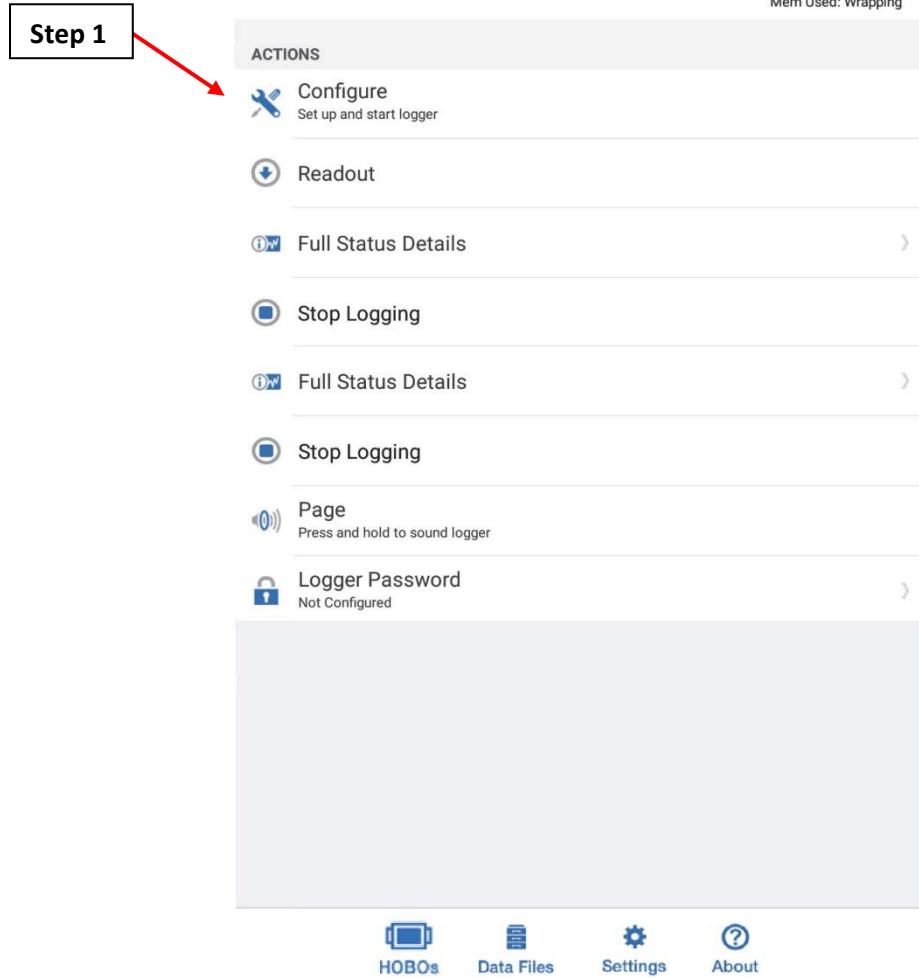


Figure A.6.3: HOBOMobile “Connected” screen.

The following steps will guide you on which settings to choose in the “Configure” screen shown on Figure A.6.4.

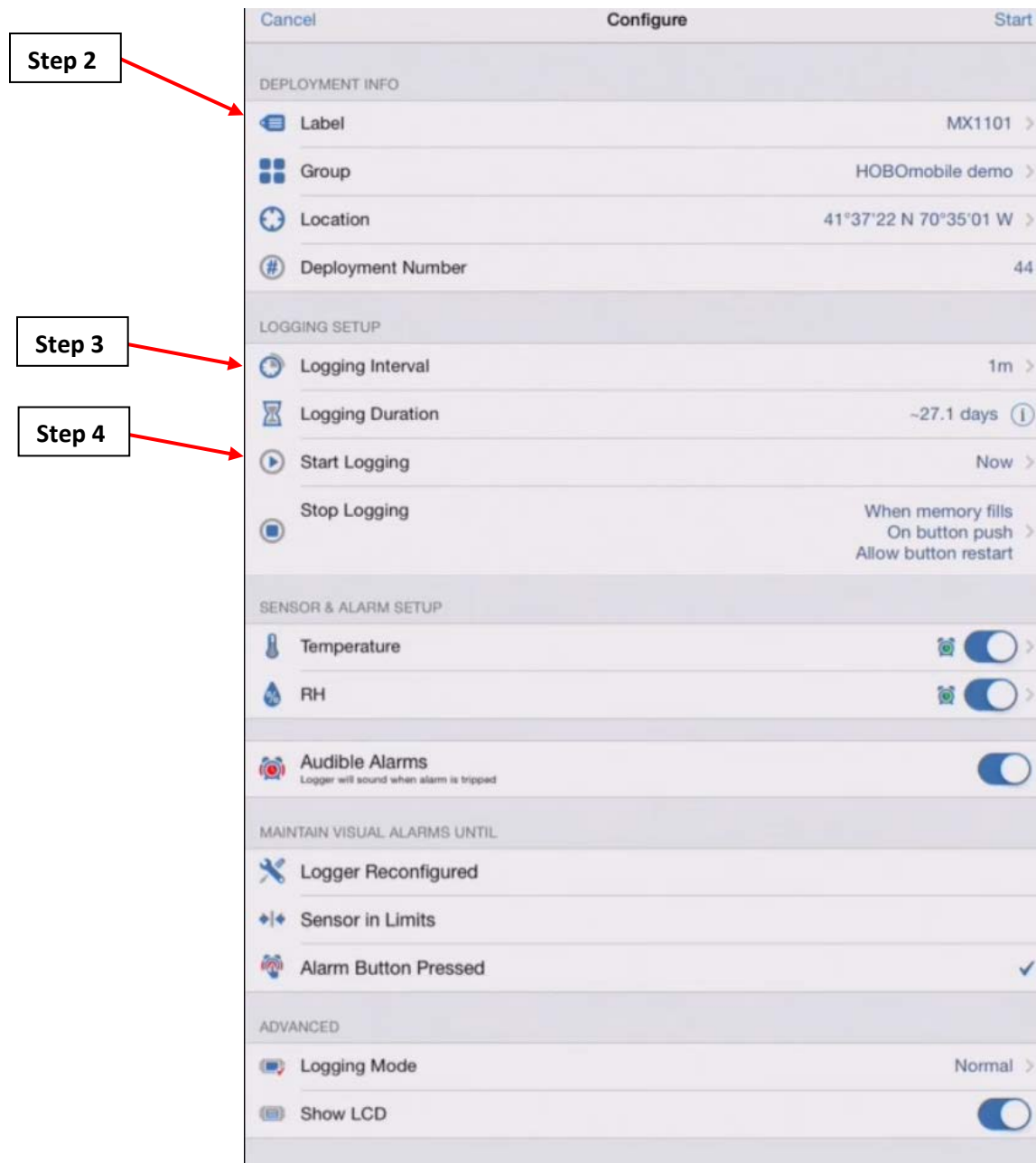


Figure A.6.4: HOBOMobile "Configure" screen.

2. Tap on the "Label" option, which will open the "Deployment Label" screen as shown on Figure A.6.5.
 - a. Set the name for the MX1101 Data Logger. The "Label" should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - i. For example, for an AHU system, we can set a name with the facility's name, the AHU number, and whether it's a supply or return fan in this format:
facilityname_ahunumber_supply OR *facilityname_ahunumber_return*.
 - b. Tap "Done" (Figure A.6.5) to go back to the "Configure" screen.



Figure A.6.5: The “Deployment Label” screen.

3. Tap on the “Logging Interval” option to go to the “Logging Interval” screen as shown on Figure A.6.6.
 - a. On this screen, set the logging interval to 1 hour, 0 minutes, and 0 seconds.
 - b. Tap “Done” (Figure A.6.6) to go back to the “Configure” screen.

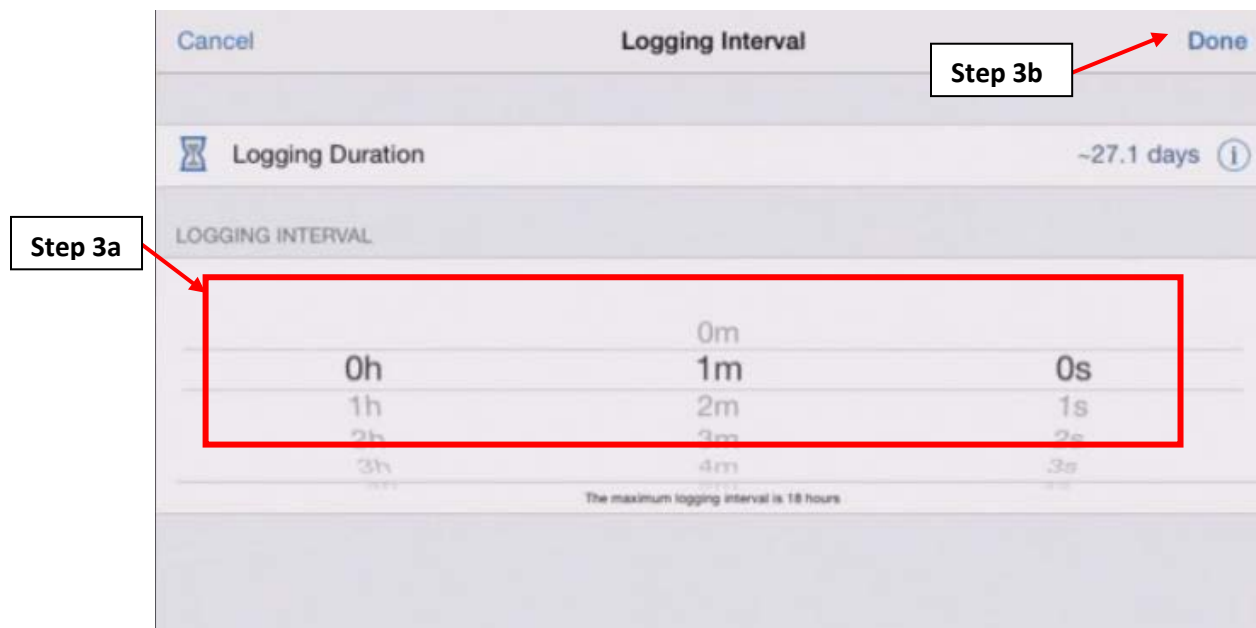


Figure A.6.6: The “Logging Interval” screen.

4. At the “Configure” screen (Figure A.6.4) , select the “Start Logging” option to go to the “Start Logging” screen as shown on Figure A.6.7.
 - a. On the “Start Logging” screen, tap the “On Date/Time...” option which will take you to the “Date/Time” screen shown on Figure A.6.8.
 - b. On the “Date/Time” screen (Figure A.6.8) Set the date and time for which you would like the MX1101 Data Logger to start collect data.
 - i. If multiple MX1101 Data Loggers are deployed, make sure that they are all set to start logging at the same date and time.
 - c. After setting the start date and time, tap “Done” (Figure A.6.8).

- d. Tap “Done” (Figure A.6.7) on the “Start Logging” screen to complete start date and time setup.



Figure A.6.7: The “Start Logging” screen.

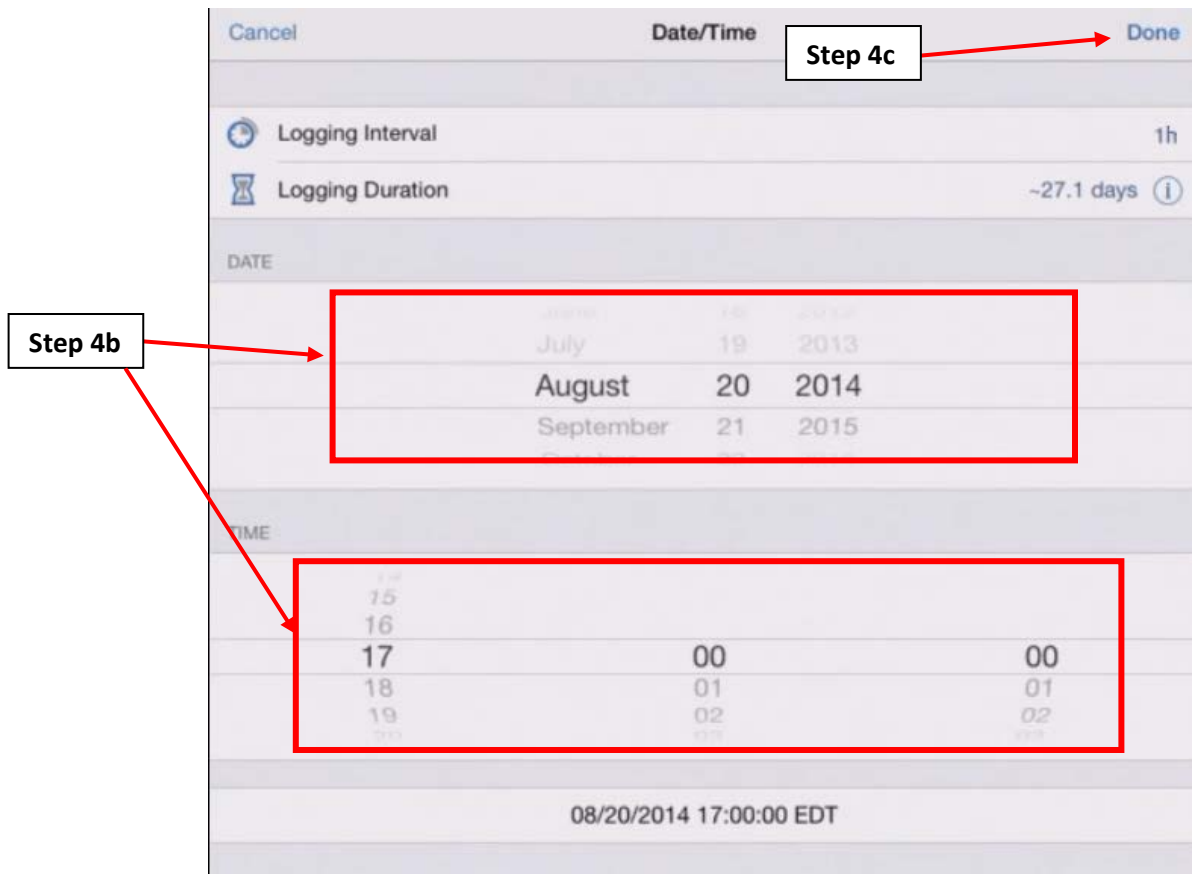


Figure A.6.8: The “Date/Time” screen.

5. At the “Configure” screen (Figure A.6.4), select the “Stop Logging” option to go to the “Stop Logging” screen as shown on Figure A.6.9.
 - a. Select the “When Memory Fills...” option. Ensure that there is a checkmark right next to this option.
 - b. Make sure that all the other options are unchecked.
 - c. Tap “Done” to return to the “Configure” screen.

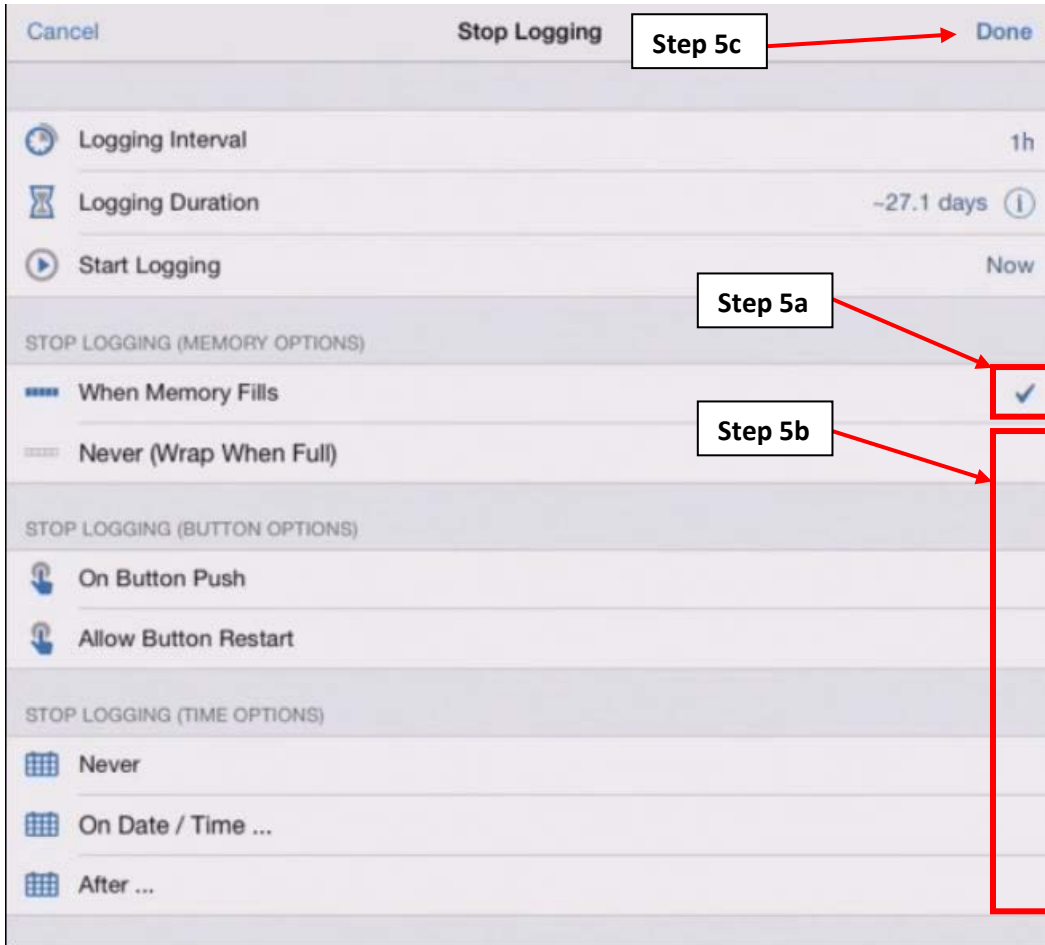


Figure A.6.9: The “Stop Logging” screen.

A.6.3: Setting the Advanced Features and Deployment of the MX1101 Data Logger

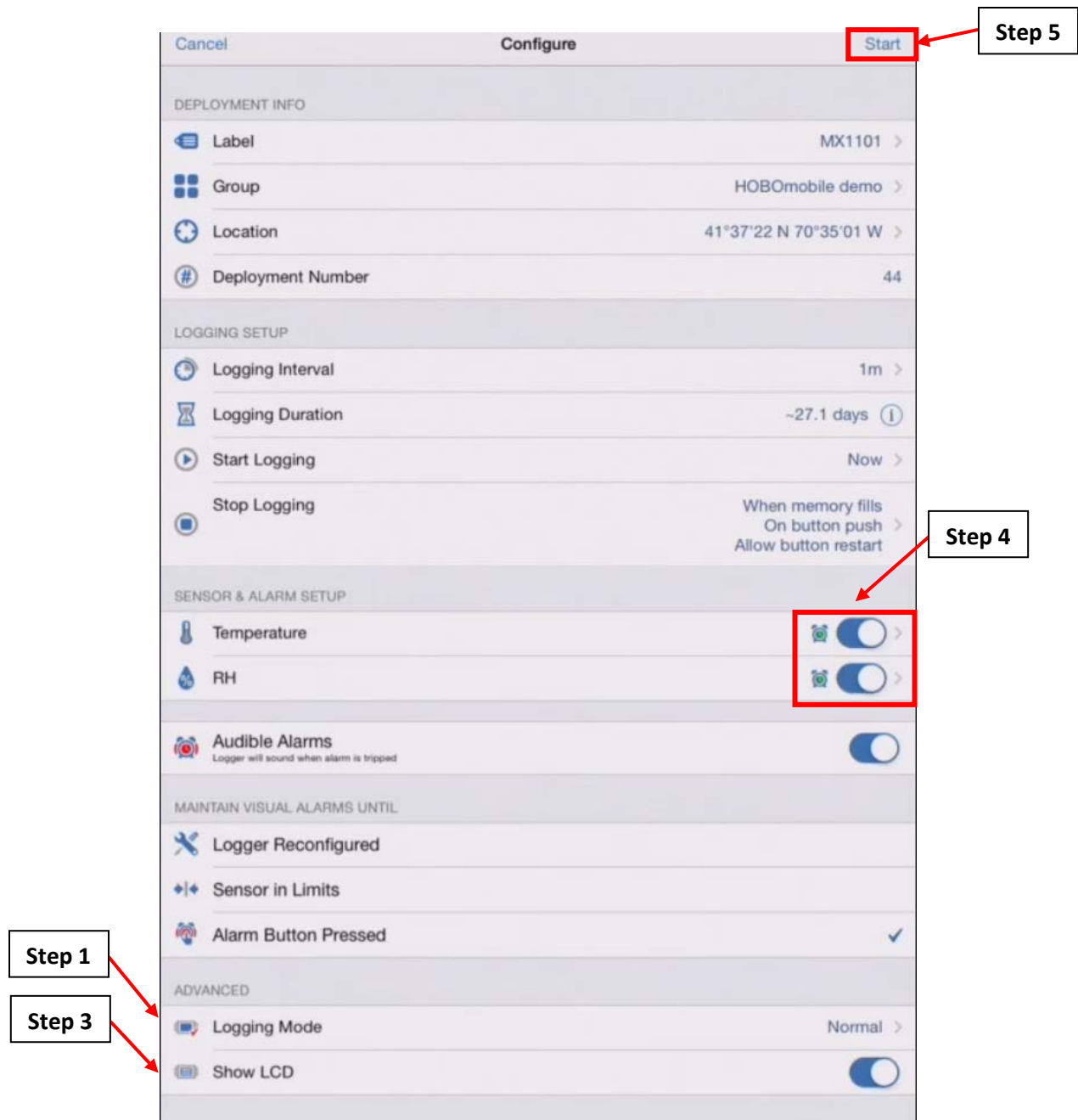


Figure A.6.10: The "Configure" screen.

1. On the "Configure" screen, go to the "Advanced" section and tap the "Logging Mode" option, which will take you to the "Logging Mode" screen as shown on Figure A.6.11.
 - a. Tap on the "Fixed Interval Logging" option. A checkmark should appear next to this option. The "Burst Logging" option should have no checkmark.
 - b. Tap the "Normal" option if there is no checkmark next to this option.
 - c. Take the "Average" option in the "Statistics" section. Make sure "Maximum" and "Minimum" are unchecked.

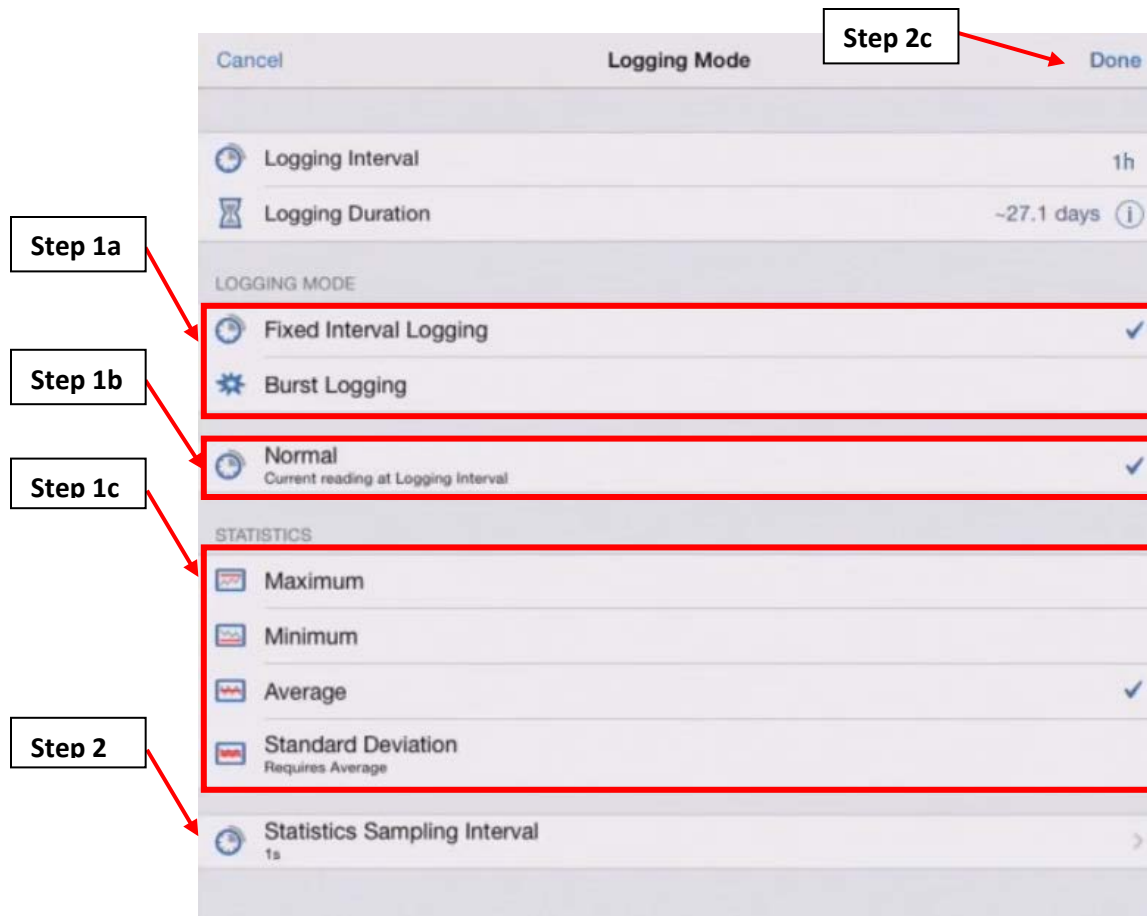


Figure A.6.11: The “Logging Mode” screen.

2. Tap the “Statistics Sampling Interval” option which will take you to the “Statistics Sampling Interval” screen as shown on Figure A.6.12.
 - a. In the “Statistics Sampling Interval” screen (Figure A.6.12), set the “Statistics Sampling Interval” to 1 second.
 - b. Tap “Done” to return to the “Logging Mode” screen (Figure A.6.12).
 - c. Tap “Done” to return to the “Configure” screen (Figure A.6.11).

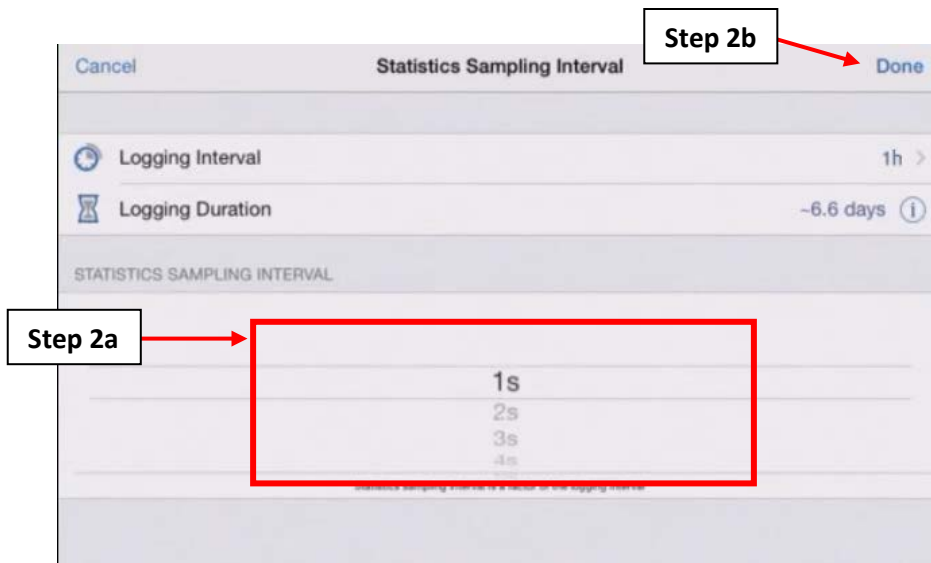


Figure A.6.12: The “Statistics Sampling Interval” screen.

3. At the “Configure” screen (Figure A.6.10), identify if the LCD screen should remain on. If the logger will be deployed for more than one month, turn off the screen to conserve battery life.
4. Make sure that both the “Temperature” and “RH” sensors are activated as shown on Figure A.6.10. The circular sliders should be on the right. If not, tap on the sliders to shift them from the left to the right.
5. Tap “Start” to complete the configuration. The screen of the MX1101 Data Logger will display what is shown on the left of Figure A.6.13. This means that the settings that were set in this section and section A.6.2 are being sent to the MX1101 Data Logger.

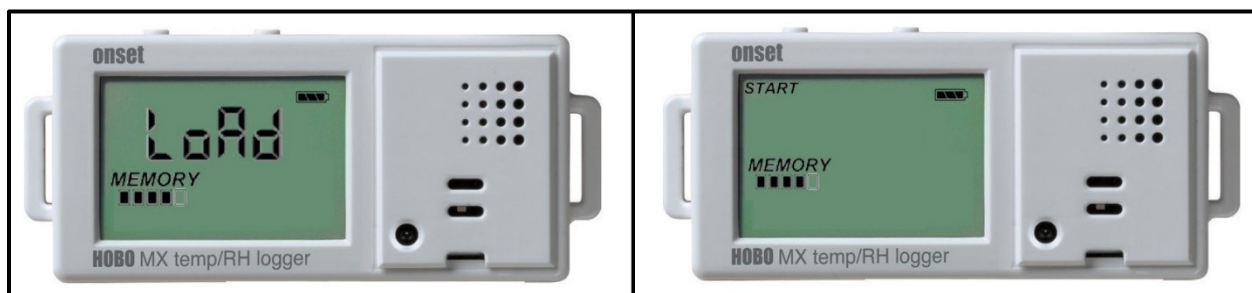


Figure A.6.13: The MX1101 Data Logger with HOBOMobile settings being loaded (left) and settings done loading (right).

6. Once HOBOMobile is done sending its user defined settings to the MX1101 Data Logger, the logger’s LCD screen will display what is shown on the right of Figure A.6.13. The logger will begin collecting data on the date and time that was set on step 4.b of section A.6.2.

A.6.4: MX1101 Data Logger Field Setup

This section will guide you through the field setup of the MX1101 Data Logger. Please exercise the appropriate safety precautions while performing the field setup.

1. Someone familiar with the building's system should identify the system in which the MX1101 Data Logger will be installed onto.
2. Have the electrician turn off the system.
3. Place the MX1101 Data Logger at the part of the system where you would like to record the temperature. Note that the back of the logger is magnetic, and the logger should be placed on the part of the system where temperature will be measured. Please see Figure A.6.14 and Figure A.6.15 for example installations.



Figure A.6.14: Before and after of MX1101 Data Logger installed inside a direct controlled ventilation duct.



Figure A.6.15: Before and after of an MX1101 Data Logger installed onto a part of a direct controlled ventilation system.

A.6.5: Verification of Data Collection for the MX1101 Data Logger

It is important to verify the MX1101 Data Logger is collecting accurate data while installed on the system. Like HOBOWare, HOBOMobile offers an easy way to check collected data without interfering with the initial setup from the previous sections.

1. Make sure that your iOS or Android device which was used to install HOBOMobile and configure the logger is in range with the MX1101 Data Logger.
2. Open the HOBOMobile app on your iOS or Android device.

3. If you are not on the “Connected” screen. Tap the “HOBOS” icon as shown on Figure A.6.16.
 - a. Find your device that you connected to in step 6 of section A.6.1.
 - b. Tap on the row that contains your device, which will take you to the “Connected” screen.

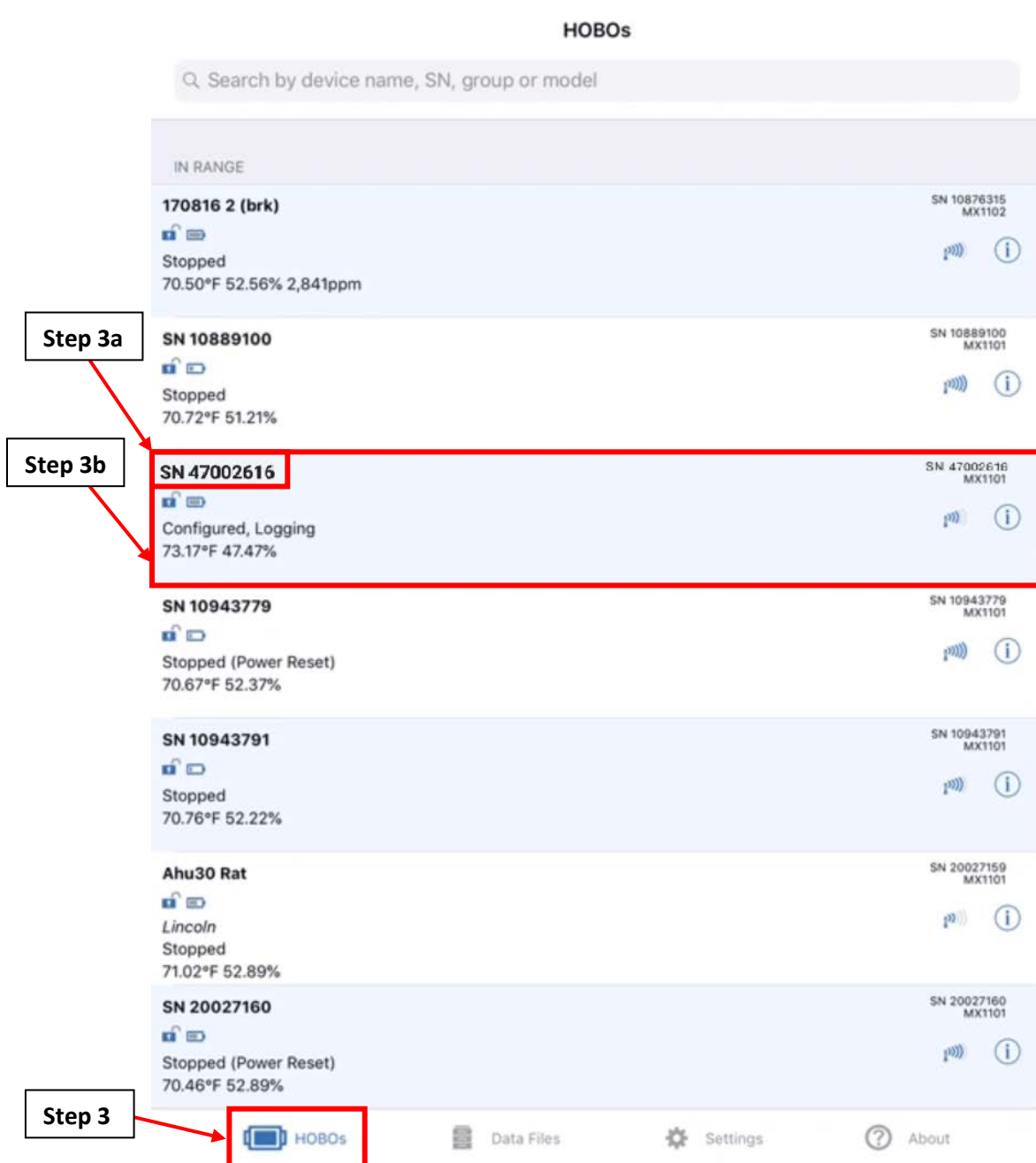


Figure A.6.16: The HOBOMobile HOBOS screen.

4. On the “Connected” screen, right under the words “Configured, Logging”, you will see the temperature and relative humidity percentage readouts of the logger at the current date and time as shown on Figure A.6.17. Make sure that these readouts are consistent with your expectations. If not, check the placement of the MX1101 Data Logger.

- Return to the measurement site periodically to ensure that the MX1101 Data Logger is still collecting temperature and relative humidity percentage readings which are consistent with your expectations.

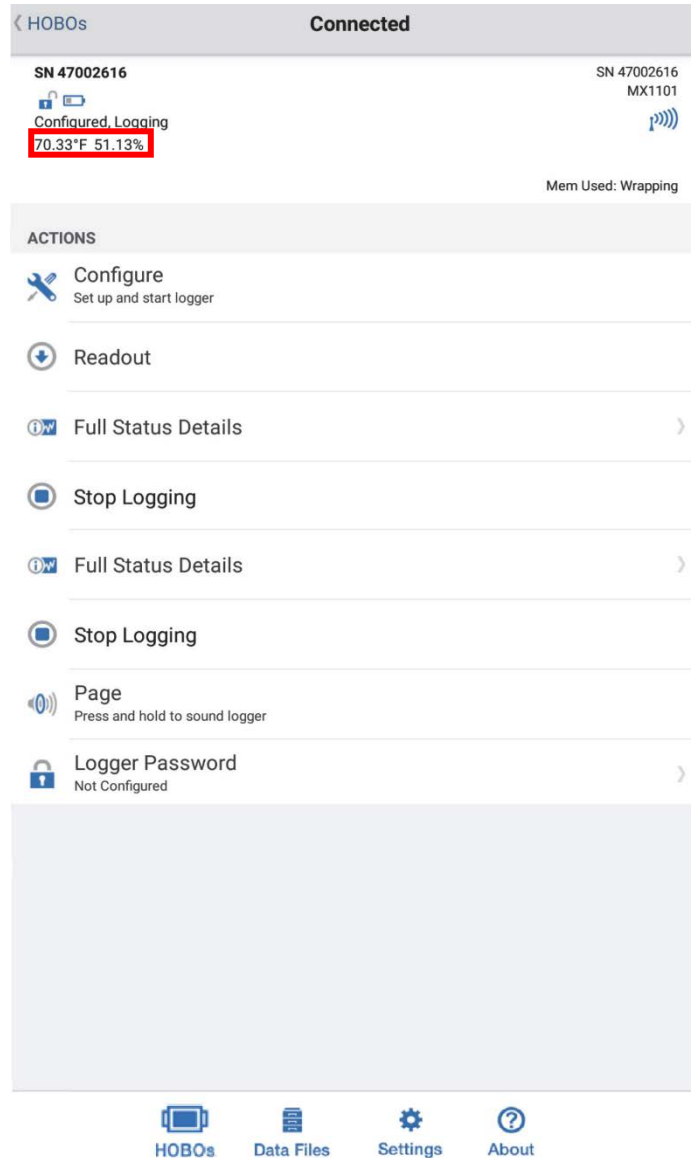


Figure A.6.17: The HOBOMobile “Connected” Screen. The temperature and relative humidity percentage at the current date and time is displayed in the red box.

A.6.6: Exporting Data from the MX1101 Data Logger to a .csv File

After the allotted measurement period (based on the measurement guide) the entire dataset can be extracted and used to trend the temperature of the system component.

1. At the end of the measurement period, follow the procedure in section A.6.5 to verify that the collected data is accurate.
2. If satisfied with the accuracy of the measurements, follow steps 1, 2, and 3 in section A.6.5 to return to the “Connected” screen as shown on Figure A.6.18.
 - a. On the “Connected” screen. Click on the “Readout” option. This will readout the data from the MX1101 Data Logger. Tap “OK” on any popups that are shown on the screen while the logger is being read out.
 - b. In the “Data Files” option on the bottom of the screen, there should be a red circle with the number 1 inside it. This indicates that you now have a new file. Tap on the “Data Files” option.

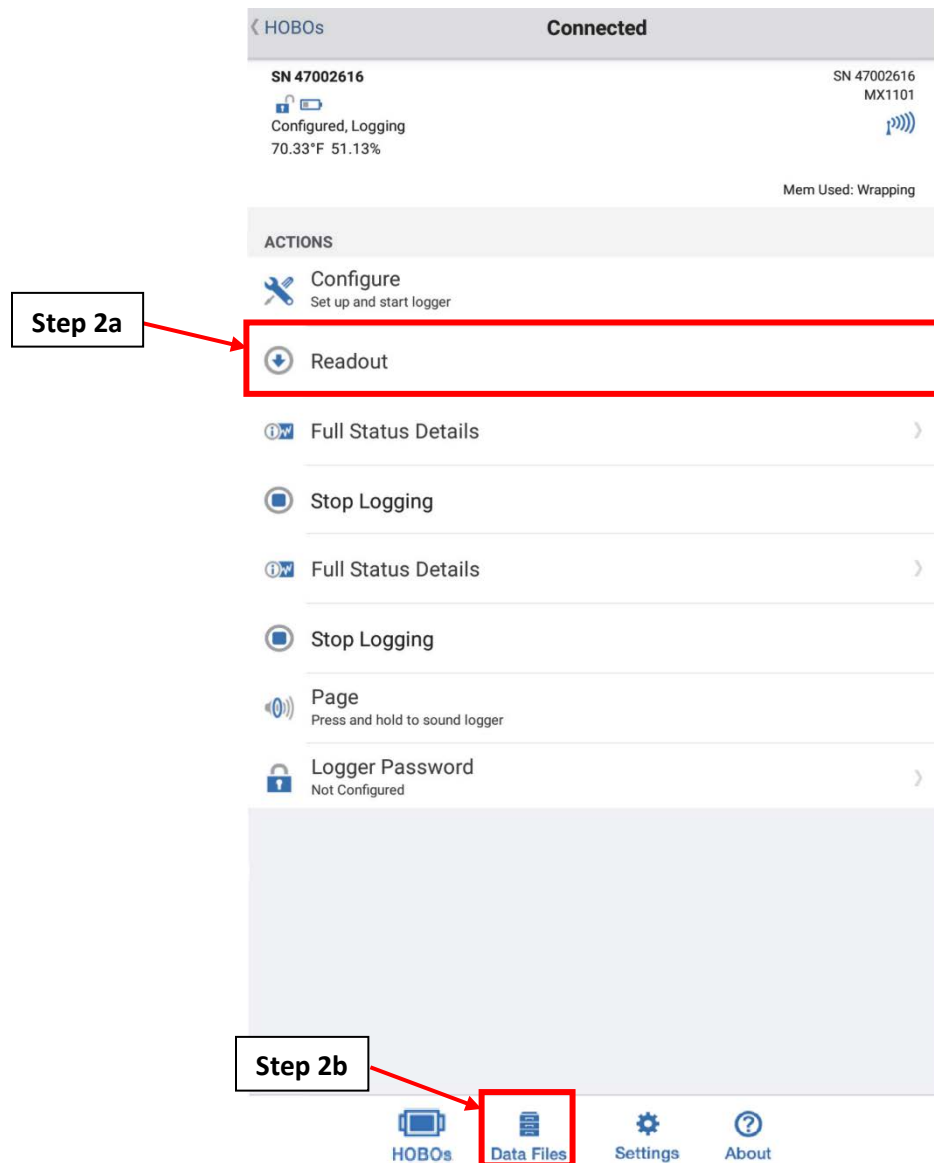


Figure A.6.18: The HOBOMobile “Connected” screen.

3. After selecting the “Data Files” option, the “Close Connection?” pop-up window will show on the screen as shown on Figure A.6.19. Tap “Yes” to proceed. After performing this step, the MX1101 Data Logger can be removed from the site.

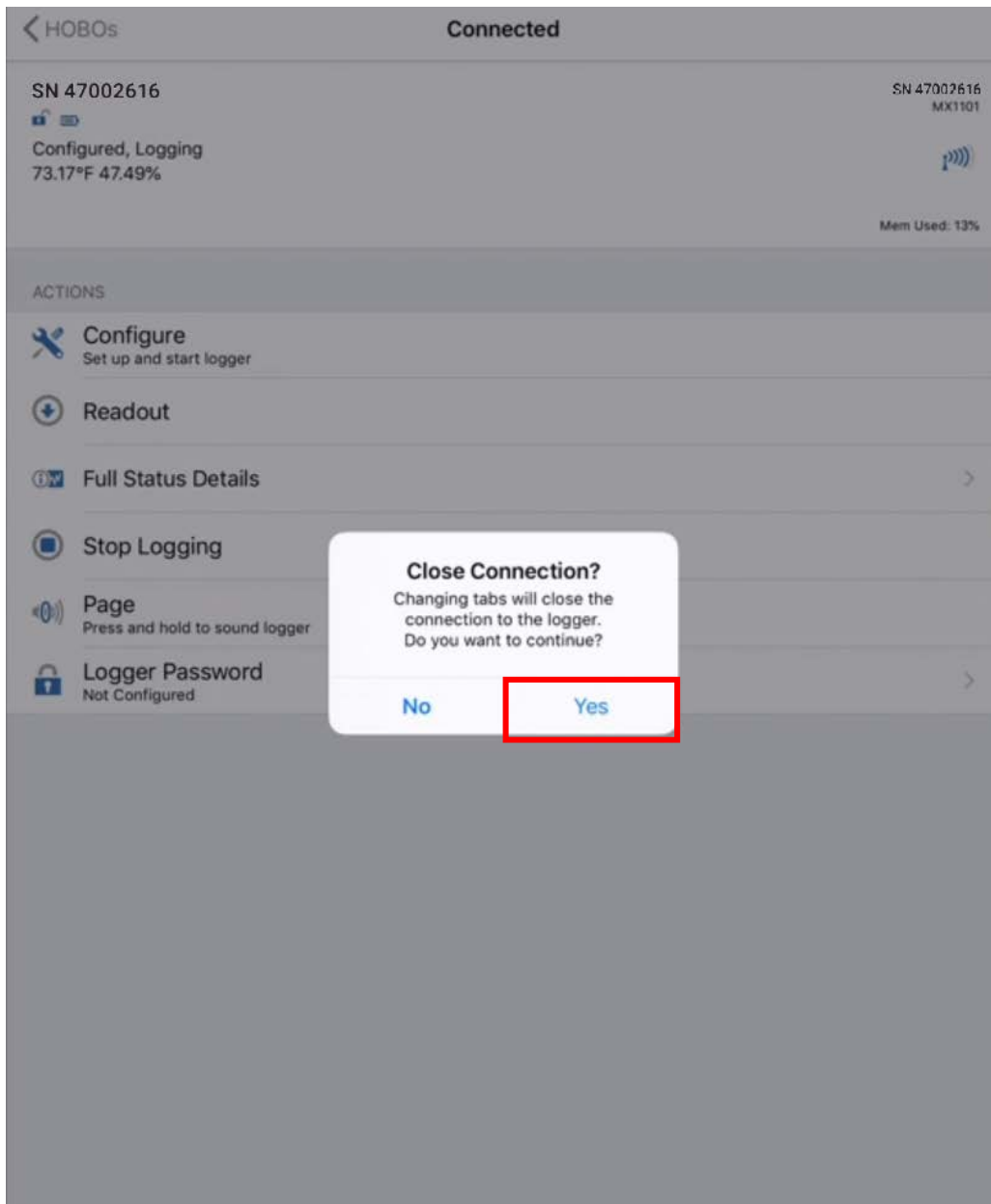


Figure A.6.19: The “Close Connection?” pop-up window.

4. At the “Data Files” screen as shown on Figure A.6.20, tap on the graph that has the name that you set at step 2.a of section A.6.2. For this guide, the name was left as the default name of the MX1101 Data Logger, which is boxed in on Figure A.6.20. Tapping on the small graph will bring you to the larger graph as shown on Figure A.6.21.

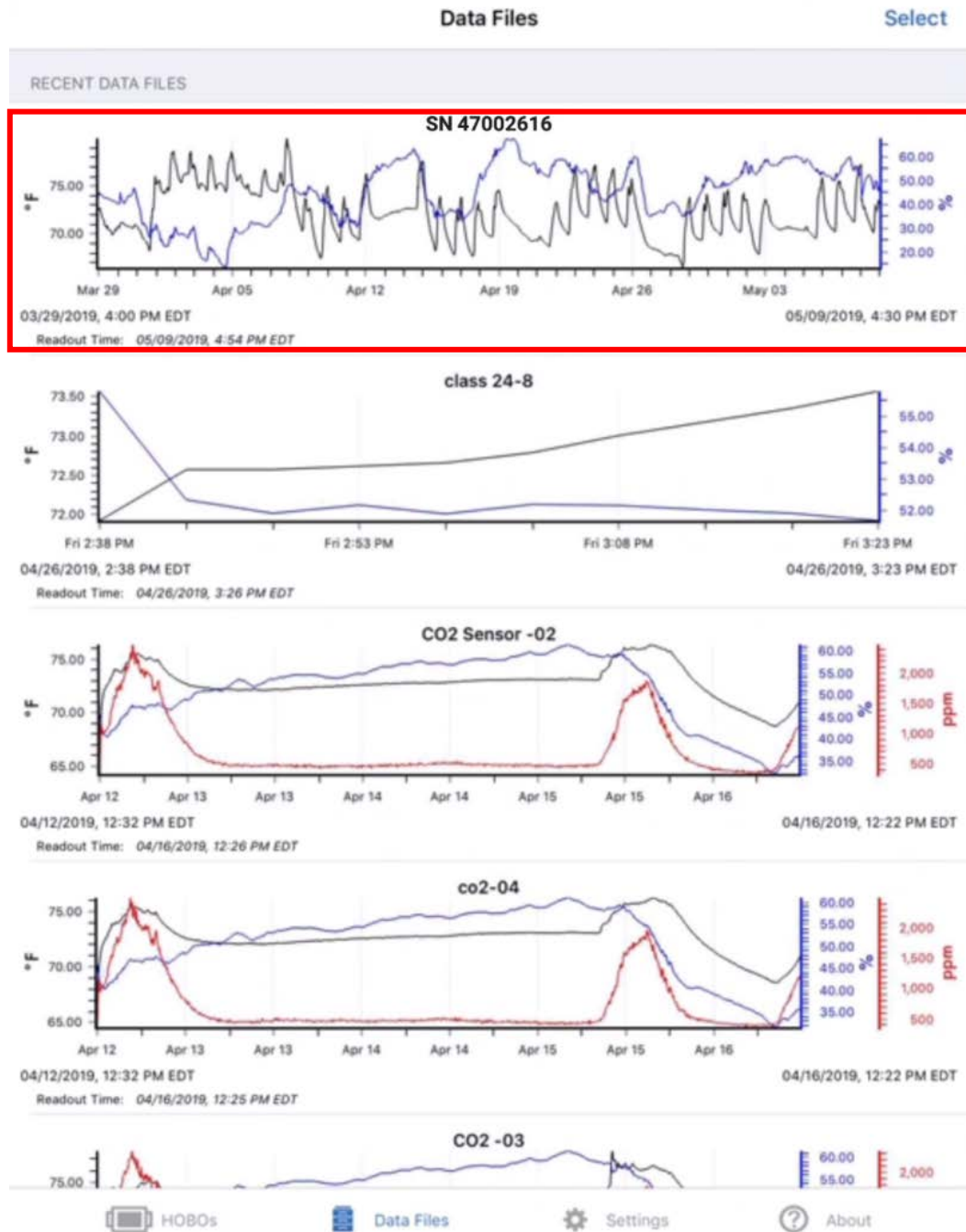


Figure A.6.20: The “Data Files” screen.

5. On the larger graph as shown on Figure A.6.21, you can closely inspect the data by zooming in and out with your fingers, or turning the device to landscape mode if currently in portrait mode.
6. Tap on the “Share” icon, which is boxed in on the top right of Figure A.6.21. This will take you to the “Share” screen.

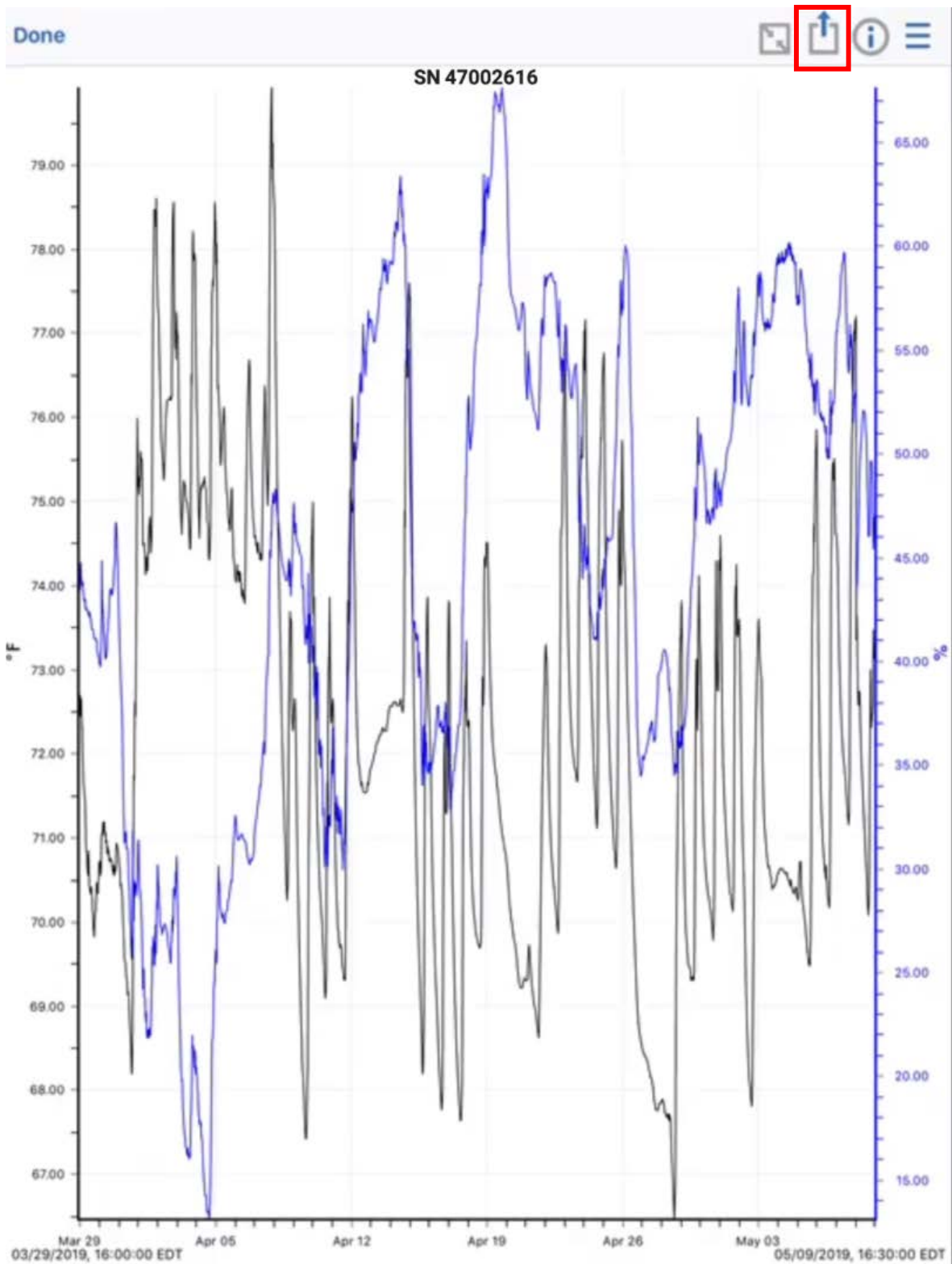


Figure A.6.21: The larger graph.

- At the “Share” screen. Tap the “CSV” option, boxed in on Figure A.6.22. Make sure that your iOS or Android device is connected to the internet before proceeding.

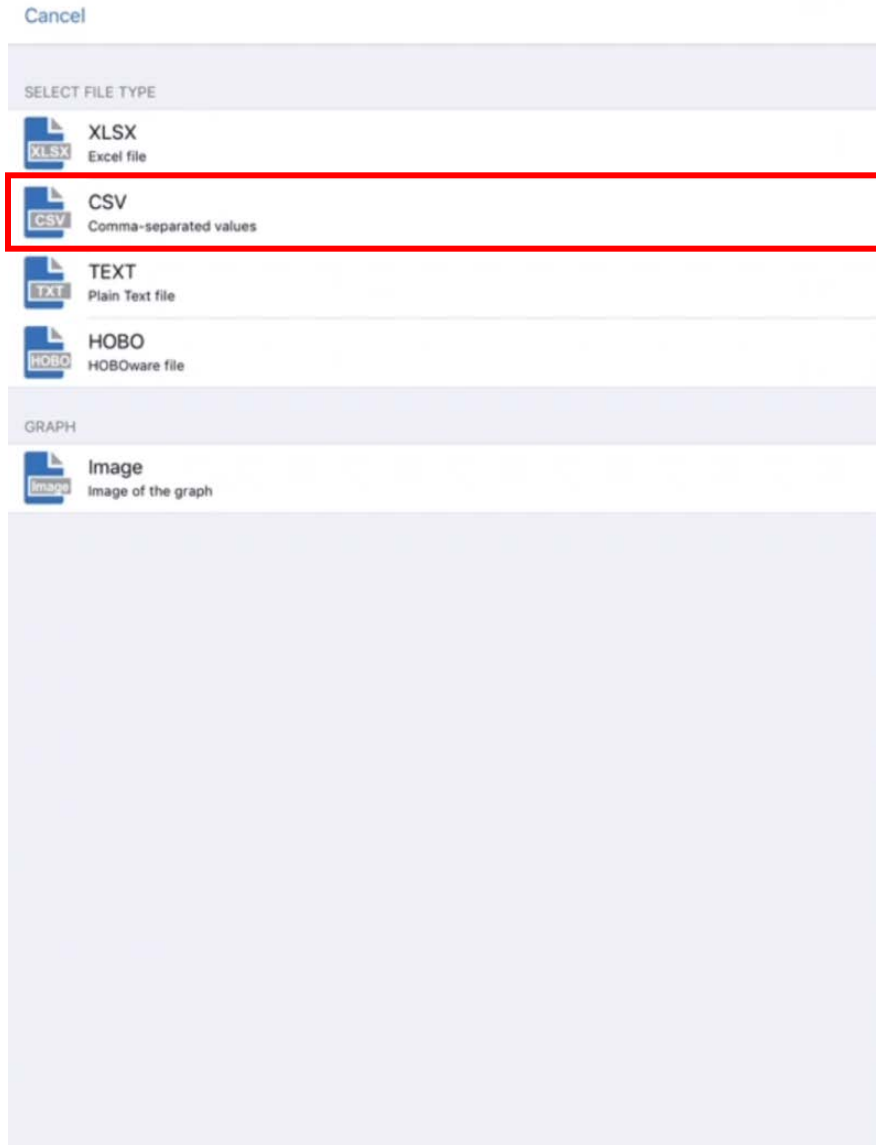


Figure A.6.22: The HOBOMobile “Share” screen.

In writing this guide, the next steps were written with respect to an iOS device. The options shown in Figure A.6.23 and Figure A.6.24 will be different on an Android device. Please select similar options if you are using an Android device.

8. At the menu that pops up after selecting the “CSV” option, shown on Figure A.6.23, select the “Mail” option.
 - a. Enter the email that you would like to send the .csv file to.
 - b. Tap “Send” to send the .csv file to the email that you specified in the last step.



Figure A.6.23: The various options for exporting the data from the MX1101 Data Logger as a .csv file. For this guide, select the "Mail" option.

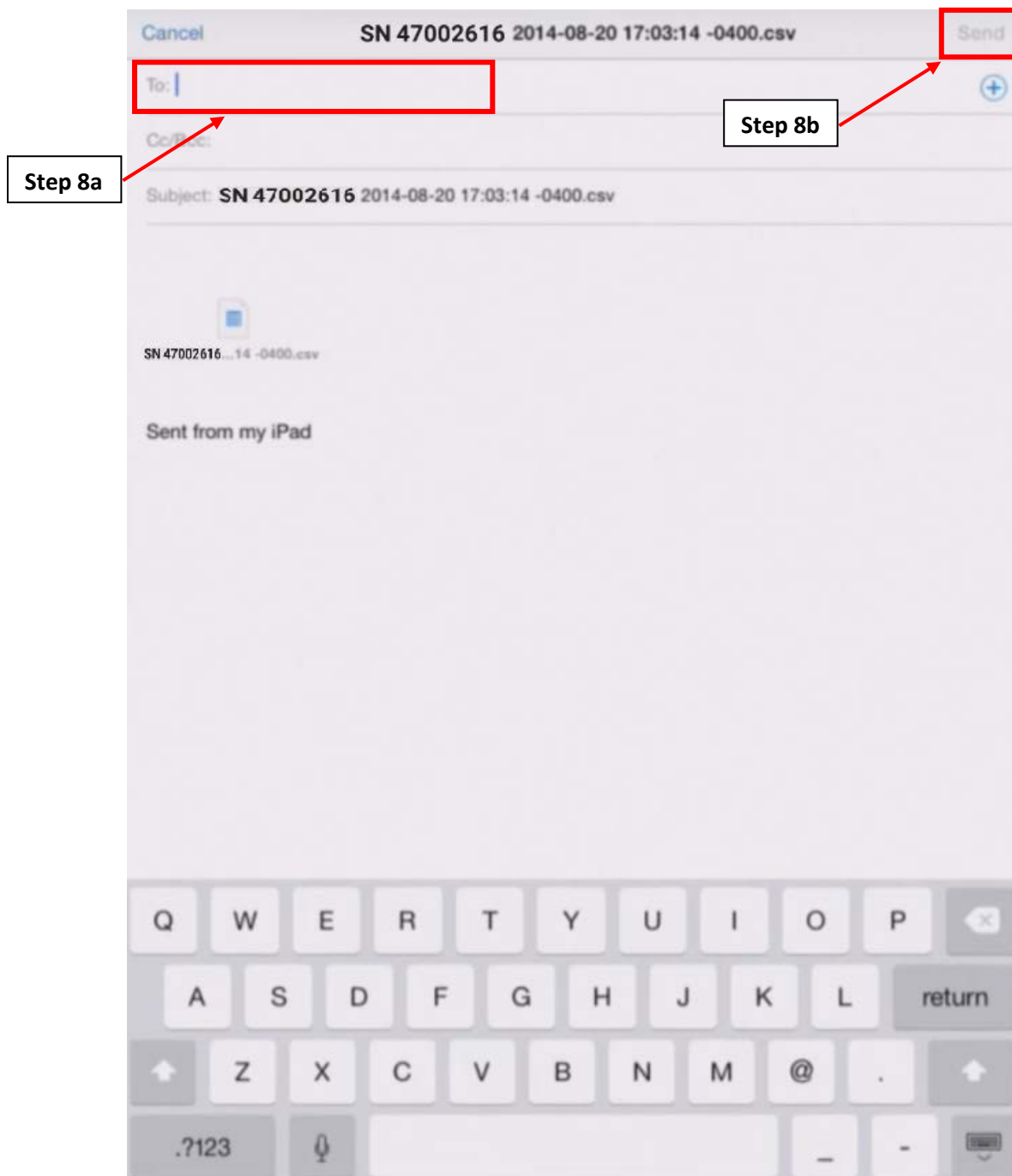


Figure A.6.24: Exporting the .csv file to an email.

A.7: Onset HOBO Temperature/Relative Humidity Weatherproof Data Logger (MX2301)

Sections A.7.1, A.7.2, A.7.3, A.7.5 and A.7.6 require the use of the HOBOMobile app. For iOS devices, this app can be downloaded from the App Store for free. For Android devices, this app can be downloaded from the Google Play Store. For this guide, the Onset HOBO Temperature/Relative Humidity Data Logger will be referred to as the MX2301 Data Logger.

A.7.1: MX2301 Data Logger Connection to iOS or Android Device

Please follow this section to connect the MX2301 Data Logger to the HOBOMobile app on your iOS or Android device.

1. Ensure that your iOS or Android device is within 100 feet of the MX2301 Data Logger.
2. Press the start button as shown on Figure A.7.1. This will cause the alarm and status LEDs to blink, indicating that the MX2301 Data Logger has been turned on.

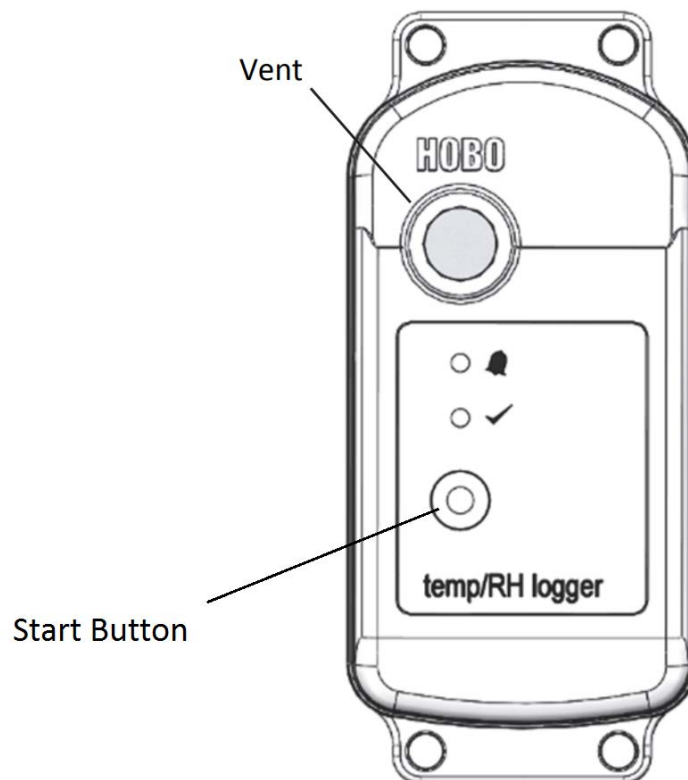


Figure A.7.1: The MX2301 Data Logger diagram.

3. Enable Bluetooth on your iOS or Android device. This varies between different devices, but most devices allow you to configure Bluetooth in the "Settings" option.
4. On the HOBOMobile app, tap the "HOBOS" button on the bottom of the screen to go to the "HOBOS" screen.
5. The MX2301 Data Logger should be displayed in the "Recently Seen/In Range" list starting with the letters "SN", and then continuing with the serial number. This is the default name for the MX2301 Data Logger.
6. Check the battery level to confirm that the MX2301 Data Logger is sufficiently powered and doesn't require a battery replacement.

7. Tap the row in the “In Range” list to connect to the MX2301 Data Logger.

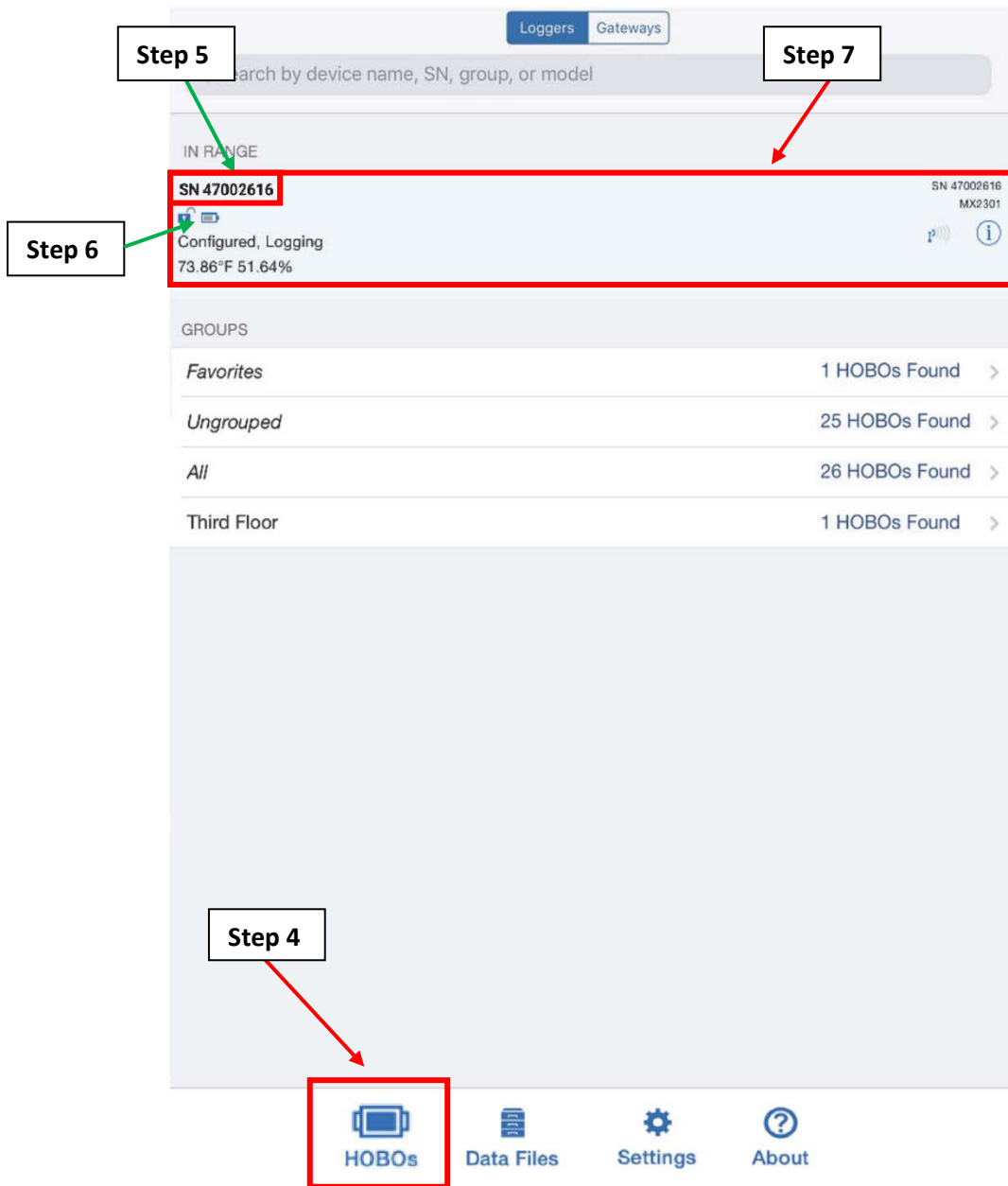


Figure A.7.2: “HOBOS” screen on HOBOMobile app.

A.7.2: Logging Setup for the MX2301 Data Logger

1. After connecting to the MX2301 Data Logger by following section A.7.1, tap the “Configure” option (Figure A.7.3).

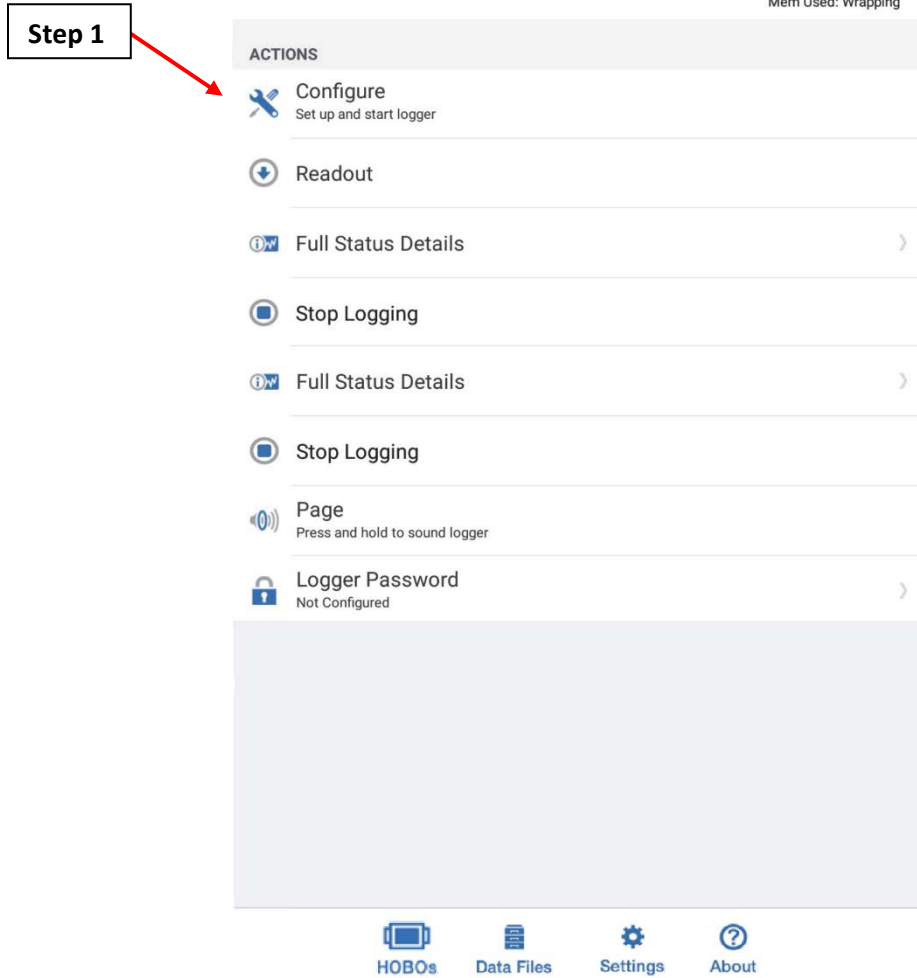


Figure A.7.3: HOBOMobile "Connected" screen.

The following steps will guide you on which settings to choose in the "Configure" screen shown on Figure A.7.4.

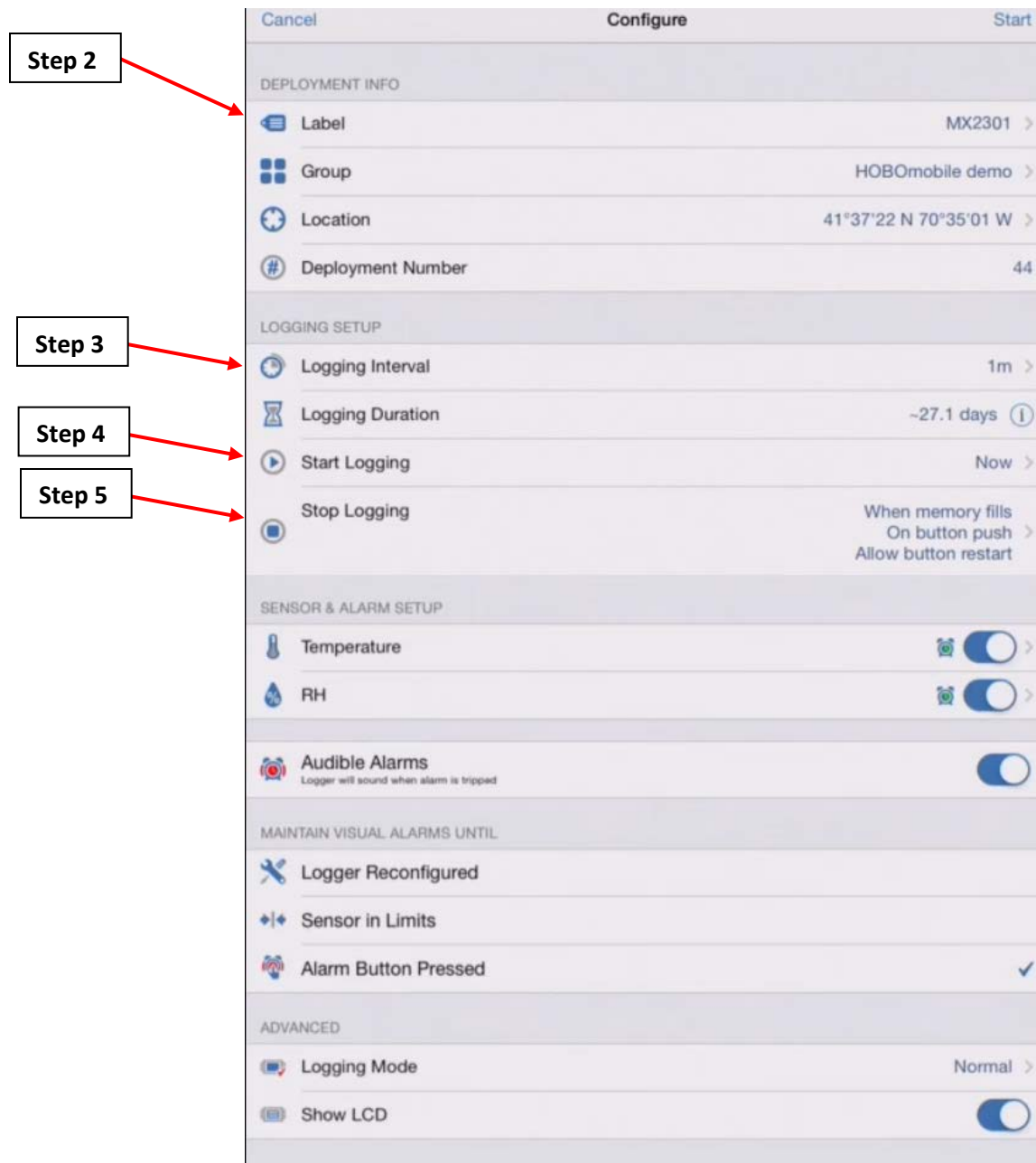


Figure A.7.4: HOBOMobile "Configure" screen.

2. Tap on the "Label" option, which will open the "Deployment Label" screen as shown on Figure A.7.5.
 - a. Set the name for the MX2301 Data Logger. The "Label" should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - i. For example, for an AHU system, we can set a name with the facility's name, the AHU number, and whether it's a supply or return fan in this format:
facilityname_ahunumber_supply OR *facilityname_ahunumber_return*.
 - b. Tap "Done" (Figure A.7.5) to go back to the "Configure" screen.

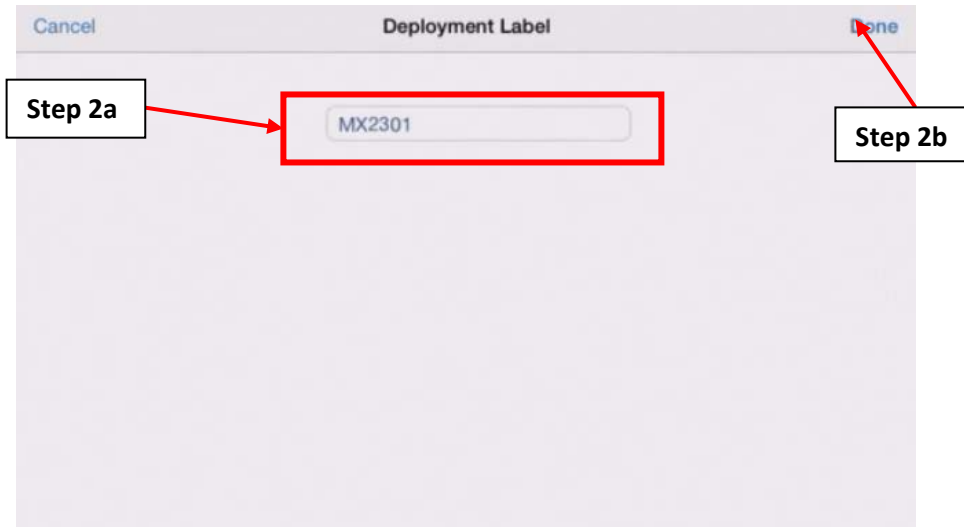


Figure A.7.5: The “Deployment Label” screen.

3. Tap on the “Logging Interval” option to go to the “Logging Interval” screen as shown on Figure A.6.6.
 - a. On this screen, set the logging interval to 1 hour, 0 minutes, and 0 seconds.
 - b. Tap “Done” (Figure A.7.6) to go back to the “Configure” screen.

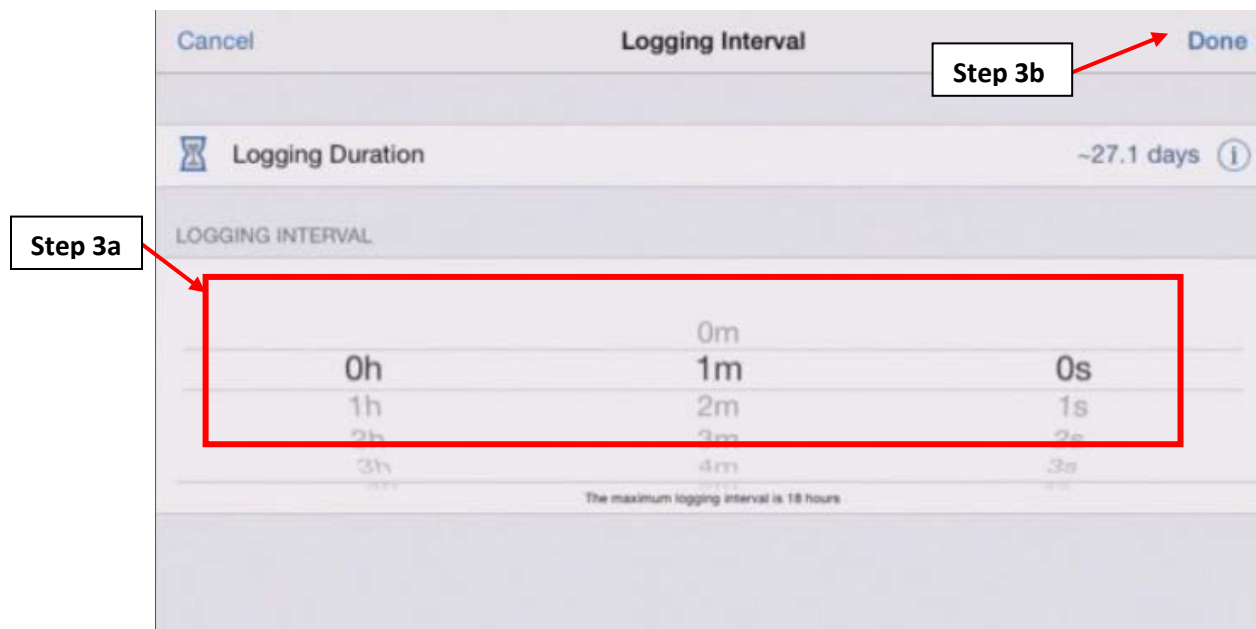


Figure A.7.6: The “Logging Interval” screen.

4. Select the “Start Logging” option to go to the “Start Logging” screen as shown on Figure A.7.7.
 - a. On the “Start Logging” screen, tap the “On Date/Time...” option which will take you to the “Date/Time” screen shown on Figure A.7.8.
 - b. On the “Date/Time” screen (Figure A.7.8) Set the date and time for which you would like the MX3201 Data Logger to start collect data.

- i. If multiple MX2301 Data Loggers are deployed, make sure that they are all set to start logging at the same date and time.
- c. After setting the start date and time, tap “Done” (Figure A.7.8).
- d. Tap “Done” (Figure A.7.7) on the “Start Logging” screen to complete start date and time setup.

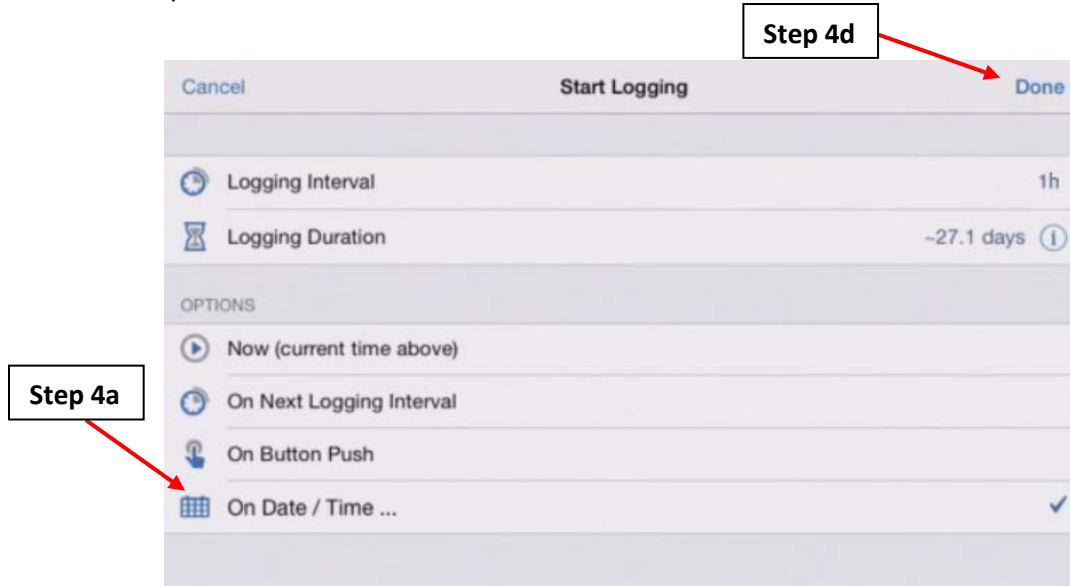


Figure A.7.7: The “Start Logging” screen.

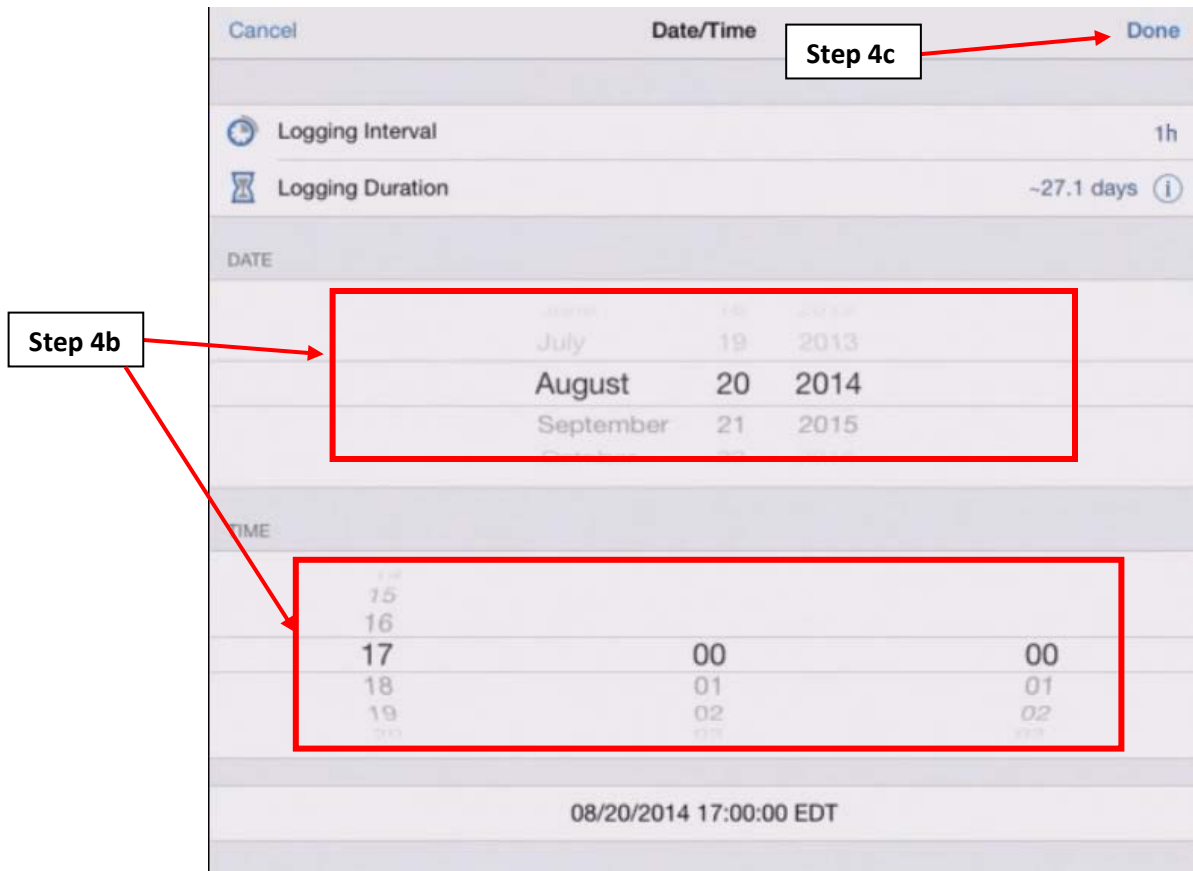


Figure A.7.8: The “Date/Time” screen.

5. Select the “Stop Logging” option (Figure A.7.4) to go to the “Stop Logging” screen as shown on Figure A.7.9.
 - a. Select the “When Memory Fills...” option. Ensure that there is a checkmark right next to this option.
 - b. Make sure that all the other options are unchecked.
 - c. Tap “Done” to return to the “Configure” screen.

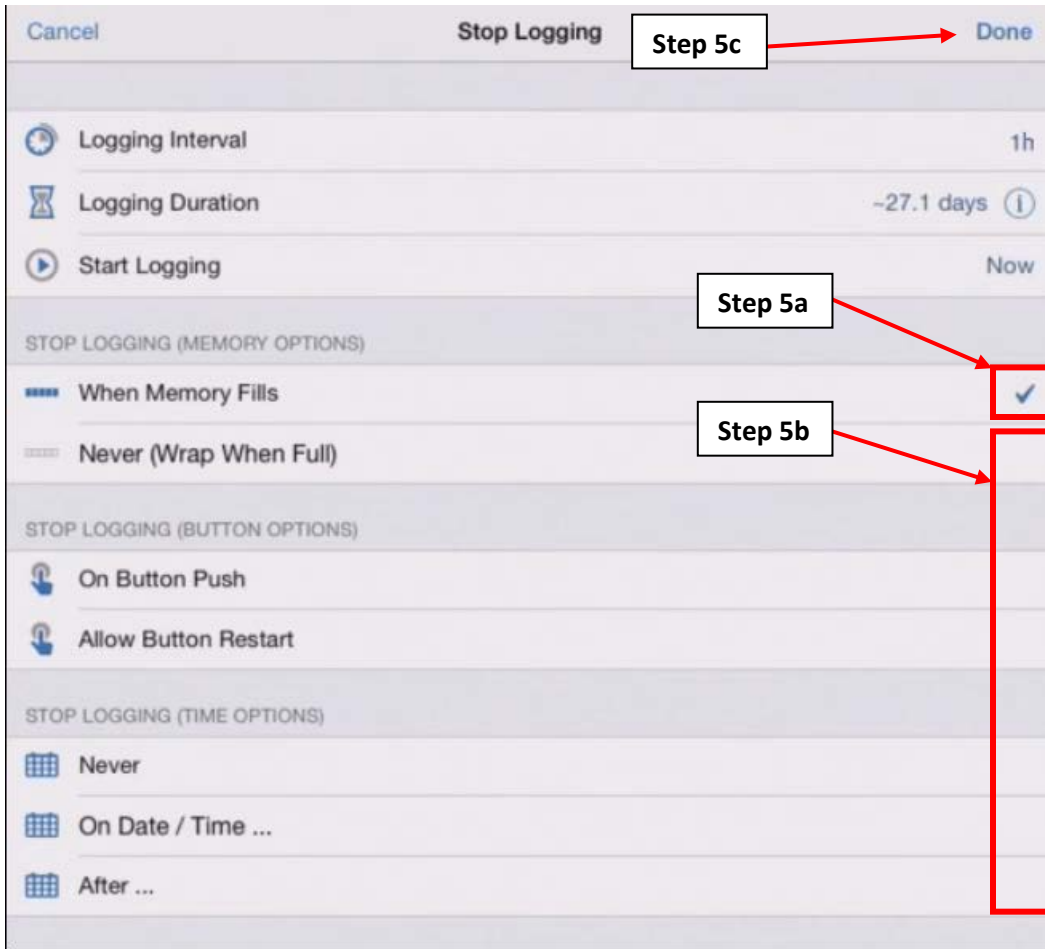


Figure A.7.9: The "Stop Logging" screen.

A.7.3: Setting the Advanced Features and Deployment of the MX2301 Data Logger



Figure A.7.10: The “Configure” screen.

1. On the “Configure” screen (Figure A.7.10), go to the “Advanced” section and tap the “Logging Mode” option, which will take you to the “Logging Mode” screen as shown on Figure A.7.11.
 - a. Tap on the “Fixed Interval Logging” option. A checkmark should appear next to this option. The “Burst Logging” option should have no checkmark.
 - b. Tap the “Normal” option if there is no checkmark next to this option.
 - c. Take the “Average” option in the “Statistics” section. Make sure “Maximum” and “Minimum” are unchecked.

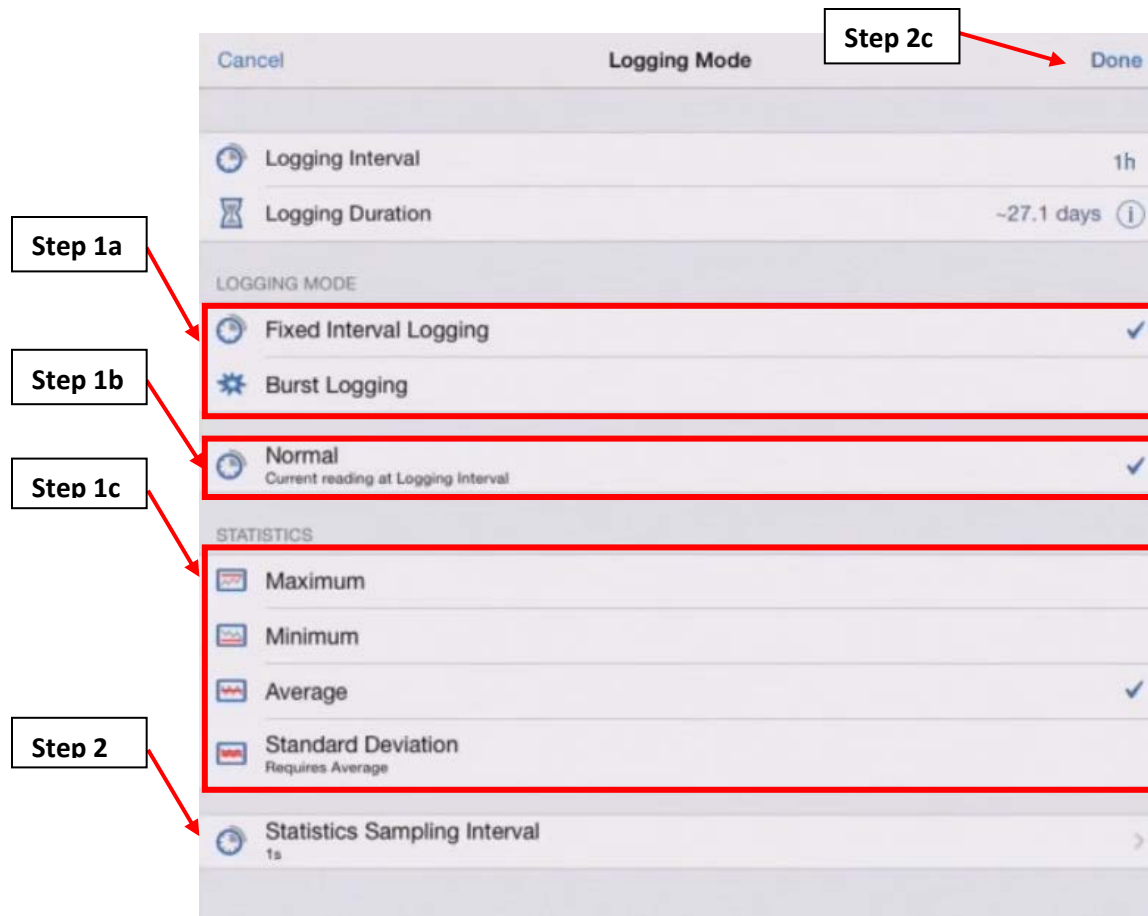


Figure A.7.11: The “Logging Mode” screen.

2. Tap the “Statistics Sampling Interval” option which will take you to the “Statistics Sampling Interval” screen as shown on Figure A.7.12.
 - a. In the “Statistics Sampling Interval” screen, set the “Statistics Sampling Interval” to 1 second.
 - b. Tap “Done” to return to the “Logging Mode” screen.
 - c. Tap “Done” to return to the “Configure” screen (Figure A.7.11).

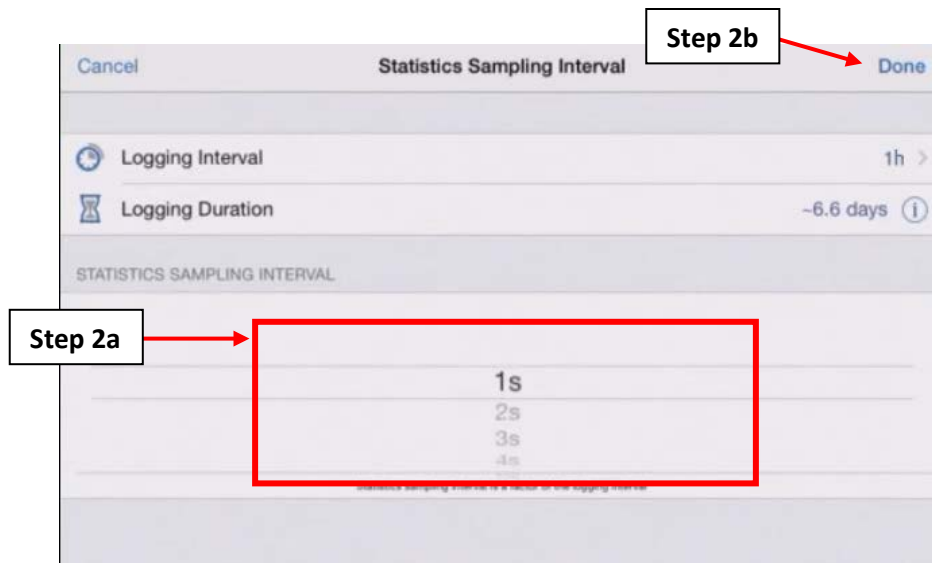


Figure A.7.12: The “Statistics Sampling Interval” screen.

3. At the “Configure” screen (Figure A.7.10), Identify if the LCD screen should remain on. If the logger will be deployed for more than one month, turn off the screen to conserve battery life.
4. Make sure that both the “Temperature” and “RH” sensors are activated as shown on Figure A.7.10. The circular sliders should be on the right. If not, tap on the sliders to shift them from the left to the right.
5. Tap “Start” to complete the configuration. The settings that were set in this section and section A.7.2 are being sent to the MX2301 Data Logger. Once HOBOMobile is done sending its user defined settings to the MX2301 Data Logger, the logger will begin collecting data on the date and time that was set on step 4.b of section A.7.2.

A.7.4: MX2301 Data Logger Field Setup

This section will guide you through the field setup of the MX2301 Data Logger.

A.7.5: Verification of Data Collection for the MX2301 Data Logger

It is important to verify the MX2301 Data Logger is collecting accurate data while installed on the system. Like HOBOWare, HOBOMobile offers an easy way to check collected data without interfering with the initial setup from the previous sections.

1. Make sure that your iOS or Android device which was used to install HOBOMobile and configure the logger is in range with the MX2301 Data Logger.
2. Open the HOBOMobile app on your iOS or Android device.
3. If you are not on the “Connected” screen. Tap the “HOBOS” icon as shown on Figure A.7.13.
 - a. Find your device that you connected to in step 7 of section A.7.1.
 - b. Tap on the row that contains your device, which will take you to the “Connected” screen.



Figure A.7.13: The HOBOMobile HOBOS screen.

- On the "Connected" screen, right under the words "Configured, Logging", you will see the temperature and relative humidity percentage readouts of the logger at the current date and time as shown on Figure A.7.14. Make sure that these readouts are consistent with your expectations. If not, check the placement of the MX2301 Data Logger.
- Return to the measurement site periodically to ensure that the MX2301 Data Logger is still collecting temperature and relative humidity percentage readings which are consistent with your expectations.

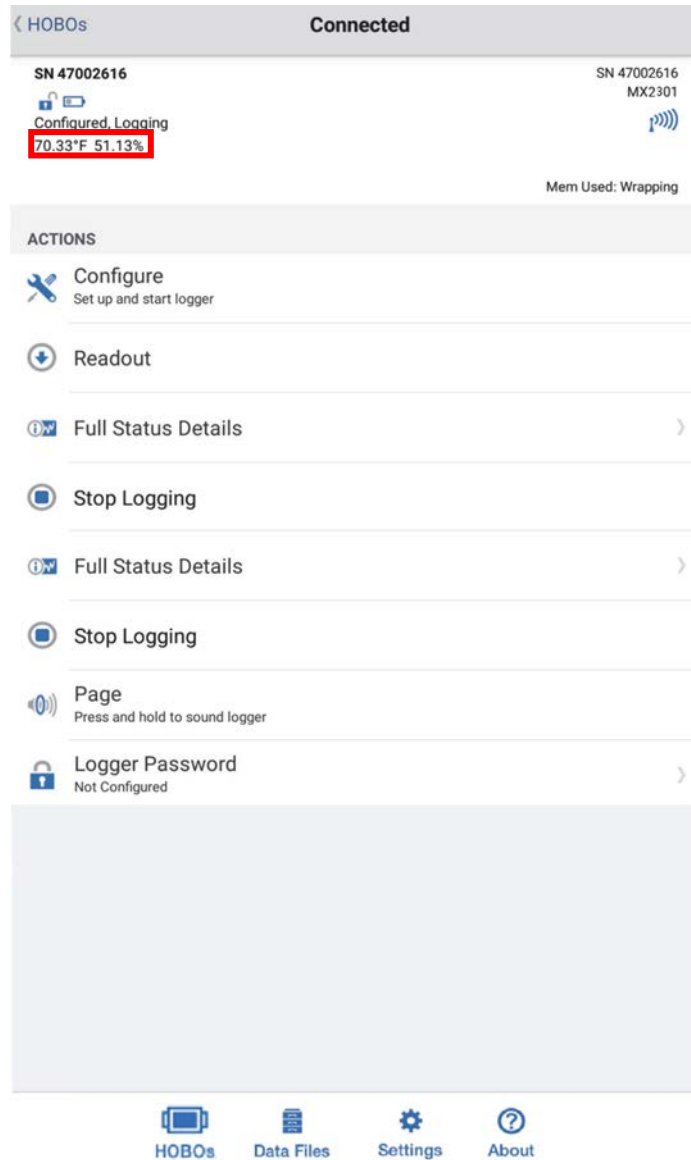


Figure A.7.14: The HOBOMobile “Connected” Screen. The temperature and relative humidity percentage at the current date and time is displayed in the red box.

A.7.6: Exporting Data from the MX2301 Data Logger to a .csv File

After the allotted measurement period (based on the measurement guide) the entire dataset can be extracted and used to trend the temperature of the system component.

1. At the end of the measurement period, follow the procedure in section A.7.5 to verify that the collected data is accurate.
2. If satisfied with the accuracy of the measurements, follow steps 1, 2, and 3 in section A.7.5 to return to the “Connected” screen as shown on Figure A.7.15.
 - a. On the “Connected” screen. Click on the “Readout” option. This will readout the data

- from the MX2301 Data Logger. Tap “OK” on any popups that are shown on the screen while the logger is being read out.
- b. In the “Data Files” option on the bottom of the screen, there should be a red circle with the number 1 inside it. This indicates that you now have a new file. Tap on the “Data Files” option.

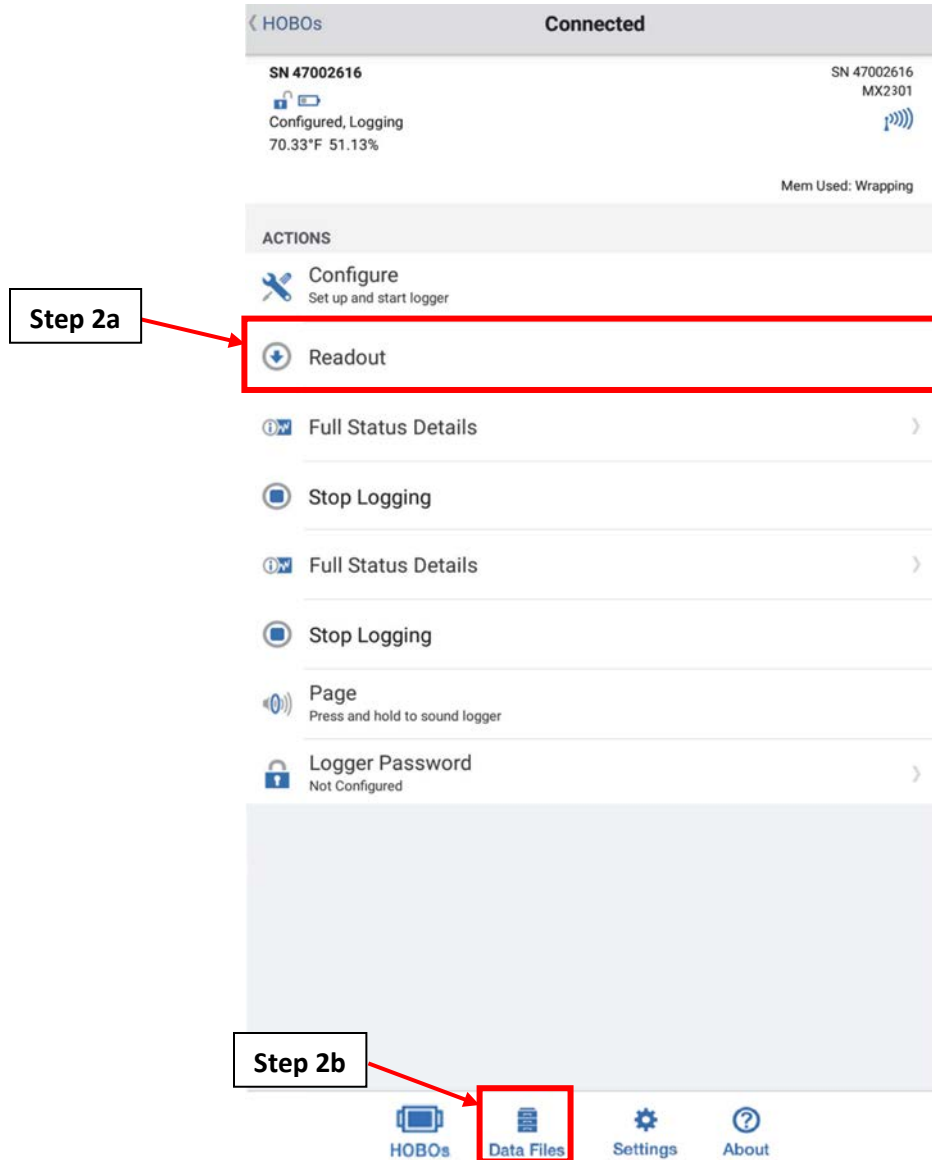


Figure A.7.15: The HOBOMobile “Connected” screen.

3. After selecting the “Data Files” option, the “Close Connection?” pop-up window will show on the screen as shown on Figure A.7.16. Tap “Yes” to proceed. After performing this step, the MX2301 Data Logger can be removed from the site.

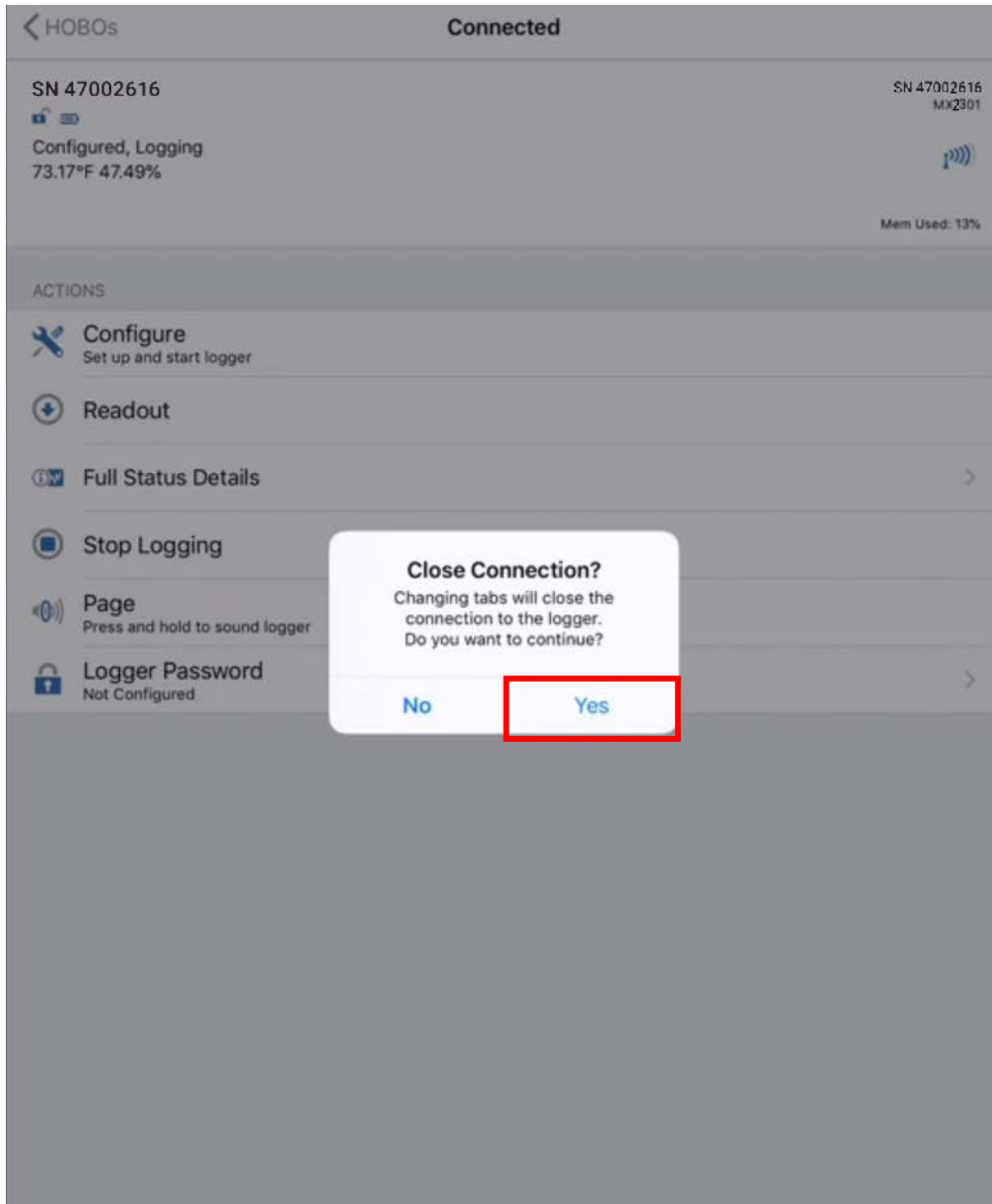


Figure A.7.16: The “Close Connection?” pop-up window.

4. At the “Data Files” screen as shown on Figure A.7.17, tap on the graph that has the name that you set at step 2.a of section A.7.2. For this guide, the name was left as the default name of the MX2301 Data Logger, which is boxed in on Figure A.7.17. Tapping on the small graph will bring you to the larger graph as shown on Figure A.7.18.

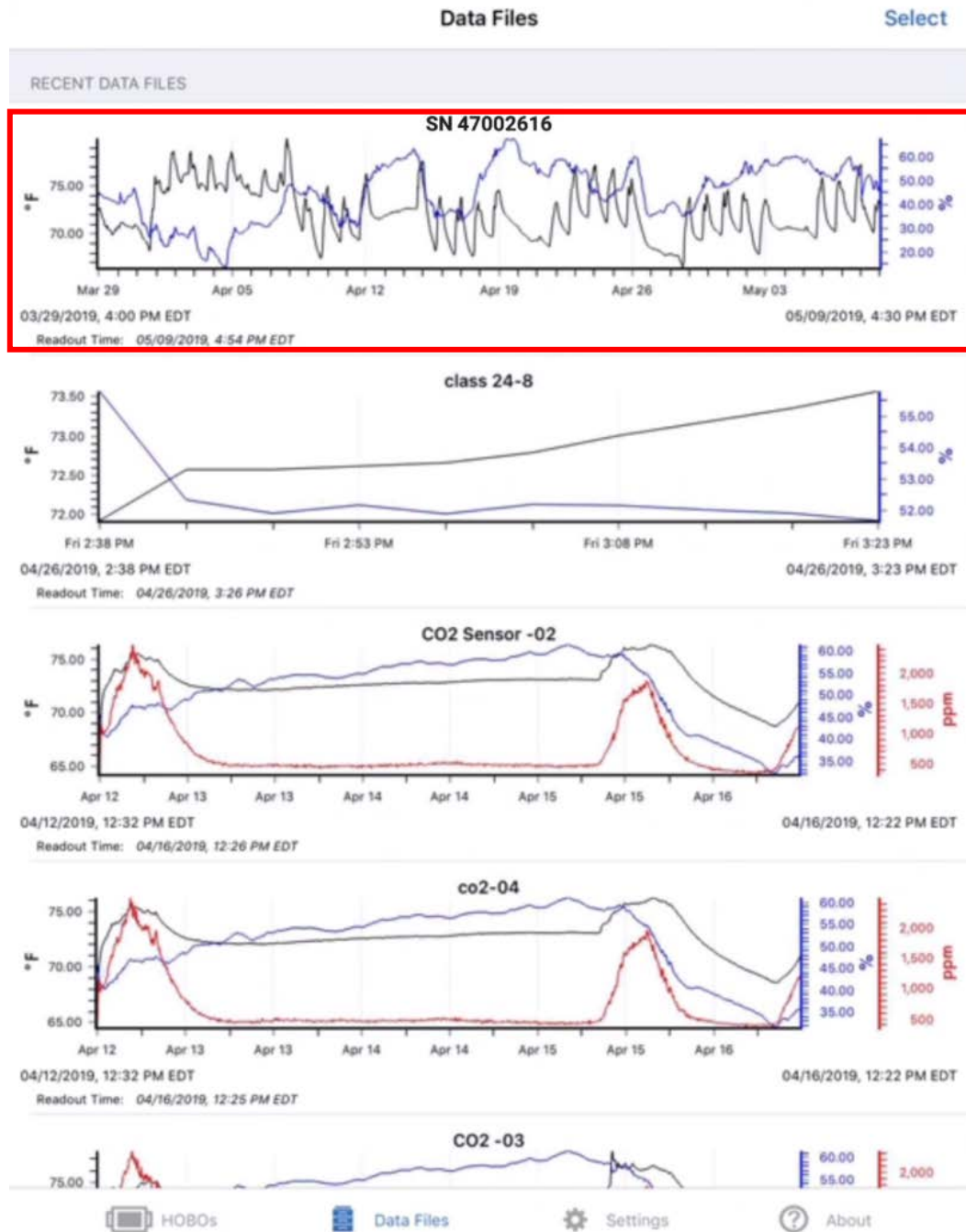


Figure A.7.17: The “Data Files” screen.

5. On the larger graph as shown on Figure A.7.18, you can closely inspect the data by zooming in and out with your fingers, or turning the device to landscape mode if currently in portrait mode.
6. Tap on the “Share” icon, which is boxed in on the top right of Figure A.7.18. This will take you to the “Share” screen.

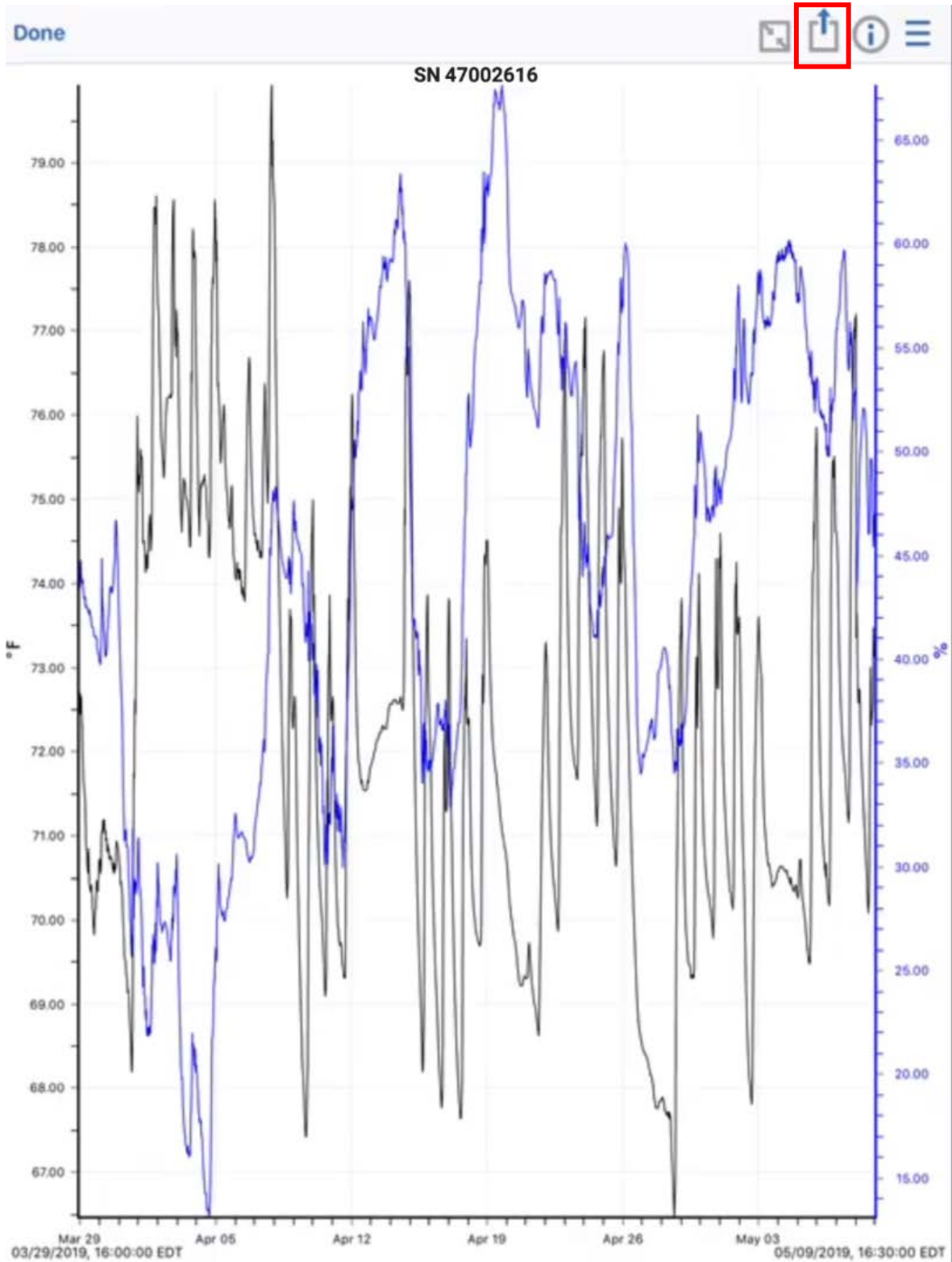


Figure A.7.18: The larger graph.

- At the “Share” screen. Tap the “CSV” option, boxed in on Figure A.7.19. Make sure that your iOS or Android device is connected to the internet before proceeding.

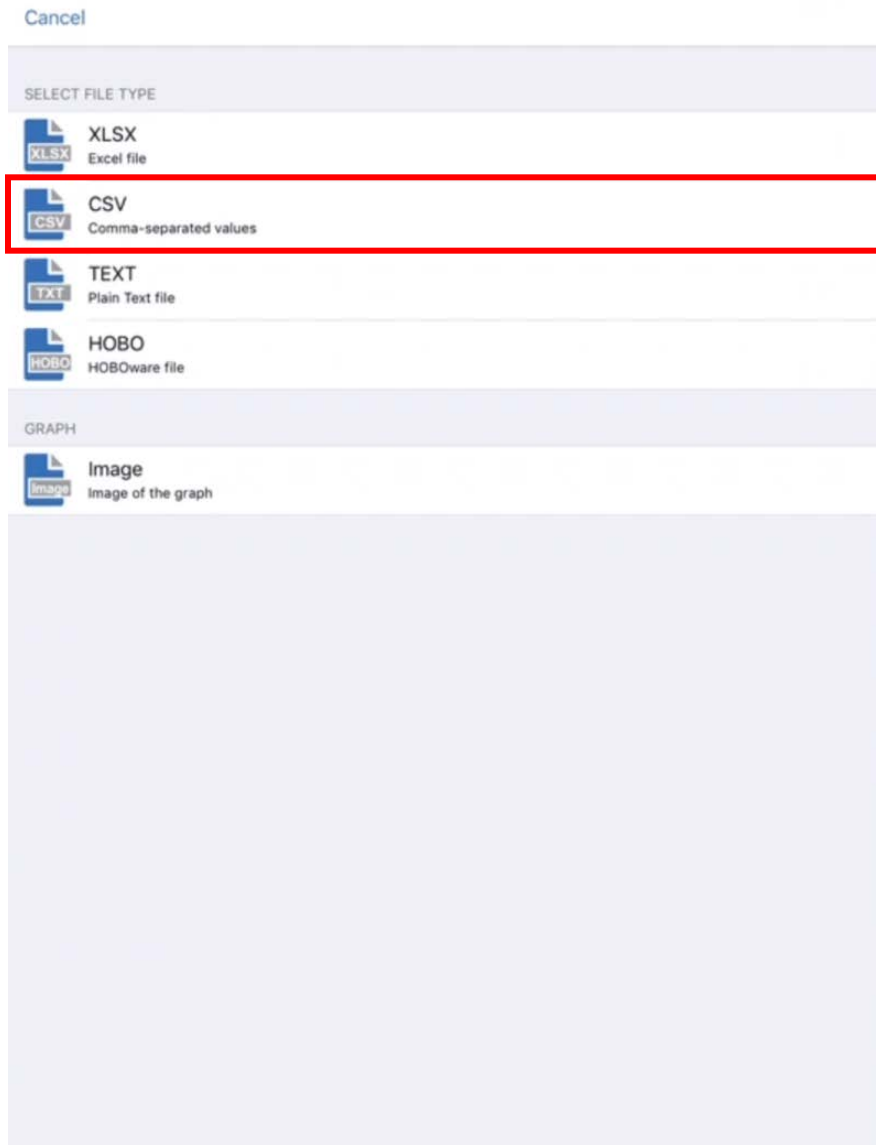


Figure A.7.19: The HOBOMobile “Share” screen.

In writing this guide, the next steps were written with respect to an iOS device. The options shown in Figure A.7.20 and Figure A.7.21 will be different on an Android device. Please select similar options if you are using an Android device.

8. At the menu that pops up after selecting the “CSV” option, shown on Figure A.7.20, select the “Mail” option.
 - a. Enter the email that you would like to send the .csv file to.
 - b. Tap “Send” to send the .csv file to the email that you specified in the last step.



Figure A.7.20: The various options for exporting the data from the MX1101 Data Logger as a .csv file. For this guide, select the "Mail" option.

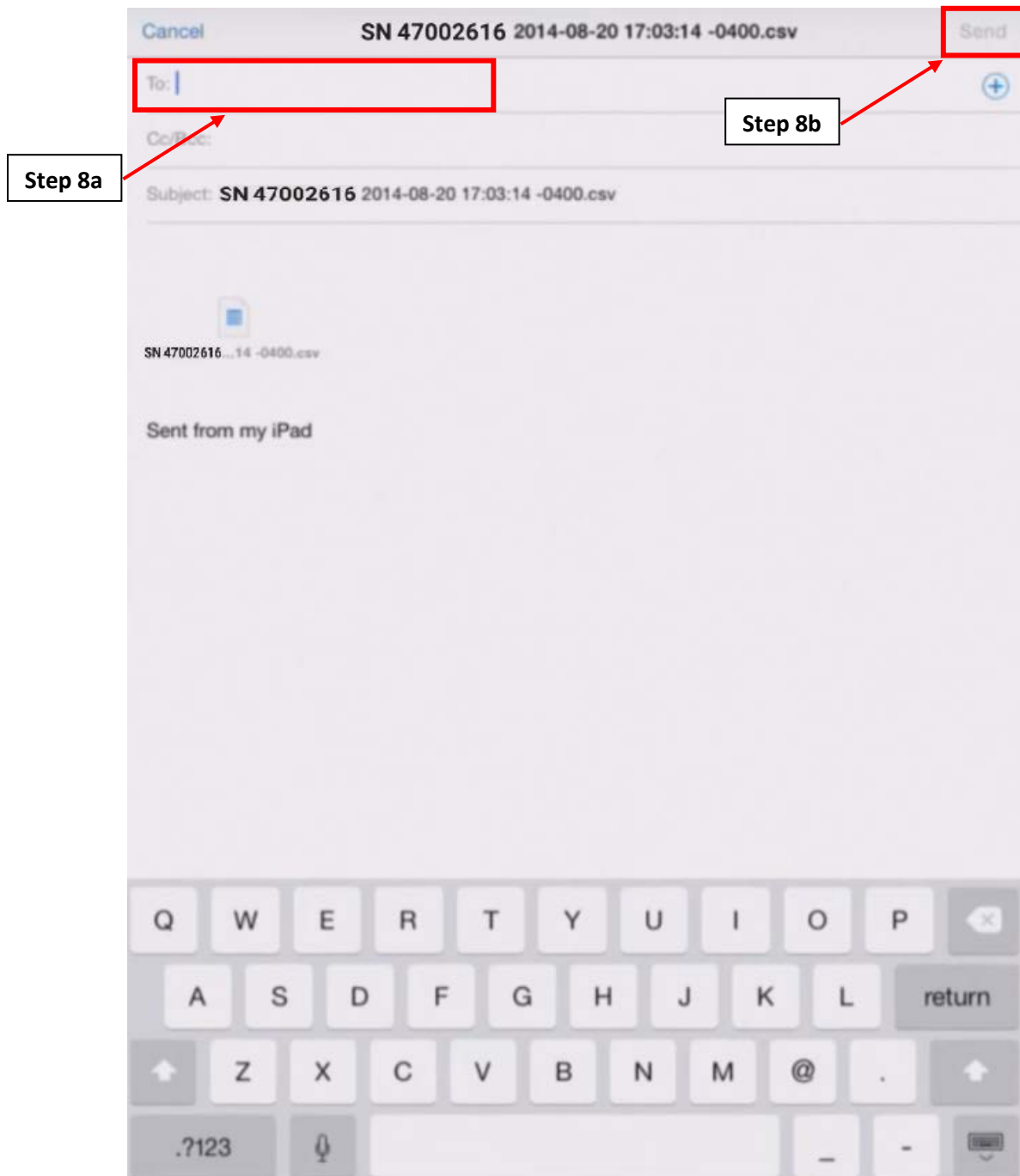


Figure A.7.21: Exporting the .csv file to an email.

A.8: Onset HOBO Temperature Data Logger (UX100-001)

Sections A.8.1, A.8.2, A.8.3, A.8.5, and A.8.6 will require the use of the HOBOWare software. The HOBOWare software will be provided through a mini USB drive. Alternatively, HOBOWare Free can be downloaded from the following website: <https://www.onsetcomp.com/hoboware-free-download>. For this guide, the Onset HOBO Temperature Data Logger (UX100-001) will be referred to as the UX100 Data Logger.

A.8.1: UX100 Data Logger Connection to Computer

This section provides steps on how to connect the UX100 Data Logger to the computer. This is necessary in order to perform an initial setup of the logger prior to being deployed on the site.

1. Open the HOBOWare software and connect the UX100 Data Logger to computer using a mini-USB cable as shown on Figure A.8.1.
2. Confirm that the logger name is displayed on the bottom left of the screen and that “1 device connected” is displayed on the bottom right, as shown in Figure A.8.2. If both messages are present, click the “Launch” button, boxed in on the top left. This will open the “Launch Logger” pop-up window as shown on where you select the parameters for collecting data.



Figure A.8.1: The logger connected to laptop computer via USB.

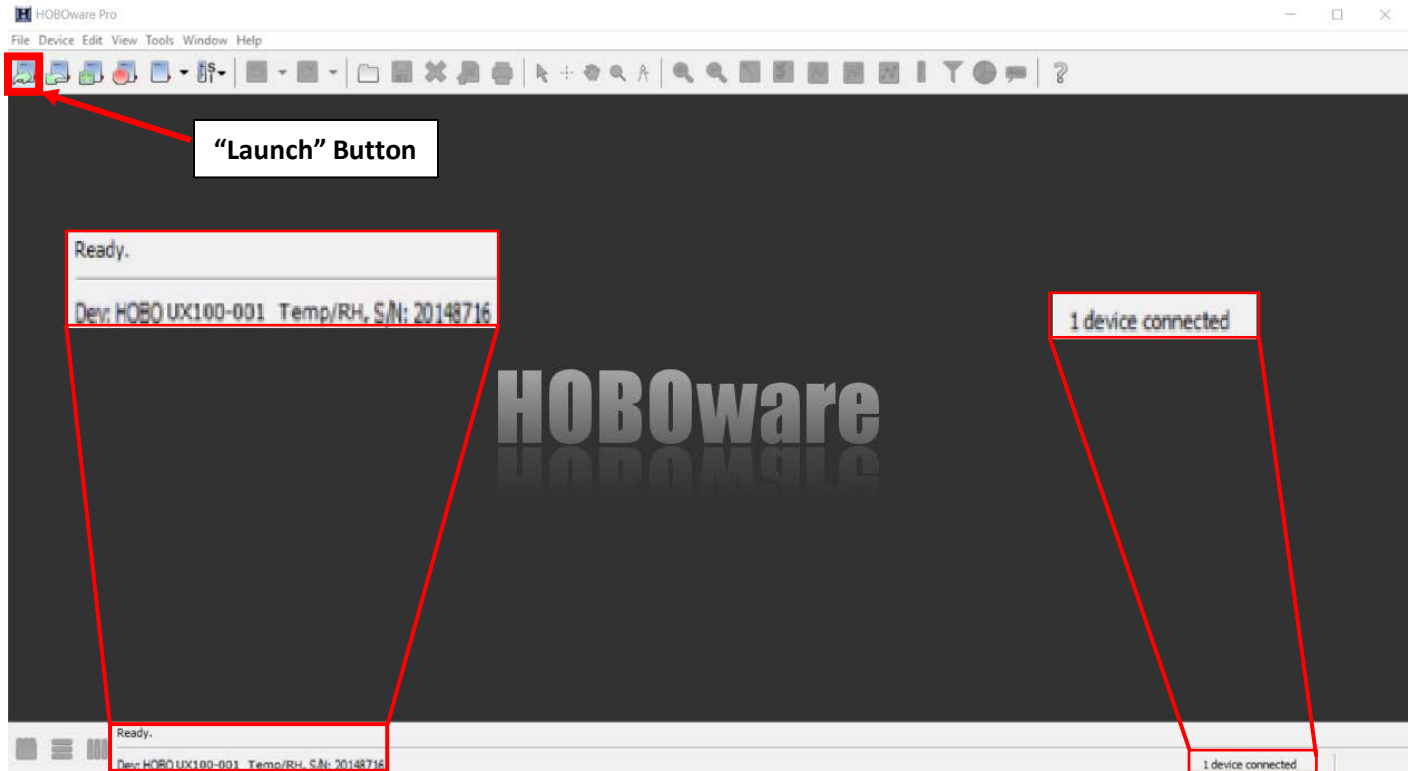


Figure A.8.2: HOBOWare launch menu

A.8.2: Configuring the UX100 Data Logger

In the “Launch Logger” window shown on Figure A.8.3:

1. In the “Name” field, enter a meaningful label. Ideally, the “Name” field should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - a. For example, for an AHU system, we can set a name with the facility’s name, the AHU number, and whether it’s a supply or return fan in this format:
facilityname_ahunumber_supply OR *facilityname_ahunumber_return*.
2. Check the battery level to confirm that the UX100 Data Logger is sufficiently powered and doesn’t require a battery replacement.
3. Within the “Launch Logger” window:
 - a. Make sure the checkbox for the internal temperature is checked.
 - b. Write in the “Label” box the same name that was given in step 1.
 - c. Click on the “Filters” button, which will bring up the “Filter Series” pop-up window shown on Figure A.8.4.

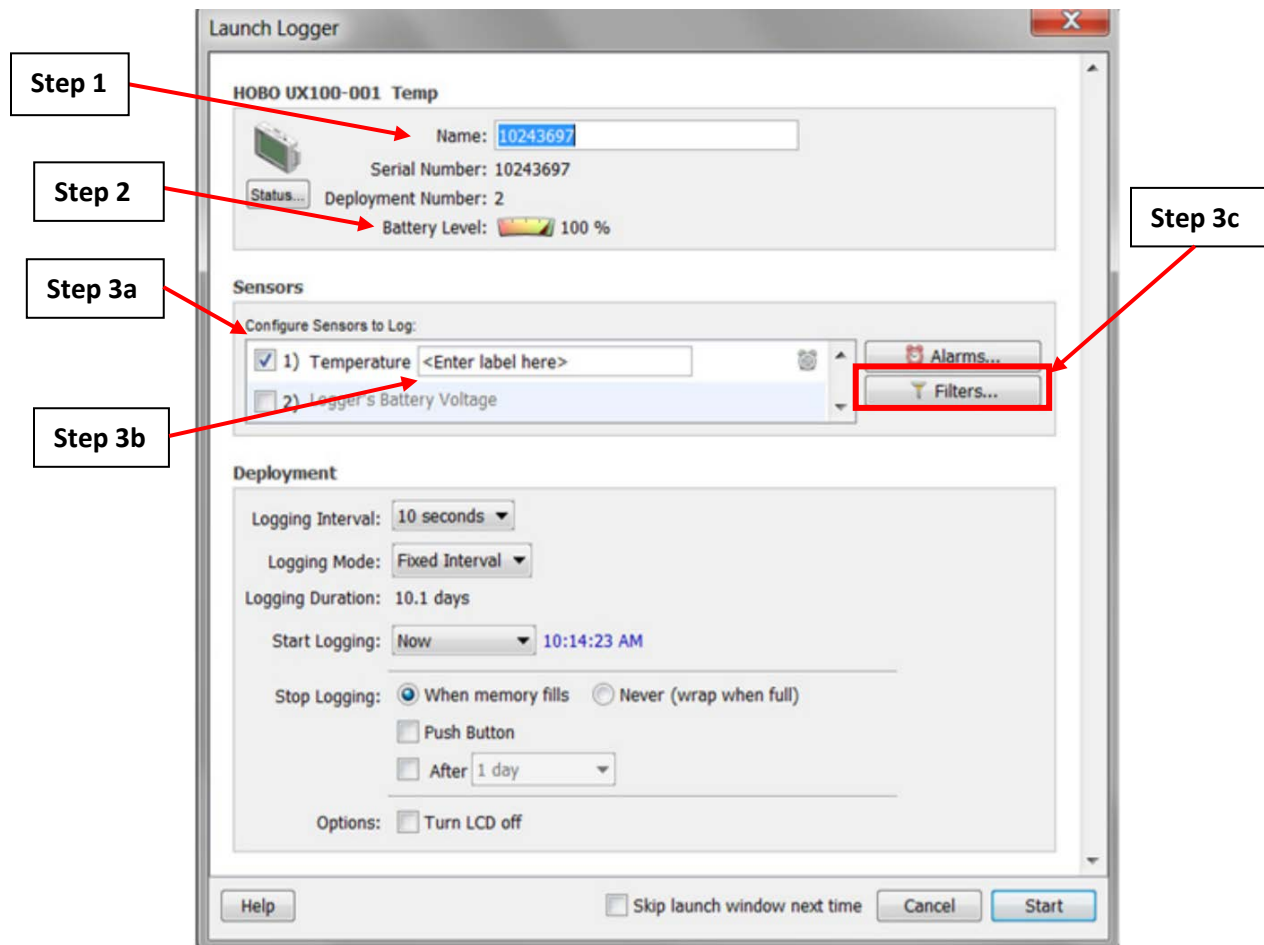


Figure A.8.3: "Launch Logger" Window with Configuration Steps

4. To configure the "Filter Series" pop-up window shown on Figure A.8.4:
 - a. In the "Show the" dropdown menu, select the "Total Motor on" option. This configures the logger to show the total motor operational time.
 - b. Set the interval to "1 Hour". This indicates that the logger will trend how many seconds the motor is running for each hour.
 - c. Click "Create New Series."
 - d. Click "Done" on the bottom right corner of the window.

The screenshot shows the 'Filter Series' configuration window. At the top, there is a 'Select channel to filter:' dropdown menu with '1) Motor on' selected. Below it, the 'Show the' dropdown is set to 'Total Motor on', followed by 'in each' with a value of '1' and a 'Hour' interval. The 'Start day' is set to 'First data point'. The 'Resultant Series Name' field contains 'Total: Motor on'. A 'Create New Series' button is on the right. Below this is a 'Filter Series' table with an empty body and 'Edit' and 'Delete' buttons on the right. At the bottom, there are 'Help', 'Done', and 'Step 4d' buttons. Red arrows and boxes highlight the following steps:

- Step 4a:** Points to the 'Total Motor on' dropdown.
- Step 4b:** Points to the 'Hour' interval dropdown.
- Step 4c:** Points to the 'Create New Series' button.
- Step 4d:** Points to the 'Done' button.

Figure A.8.4: “Filter Series” Configuration Steps

A.8.3: Deploying the UX100 Data Logger

Below the “Sensors” table you will see the “Deployment” table as shown in Figure A.8.7. This allows you to specify your logger deployment with details such as when to start and stop logging.

To deploy the logger:

1. Click the arrow in the “Logging Interval” dropdown menu and select 1 hour as the logging interval.
2. Set the logging mode to “Statistics”.
3. Click the “Edit” button to make the Statistics window appear.



Figure A.8.5: Setting the Logging Interval and the Logging Mode in the Deployment table.

4. Following Figure A.8.6, select the checkbox labeled “Average” and uncheck the other boxes.
5. Click on the drop-down menu for “Sampling every:” and select 1 second (as shown above). This stipulates that the UX100 Data Logger will record the 1-hour average current draw based on 1 second measurements.
6. Click “OK” to close the Statistics window.

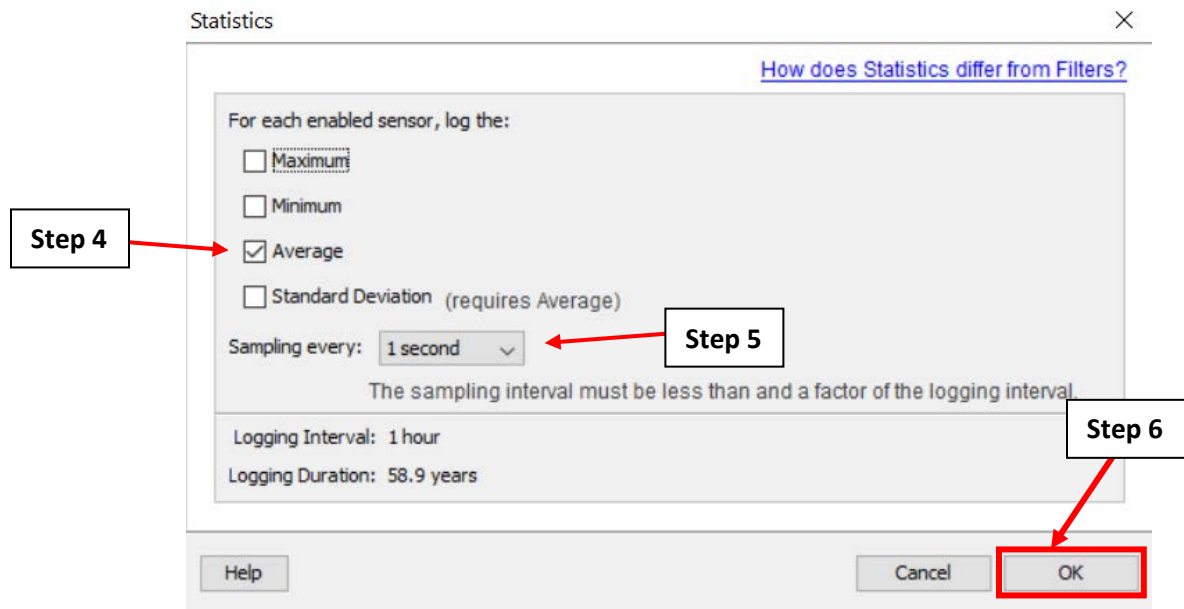


Figure A.8.6: Setting the sampling rate in the Statistics pop-up window.

Back on the “Launch Logger” screen (Figure A.8.7), go to the “Deployment” table. Click on the “Start Logging” dropdown menu. Select “On Date/Time” to specify the date and time that the logger will begin to collect measurements.

7. Set the date and time for the logger to begin taking measurements in the two new boxes that appear on the right.
 - a. Note that if you have multiple loggers being deployed on your site, all loggers should be set to begin at the same date and time.

8. Set the “Stop Logging” option to “When memory fills”. This specifies that the data logger will stop collecting measurements when the internal memory of the logger is filled. Ensure that the “Push Button”, “Allow button restart” and “After” checkboxes are unchecked.
9. Identify if the LCD screen should remain on. If the logger will be deployed for more than one month, turn off the screen to conserve battery life.
10. Click “Delayed Start” to complete the configuration process. Do not unplug the logger from the computer until deployment is complete (shown in Figure A.8.8).

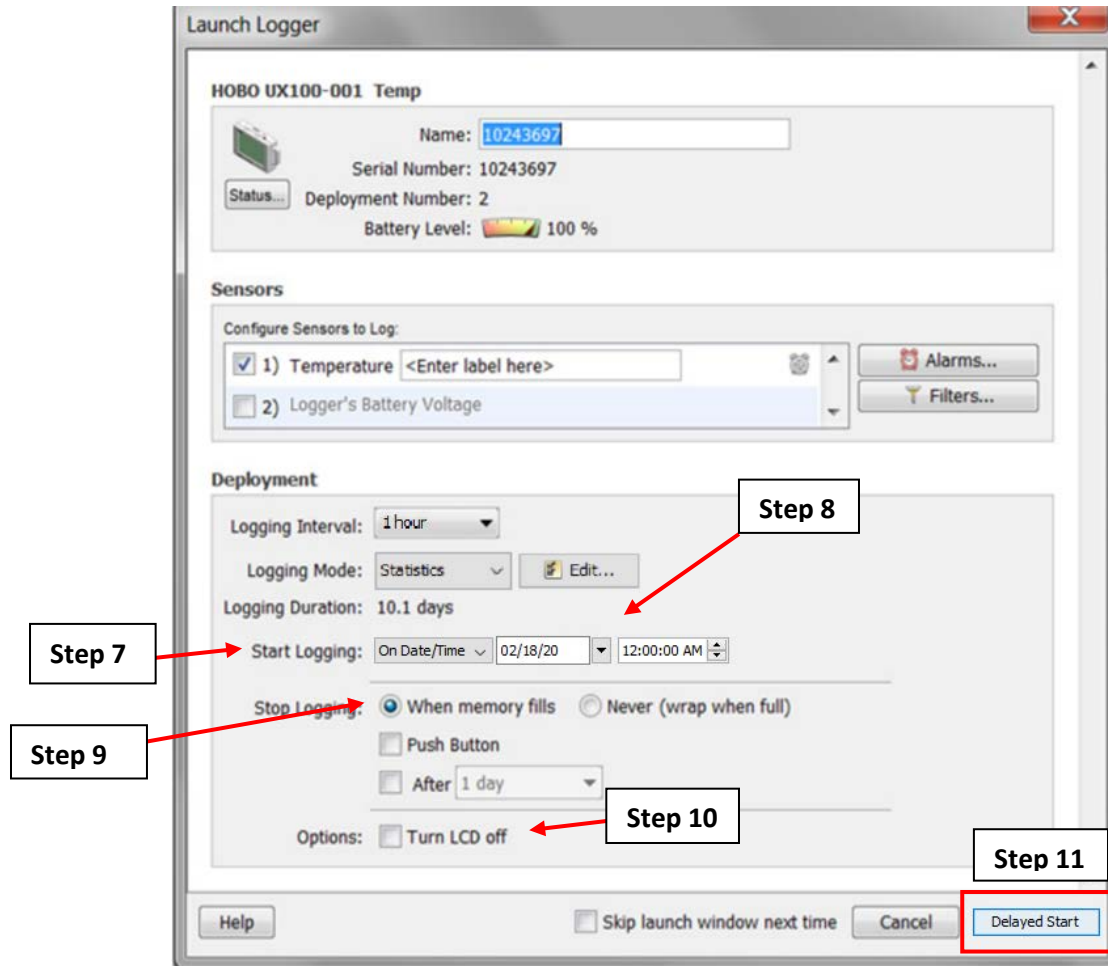


Figure A.8.7: “Launch Logger” Window with Deployment Steps

11. If the logger needs to be reconfigured, click the “Launch” button shown in Figure A.8.2 and repeat the steps in sections A.8.2 and A.8.3.

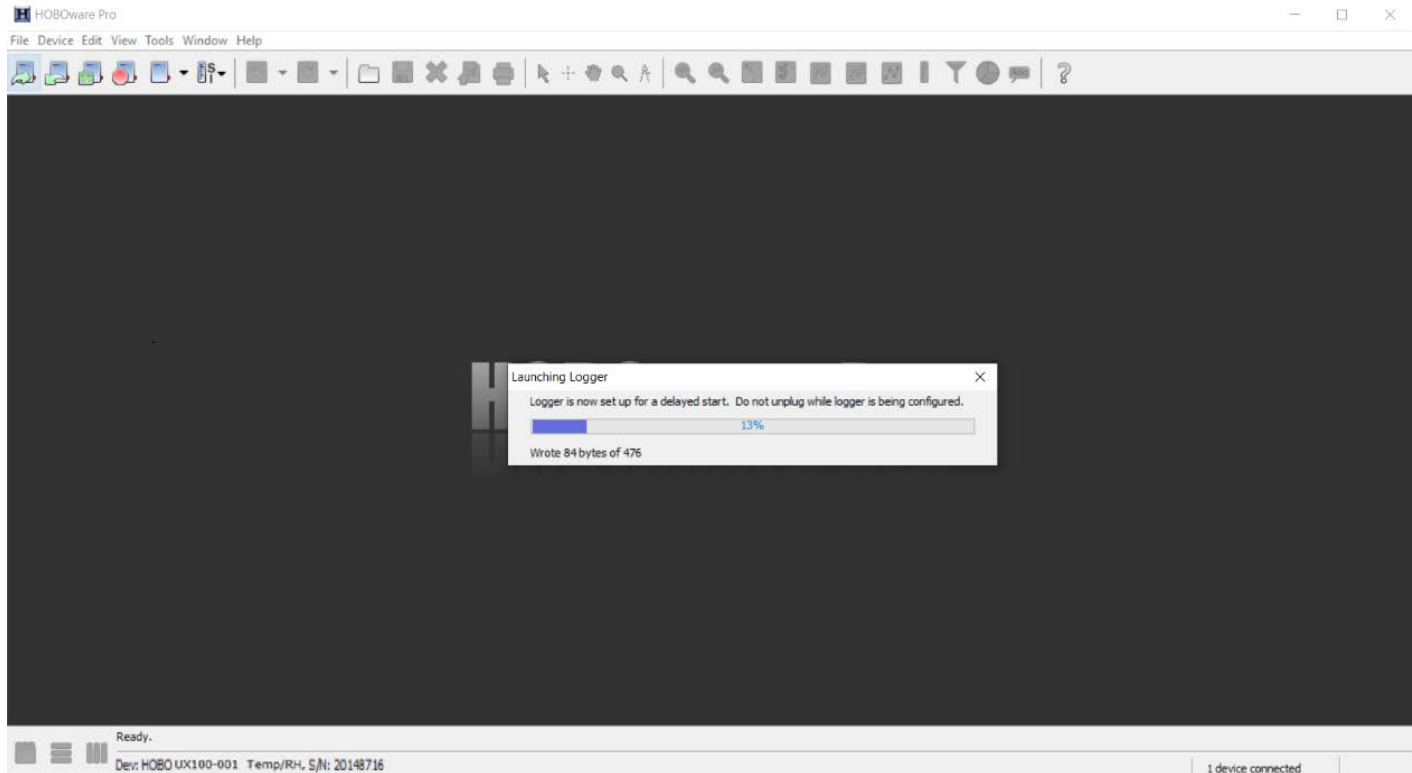


Figure A.8.8: Logger Launching from HOBOWare

A.8.4: UX100 Data Logger Field Setup

This section will guide you through the field setup of the UX100 Data Logger. Please exercise the appropriate safety precautions while performing the field setup.

1. Someone familiar with the building's system should identify the system in which the UX100 Data Logger will be installed onto.
2. Have the electrician turn off the system.
3. Place the UX100 Data Logger at the part of the system where you would like to record the temperature. Note that the back of the logger is magnetic, and the logger should be placed on the part of the system where temperature will be measured. Please see Figure A.8.9 and Figure A.8.10 for example installations.

Before



After

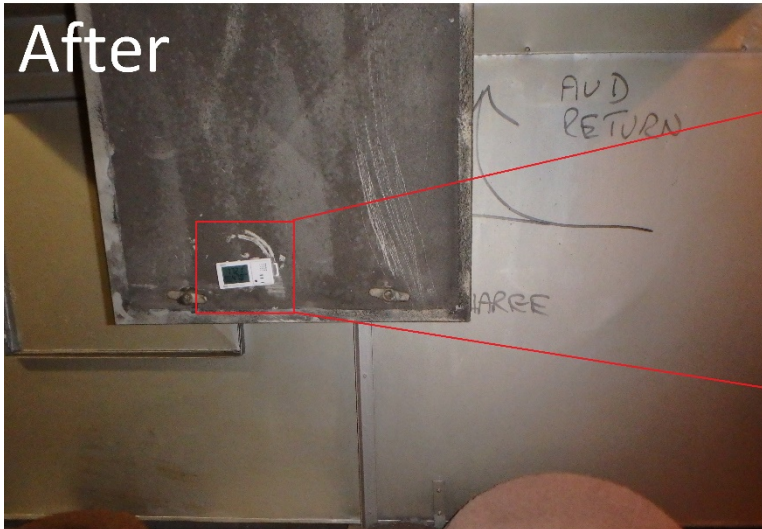


Figure A.8.9: Before and after of UX100 Data Logger installed inside a direct controlled ventilation duct.



Figure A.8.10: Before and after of an UX100 Data Logger installed onto a part of a direct controlled ventilation system.

A.8.5: Verification of Data for the UX100 Data Logger

It is important to verify the UX100 Data Logger is collecting accurate data. HOBOWare offers an easy way to check collected data without interfering with the initial setup from the previous sections.

6. Open the HOBOWare software on your computer.
7. Connect the USB-mini cable to the logger. **Do not move the logger or sensors.**
8. Click the readout button on the top menu as shown on Figure A.4.14.

9. The “Stop Logger?” pop-up window will appear asking if you want to stop logging as shown on Figure A.4.15, click “Don’t Stop”.

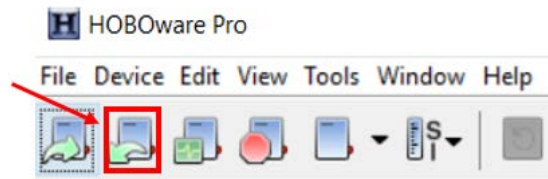


Figure A.8.11: The HOBOWare readout button.

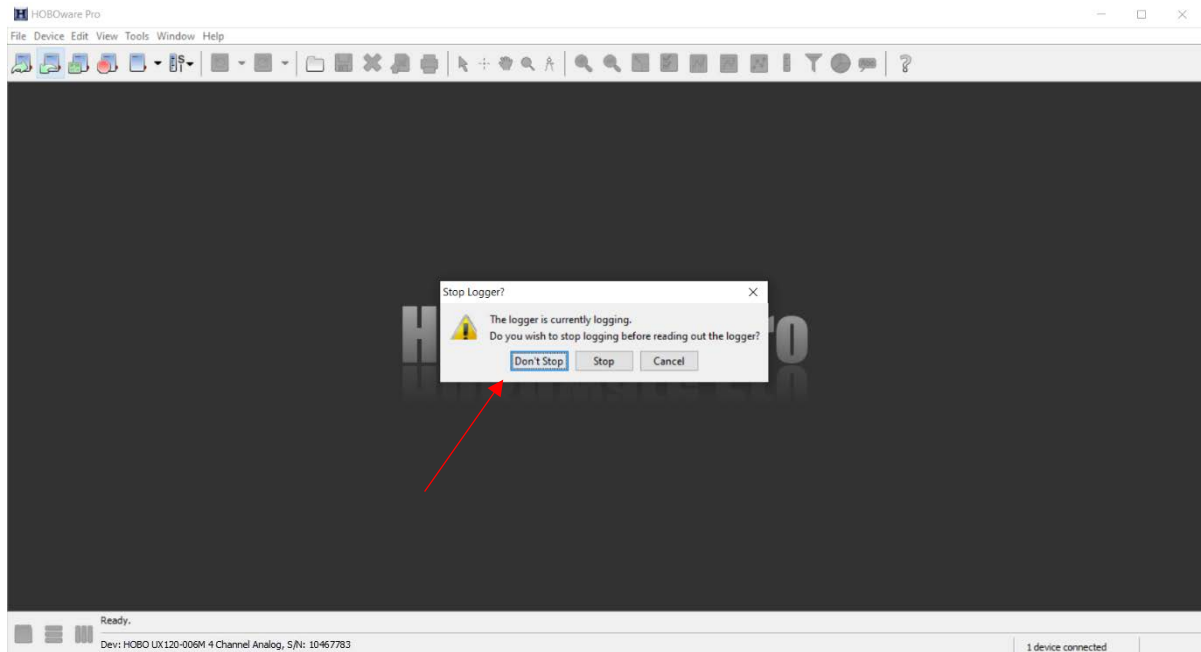


Figure A.8.12: The “Stop Logger?” pop-up window.

10. The “Plot Setup” window will open (see Figure A.8.13).
- Name your data in the same way as in step 1 of section A.8.2.
 - Select the “Temperature – Avg” measurements (Unit: “degrees Fahrenheit”) to plot.
 - Deselect the three “Event Types” at the bottom of the menu.
 - Click “Plot” to display your graph.

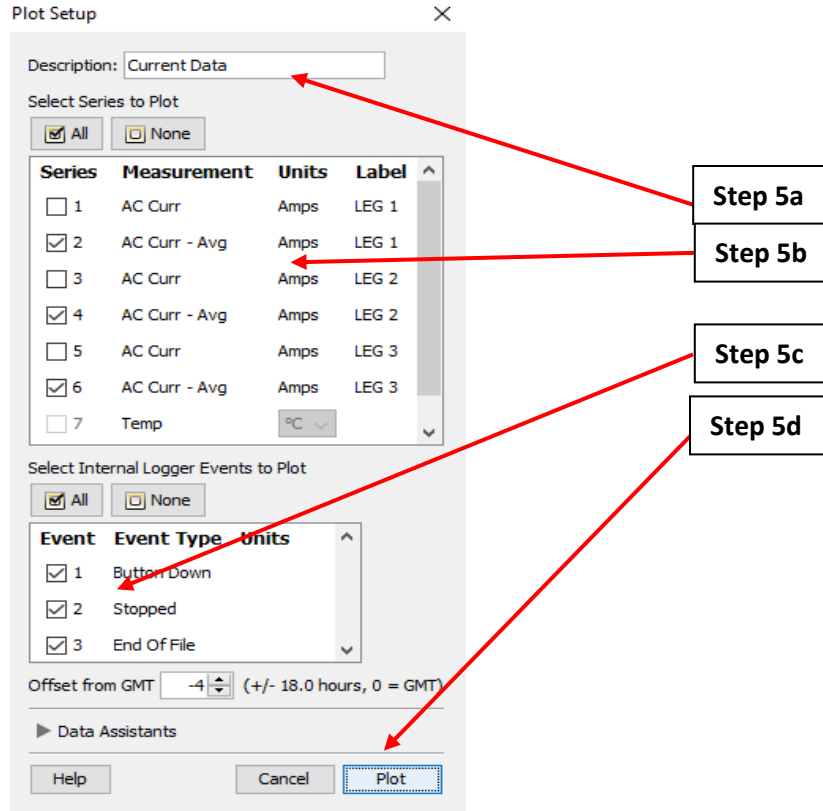


Figure A.8.13: The “Plot Setup” pop-up window with the corresponding steps.

12. After following step 5, HOBOWare will open a new tab with data from the logger. Focus your attention on the “Data Table” pane at the top of the window as shown on Figure A.8.14. Here you will see:
 - a. The date and time of the logged data stored in the first column.
 - b. The average temperature of the system component detected by the logger at that date and time in the 2nd column.

#	Time, GMT-05:00	Temp - Avg, °F
1	01/25/13 01:10:38 PM	68.706
2	01/25/13 02:10:38 PM	69.307
3	01/25/13 03:10:38 PM	68.792
4	01/25/13 04:10:38 PM	68.362
5	01/25/13 05:10:38 PM	68.234
6	01/25/13 06:10:38 PM	67.977
7	01/25/13 07:10:38 PM	68.020
8	01/25/13 08:10:38 PM	68.491

Figure A.8.14: HOBOWare data table pane.

13. Scroll through the table and assess the collected data to ensure that the temperature readings are consistent with your expectations.
14. If the measured data is unusual or inaccurate based on your understanding of the system, then the UX100 Data Logger may need to be relaunched or recalibrated.

A.8.6: Exporting Data from the UX100 Data Logger to a .csv File

After the allotted measurement period, the entire dataset can be extracted and used to analyze the temperature measurements from the UX100 Data Logger.

1. At the end of the measurement period, follow the procedure in section A.8.5 to verify that the collected data is accurate.
2. If satisfied with the accuracy of the measurements, click the “Stop Logging” button on the top left corner of the screen (Figure A.8.15).

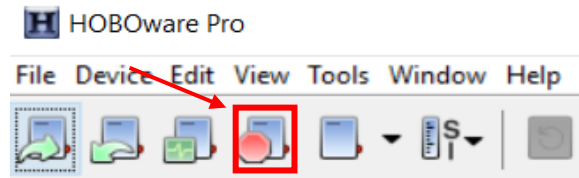


Figure A.8.15: HOBOWare “Stop Logging” Button

3. Click “File” > “Export Table Data” (Figure A.8.16).

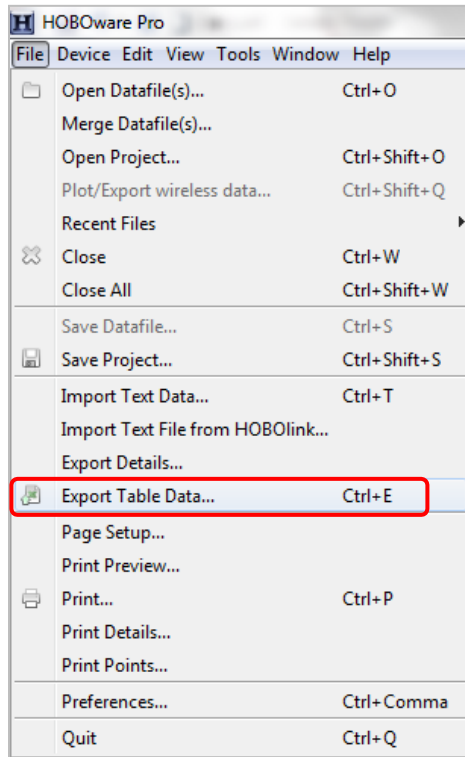


Figure A.8.16: File menu options.

4. The “Export” window will open and display the data available to export (Figure A.8.17).

5. Select “Temp-Avg” and uncheck all other boxes.
6. Click “Export...” to export the data.

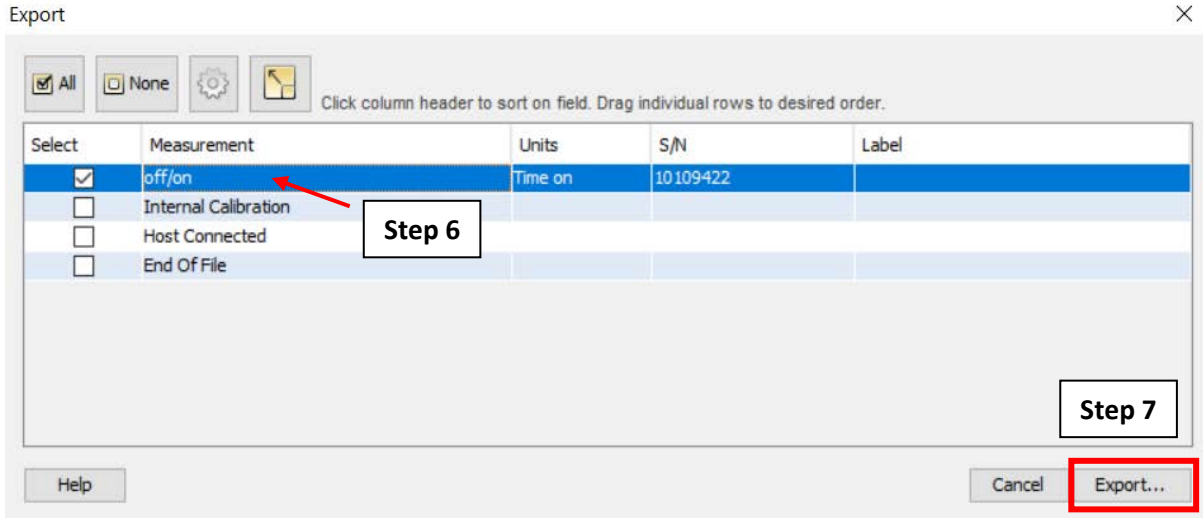


Figure A.8.17: The “Export” Window and corresponding steps.

7. Choose a location to save the file.
8. Name the file the same way as step 1 of section A.8.2.
9. Click “Save” to complete the .csv exporting process (Figure A.8.18).

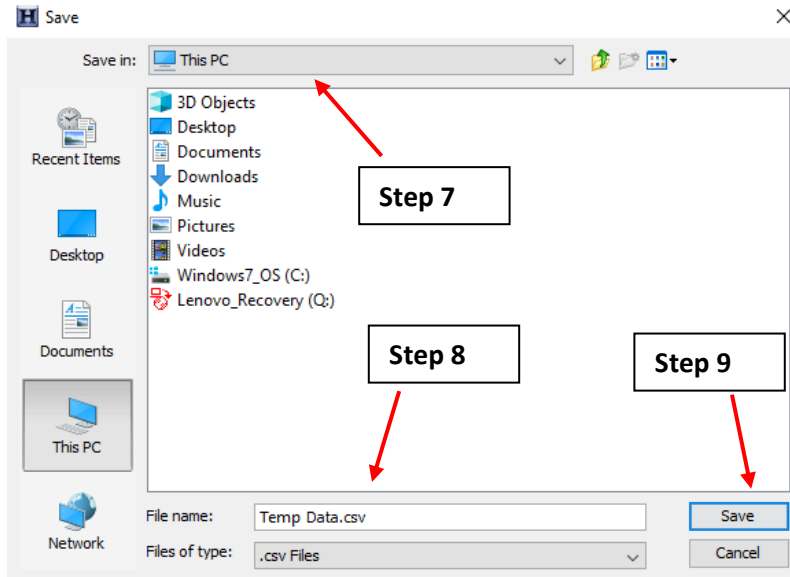


Figure A.8.18: “Save” pop-up window.

A.9: Onset HOBO 4-Channel Analog Logger (UX120-006M) with Onset HOBO Gauge Pressure Sensor (T-ASH-G2-500)

A.9.1: Onset HOBO 4-Channel Analog Logger Connection to Computer

This section provides steps on how to connect the Onset HOBO 4-Channel Analog Logger to the computer. This is necessary in order to perform an initial setup of the logger prior to being deployed on the site.

1. **Open** the HOBOWare software and **connect** the logger to computer using a mini-USB cable as shown on Figure A.4.10.
2. Confirm that the logger name is displayed on the bottom left of the screen and that “1 device connected” is displayed on the bottom right, as shown in Figure A.4.11. If both messages are present, click the “Launch” button, boxed in on the top left. This will open the “Launch Logger” pop-up window as shown on where you select the parameters for collecting data.



Figure A.9.1: Onset HOBO 4-Channel Analog Logger connected to computer via USB.

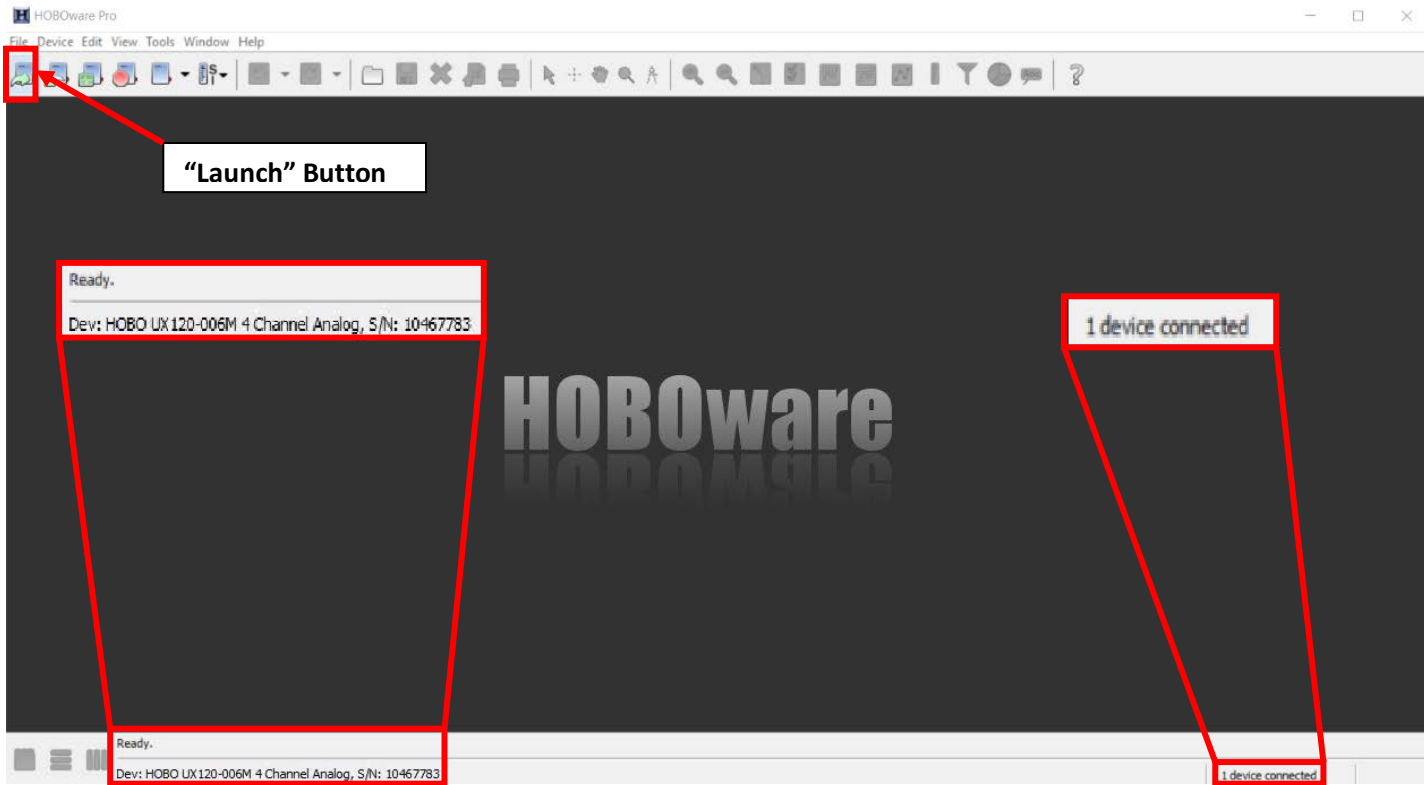


Figure A.9.2: HOBOWare launch menu.

A.9.2: Configuring the Onset HOBO 4-Channel Analog Logger with Onset HOBO Gauge Pressure Sensor

1. In the “Name” field, enter a meaningful label. Ideally, the “Name” field should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - a. For example, for a chiller system, we can set a name with the facility’s name, the chiller number, and any other distinguishing characteristics: *facilityname_chillernumber_pump* for example.
2. Check the battery level to confirm that the logger is sufficiently powered and doesn’t require a battery replacement (Figure A.4.13).
3. Within the “Launch Logger” window, the “Sensors” table allows you to configure each input port of the data logger (labeled as “Step 3” in Figure A.4.13).
4. Figure A.4.5 shows what setting to enable in the “Sensors” table.
 - a. There are 4 checkboxes which represent the different channels that can be configured on the Onset HOBO 4-Channel Analog Logger. Check the appropriate number of checkboxes which correspond to the number of sensors that will be used to collect measurements.
 - b. Click the grey box to the right of the logger port number. This box will be used to specify the type of sensor connected to the port. Select the sensor that you will be using at the field site from the dropdown menu.
 - c. Fill in the recommended settings for the Onset HOBO Gauge Pressure Sensor:
 - i. Set “Channel Name” to “Pressure”.
 - ii. Set the “Warm-Up” to 0.03 seconds.
 - iii. Set the “Measurement Type” to “Voltage”.
 - iv. Set “Raw Value 1” to 0.
 - v. Set “Raw Value 2” to 5.
 - vi. Set “Raw Units” to “V”.
 - vii. Set “Scaled Value 1” to 0.
 - viii. Set “Scaled Value 2” to 500.
 - ix. Set “Scaled Units” to “PSIG”.
 - d. Perform steps 4.b to 4.d for all sensors if more than one will be used.



Figure A.9.3: The Onset HOB0 Gauge Pressure Sensor (T-ASH-G2-500).

The screenshot shows the 'Launch Logger' window for a 'HOB0 UX120-006M 4 Channel Analog' logger. The window is divided into several sections:

- Device Information:** Name: Current Logger, Serial Number: 20015330, Deployment Number: 11, Battery Level: 71%.
- Sensors:** A table for configuring sensors to log. The first sensor, 'CTx-C (0-100 Amp AC)', is selected with a checked checkbox. The other three sensors, 'CTx-B (0-50 Amp AC)', are not selected.
- Deployment:** Logging Interval: 15 minutes, Logging Mode: Statistics, Logging Duration: 9.8 years, Start Logging: On Date/Time (01/01/20, 12:00:00 AM), Stop Logging: When memory fills (selected), Push Button (checked), After: 1 day, Options: Turn LCD off (unchecked).

Three steps are indicated by red boxes and arrows:

- Step 1:** Points to the 'Name' field in the device information section.
- Step 2:** Points to the 'Battery Level' indicator in the device information section.
- Step 3:** Points to the 'Configure Sensors to Log' table in the sensors section.

At the bottom of the window, there are buttons for 'Help', 'Skip launch window next time', 'Cancel', and 'Delayed Start'.

Figure A.9.4: The "Launch Logger" pop-up window for the Onset HOB0 4-Channel Analog Logger.

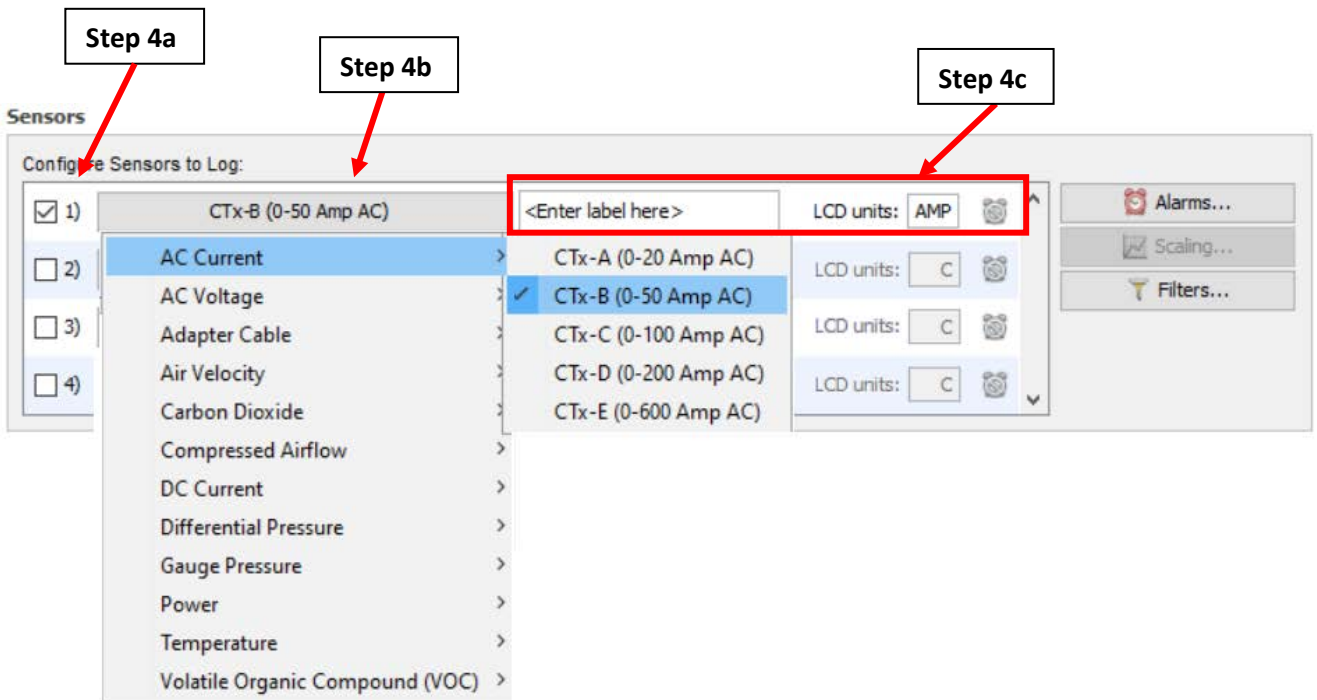


Figure A.9.5: Configuring the Onset HOBO Gauge Pressure Sensor in the “Sensors” table.

A.9.3: Deploying the Onset HOBO 4-Channel Analog Logger with Onset HOBO Gauge Pressure Sensor

Below the “Sensors” table you will see the “Deployment” table as shown on Figure A.9.6. This allows you to specify your logger deployment with details such as when to start and stop logging.

To deploy the logger:

1. Click the arrow in the “Logging Interval” dropdown menu and select 1 hour as the logging interval.
2. Set the logging mode to “Statistics”.
3. Click the “Edit” button to make the Statistics window appear.

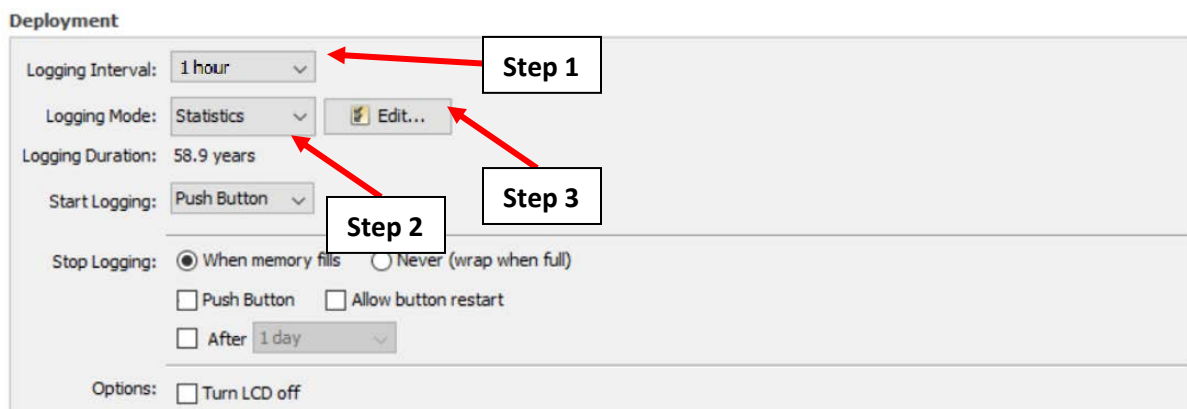


Figure A.9.6: Setting the Logging Interval and the Logging Mode in the Deployment table.

4. Following Figure A.9.7, select the checkbox labeled “Average” and uncheck the other boxes.
5. Click on the drop-down menu for “Sampling every:” and select 1 second (as shown above). This stipulates that the Onset HOB0 4-Channel Analog Logger will record the 1-hour average draw for the sensor being used based on 1 second measurements.
6. Click “OK” to close the Statistics window.

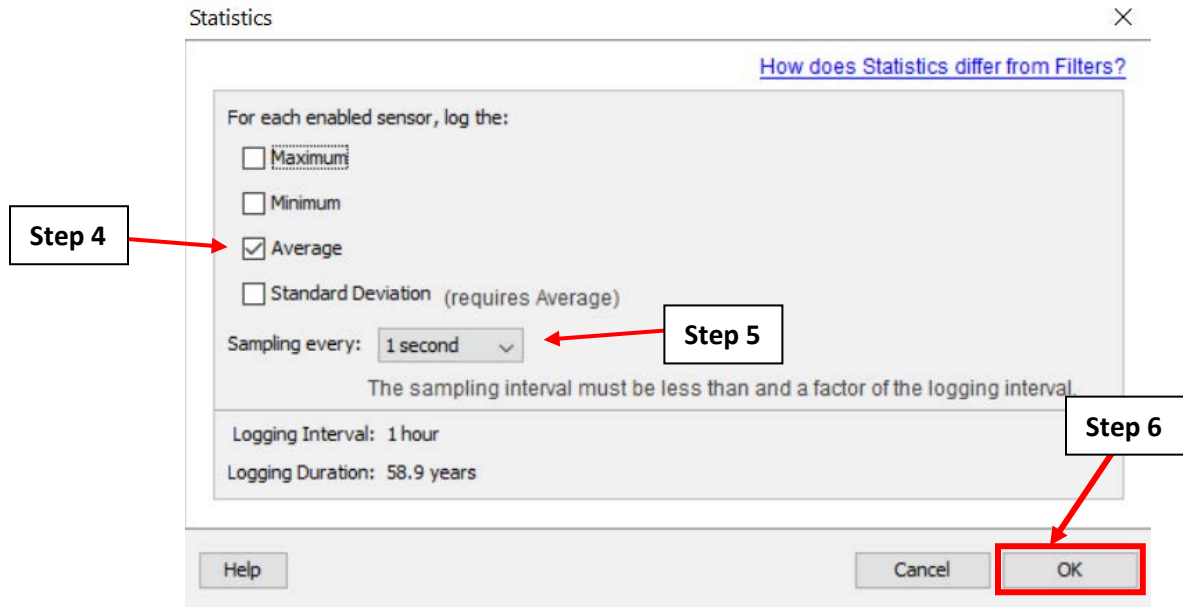


Figure A.9.7: Setting the sampling rate in the Statistics pop-up window.

7. Back on the “Launch Logger” screen (Figure A.4.8), go to the “Deployment” table. Click on the “Start Logging” dropdown menu. Select “On Date/Time” to specify the date and time that the logger will begin to collect measurements.
8. Set the date and time for the logger to begin taking measurements in the two new boxes that appear on the right.
 - a. Note that if you have multiple loggers being deployed on your site, all loggers should be set to begin at the same date and time.
9. Set the “Stop Logging” option to “When memory fills”. This specifies that the data logger will stop collecting measurements when the internal memory of the logger is filled. Ensure that the “Push Button”, “Allow button restart” and “After” checkboxes are unchecked.
10. Identify if the LCD screen should remain on. If the logger will be deployed for more than one month, turn off the screen to conserve battery life.
11. Click “Delayed Start” to complete the configuration process. Do not unplug the logger from the computer until deployment is complete (Figure A.9.9).
12. If the logger needs to be reconfigured, click the “Launch” button shown in Figure A.9.2 and repeat the steps in sections A.9.2 and A.9.3.

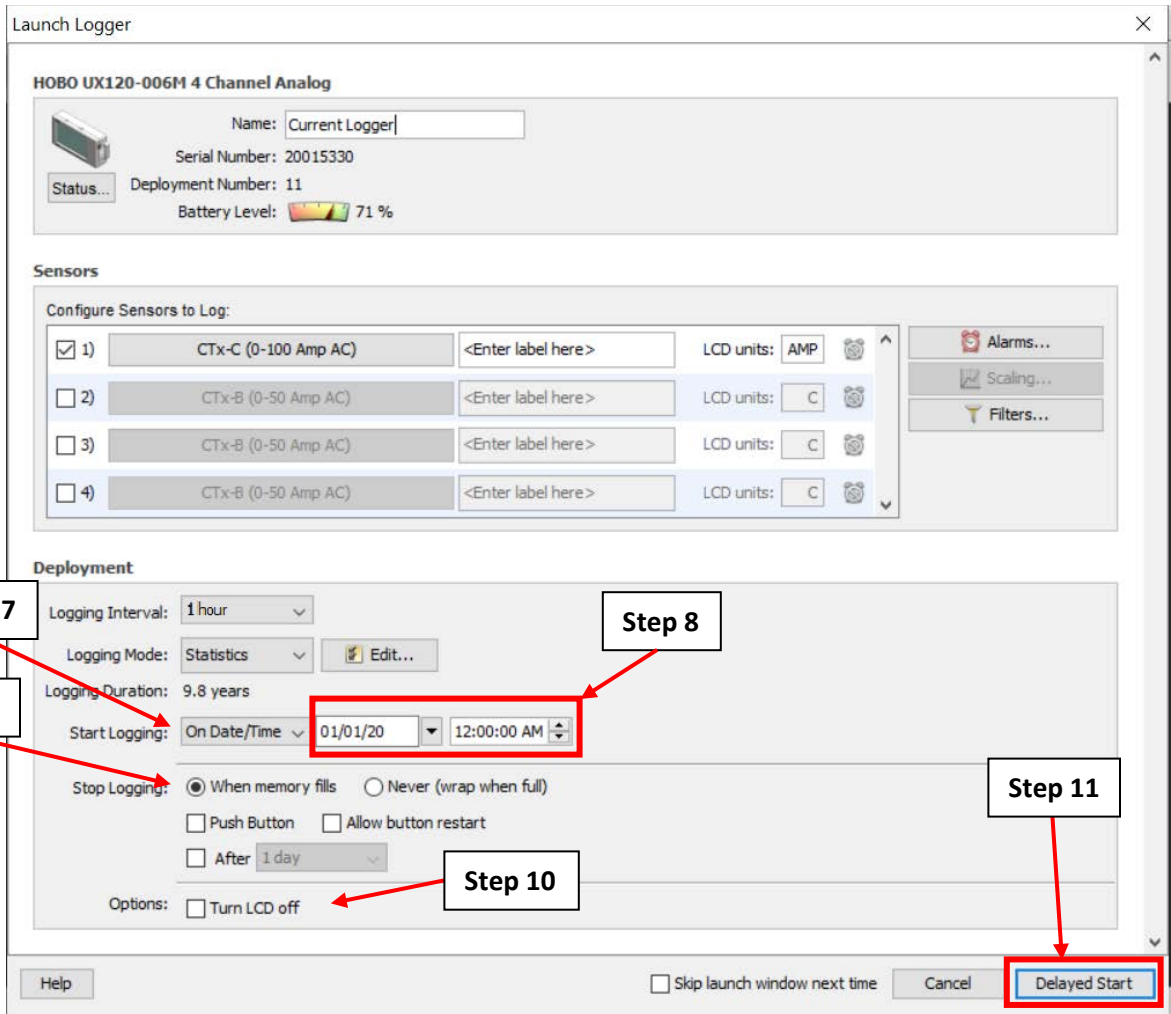


Figure A.9.8: The "Launch Logger" window with the deployment steps.

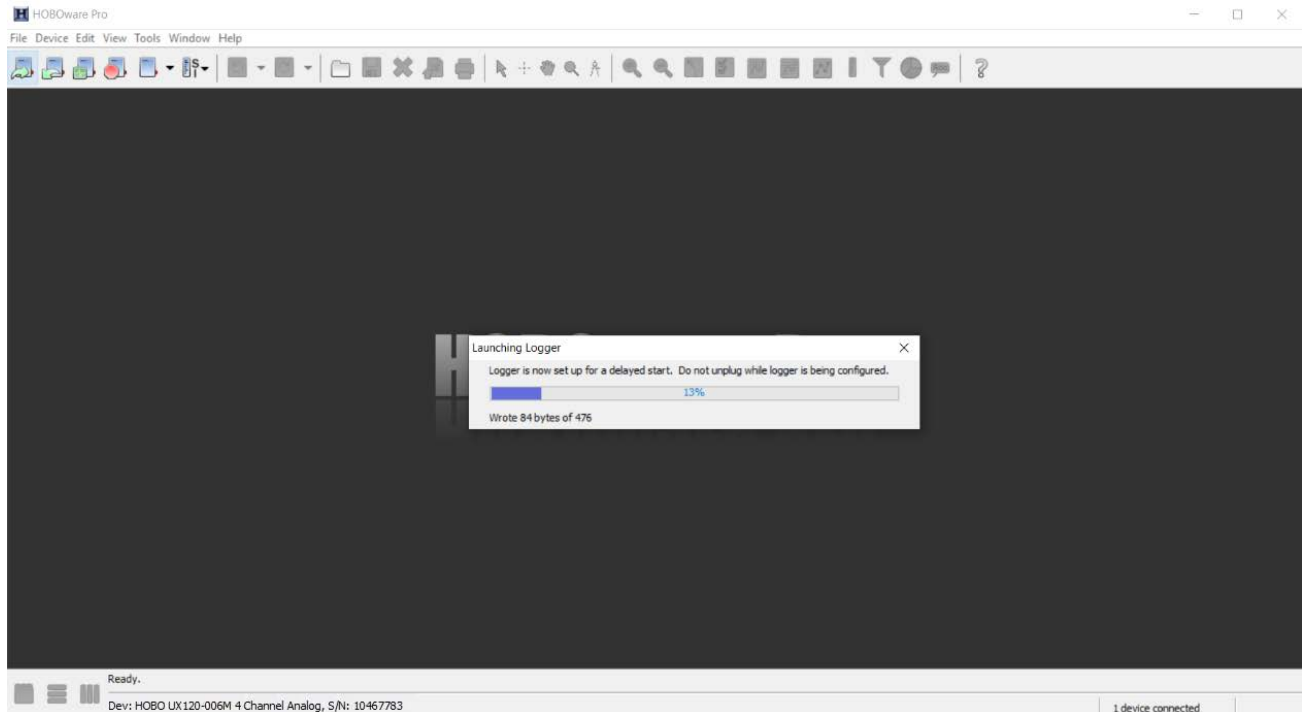


Figure A.9.9: Launching the logger using the HOBOWare software.

A.9.4: Onset HOBO 4-Channel Analog Logger with Onset HOBO Gauge Pressure Sensor Field Setup

This section will show you how to attach the Onset HOBO Gauge Pressure Sensor to a pressure gauge. Please exercise the appropriate safety precautions while performing this field setup.

One of the wires for the Onset HOBO Gauge Pressure Sensor needs to be plugged into a power outlet. Check with the building personnel that the room in which the measurements will be taken has a nearby power outlet and an extension cord long enough to connect the wire to the power outlet.

For every (1) Onset HOBO Gauge Pressure Sensor, you will also need to bring with you 1 tee fitting, 1 nipple and a roll of Teflon thread tape (or as much as you need to wrap around the threads of the Onset HOBO Gauge Pressure Sensor). Please ask for these components from the CUNY BPL FELL if you do not have them. Also, a pair of pipe wrench pliers are required in order to secure the connections between the gauge, sensor, tee, and nipple. Figure A.9.13 shows all the components in the completed setup.

1. Locate the pressure gauge attached to the shutoff for the system in which measurements will be taken from. See Figure A.9.10.

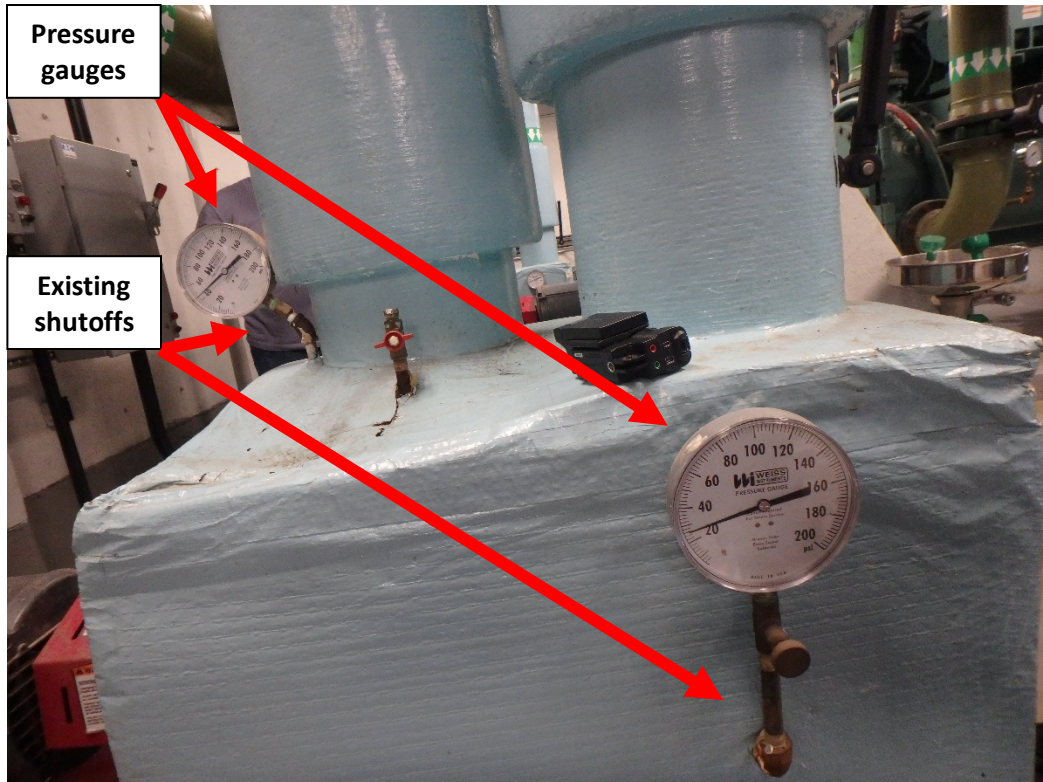


Figure A.9.10: Pressure gauges on an evaporator pump for a chilled water system.

2. Have the building personnel shut off the valve for the water flow before installing any equipment.
3. Watch the gauge after shutting off the valve. Wait the meter on the pressure gauge reads 0 PSI before proceeding to the next step.

For the next several steps, please look at Figure A.9.13 after completing each of the subsequent steps to ensure that the tee connections match those of what is shown on that figure. For all the connections in this section which mention the use of Teflon threaded tape, please wrap the necessary threads 3 to 5 times (see Figure A.9.11).

4. Carefully remove the pressure gauge from the shutoff itself.
5. Wrap the tape around one end of the tee 3 to 5 times. Then cut the tape off the roll as shown on Figure A.9.11.

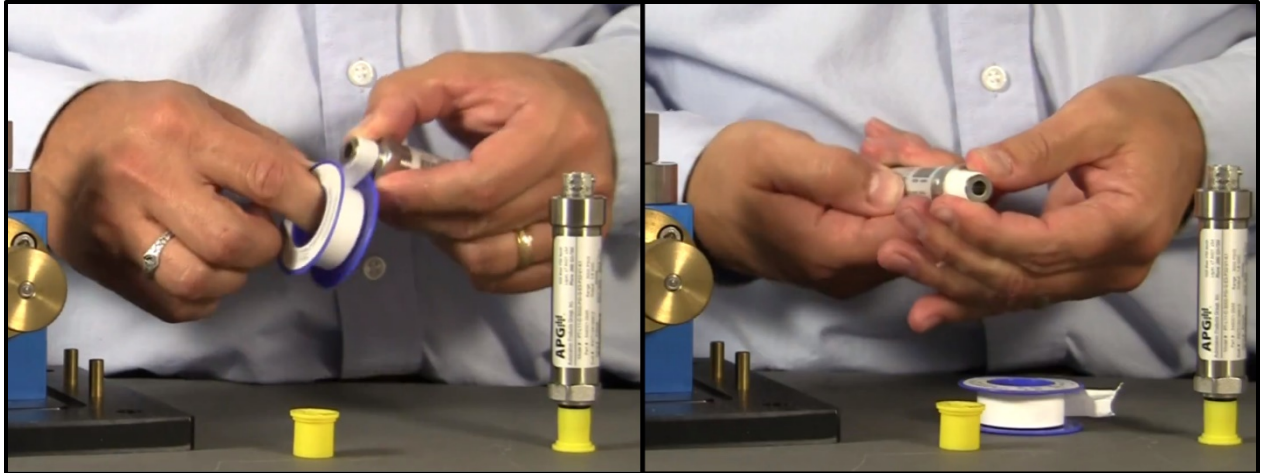


Figure A.9.11: Wrapping of the Teflon threaded tape around the threads of a pressure transducer. The same procedure can be used to generate a sufficient seal between the tee and nipple threads.

6. Screw the pressure gauge onto one end of the tee (Figure A.9.12). Do not screw it in all the way. Screw it in enough so that the pressure gauge does not fall off the tee. The pipe wrench pliers will be used later in order to secure the connection between the pressure gauge and the tee and to generate a sufficient seal.

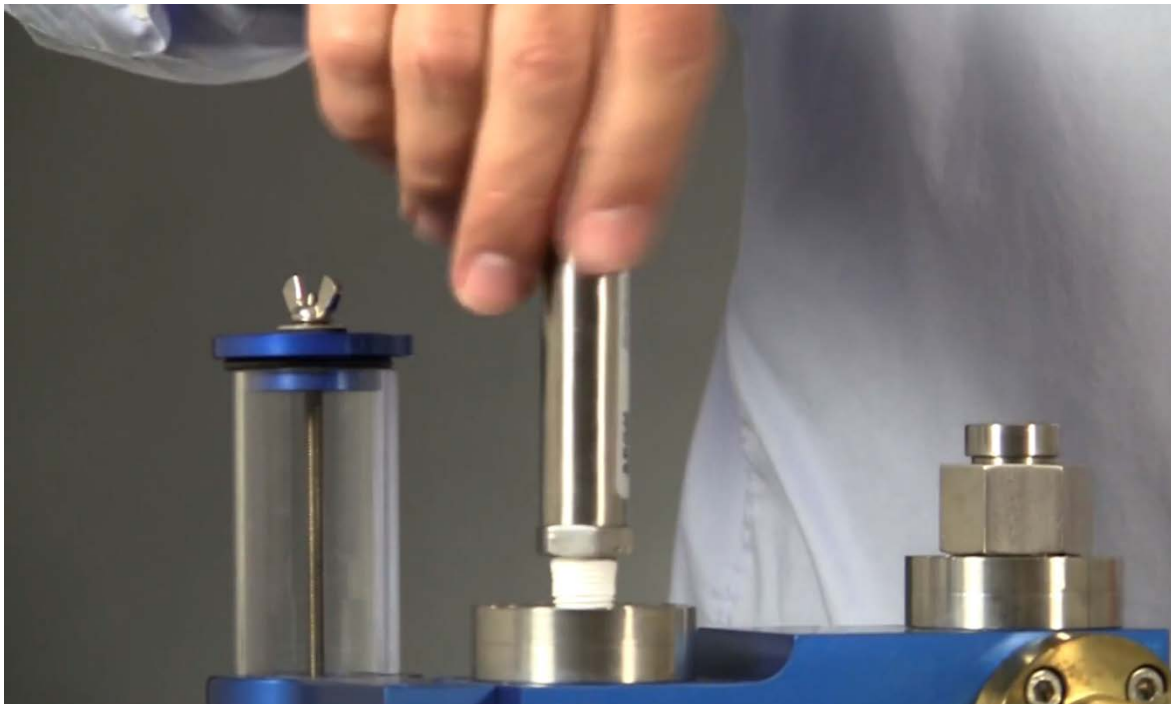


Figure A.9.12: Screwing in a pressure sensor into a thread by hand.

7. Wrap Teflon threaded tape around the other end of the tee and hand screw the nipple onto the other end of the tee. Do not screw the two components together all the way similar to what was done on step 6.

8. Wrap Teflon threaded tape onto the other end of the nipple and screw that other end onto the existing shut off as shown on Figure A.9.13. Do not screw the nipple into the shutoff all the way similar to what was done on step 6. Note that at this point, the Onset HOBO Gauge Pressure Sensor should NOT be installed.

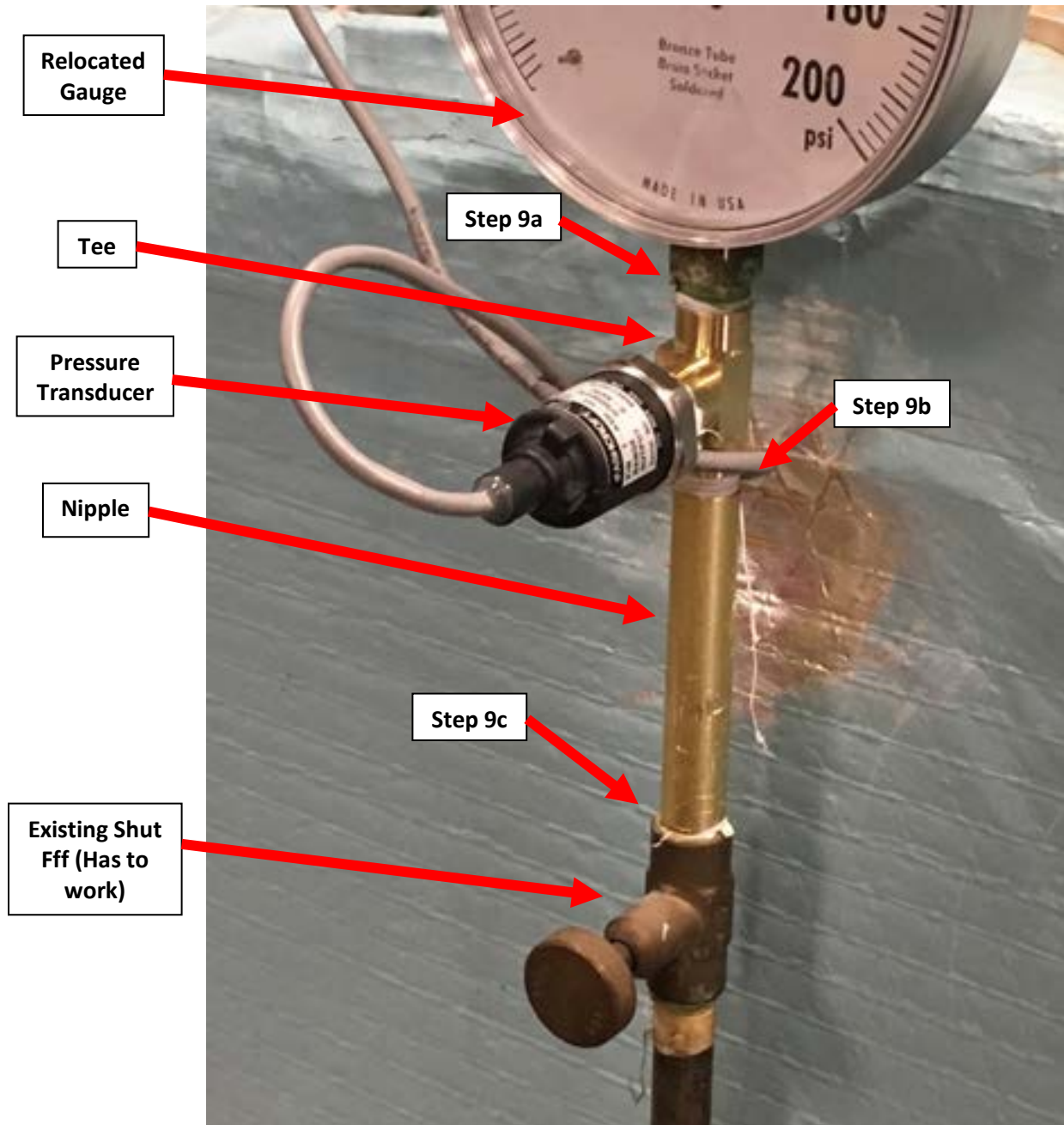


Figure A.9.13: The completed field setup for the Onset HOBO Gauge Pressure Sensor.

9. Tighten the following connections with the pipe wrench pliers (see Figure A.9.14 for an example):
 - a. The connection between the tee and the pressure gauge.
 - b. The connection between the tee and the nipple.

- c. The connection between the nipple and the existing shut off.



Figure A.9.14: Using the pipe wrench pliers in order to create a sufficient seal between the pressure gauge and the tee.

10. Wrap Teflon threaded tape around the threads of the Onset HOB0 Gauge Pressure Sensor as shown on Figure A.9.15.



Figure A.9.15: Wrapping Teflon threaded tape around the threads of an Onset HOB0 Gauge Pressure Sensor.

11. Hand screw in the Onset HOB0 Gauge Pressure Sensor until it does not fall off the tee. Then, use the pipe wrench pliers in order to secure the connection as shown on Figure A.9.16.

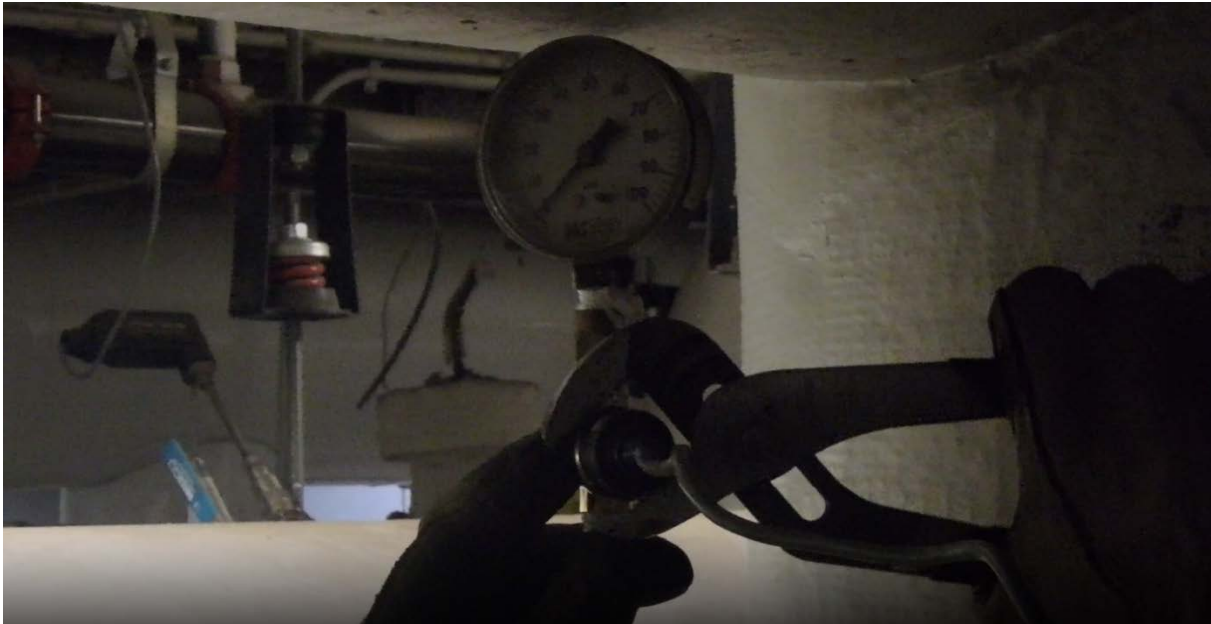


Figure A.9.16: Securing the Onset HOB0 Gauge Pressure Sensor to the tee with pipe wrench pliers.

12. Field set up is now complete and the logger will automatically start collecting data at the date and time that was set on step 7 of section A.9.3.

A.9.5: Verification of Data Collection for the Onset HOB0 4-Channel Analog Logger with Onset HOB0 Gauge Pressure Sensor

It is important to verify the Onset HOB0 4-Channel Analog Logger is collecting accurate data. HOB0ware offers an easy way to check collected data without interfering with the initial setup from the previous sections.

11. Open the HOB0ware software on your computer.
12. Connect the USB-mini cable to the logger. **Do not move the logger or sensors.**
13. Click the readout button on the top menu as shown on Figure A.9.17.
14. The “Stop Logger?” pop-up window will appear asking if you want to stop logging as shown on Figure A.9.18, click **“Don’t Stop”**.

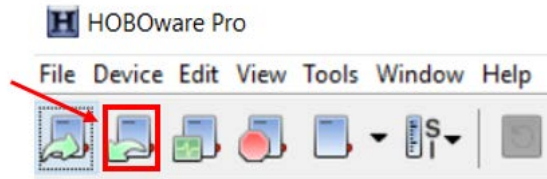


Figure A.9.17: The HOBOWare readout button.

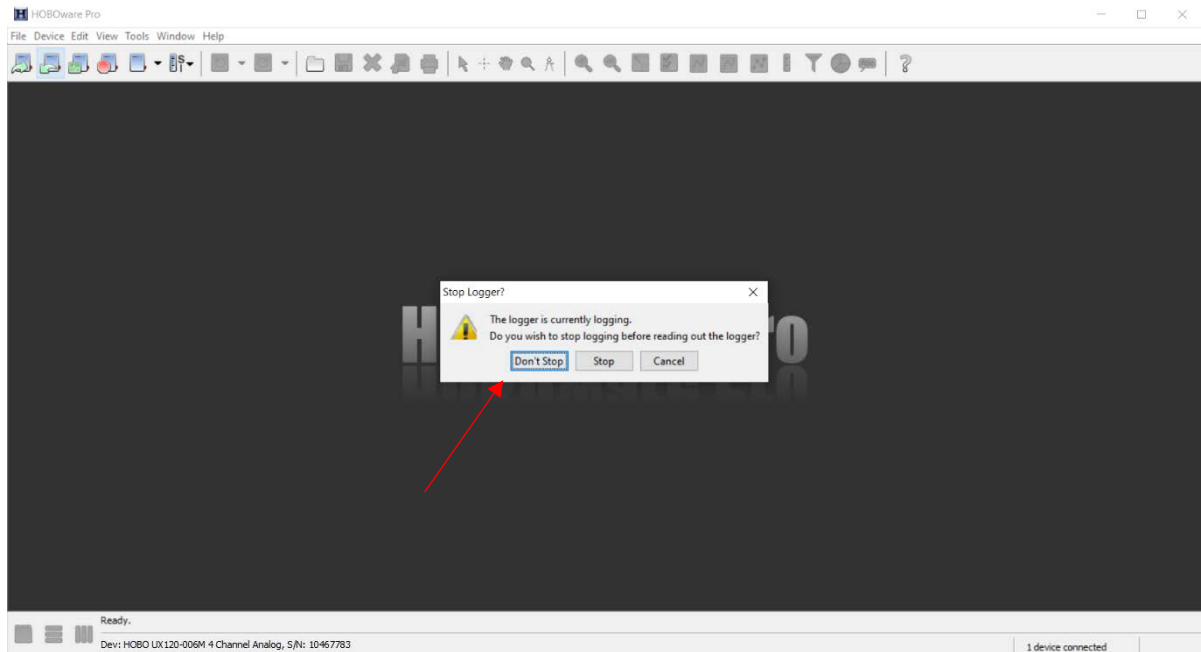


Figure A.9.18: The “Stop Logger?” pop-up window.

15. The “Plot Setup” window will open (see Figure A.9.19).
 - a. Name your data in the same way as in step 1 of section A.9.2.
 - b. Select the measurements that are required for the M&V guide that is being followed. Deselect all other series.
 - i. For example, for the Onset HOBOWare Split-Core Current Sensor, the “AC Curr – Avg” measurements (Unit: “Amps”) were selected as shown on Figure A.9.19.
 - c. Deselect the three “Event Types” at the bottom of the menu.
 - d. Click “Plot” to display your graph.

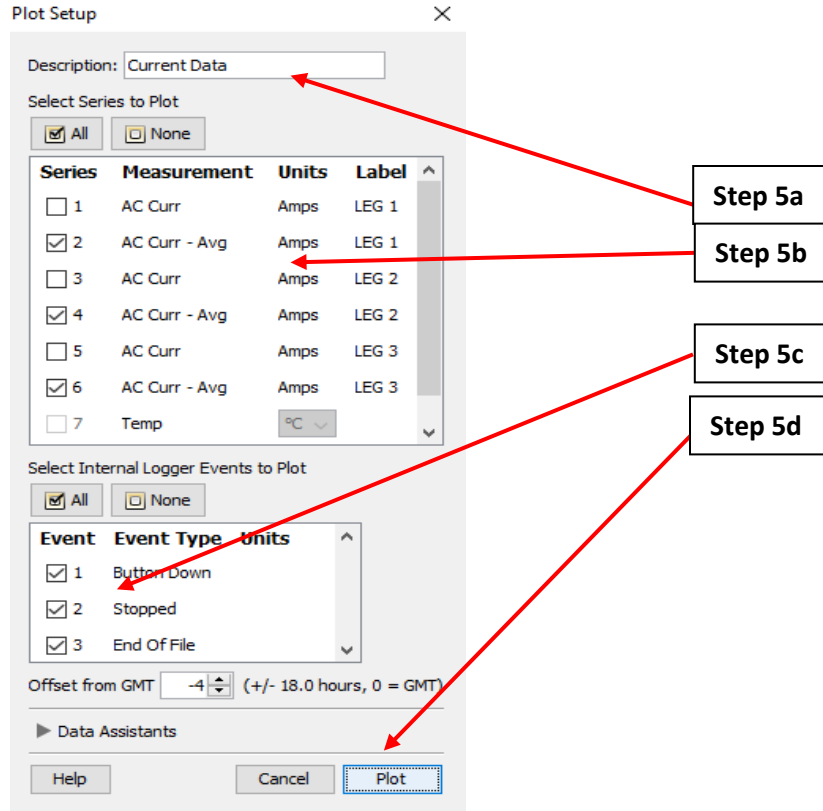


Figure A.9.19: The “Plot Setup” pop-up window with the corresponding steps.

15. After following step 5, HOBOWare will open a new tab with data from the logger. Focus your attention on the “Data Table” pane at the top of the window as shown on Figure A.9.20. Here you will see:
 - a. The date and time of the logged data stored in the first column.
 - a. The columns after the date and time column will display the different pressure readouts corresponding to the times in the first column. Note that Figure A.9.20 is just an example. Your “Data Table” will look different from the one shown on the figure.

#	Time, GMT-04:00	off/on, Time on (hh:mm:ss)	Internal Calibration	Host Connected	End Of File
1	03/10/20 10:00:00 PM		Logged		
2	03/10/20 11:00:00 PM	00:06:56			
3	03/11/20 12:00:00 AM	00:00:00			
4	03/11/20 01:00:00 AM	00:00:00			
5	03/11/20 02:00:00 AM	00:00:00			
6	03/11/20 03:00:00 AM	00:00:00			

Figure A.9.20: HOBOWare data table pane.

16. Scroll through the table and assess the collected data to ensure that the measured operational time corresponds to expected motor operation.

17. If the measured data is unusual or inaccurate based on your understanding of the system, then the Onset HOBO 4-Channel Analog Logger may need to be recalibrated.

A.9.6: Exporting Data from the Onset HOBO 4-Channel Analog Logger to a .csv File

After the allotted measurement period, the entire dataset can be extracted and used to calculate other parameters with respect to the M&V guide being followed.

1. At the end of the measurement period, follow the procedure in section A.9.5 to verify that the collected data is accurate.
2. If satisfied with the accuracy of the measurements, click the “Stop Logging” button on the top left corner of the screen (Figure A.9.21).

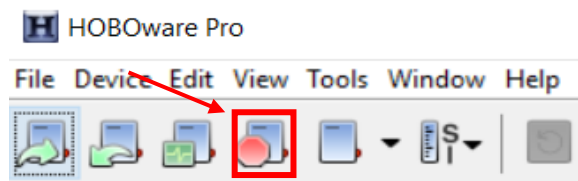


Figure A.9.21: HOBOWare “Stop Logging” Button

3. Click “File” > “Export Table Data” (Figure A.9.22).

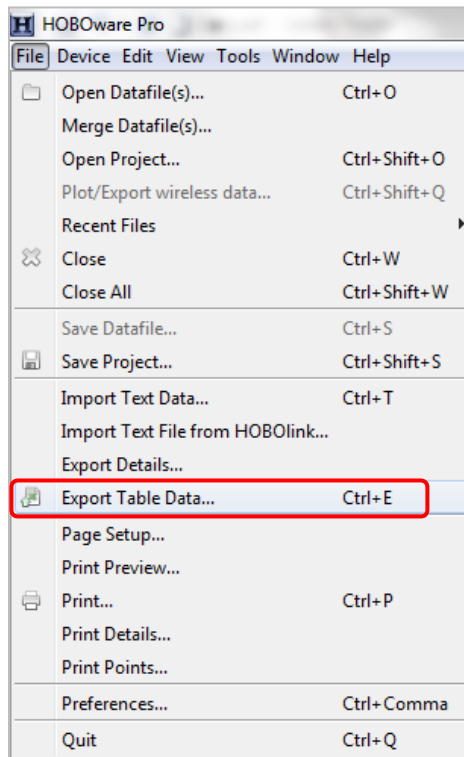


Figure A.9.22: File menu options.

4. The “Export” window will open and display the data available to export (Figure A.9.23).
5. Select “off/on” and uncheck all other boxes.
6. Click “Export...” to export the data.

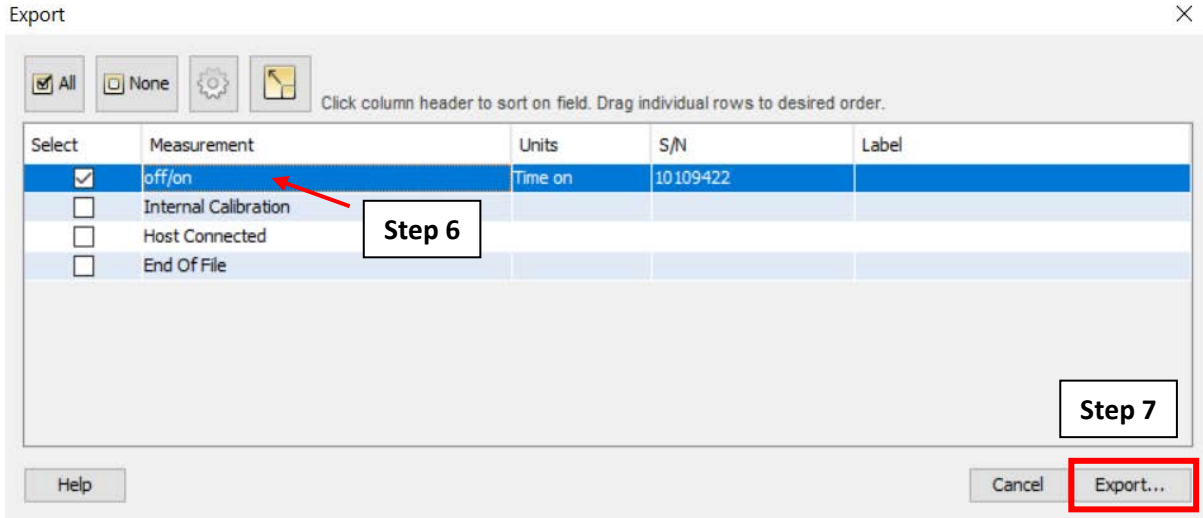


Figure A.9.23: The “Export” Window and corresponding steps.

7. Choose a location to save the file.
8. Name the file the same way as step 1 of section A.9.2.
9. Click “Save” to complete the .csv exporting process.

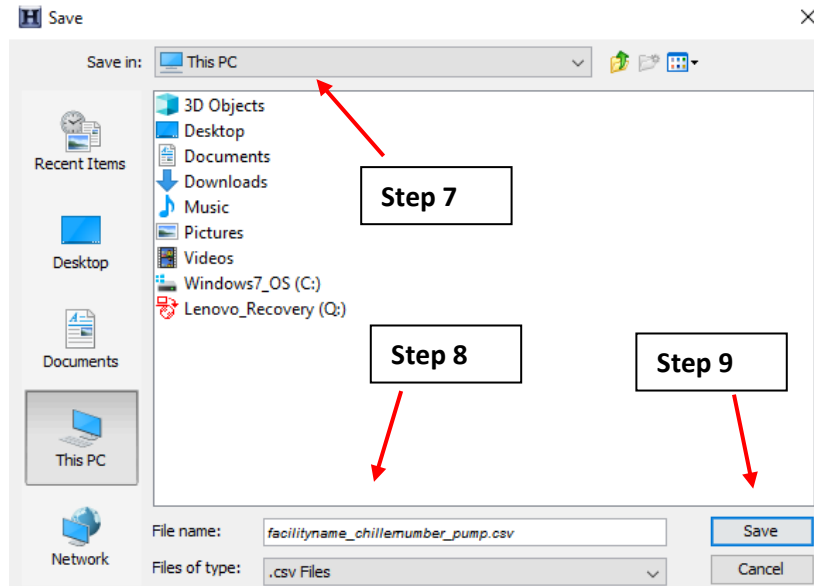


Figure A.9.24: “Save” pop-up window.

A.10: TSI-9545 Velocicalc Air Velocity Meter /TSI AVM430 Hot Wire Anemometer

A.10.1: TSI-9545 Velocicalc Air Velocity Meter Initial Setup

This section will guide you through a preliminary setup of the TSI-9545 Air Velocity Meter. Please exercise the appropriate safety precautions during usage.

1. At the field site, press the “on/off” key as shown on Figure A.10.1. The screen should display the model number, the serial number, the software revision, and the last date the that TSI-9545 Air Velocity Meter was calibrated.
2. Press the “Menu” soft key (Figure A.10.1) which will take you to the “Menu” screen.
3. Use the up and down arrow keys to navigate to the “Display Setup” option and select it using the back-arrow key.



Figure A.10.1: The TSI-9545 Air Velocity Meter's "Menu" screen.

4. On the “Display Setup” screen shown on Figure A.10.2, notice that all of the variables have the word “OFF” right next to them. The variables that have the word “OFF” right next to them will not be displayed on the screen once measurement collection has started.
 - a. Use the up and down arrow keys to navigate to the variable(s) that you would like for the TSI-9545 Air Velocity Meter to display on the screen.
 - b. Press the middle soft key to activate these variables, this will cause the word “OFF” right next to the variable to change to the word “ON”.
 - i. For example, if you wish to determine the flow rate of a duct in CFM (cubic feet per minute), navigate to the “Flow” option, and use the middle soft key to change the word to the right from “OFF” to “ON”.
 - c. Press the back-arrow key to go back to the “Menu” screen.



Figure A.10.2: The “Display Setup” screen for the TSI-9545 Air Velocity Meter. As an example, “Flow” has been set to “ON”. The instantaneous flow measurements in CFM that are being picked up by the meter will be displayed on the screen once the initial setup is complete. Since all the other options are set to “OFF”, only the flow measurements will be displayed on the screen.

5. Back at the “Menu” screen. Use the up and down arrow keys to navigate to the “Flow Setup” option and select it using the back-arrow key, which will take you to the “Flow Setup” screen as shown on Figure A.10.3.
 - a. On the “Flow Setup” screen, make sure “Flow Type” is highlighted, then use the left and right soft keys to navigate to the duct type that best fits the duct that you are taking measurements from.
 - i. For example, if your duct has a rectangular cross section, select the “Rectangular Duct” option.
 - ii. If the duct cross sectional area is neither round nor rectangular, determine the cross-sectional area of the duct, then select the “Duct Area” option.
6. At the “Flow Setup” screen, press the down arrow key to navigate to the “Enter Settings” option. Press the back-arrow key to enter the “Enter Settings” screen as shown on Figure A.10.4.



Figure A.10.3: The “Flow Setup” screen for the TSI-9545 Air Velocity Meter

7. In the “Enter Settings” screen, shown on the right of Figure A.10.4, set the dimensions of the duct using the up and down arrow keys.
 - a. For example, assume that measurements are taken from a circular duct. The “Enter Settings” screen will display a numeric value which is the diameter of the duct. Press the up and down arrow keys to increase or decrease the diameter by 0.1 inches in order to match the diameter of the duct to which measurements are being taken.



Figure A.10.4: The “Enter Settings” screens for the TSI 9545 Velocicalc Air Velocity Meter

8. Once the appropriate dimensions have been set, press the back-arrow key. The words “Changes Saved” should be displayed on the screen as shown on the right of Figure A.10.4. Then you will automatically be taken back to the “Flow Setup” screen. Press the “ESC” button (Figure A.10.3) in order to return to the “Menu” screen.

A.10.2: Setting the “Data Logging” Options/Initial Setup Completion for the TSI 9545 Velocicalc Air Velocity Meter

9. At the “Menu” screen, navigate to the “Data Logging” option and select it using the back-arrow key (left of Figure A.10.5), which will take you to the “Data Logging” screen (right of Figure A.10.5). The “Data Logging” option allows you to select the mode in which measurements will be saved onto the TSI 9545 Velocicalc Air Velocity Meter.

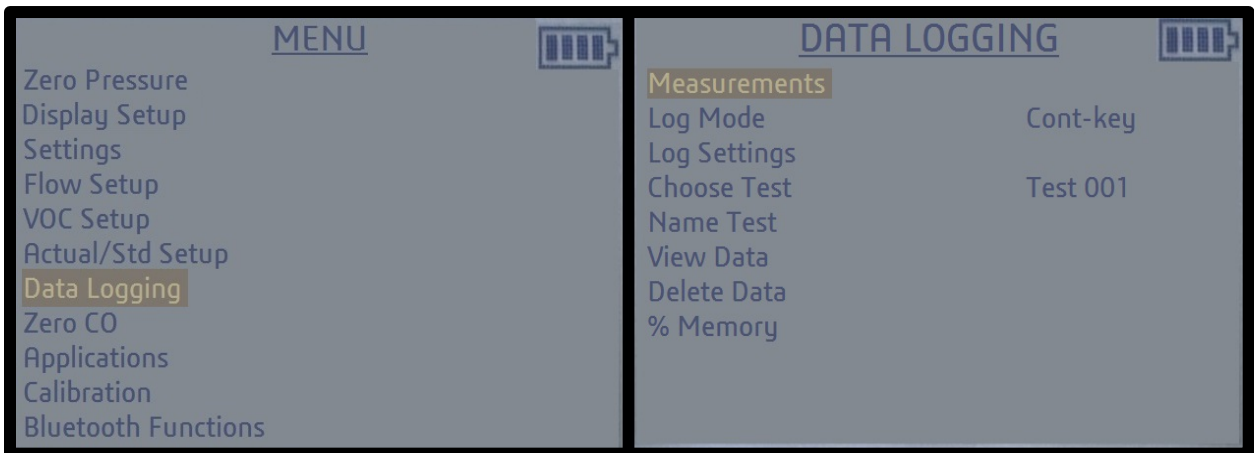


Figure A.10.5: The “Data Logging” option highlighted on the “Menu” screen shown on the left. The “Data Logging” screen is shown on the right.

10. Navigate to the “Measurements” option and select it using the back-arrow key, which will take you to the “Measurements” screen as shown on Figure A.10.6. On the “Measurements” screen, make sure that the measurement variables that were set in step 4.a have the words “DISPLAY” or “ON” right next to it.

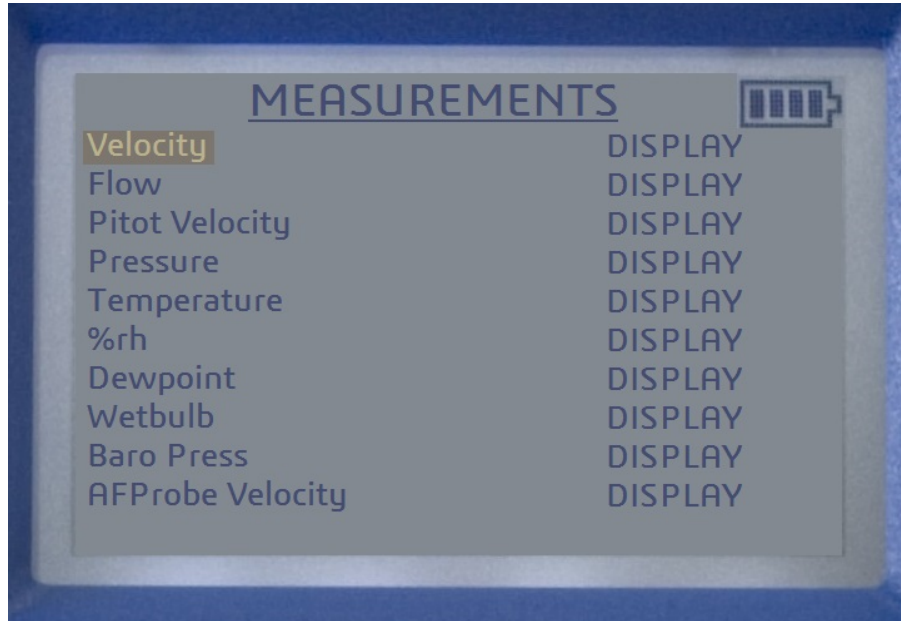


Figure A.10.6: The “Measurements” screen.

11. Press the back-arrow key button to return to the “Data Logging” screen (Figure A.10.7).
12. Use the up and down arrow keys to navigate to the “Log Mode” setting.
13. Use the left or right soft keys to change the “Log Mode” to “Cont-key” (Figure A.10.7). The “Cont-key” allows for continuous readings to be taken from when the user presses first presses the back-arrow key until the user presses the back-arrow key again.
14. Press the back-arrow key to save the “Log Mode” that was selected.



Figure A.10.7: The steps which must be taken to configure the “Log Mode” option.

15. Use the up and down arrows to navigate to the “Log Settings” option (left of Figure A.10.8) and press the back-arrow key, which will take you to the “Sample Time” screen (right of Figure A.10.8).
16. On the “Sample Time” screen, make sure that the sample time that is displayed on the screen is “00:01” indicating 0 minutes and 1 seconds. If not, use the left and right soft keys to navigate between the minutes and seconds, and use the up and down arrow keys to increase or decrease the minutes and seconds.
 - a. Press the back-arrow key to return to the “Data Logging” screen.

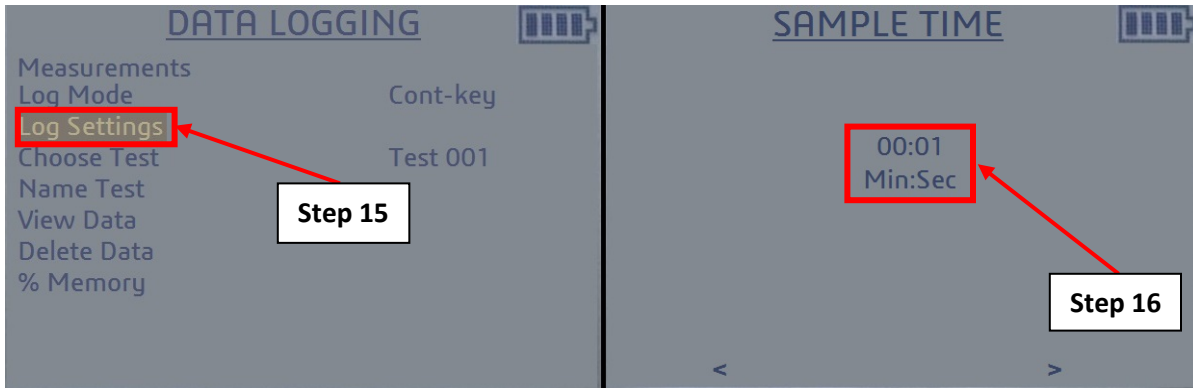


Figure A.10.8: The “Log Settings” option on the “Data Logging” screen is shown highlighted on the left. The “Sample Time” screen is shown on the right.

17. The “Data Logging” screen has a “Choose Test” option as shown on Figure A.10.9. To the right of this option, the words “Test ###” are present, with “###” indicating the test number to which all the measurements will be saved under. If readings taken across multiple ducts are required, complete the first set of measurements for one duct. Then, come back to the “Choose Test” option and use the right soft key to navigate to the next test number.
 - a. For example, you have two ducts. Duct # 1 and Duct # 2. The first duct that you take measurements from is for Duct # 1. At this point, the words “Test 001” are displayed right next to the “Choose Test” option. After the measurements are saved, go back to the “Choose Test” option and use the right soft key to change the test number from “001” to “002”. Now measurements can be taken and saved for Duct # 2.

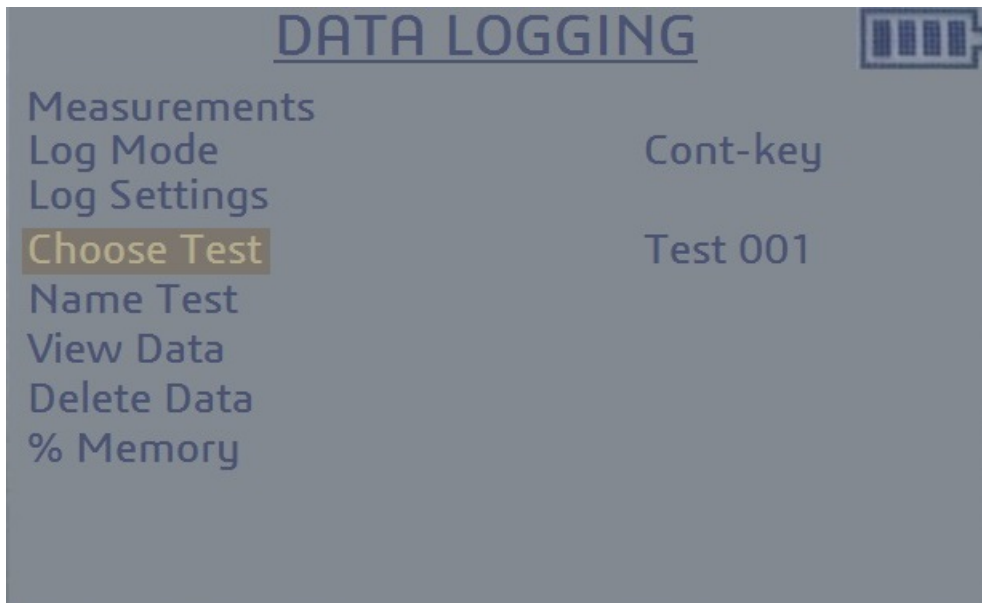


Figure A.10.9: The “Data Logging” screen with the “Choose Test” option highlighted.

18. Initial setup is complete, press the “ESC” button twice on the TSI 9545 Velocicalc Air Velocity Meter’s keypad which will take you to the screen where the measurements will be displayed as shown on Figure A.10.10.



Figure A.10.10: An example screenshot of the TSI 9545 Velocicalc Air Velocity Meter screen after the initial setup is complete. Notice that only the flow measurements in CFM are displayed on the screen as a result of “Flow” being the only parameter selected on Figure A.10.2.

A.10.3: TSI 9545 Velocicalc Air Velocity Meter Field Setup

This section will guide you on how to take measurements using the TSI 9545 Velocicalc Air Velocity Meter at the field site. Please follow along sections A.10.1 and A.10.2 before proceeding.

The probe can either be inserted into a duct or placed in front of an airstream in order to collect measurements as shown on Figure A.10.11. It is optimal to use the TSI 9545 Velocicalc Air Velocity Meter in a duct as shown on the right of Figure A.10.11 as opposed to putting it in a ductless airstream as shown on the left of Figure A.10.11. **Make sure that if measurements are being taken in a duct, that the duct has access points to the flow where the probe can enter.**



Figure A.10.11: Taking measurements with respect to a ductless airflow is shown on the left. Taking measurements inside a duct is shown on the right.

Insert the probe into the airflow similar to what is shown on Figure A.10.11. Make sure that the orientation dimple is facing upstream. Make sure that the probe is in the proper position within the duct or airflow. If temperature measurements are being taken, make sure that at least 3 inches of the probe is in the airflow to allow the temperature sensor to be in the airstream.

For a Ductless Airflow

1. Press the back-arrow key on the TSI 9545 Velocicalc Air Velocity Meter's keypad to begin taking measurements.
2. Move the probe around the airflow for 20 seconds. The sampling time was set at 1 second (Figure A.10.8), which means that in 1 second, all of the instantaneous values that were collected by the probe are averaged. This means that in 20 seconds, the TSI 9545 Velocicalc Air Velocity Meter has collected 20 averaged values.
3. After 20 seconds have elapsed, press the back-arrow key again to stop the TSI 9545 Velocicalc Air Velocity Meter from taking measurements.

For Airflow in a Duct

1. Press the back-arrow key on the TSI 9545 Velocicalc Air Velocity Meter's keypad to begin taking measurements.
2. For a circular duct, it is important to measure the airflow along the points shown on Figure A.10.12. The same applies for a rectangular duct as shown on Figure A.10.13.

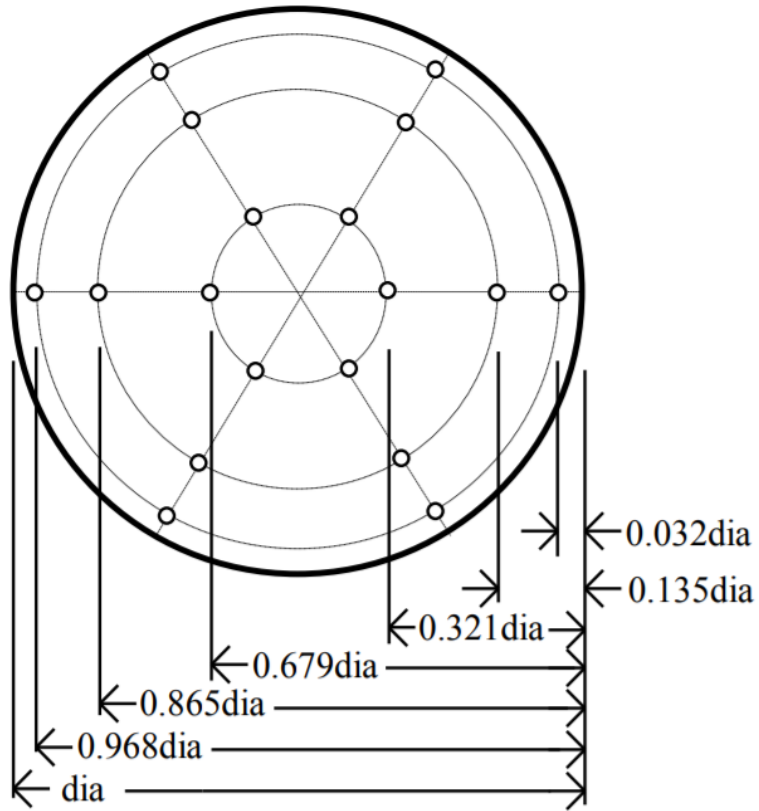


Figure A.10.12: Measurement points for a circular duct using the log-Tchebycheff method.

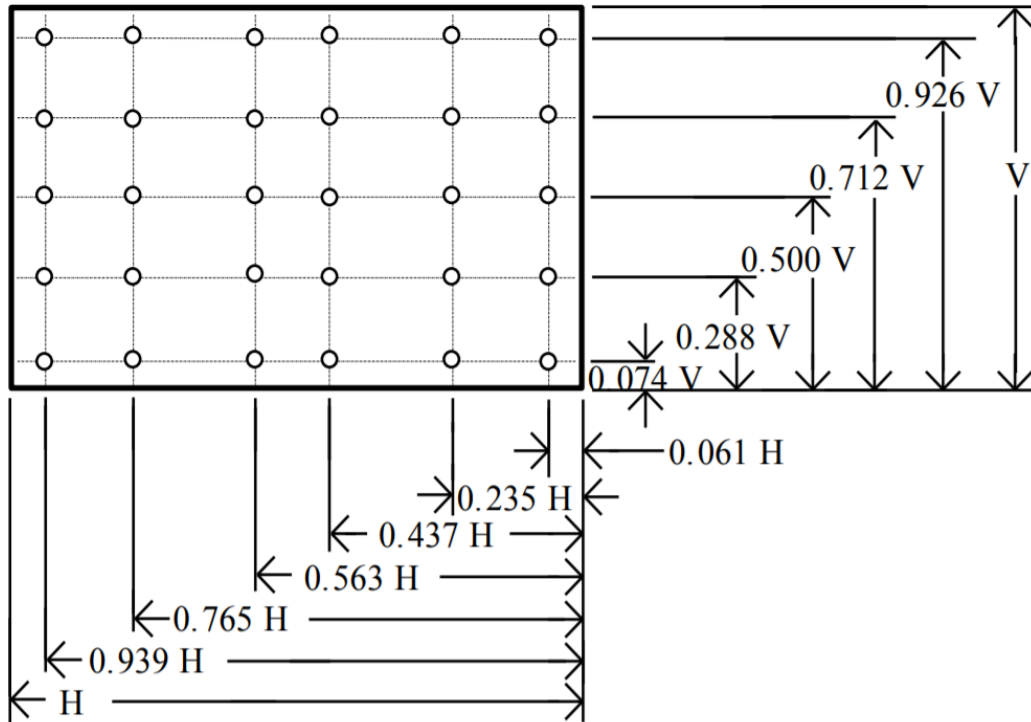


Figure A.10.13: Measurement points for a rectangular duct using the log-Tchebycheff method.

3. Find a point to start at and press the back-arrow key to begin taking measurements. Keep the probe at this point for 10 seconds. Then press the back-arrow key again to conclude measuring the airflow at this point.
4. Move the probe to a new point on the duct and repeat step 3 for all the points on the type of duct from which measurements are being taken.

A.10.4: Viewing the Measurements on the TSI 9545 Velocicalc Air Velocity Meter

1. After following along section A.10.3, press the right soft key as indicated on Figure A.10.14. This will open the statistics screen as shown on Figure A.10.15.
2. The "Avg" value boxed in on Figure A.10.15 is the average flow rate of the duct in CFM based on the measurements that were taken and duct type, which is the value of interest for the various M&V guides.



Figure A.10.14: The screen on which the measurements are displayed on the TSI 9545 Velocicalc Air Velocity Meter.

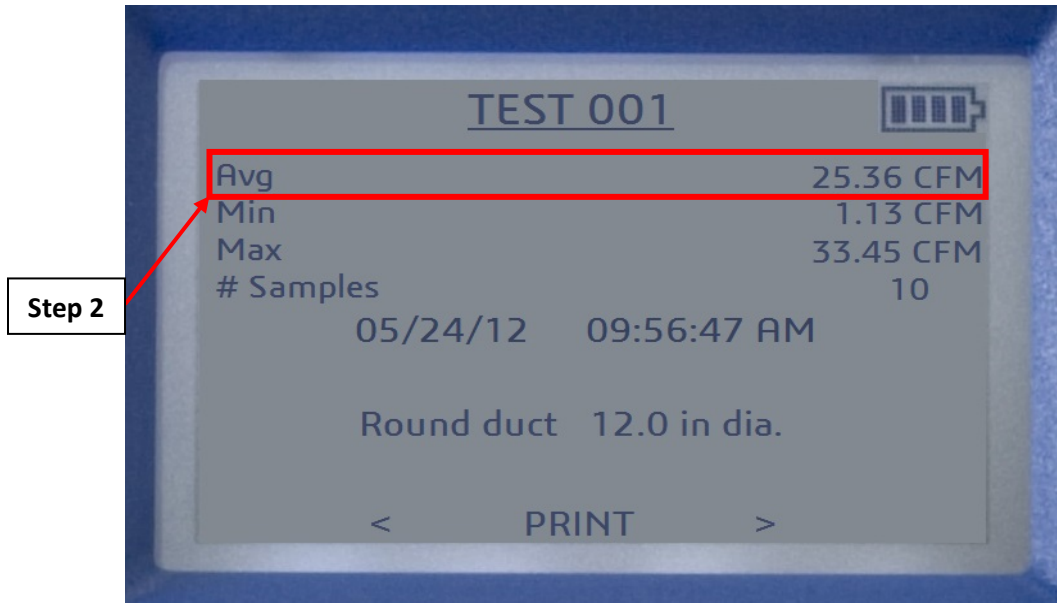


Figure A.10.15: The “Statistics” screen for the TSI 9545 Velocicalc Air Velocity Meter. Note that the average value of the measurements that was taken in section A.10.3 is boxed in red.

A.11: Brinno TLC200 Pro Time Lapse Camera

The following sections will show you how to setup and take time lapse photos using the Brinno TLC200 Pro Time Lapse Camera.

An LED light, the LED light wall charger, and JOBY GorillaPod Original Tripod are required for section A.11.2. These items are available from the CUNY BPL FELL when picking up the Brinno TLC200 Pro Time Lapse Camera. Also, check with the building personnel that there is an outlet and extension cord long enough to read the camera setup in the same room. A video player capable of playing .AVI videos should be installed on the computer in order to view the time lapse videos on the camera. Windows computers come preinstalled with Windows Media Player, which can play .AVI videos. Also, ensure that your computer has a built in SD card reader. If not, please obtain one in order to import the videos from the SD card onto your computer.

A.11.1: Brinno TLC200 Pro Time Lapse Camera Initial Setup

1. Switch on the device by moving the power switch counterclockwise. The setup screen will appear as shown on Figure A.11.1.
 - a. Make sure that the battery is at a sufficient level.
 - b. The date and time shown on screen is the current date and time. Make sure that this is accurate. If not, follow step 9.



Figure A.11.1: The Brinno TLC200 Pro Time Lapse Camera.

2. Click on the “TIME” button. This will take you to the “TIME” screen as shown on the top left of Figure A.11.2. This screen allows you to set the time interval in which the Brinno TLC200 Pro Time Lapse Camera will wait before taking the next time lapse photo.
3. Use the “MENU” and “TIME” buttons right under the LCD screen to go back and forth between the different time intervals.
 - a. Stop at the time interval that suitable for the M&V guide that you are following.
 - b. Select the “CUSTOM” option if you would like to set a custom time interval as shown on the bottom left of Figure A.11.2. Use the “MENU” and “TIME” buttons to set up the hours, minutes, and seconds, pressing “OK” after setting each time value to move onto the next time value.
 - c. Press the “OK” button which will take you back to the setup screen. The setup screen should display the interval that you have selected as shown on the right of Figure A.11.2.

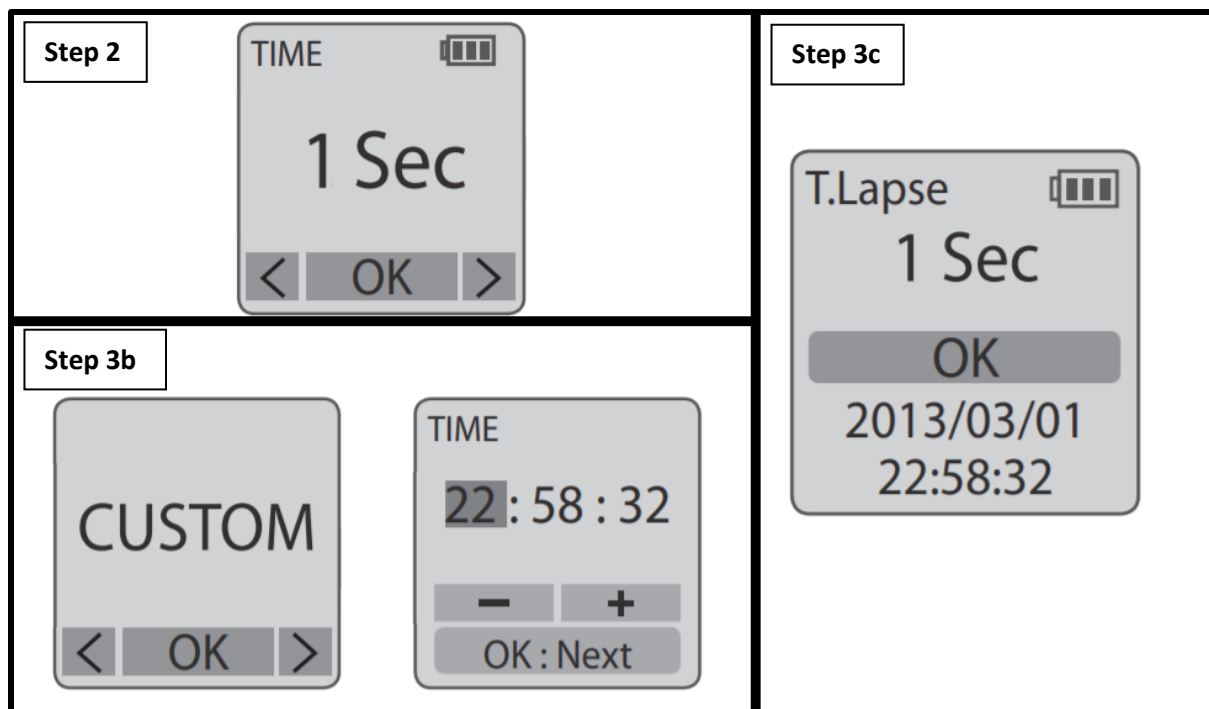


Figure A.11.2: The different “Time” screens are shown on the left. The setup screen with the chosen time interval is shown on the right.

4. Back at the setup screen, press the “MENU” button which will take you to the “Settings” option as shown on the left of Figure A.11.3.
 - a. Press the “MENU” button which will take you to the “SD Storage” screen as shown on the right of Figure A.11.3. Make sure that there is sufficient enough storage for the measurement period. Then press the “OK” button which will take you to back to the “Setting” option.
 - b. Press the “OK” button to enter the “Settings” screen.

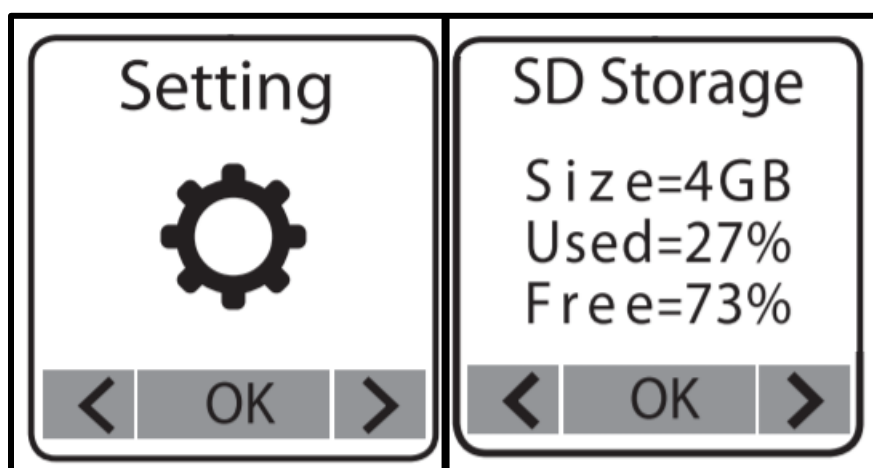


Figure A.11.3: The “SD Storage” screen shown on the right can be accessed by pressing the “MENU” button on the Brinno TLC200 Pro Time Lapse Camera’s body while at the “Settings” option shown on the left.

5. Use the “MENU” and “TIME” buttons to scroll through the various options in the “Settings” screen until the “Time Lapse Frame Rate” option is shown on screen (left of Figure A.11.4).
 - a. Use the “MENU” and “TIME” buttons to scroll through the various FPS options until the “5 FPS” option is arrowed in as shown on the right of Figure A.11.4. Press “OK” to select this option.

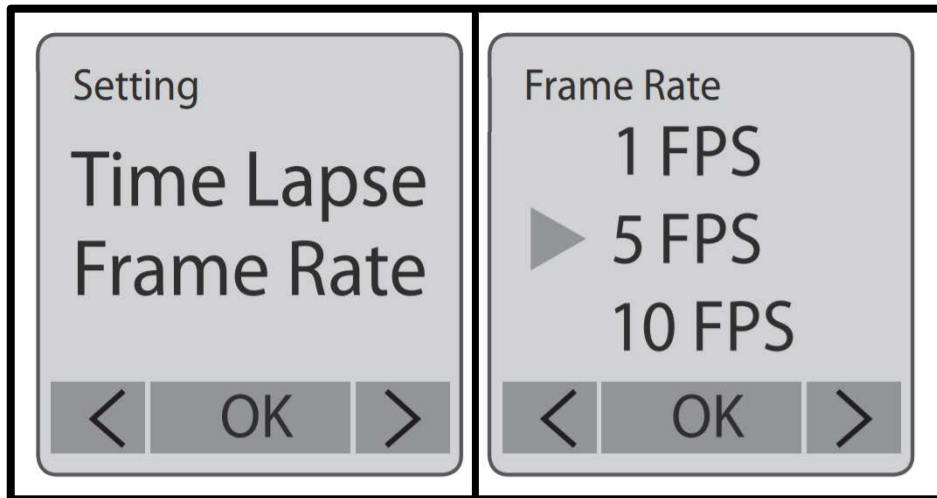


Figure A.11.4: Setting the frame rate.

6. Back at the “Settings” option, press the “OK” button to re-enter the “Settings” screen. On this screen, use the “MENU” and “TIME” buttons to navigate to the “Image Quality” option as shown on the left of F. Press the “OK” button to select this option.
 - a. Check and see that the “Red” arrow is on the “Best” option as shown to the right of F. If it is, press the “OK” button. If not, use the “MENU” and “TIME” buttons to navigate to the “Best” option and press the “OK” button to select it. This ensures that the best possible quality pictures are taken at each time interval.



Figure A.11.5 Setting the image quality.

7. Press the "OK" button to re-enter the "Settings" screen. On this screen, use the "MENU" and "TIME" buttons to navigate to the "Time" option as shown on the left of Figure A.11.6. Press the "OK" button to select this option.
 - a. Use the "MENU" and "TIME" buttons to move the arrow to the "Cancel" option as shown on the right of Figure A.11.6. Press "OK" to select this option. The "Timer" option allows you to pre-set a recording period. For example, you can set the timer to be between "0600 – 1200", which means that time lapse photos will only be taken between the hours of 6 AM to 12 PM. Pictures must be taken continuously, which is why the "Cancel" option was selected.

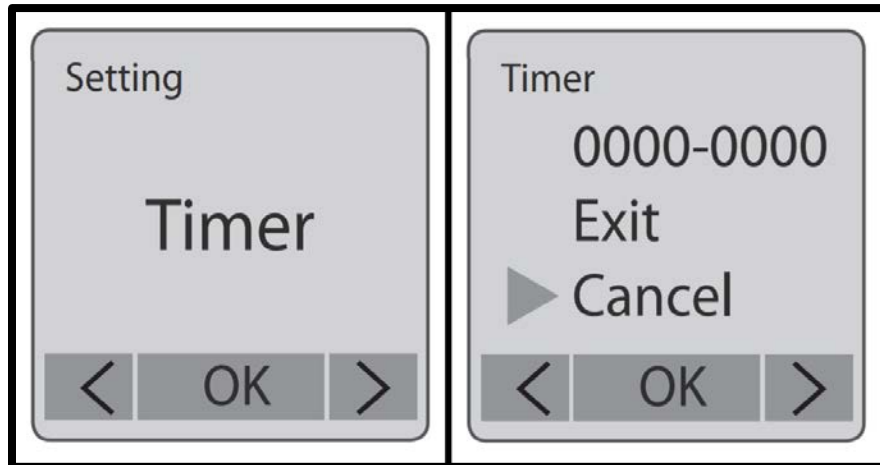


Figure A.11.6: Configuring the timer.

8. Press the "OK" button to re-enter the "Settings" screen. On this screen, use the "MENU" and "TIME" buttons to navigate to the "MORE ..." option as shown on the left of Figure A.11.7. Press the "OK" button to select this option.
 - a. Use the "MENU" and "TIME" buttons to navigate to the "Time Stamp" option as shown on the middle of Figure A.11.7. Press the "OK" button to enter the "Time Stamp" screen as shown on the right of Figure A.11.7.
 - b. Make sure that the arrow is on the "On" option. If not, use the "MENU" and "TIME" keys to move the arrow to the "On" option. Then press the "OK" button. This puts a time stamp on the bottom of the video in a black box.

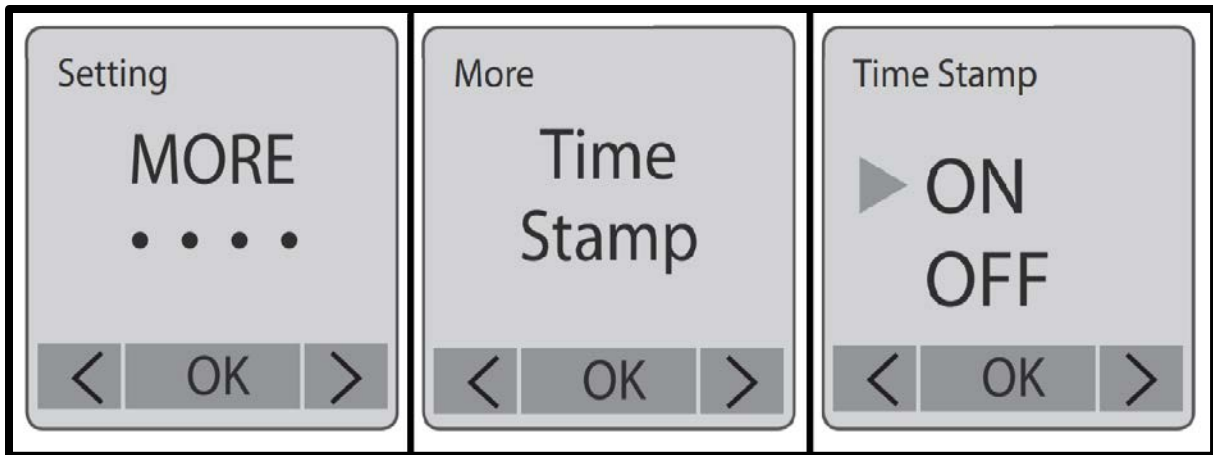


Figure A.11.7: Setting the time stamp which will be affixed on the bottom of the time lapse photos.

9. Only follow this step if the date and time in step 1 was accurate. If not, go back to the “MORE ...” screen by following step 8.
 - a. Use the “MENU” and “TIME” buttons to navigate to the “Set Date & Time” option as shown on the left of Figure A.11.8. Press the “OK” button to enter the “Set Date & Time” screen as shown on the right of Figure A.11.8.
 - b. The year will be highlighted initially. Use the “MENU” and “TIME” buttons to bring the year up and down to the current year. Then press “OK”.
 - c. The highlight to the month at which point you will be able to set the month. The same process applies for the day and time.
 - d. After setting the seconds and pressing “OK”, you will automatically be taken back to the setup screen as shown on Figure A.11.1.²

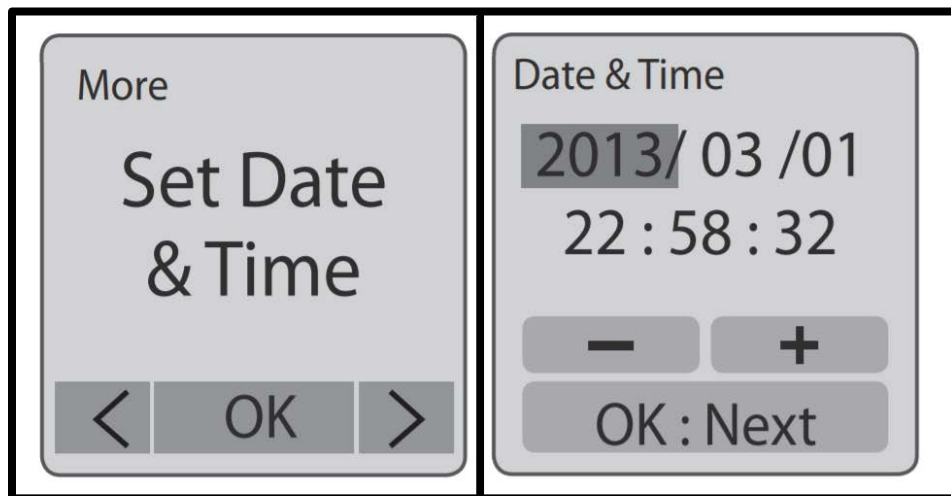


Figure A.11.8: Setting the date and time.

10. Navigate to the “Settings” screen by refollowing step 4. Use the “MENU” and “TIME” buttons to navigate to the “White Balance Mode” option as shown on the left of Figure A.11.9.

² The Brinno TLC200 Pro Time Lapse Camera will not account for daylight savings time. This will be evident in the timestamp.

- a. The “Auto” option ensures that the color temperature of the lights in the room does not affect the actual colors of the subject being photographed. Make sure that the arrow is pointed at the “Auto” option as shown on the right of Figure A.11.9. If not, use the “MENU” and “TIME” buttons to move the arrow to the “Auto” option, then press “OK” which will take you to the “Settings” option (left of Figure A.11.3).

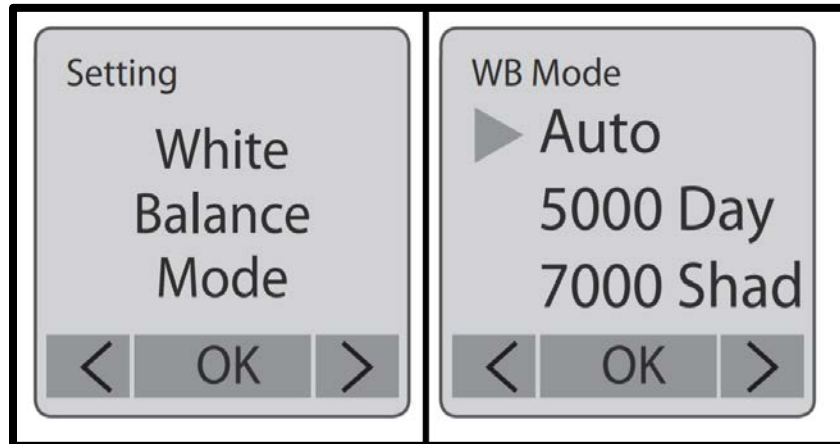


Figure A.11.9: Setting the white balance to “Auto”.

11. At the “Settings” option, press the “OK” button to re-enter the “Settings” screen. Then press the “Menu” button which will take you back to the setup screen. The initial setup is complete.

A.11.2: Brinno TLC200 Pro Time Lapse Camera Field Setup

1. At the field site, install the JOBY GorillaPod Original Tripod into the base of the Brinno TLC200 Pro Time Lapse Camera. Then place the light on the JOBY GorillaPod Original Tripod or any other applicable surface in which the LED light shines on the meter. The setup should look like what is shown on Figure A.11.10.
 - a. Note that the lens that is installed onto the Brinno TLC200 Pro Time Lapse Camera is not the original stock lens that came with the camera. The lens was replaced in order to give the user the ability to adjust the zoom. This replacement lens is heavy enough that it is unable to hold itself in position on the Brinno TLC200 Pro Time Lapse Camera’s body. That is why as shown on Figure A.11.10, the Brinno TLC200 Pro Time Lapse Camera’s body is tilted at an angle, in order to hold the lens at the appropriate position to take time lapse photos of the meter. Please take note of this when setting up the Brinno TLC200 Pro Time Lapse Camera.

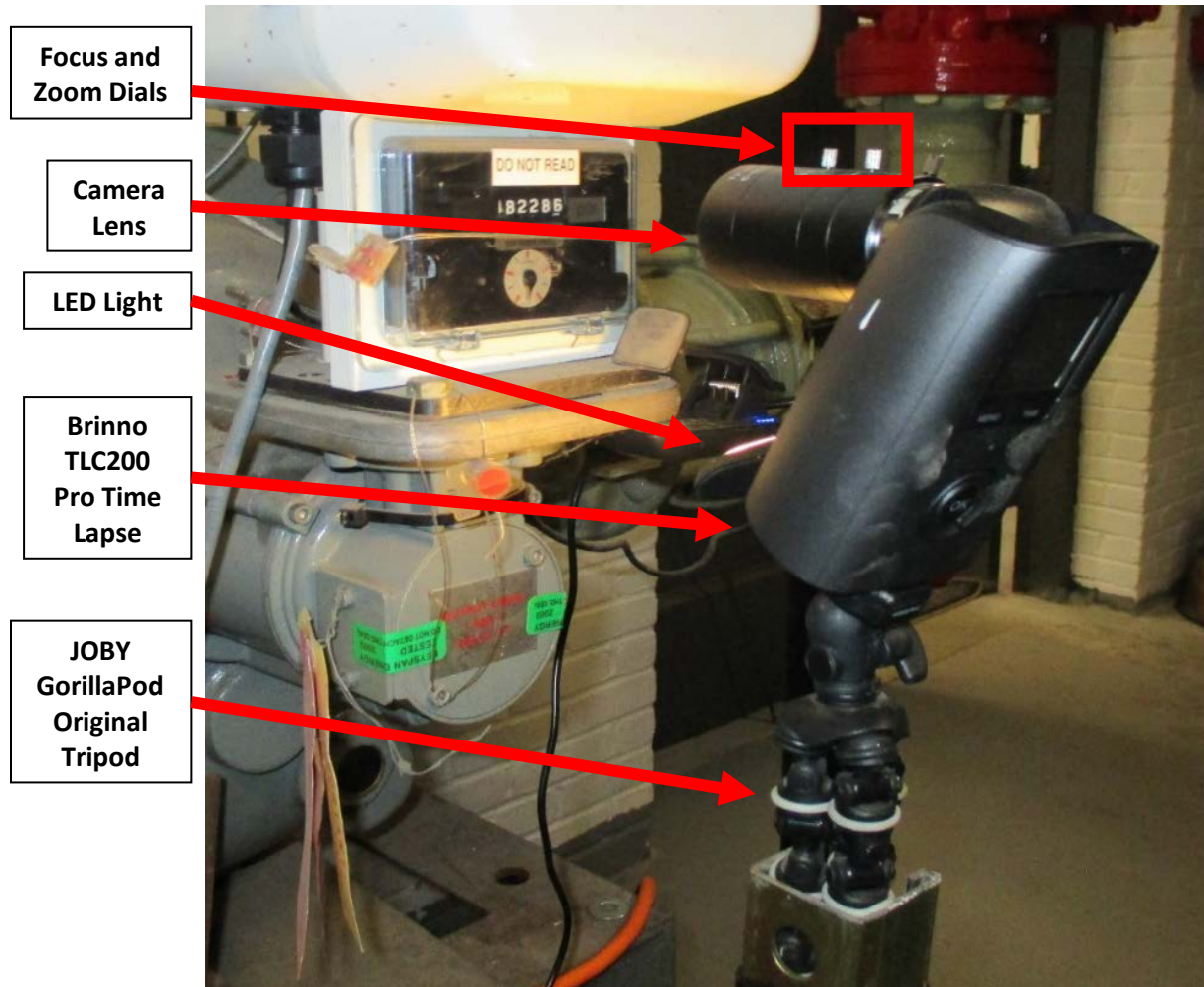


Figure A.11.10: Brinno TLC200 Pro Time Lapse Camera field setup for a boiler fuel consumption meter.

2. Navigate to the Brinno TLC200 Pro Time Lapse Camera's setup screen and press the "OK" button. This will bring up the preview screen as shown on Figure A.11.11.



Figure A.11.11: The Brinno TLC200 Pro Time Lapse Camera's preview screen.

3. Make sure that the image on screen is as clear as possible. Do this by turning the focus and zoom dials on the camera lens (Figure A.11.10). See Figure A.11.12. Note that the dial window may also be dirty, and should be cleaned before recording.
4. Low light will degrade the image. Turn on the LED light in order to improve the image quality. See Figure A.11.12.

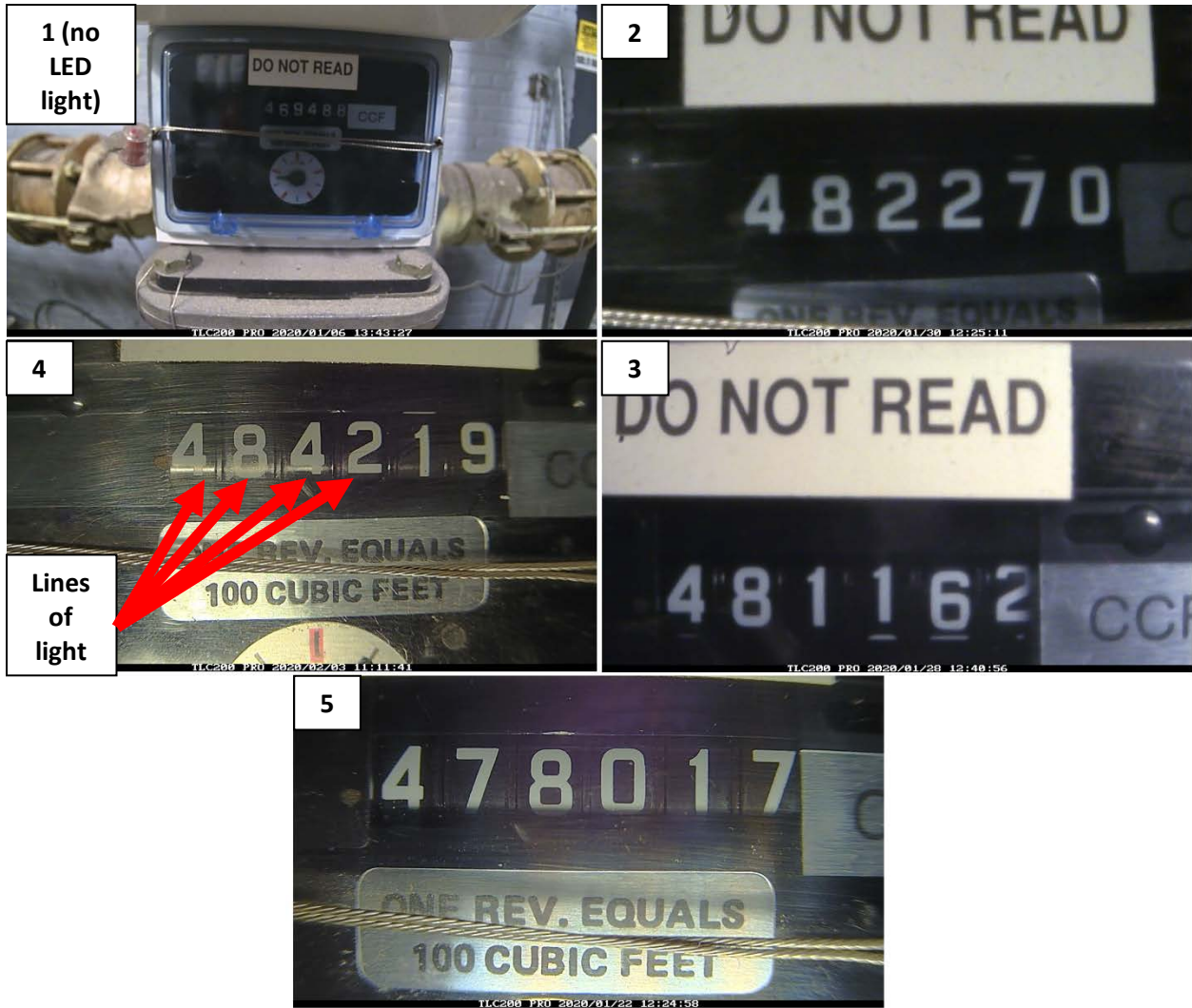


Figure A.11.12: 5 different time lapse photo scenarios for the boiler fuel consumption meter shown in Figure A.11.1 with 1 being the worst one and 5 being the best one. Note that for # 4, there is a line of light that goes through the first 4 numbers as a result of the LED light. Adjust LED light or Brinno TLC200 Pro Time Lapse Camera to avoid these lines.

5. Press the “OK” button on the Brinno TLC200 Pro Time Lapse Camera which will have the camera begin to record pictures as shown on the left of Figure A.11.13. After several seconds, the LCD screen on the camera will turn off to save battery as shown on the right of Figure A.11.13. Field setup is complete. Come back to the site once every several days in order to make sure that the meter window is free of dirt and other obstructions until the measurement period has elapsed.



Figure A.11.13: The Brinno TLC200 Pro Time Lapse Camera's recording screen shown on the left. After several seconds, the screen will automatically turn off as shown on the right.

A.11.3: Verification of Data Collection for the Brinno TLC200 Pro Time Lapse Camera

Please follow along this section to verify that the images being taken on the Brinno TLC200 Pro Time Lapse Camera are clear. In order to verify that the images taken on the camera are clear, wait some time after the camera has started recording, then stop the recording process. This section of the appendix will guide you on this process.

Assume that a time interval of 1 second was chosen in step 3.a of section A.11.1. Also assume that the time-lapse frame rate was set to 5 FPS when step 5.a of the same section was followed. This means that in order to get a .AVI video that lasts 1 second, 5 real-time seconds must elapse at the field site where the camera is setup. To get a .AVI video that last 30 seconds, multiply the number of frames per second by the number of seconds the .AVI video should be:

$$\frac{5 \text{ frames}}{\text{Second}} \times 30 \text{ seconds} \times \frac{1 \text{ second}}{\text{frame}} = 150 \text{ seconds}$$

Since a time interval of 1 second was chosen, 150 real-time seconds must elapse at the field site with the camera installed in order to get a video that lasts 30 seconds. If one were to wait only a couple of real-time seconds before stopping the recording, then there is the possibility of the video playing too quickly, which prevents the user from being able to judge the quality of the video. Please generate a 30 second video, which should be enough time to judge the quality of the video, using equation 1.

$$\text{Time Lapse Frame Rate} \times \text{Video Length} \times \text{Time Interval} = \# \text{ of Real - Time Seconds} \quad (1)$$

Time Lapse Frame Rate is the frame rate that was set in step 5.a of section A.11.1, which is in frames per second. *Video Length* is the length of the .AVI video in seconds, which should be set to 30 seconds. *Time Interval* is the interval (in seconds) that the camera waits between taking pictures which was set in step 3.a of section A.11.1. *# of Real-Time Seconds* is the number of real time seconds that must elapse at the field site where the camera is installed in order to get an .AVI video with a length of *Video Length*.

1. After following the last step of the previous section, come back to the Brinno TLC200 Pro Time Lapse Camera after the desired number of real-time seconds has elapsed. Stop the recording by

holding the “OK” button on the camera’s body. The LCD screen will turn on, and the word “Processing” will appear on screen as shown on the left of Figure A.11.14.

2. The word “Ready” will show on the screen as shown on the right of Figure A.11.14. At this point, the SD card is ready to be extracted.
3. To resume recording, make sure the SD card is inside the camera’s body, then on the preview screen of the camera, press “OK” on the Brinno TLC200 Pro Time Lapse Camera’s body to start recording again. This will place subsequent time lapse photos onto a new .AVI video.



Figure A.11.14: The preview screen will display the word “Processing” as shown on the left which means that all of the time lapse photos are being processed into a .AVI video. Then the word “READY” will be displayed on screen as shown on the right which means that the SD card can be extracted, or a new set of time lapse photos are ready to be recorded.

4. Follow along the next section in order to view the 30 second video to verify data collection.

A.11.4: Viewing and exporting the .AVI videos from the SD card to your Computer

Follow along this section of the appendix to check the quality of the videos or after the measurement period has elapsed.

1. Extract the SD card from the side of the Brinno TLC200 Pro Time Lapse Camera’s body as shown on Figure A.11.15.



Figure A.11.15: Open the SD card cover as shown on the left. Extract the SD card as shown on the middle. Close the SD card cover in order to prevent dust and debris from entering the Brinno TLC200 Pro Time Lapse Camera as shown on the right.

2. Insert the SD card into the SD card reader on the computer. For a Windows PC, the SD card will show up on the File Explorer as shown on Figure A.11.16. Double click on the SD card to view its contents.

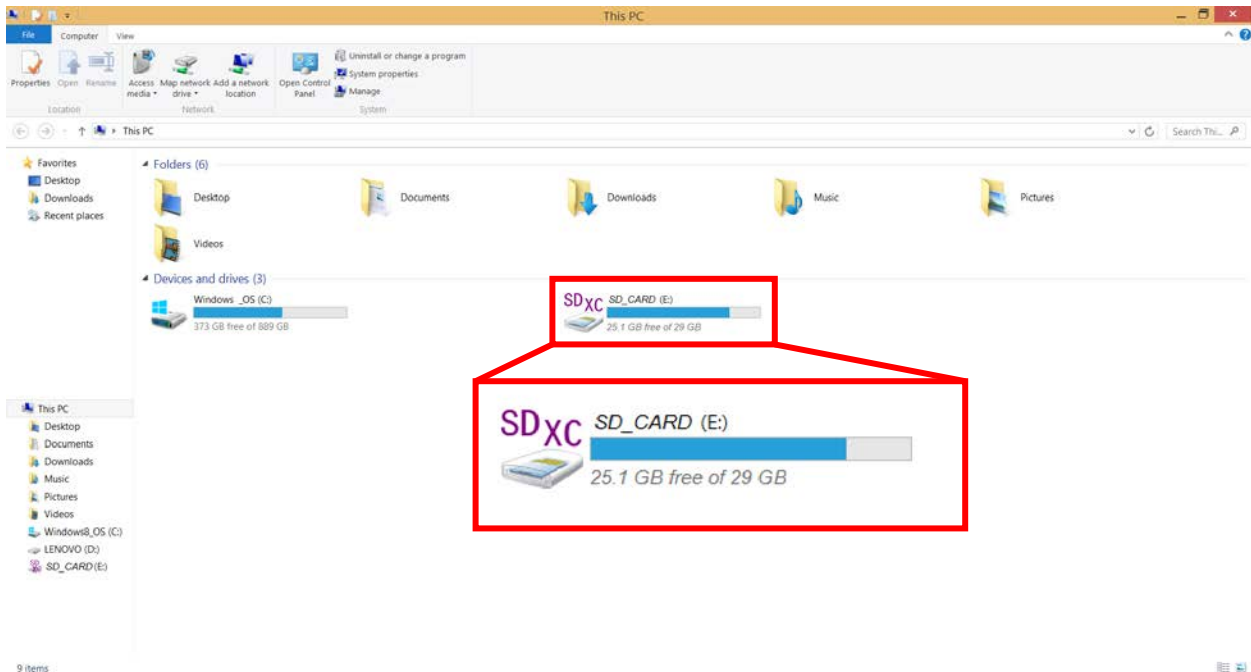


Figure A.11.16: On a Windows computer, once the SD card is inserted into the SD card reader, it should show up on the File Explorer as shown on this figure.

3. Double click on a time lapse video on the SD card to view it using Windows Media Player or similar video playing software as shown on Figure A.11.17.



Figure A.11.17: The .AVI video files containing the time lapse images are shown at the top. One of the videos is being played on Windows Media Player as shown on the bottom.

4. If after performing the previous step you are satisfied with the quality of your video(s):
 - a. If performing a periodic check of the videos for clearness, safely remove the SD card from the computer (Figure A.11.18). Then, reinsert the SD card into the Brinno TLC200 Pro Time Lapse Camera's body and reflow steps 2 – 5 in section A.11.2.
 - b. If the measurement period has elapsed, copy and paste the videos from the SD card onto a folder on your computer. Once the copying is complete, safely remove the SD card from the computer (Figure A.11.18). Then, reinsert the SD card into the TLC200 Pro Time Lapse Camera's body. Disassemble the setup from the field site and return all equipment to FELL.

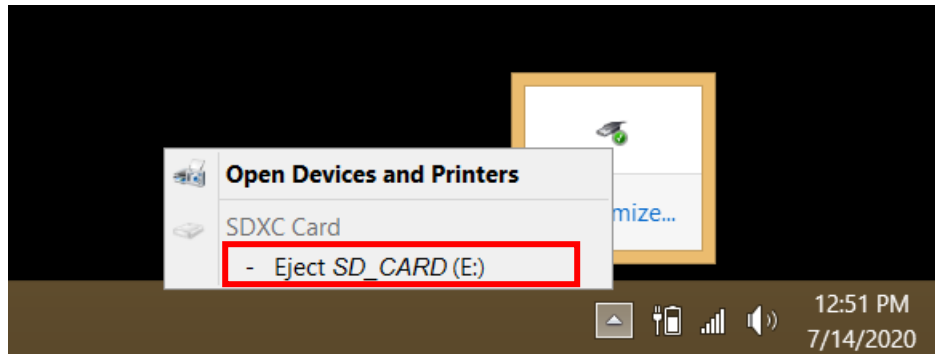


Figure A.11.18: Please remember to safely remove the SD card. On a Windows computer, find the small upright arrow on the bottom right of your desktop. Click on it, then right-click on the USB icon. Then select "- Eject SD_CARD (E:)" (or whatever the name of your SD card is) which is boxed in red on the figure.

A.12: Onset HOBO 4-Channel Thermocouple Logger (UX120-014M)

A.12.1: Onset HOBO 4-Channel Thermocouple Logger Connection to Computer

This section provides steps on how to connect the Onset HOBO 4-Channel Thermocouple Logger to the computer. This is necessary in order to perform an initial setup of the logger prior to being deployed on the site.

1. Open the HOBOWare software and connect the logger to computer using a mini-USB cable.
2. Confirm that the logger name is displayed on the bottom left of the screen and that "1 device connected" is displayed on the bottom right, as shown on Figure A.12.2. If both messages are present, click the "Launch" button, boxed in on the top left. This will open the "Launch Logger" pop-up window as shown on where you select the parameters for collecting data.



Figure A.12.1: The logger connected to laptop computer via USB.

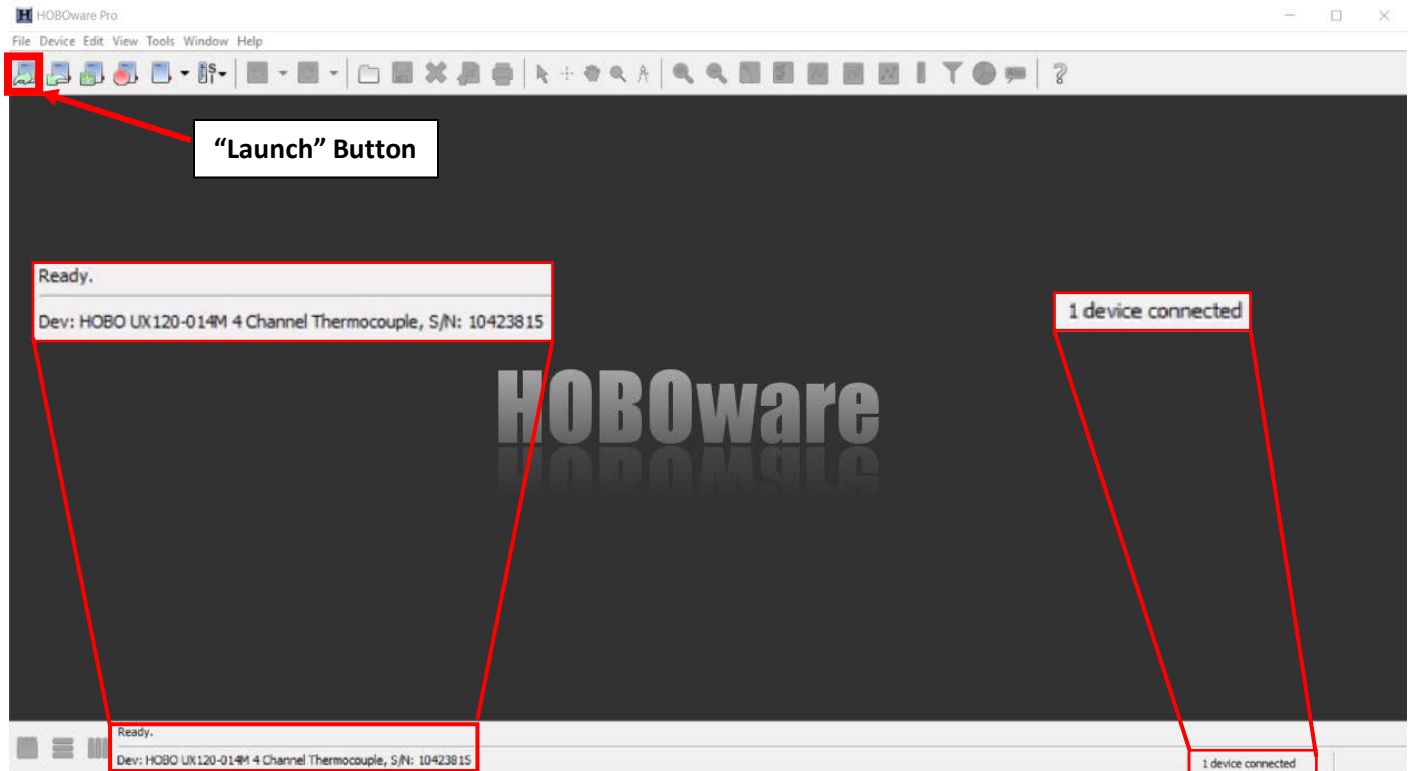


Figure A.12.2: HOBOWare launch menu

A.12.2: Configuring the Onset HOBO 4-Channel Thermocouple Logger

In the “Launch Logger” window shown on Figure A.12.3:

1. In the “Description” field, enter a meaningful label. Ideally, the “Name” field should have the name of the facility, the number of the system if there are multiple systems, and any other distinguishing characteristics.
 - a. For example, for a chiller system, we can set a name with the facility’s name, the chiller number, and any other distinguishing characteristics: *facilityname_chillernumber_supply* OR *facilityname_chillernumber_return*.
2. Check the battery level to confirm that the Onset HOBO 4-Channel Thermocouple Logger is sufficiently powered and doesn’t require a battery replacement.
3. Within the “Launch Logger” window, the “Sensors” table allows you to configure each input port of the Onset HOBO 4-Channel Thermocouple Logger.

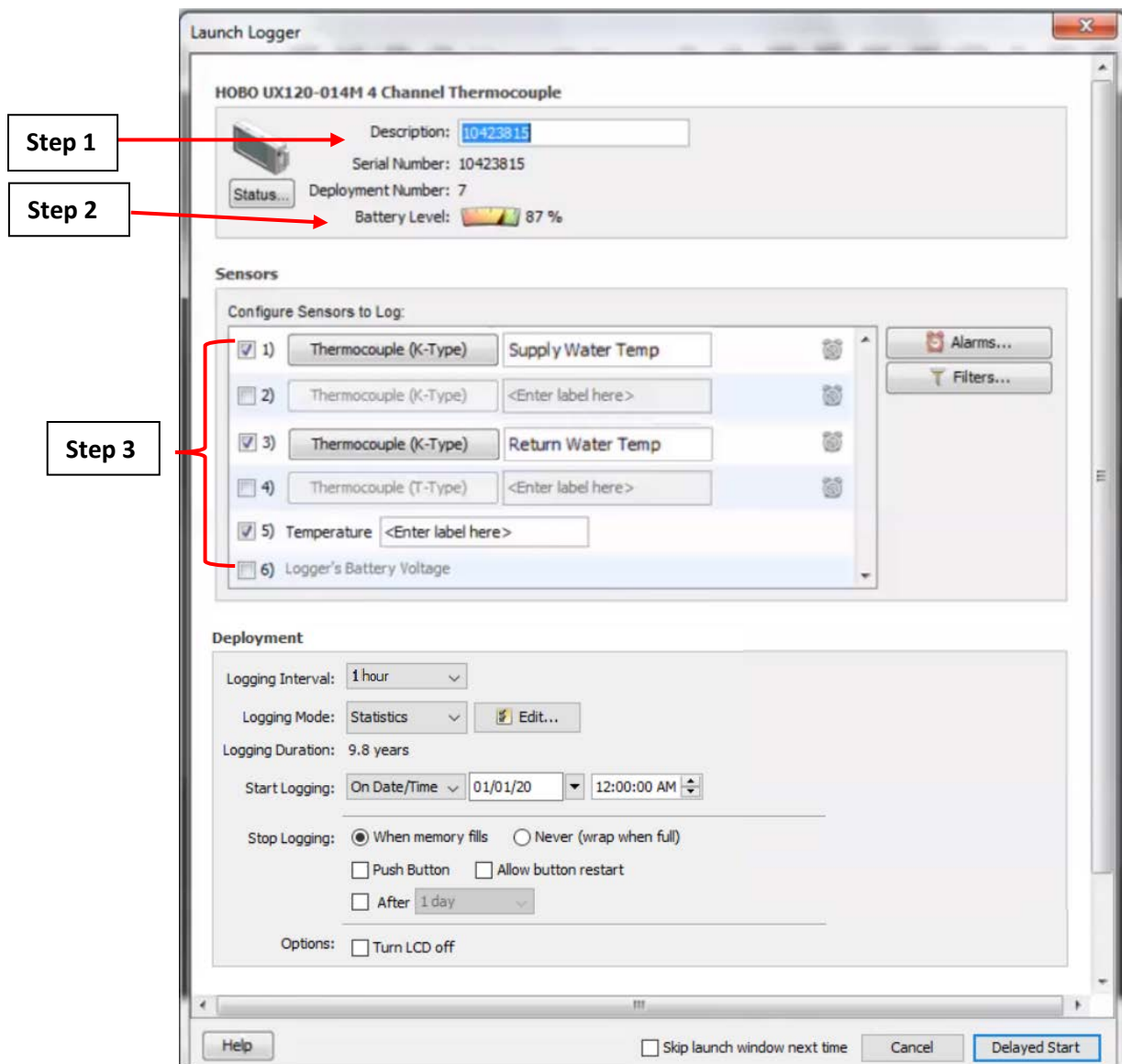


Figure A.12.3: The "Launch Logger" window with the necessary configuration steps.

4. Figure A.12.4 shows what settings to enable in the "Sensors" table:
 - a. Select the number of checkboxes which correspond to the number of thermocouples that you would like to use on the Onset HOBO 4-Channel Thermocouple Logger. For example, Figure A.12.4 shows only one checkbox has been checked in, which means only 1 thermocouple will be connected to the Onset HOBO 4-Channel Thermocouple Logger.
 - b. Click the dropdown menu which will bring up a list of different thermocouples that can be used with the Onset HOBO 4-Channel Thermocouple Logger. At the time of writing, the CUNY BPL FELL only offers type T thermocouples, which is the option that is selected as shown on Figure A.12.4. Make sure to select the correct thermocouple for the correct port on the logger, as selecting the incorrect thermocouple will result in an incorrect reading. See Figure A.12.5 for an example for the supply and return water temperature for an evaporator.
 - c. The internal temperature sensor, labeled "Temperature", is for cold junction

compensation. This is because the metal at the cold junction is different from the metal at the hot junction. This sensor is optional.

- d. Label the sensor in a similar fashion to that of Step 1.

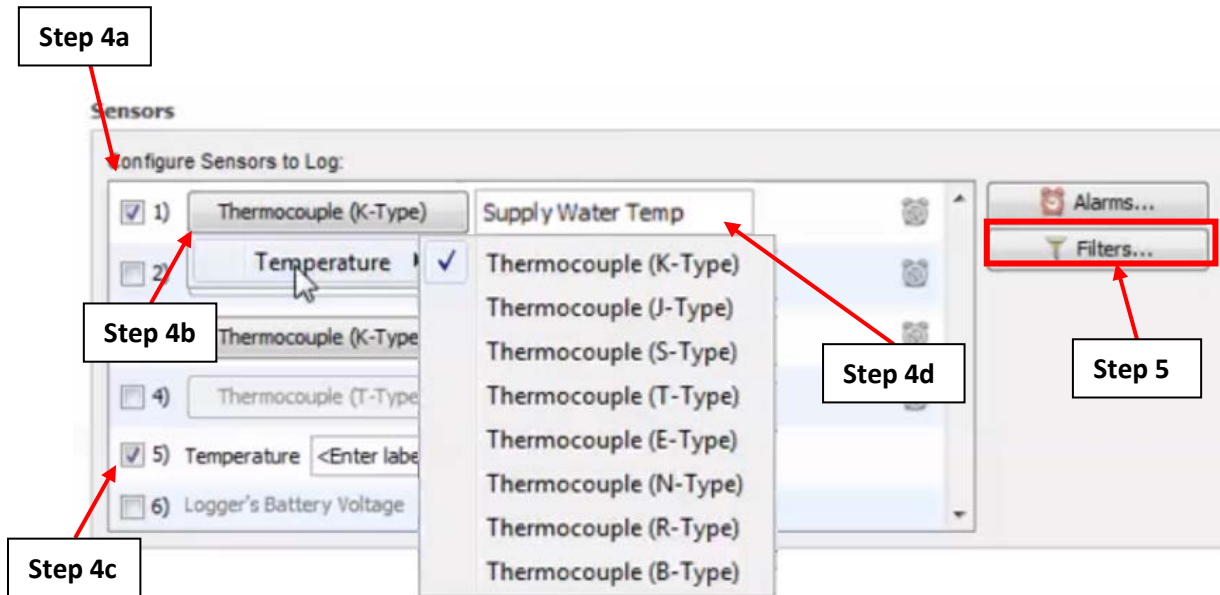


Figure A.12.4: The “Sensors” table with the necessary configuration steps.

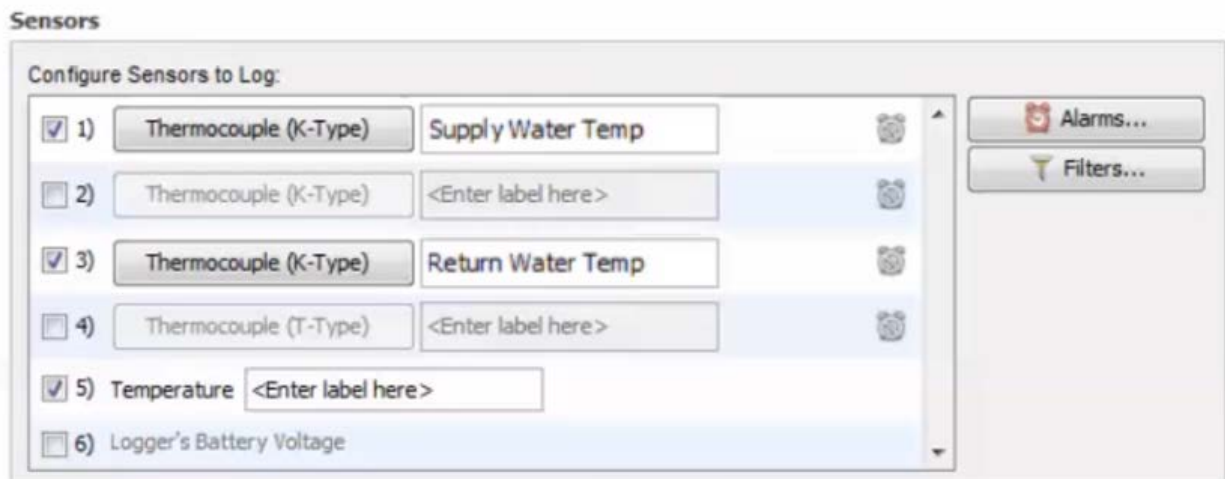


Figure A.12.5: An example “Sensors” table setup for two type T thermocouples which will be used to measure and log the supply and return water temperatures for an evaporator.

A.12.3: Deploying the Onset HOBO 4-Channel Thermocouple Logger

Below the “Sensors” table you will see the “Deployment” table as shown on Figure A.12.6. This allows you to specify your logger deployment with details such as when to start and stop logging.

To deploy the logger:

1. Click the arrow in the “Logging Interval” dropdown menu and select 1 hour as the logging interval.

2. Set the logging mode to “Statistics”.
3. Click the “Edit” button to make the Statistics window appear.

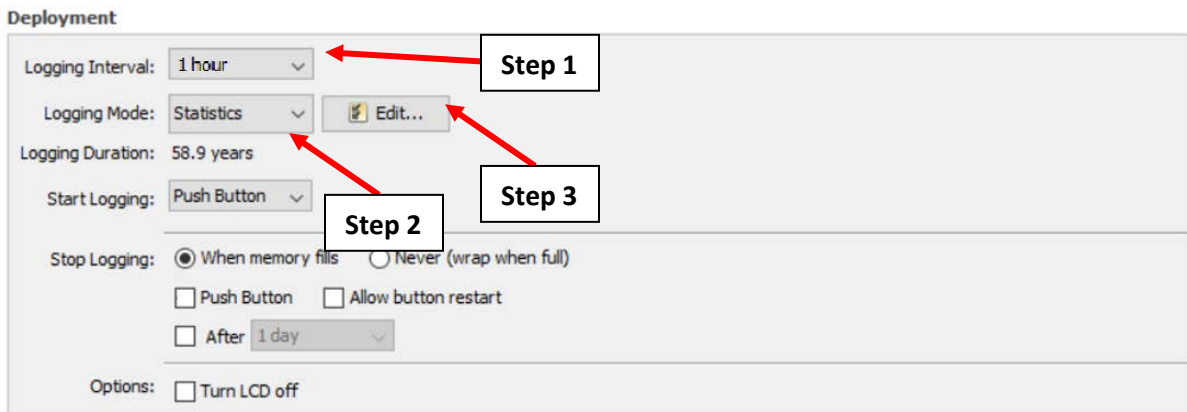


Figure A.12.6: Setting the Logging Interval and the Logging Mode in the Deployment table.

4. Following Figure A.12.7, select the checkbox labeled “Average” and uncheck the other boxes.
5. Click on the drop-down menu for “Sampling every:” and select 1 second (as shown above). This stipulates that the Onset HOBO 4-Channel Thermocouple Logger will record the 1-hour average temperature readouts based on 1 second measurements.
6. Click “OK” to close the Statistics window.

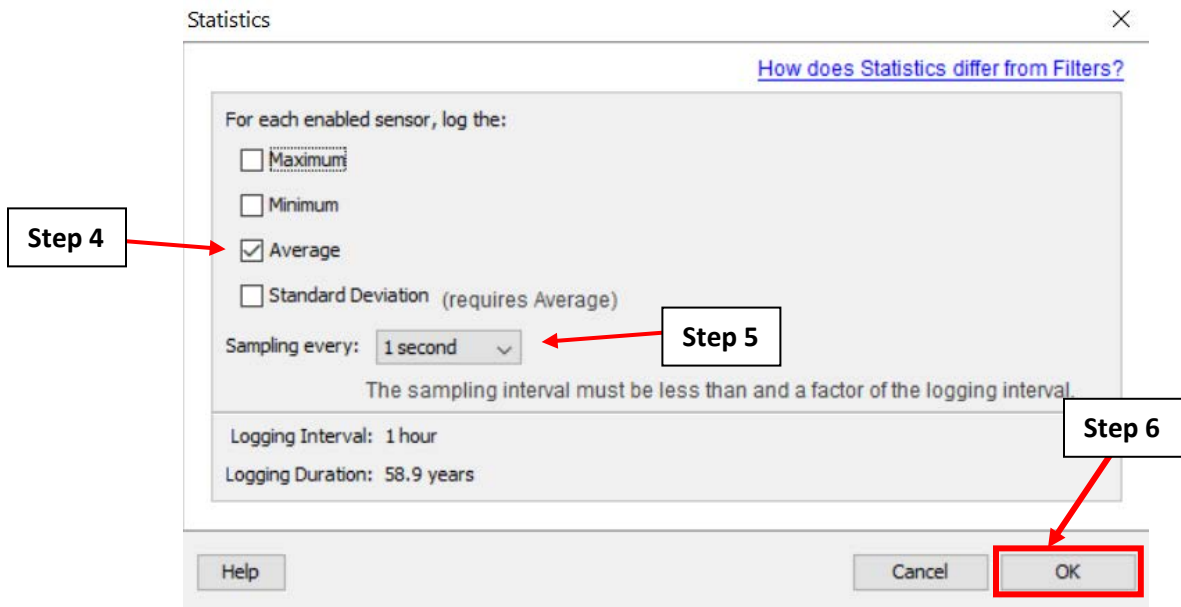


Figure A.12.7: Setting the sampling rate in the Statistics pop-up window.

7. Back on the “Launch Logger” screen (Figure A.12.8), go to the “Deployment” table. Click on the “Start Logging” dropdown menu. Select “On Date/Time” to specify the date and time that the logger will begin to collect measurements.
8. Set the date and time for the logger to begin taking measurements in the two new boxes that appear on the right.

- a. Note that if you have multiple loggers being deployed on your site, all loggers should be set to begin at the same date and time.
9. Set the “Stop Logging” option to “When memory fills”. This specifies that the data logger will stop collecting measurements when the internal memory of the logger is filled. Ensure that the “Push Button”, “Allow button restart” and “After” checkboxes are unchecked.
10. Identify if the LCD screen should remain on. If the logger will be deployed for more than one month, turn off the screen to conserve battery life.
11. Click “Delayed Start” to complete the configuration process. Do not unplug the logger from the computer until deployment is complete (shown in Figure A.12.9).
12. If the logger needs to be reconfigured, click the “Launch” button shown in Figure A.12.2 and repeat the steps in sections A.12.2 and A.12.3.

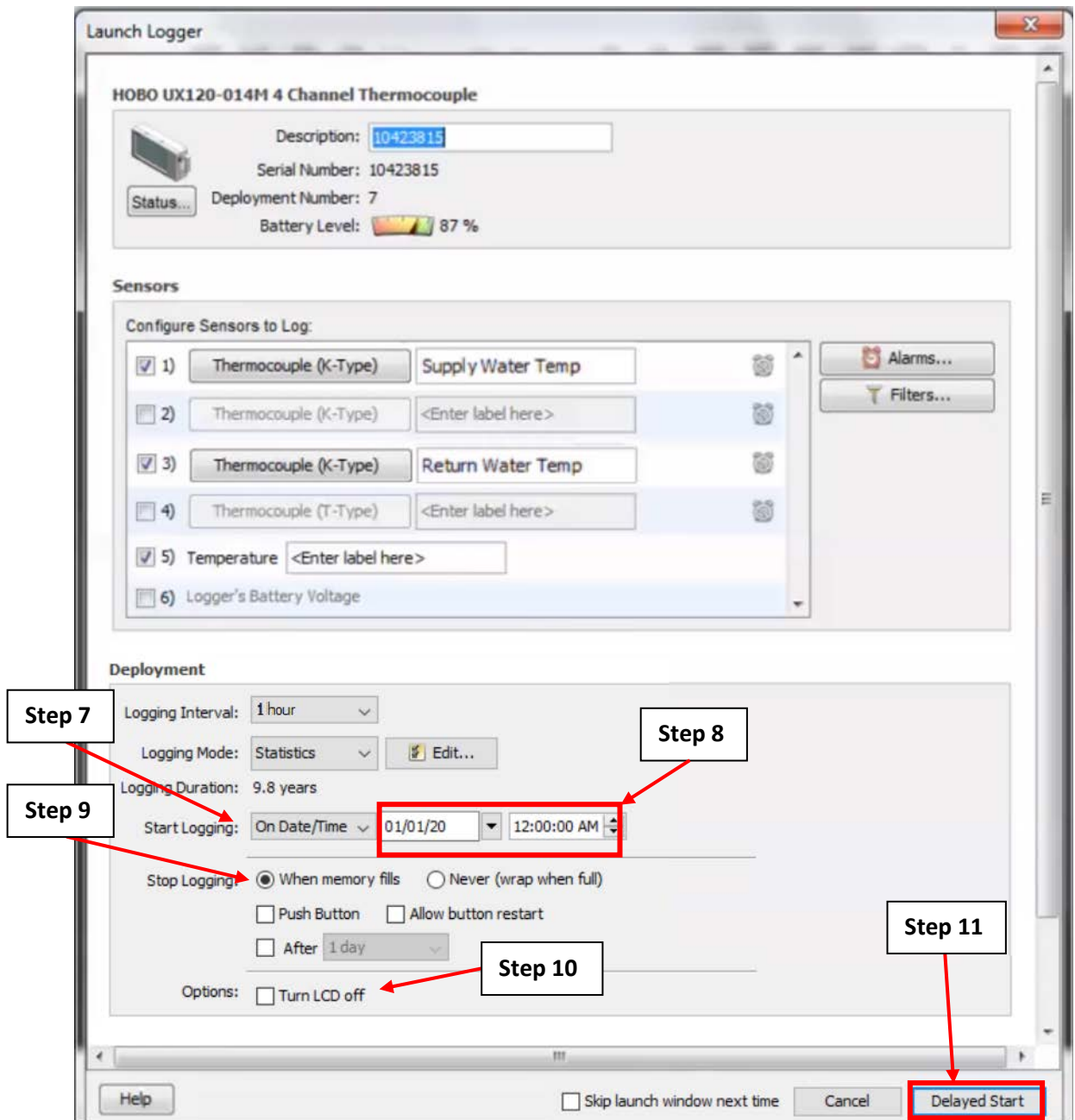


Figure A.12.8: The "Launch Logger" window with the deployment steps.

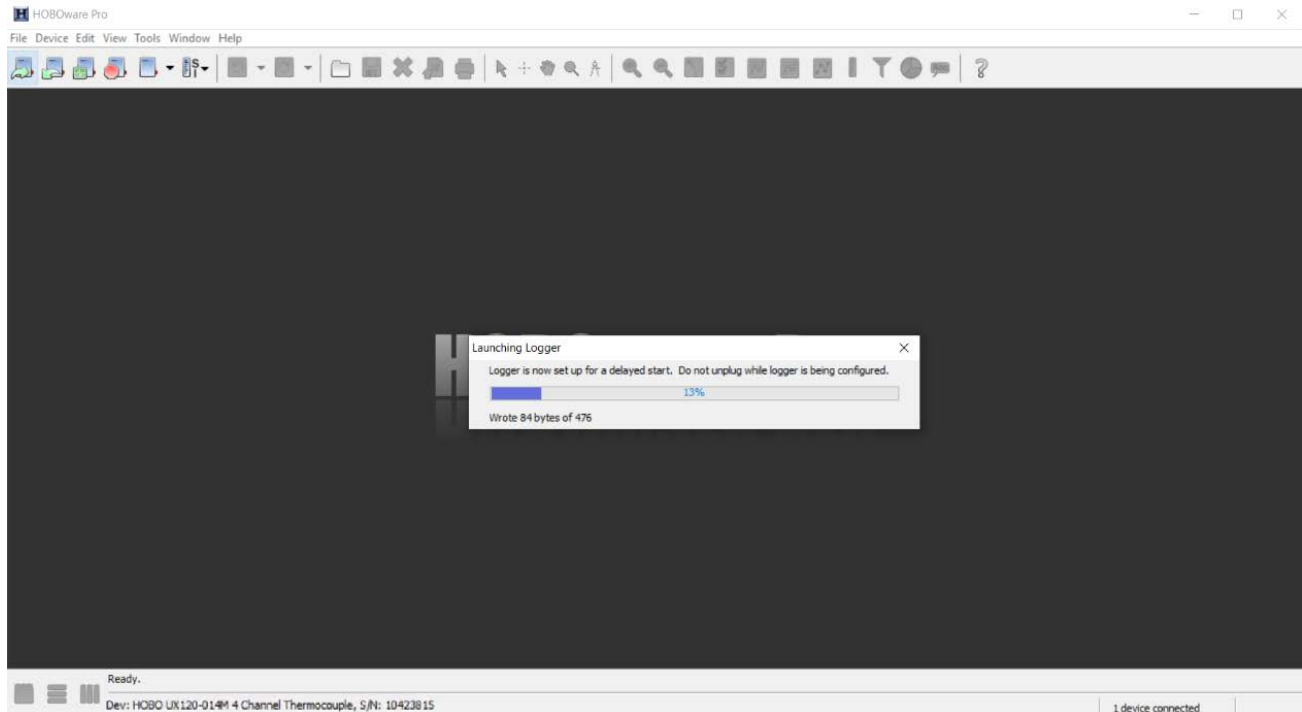


Figure A.12.9: Launching the logger using the HOBOWare software.

A.12.4: Onset HOBO 4-Channel Thermocouple Logger Field Setup

This section will guide you through the field setup of the Onset HOBO 4-Channel Thermocouple Logger. Please exercise the appropriate safety precautions while performing the field setup. Note that in order to secure the hot end of the thermocouple (the end of the thermocouple that will come in contact with the system component from which you want to take measurements from) to a surface, you must use high temperature resistant tape. Such tape is provided though the CUNY BPL FELL upon request.

1. Someone familiar with the building's system should identify the system components from which you would like to take measurements from.
2. Have the accompanying building personnel turn off the system component from which you would like to take measurements from.
3. Place the Onset HOBO 4-Channel Thermocouple Logger on a cool surface separate from the surface in which the hot end of the thermocouple will be placed. The back of the logger is magnetic, making it easy to secure to any metal surface as shown on Figure A.12.10.
4. Secure the hot end of the thermocouple onto the surface of the system component similar to what is shown on Figure A.12.10 using the high temperature resistant tape. Also see Figure A.12.11.
5. Have the building personnel turn on the system component. Field setup is complete.

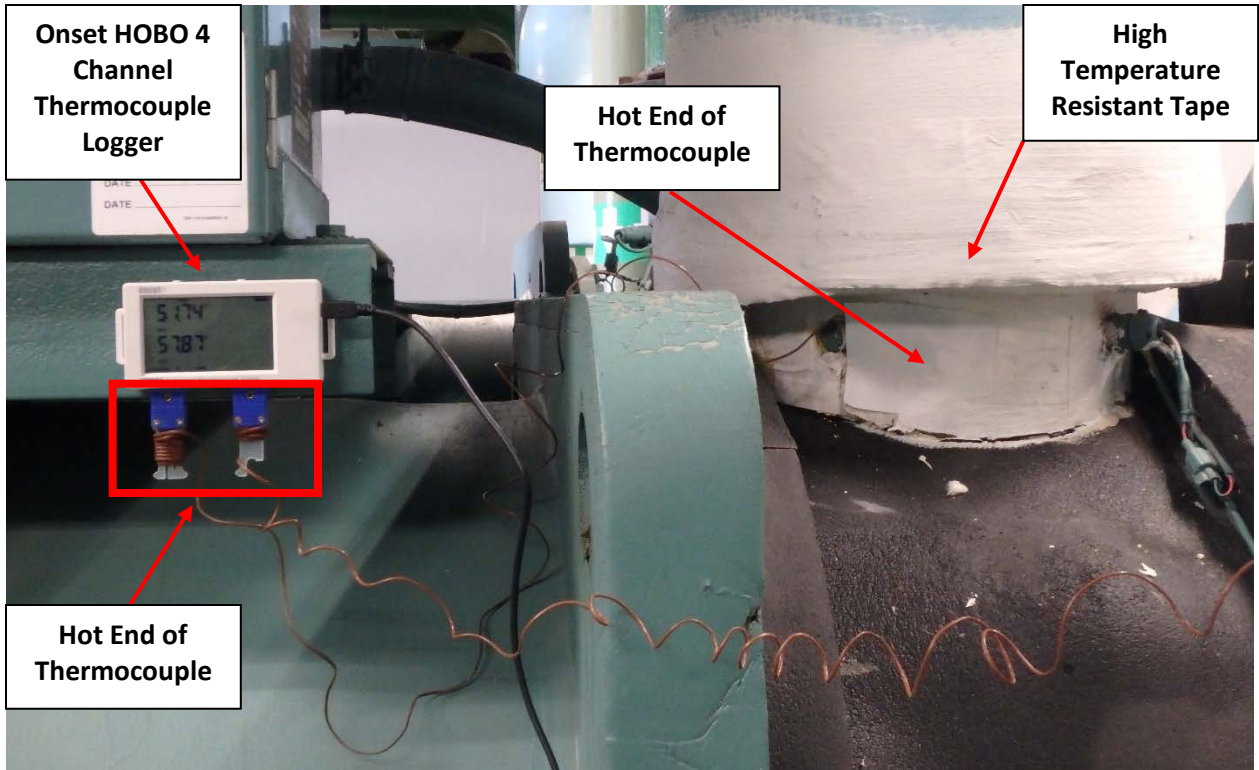


Figure A.12.10: Field setup for the Onset HOB0 4 Channel Thermocouple Logger with two type T thermocouples attached to supply and return water flow pipes.

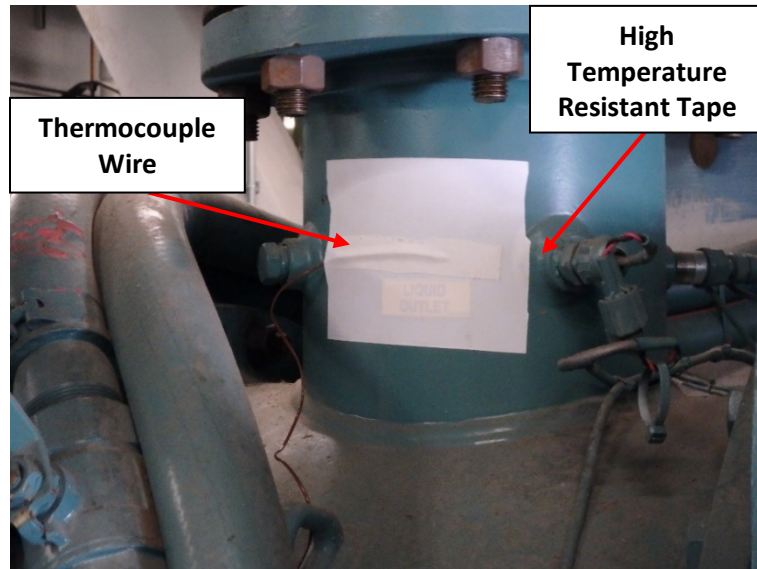


Figure A.12.11: The hot end of a thermocouple wire taped to the surface of a condenser.

A.12.5: Verification of Data Collection for the Onset HOBO 4-Channel Thermocouple Logger

It is important to verify the Onset HOBO 4-Channel Thermocouple Logger is collecting accurate data while installed on the motor. HOBOWare offers an easy way to check collected data without interfering with the initial setup from the previous sections.

2. Open the HOBOWare software on your computer.
3. Connect the USB-mini cable to the logger (Figure A.12.1). **Do not remove the thermocouple or the Onset HOBO 4-Channel Thermocouple Logger from where it was placed at the field site.**
4. Click the “Readout” button on the top left corner of the screen (Figure A.12.12).

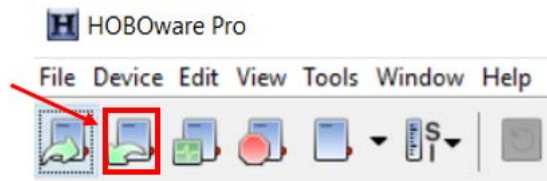


Figure A.12.12: The HOBOWare readout button.

5. The “Stop Logger” pop-up will appear (Figure A.12.13) asking if you want to stop logging. Click “Don’t Stop”.

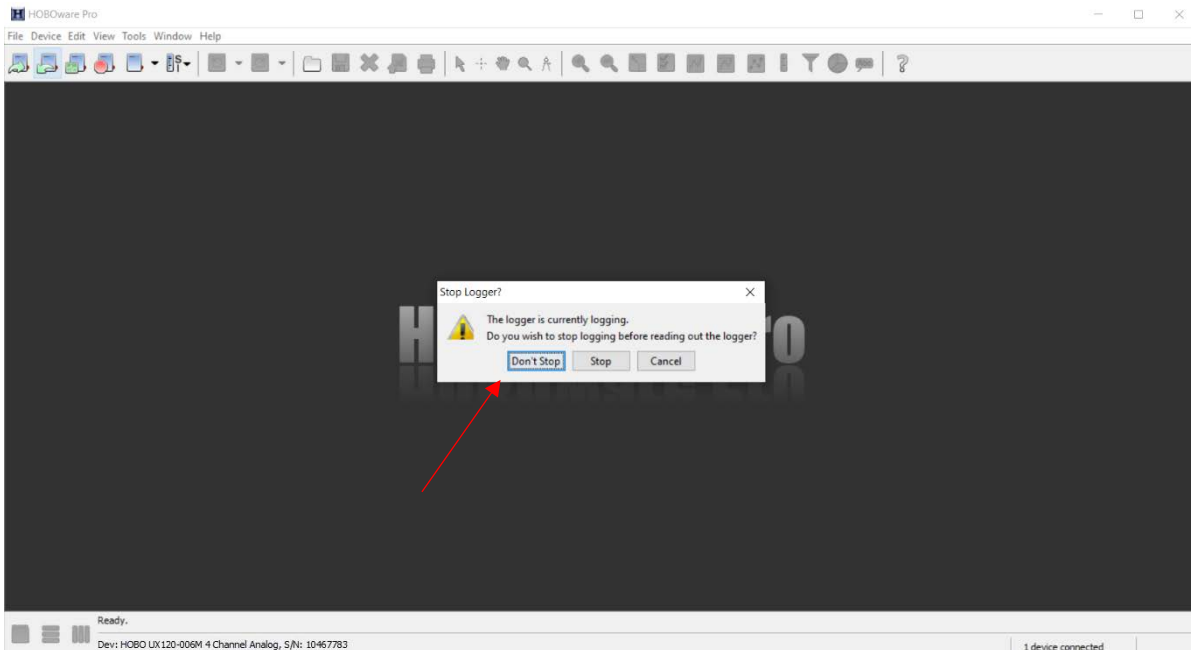


Figure A.12.13: The “Stop Logger?” pop-up window.

6. The Plot Setup window open as shown in Figure A.12.14. To set up the data series:
 - a. Name your data in the same way as in step 1 of section A.12.2.
 - b. Select the time series corresponding to the labels that were set in step 4.d of section A.12.2. Make sure to select the series with the word “Avg” in the “Measurement” column

as shown on Figure A.12.14, for example. Note that for demonstration purposes, only the average temperature data series for the “Supply Water Temp” was checked off.

- c. Deselect the three “Event Types” at the bottom of the menu.
- d. Click “Plot” to display your graph.

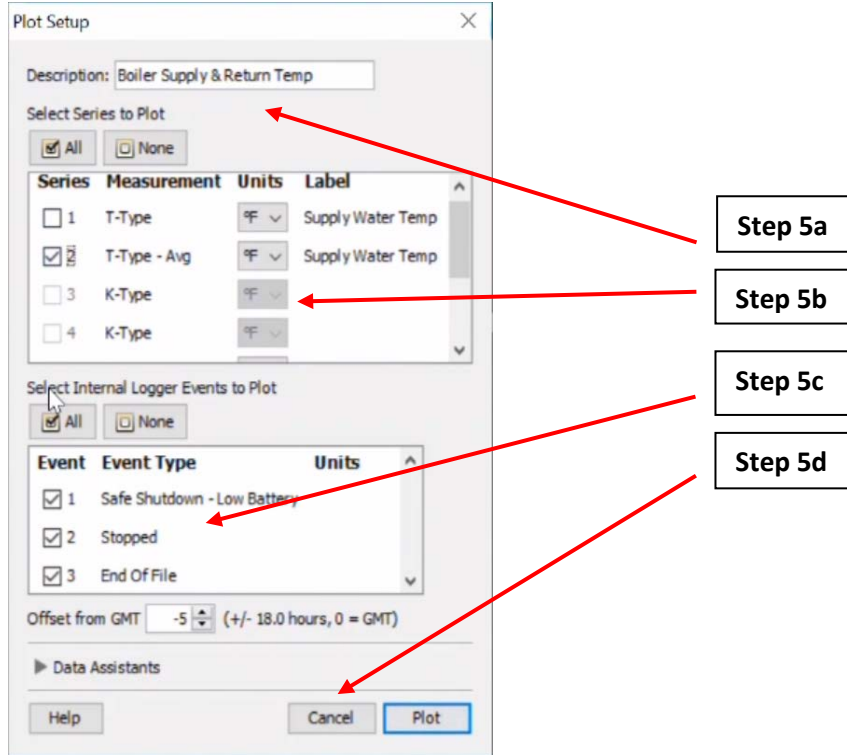


Figure A.12.14: “Plot Setup” pop-up window with the corresponding steps.

7. After following step 5, HOBOWare will open a new tab with data from the logger. Focus your attention on the “Data Table” pane at the top of the window. Here you will see:
 - a. The date and time of the logged data stored in the first column.
 - b. The temperature picked up by the hot end of the thermocouple, which on Figure A.12.15 is the “Supply Water Temp”. Note that this is just an example. Your “Data Table” will look different from the one shown on the figure.

#	Time, GMT-05:00	T-Type - Avg, °F (Supply Water Temp)	Safe Shutdown - Low Battery	Stopped	End Of File
1	12/10/18, 11:00:00 AM	167.43			
2	12/10/18, 11:15:00 AM	162.97			
3	12/10/18, 11:30:00 AM	161.47			
4	12/10/18, 11:45:00 AM	165.54			
5	12/10/18, 12:00:00 PM	162.41			
6	12/10/18, 12:15:00 PM	162.66			

Figure A.12.15: HOBOWare Data Table pane.

8. Scroll through the table and assess the collected data to ensure that the data is consistent with your expectations.

9. If the measured data is unusual or inaccurate based on your understanding of the system, then the Onset HOB0 4-Channel Thermocouple Logger may need to be recalibrated or the position of the hot end of the thermocouple(s) may need to be adjusted.

A.12.6: Exporting Data from the Onset HOB0 4-Channel Thermocouple Logger to a .csv File

After the allotted measurement period, the entire dataset can be extracted and used to calculate other parameters with respect to the M&V guide being followed.

1. At the end of the measurement period, follow the procedure in section A.12.5 to verify that the collected data is accurate.
2. If satisfied with the accuracy of the measurements, click the “Stop Logging” button on the top left corner of the screen (Figure A.12.16).

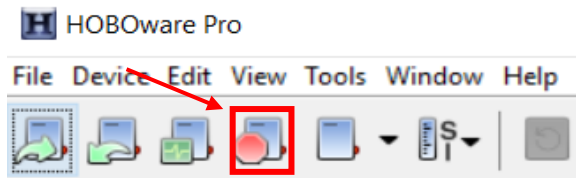


Figure A.12.16: HOB0ware “Stop Logging” Button

3. Click “File” > “Export Table Data” (Figure A.12.17).

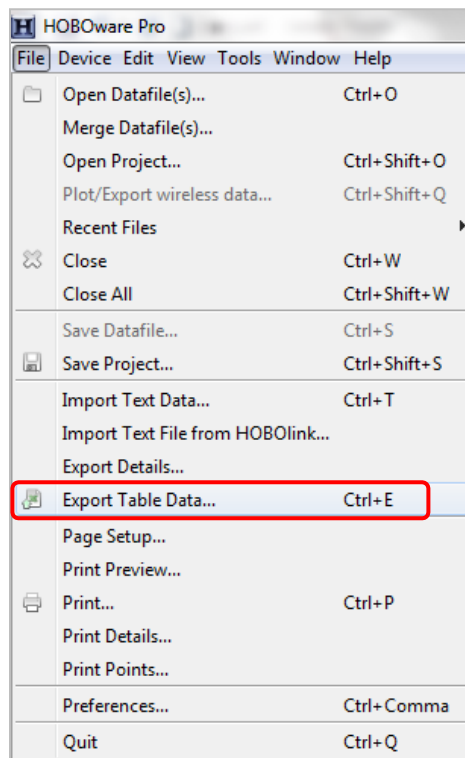


Figure A.12.17: File menu options.

4. The “Export” window will open and display the data available to export (Figure A.9.23).
5. Select “off/on” and uncheck all other boxes.
6. Click “Export...” to export the data.

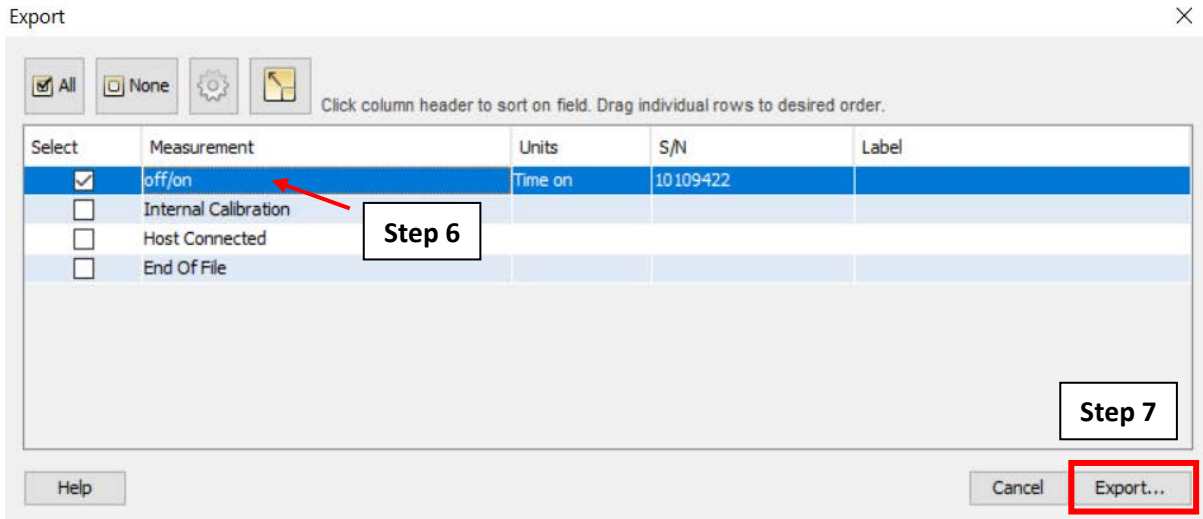


Figure A.12.18: The “Export” Window and corresponding steps.

7. Choose a location to save the file.
8. Name the file the same way as step 1 of section A.12.2.
9. Click “Save” to complete the .csv exporting process.

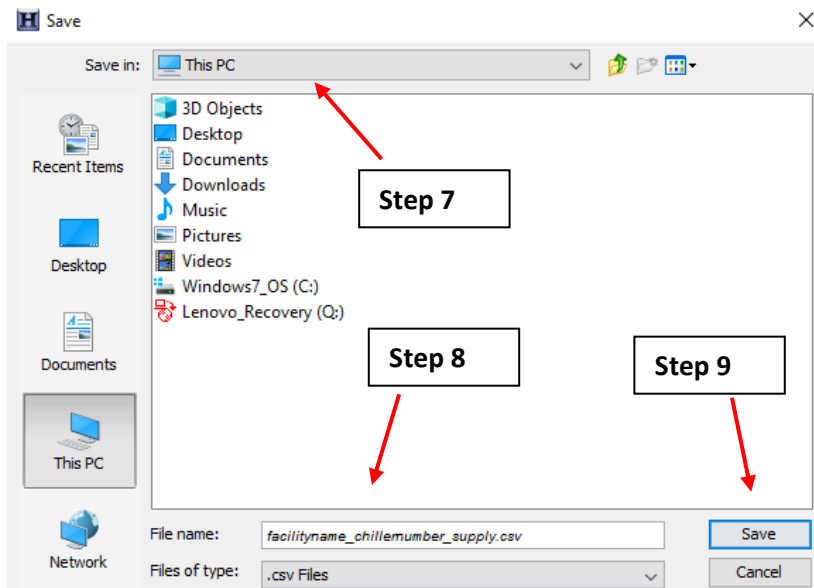


Figure A.12.19: “Save” pop-up window.

A.13: AHU Fan Calculations

Constant Speed, Constant Volume Fans Using a Motor On/Off Logger

This calculation tool is for a constant speed, constant volume system. Measured input data include spot measurements for true power and motor operational time per hour, as measured by motor on/off loggers for the supply and return fans in the AHU.

1. Convert seconds fan is on per hour to percent fan is on per hour (Worksheet: "Step 2. Percent Runtime Calcs") for supply and return fans.

$$\%FanOn_f(t_f) = \frac{On_f(t_f)}{3600} \quad (2)$$

Where,

$\%FanOn_f(t_f)$ = percent of an hour that the motor is on for either supply or return fan, f , %
 $On_f(t_f)$ = measured time that motor is on for either supply or return fan, f , in seconds

t_f = index for each measured data point for either supply or return fan, f

2. Average % hour motor is on for each hour, h , of each day of the week, d (Worksheet: "Step 3. Daily Avg Runtime Calcs").

$$\overline{\%FanOn}_{d,h,f} = \frac{\sum_{n_f=1}^{N_f(d,h)} \%FanOn_f(n_f)}{N_f(d,h)} \quad (3)$$

Where,

$\overline{\%FanOn}_{d,h,f}$ = average % time motor is on per hour for given day of week, d , and hour of day, h , for either supply or return fan, f , %

$N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of day, h , for either supply or return fan, f

$n_f \in t_f(d,h)$ = index for the subset of measured data points that fall on day of week, d , and hour of the day, h , for either supply or return fan, f

3. Find average hours per day fan is on (Worksheet: "Step 4. Results").

$$\overline{HrsOn}_{d,f} = \sum_{h=0}^{23} \overline{\%FanOn}_{d,h,f} \quad (4)$$

Where,

$\overline{HrsOn}_{d,f}$ = average hours per day for given day of week, d , for either supply or return fan, f , hours

4. Calculate energy used for full year for each fan (Worksheet: "Step 4. Results").

$$E_f = \sum_{d=1}^7 \overline{HrsOn}_{d,f} * 52 [\text{weeks per year}] * P_f \quad (5)$$

Where,

E_f = annual energy for either supply or return fan, f , kWh
 P_f = measured power for either supply or return fan, f , kW

5. Total energy used by AHU (Worksheet: "Step 4. Results").

$$E = E_{\text{supply}} + E_{\text{return}} \quad (6)$$

Where,

E = total energy usage for the AHU, kWh

Constant Speed or Two-speed, Constant Volume Fans Using a Data Logging Power Meter

This calculation tool is for a constant speed or two-speed, constant volume system. Measured input data is average hourly power draw (in kW) as measured by a data logging power meter for the supply and return fans in the AHU.

1. Average equivalent % hour motor is on full speed for each hour, h , of each day of the week, d (Worksheet: "Step 3. Avg Day of Week Calcs").

$$\bar{P}_{d,h,f} = \frac{\sum_{n_f=1}^{N_f(d,h)} P_f(t_f)}{N_f(d,h)} \quad (7)$$

Where,

$\bar{P}_{d,h,f}$ = average motor power for given day of week, d , and hour of day, h , for either supply or return fan, f , kW

$P_f(t_f)$ = measured motor power for either supply or return fan, f , kW

t_f = index for measured data points for either supply or return fan, f , datasets

$N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of day, h , for either supply or return fan, f

$n_f \in t_f(d,h)$ = index for subset of measured data points that fall on day of week, d , and hour of day, h , for either supply or return fan, f

2. Calculate energy used for full year for each fan (Worksheet: "Step 4. Results").

$$E_f = \sum_{d=1}^7 \sum_{h=1}^{24} \bar{P}_{d,h,f} * 52 [\text{weeks per year}] \quad (8)$$

Where,

E_f = annual energy for either supply or return fan, f , kWh

$\bar{P}_{d,h,f}$ = average motor power for given day of week, d , and hour of day, h , for either supply or return fan, f , kW

3. Total energy used by the AHU (Worksheet: "Step 4. Results").

$$E = E_{supply} + E_{return} \quad (9)$$

Where,

E = total energy usage for AHU, kWh

Two-speed VFD-controlled Fans OR Constant Speed, Constant Volume Fans Using a Current Transformer

This calculation tool is for VFD-controlled fans that are operated at two speeds, as well as for a constant speed, constant volume system. Measured input data include hourly average current (in Amps), as directly measured by current sensors, and spot measurements for true power at both high and low speed operation for the supply and return fans in the AHU. If the tool is used for a constant speed, constant volume system, then set the low speed input data to zeroes and enter the all the input data for high speed.

1. Convert seconds fan is on per hour to percent fan is on per hour (Worksheet: "Step 2. Percent Runtime Calcs") for supply and return fans.

$$\%FanOn_{high,f}(t_f) = \begin{cases} 100\% & \text{if } i_{high,f} * (1 + \varepsilon) < i_f(t_f) \\ \frac{i_f(t_f) - i_{low,f}}{i_{high,f} - i_{low,f}} & \text{if } i_{low,f} * (1 + \varepsilon) < i_f(t_f) < i_{high,f} * (1 - \varepsilon) \\ 0\% & \text{if } i_f(t_f) < i_{low,f} * (1 + \varepsilon) \end{cases} \quad (10)$$

$$\%FanOn_{low,f}(t_f) = \begin{cases} 100\% & \text{if } i_f(t_f) < i_{low,f} * (1 + \varepsilon) \\ 1 - \left(\frac{i_f(t_f) - i_{low,f}}{i_{high,f} - i_{low,f}} \right) & \text{if } i_{low,f} * (1 + \varepsilon) < i_f(t_f) < i_{high,f} * (1 - \varepsilon) \\ 0\% & \text{if } i_{high,f} * (1 - \varepsilon) < i_f(i) \end{cases} \quad (11)$$

Where,

$\%FanOn_{high,f}(i)$ = percent of an hour that motor is running at high speed for either supply or return fan, f , %

$\%FanOn_{low,f}(i)$ = percent of an hour that motor is running at low speed for either supply or return fan, f , %

$i_f(t_f)$ = measured current for either supply or return fan, f , Amps

t_f = index for each measured data point for either supply or return fan, f , datasets

$i_{high,f}$ = one-time measured current at high speed setpoint for either supply or return fan, f ,
Amps

$i_{low,f}$ = one-time measured current at the low-speed setpoint for either supply or return fan, f ,
Amps

ε = error tolerance to classify current as representing high-speed or low-speed operation

2. Average % hour motor is on for each hour of each day of the week (Worksheet: "Step 3. Daily Avg Runtime Calcs").

$$\overline{\%FanOn}_{s,d,h,f} = \frac{\sum_{n_f=1}^{N_f(d,h)} \%FanOn_{s,f}(n)}{N_f(d,h)} \quad (12)$$

Where,

$\overline{\%FanOn}_{s,d,h,f}$ = average % time motor is at either low speed or high speed setpoint, s , per hour
for given day of week, d , and hour of the day, h , for either supply or return fan, f , %

$N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of day, h ,
for either supply or return fan, f

$n_f \in i_f(d,h)$ = index for subset of measured data points that fall on day of week, d , and hour of
day, h , for either supply or return fan, f

3. Find the average hours per day fan is on (Worksheet: "Step 4. Results").

$$\overline{HrsOn}_{s,d,f} = \sum_{h=0}^{23} \overline{\%FanOn}_{s,d,h,f} \quad (13)$$

Where,

$\overline{HrsOn}_{s,d,f}$ = average hours at either low speed or high speed setpoint, s , per day for given day
of week, d , for either supply or return fan, f , hours

4. Calculate energy used for full year for each fan (Worksheet: "Step 4. Results").

$$E_f = \sum_{d=1}^7 (\overline{HrsOn}_{low,d,f} * P_{low,f} + \overline{HrsOn}_{high,d,f} * P_{high,f}) * 52 \text{ [weeks per year]} \quad (14)$$

Where,

E_f = annual energy for either supply or return fan, f , kWh

$P_{s,f}$ = measured power for either the low speed or high speed setpoint, s , and for either supply
or return fan, f , kW

5. Total energy used by the AHU (Worksheet: "Step 4. Results").

$$E = E_{supply} + E_{return} \quad (15)$$

Where,

E = total energy usage for the AHU, kWh

Two-speed VFD-controlled Fans Using Speed from a BAS or VFD

This calculation tool is for VFD-controlled fans that are operated at two speeds. Measured input data include hourly average motor speed (in RPM) as downloaded from a BAS or a VFD, and spot measurements for true power at both high and low speeds for supply and return fans in the AHU.

1. Convert seconds fan is on per hour to percent fan is on per hour (Worksheet: "Step 2. Percent Runtime Calcs") for supply and return fans.

$$\%FanOn_{high,f}(t_f) = \begin{cases} 100\% & \text{if } S_{high,f} * (1 + \varepsilon) < S_f(t_f) \\ \frac{S_f(t_f) - S_{low,f}}{S_{high,f} - S_{low,f}} & \text{if } S_{low,f} * (1 + \varepsilon) < S_f(t_f) < S_{high,f} * (1 - \varepsilon) \\ 0\% & \text{if } S_f(t_f) < S_{low,f} * (1 + \varepsilon) \end{cases} \quad (16)$$

$$\%FanOn_{low,f}(t_f) = \begin{cases} 100\% & \text{if } S_f(t_f) < S_{low,f} * (1 + \varepsilon) \\ 1 - \left(\frac{S_f(t_f) - S_{low,f}}{S_{high,f} - S_{low,f}} \right) & \text{if } S_{low,f} * (1 + \varepsilon) < S_f(t_f) < S_{high,f} * (1 - \varepsilon) \\ 0\% & \text{if } S_{high,f} * (1 - \varepsilon) < S_f(i) \end{cases} \quad (17)$$

Where,

$\%FanOn_{high,f}(i)$ = percent of an hour that motor is running at high speed for either supply or return fan, f , %

$\%FanOn_{low,f}(i)$ = percent of an hour that motor is running at low speed for either supply or return fan, f , %

$S_f(t_f)$ = measured speed from VFD for either supply or return fan, f , rpm

t_f = index for each measured data point for either supply or return fan, f , datasets

$S_{high,f}$ = high speed setpoint for either supply or return fan, f , rpm

$S_{low,f}$ = low speed setpoint for either supply or return fan, f , rpm

ε = error tolerance to classify current as representing high-speed or low-speed operation

2. The remaining calculations for this workbook are equations (12), (13), (14) and (15), as described in the section for the "Two-speed VFD-controlled Fans OR Constant Speed, Constant Volume Fans Using a Current Transformer" workbook.

Variable Speed, Variable Volume Fans Using Data Logging Power Meter and OAT

This calculation tool is for VFD-controlled fans that are operated at speeds proportional to the heating/cooling load as represented by proxy with OAT. Measured input data include average hourly power draw (kW) and average hourly OAT.

1. Perform second-order polynomial regression analysis of true RMS power as a function of OAT. (Worksheet: "Step 3. Regression") for supply and return fans.

$$P_f(OAT) = a * OAT^2 + b * OAT + c \quad (18)$$

Where,

P_f = average hourly true RMS power for either supply or return fan, f , kW

a, b, c = regression coefficients

OAT_f = outdoor air temperature for either supply or return fan, f

2. Average % hour motor is on for each hour of each day of the week (Worksheets: "Step 4. Schedule Calcs" and "Step 5. Daily Avg Schedule Calc").

$$On_f(t_f) = \begin{cases} 1 & \text{if } P_f(t_f) > 0 \\ 0 & \text{otherwise} \end{cases} \quad (19)$$

$$\overline{\%FanOn}_{d,h,f} = \frac{\sum_{n_f=1}^{N_f(d,h)} On_f(t_f)}{N_f(d,h)} \quad (20)$$

Where,

$P_f(t_f)$ = measured power

$On_f(t_f)$ = motor is on at time, t_f , for either supply or return fan, f , binary

$\overline{\%FanOn}_{d,h,f}$ = average % time motor is on per hour for given day of week, d , and hour of day, h , for either supply or return fan, f , %

$N_f(d, h)$ = total number of measured data points that fall on day of week, d , and hour of day, h , for either supply or return fan, f

$n_f \in t_f(d, h)$ = index for subset of measured data points that fall on day of week, d , and hour of day, h , for either supply or return fan, f

3. Total annual energy for each fan (Worksheet: "Step 6. Energy Calcs").

$$E_f = \sum_{t=1}^{8760} P_f(OAT'(t)) * \overline{\%FanOn}_{d,h,f}(t) \quad (21)$$

Where,

E_f = annual energy usage for either supply or return fan, f , kWh

$OAT'(t)$ = climate normal outdoor air temperature from National Weather Service at station closest to site, °F

4. Total energy used by AHU (Worksheet: “Step 7. Results”).

$$E = E_{supply} + E_{return} \quad (22)$$

Where,

E = total annual energy usage for AHU, kWh

A.14: Boiler Calculations

Apportion Daily Fuel Consumption

Measured input data includes motor operational time per hour and daily fuel log readings. For daily readings:

5. If using a motor runtime logger, convert seconds to hours for each hour of the measurement period for each boiler (Worksheet: “Step 2 Runtime Calcs”).

$$B_n On_{hr} = \frac{B_n On_{sec}}{3600} \quad (1)$$

Where,

$B_n On_{hr}$ = time in hours that boiler draft motor, n , is on

$B_n On_{sec}$ = time in seconds that boiler draft motor, n , is on

6. Sum the hourly runtime for all boilers (Worksheet: “Step 2 Runtime Calcs”).

$$B_{tot} On_{hr} = B_1 On_{hr} + B_2 On_{hr} + B_3 On_{hr} + \dots B_n On_{hr} \quad (2)$$

Where,

$B_{tot} On_{hr}$ = total boiler runtime for all boilers, per hour

$B_n On_{hr}$ = time in hours that boiler draft motor, n , is on

7. Calculate the number of run hours before the fuel reading is taken (Worksheet: “Step 3 Fuel Alloc”).

$$PreB_{tot} On_{xhr} = \sum_0^{n_x} B_{tot} On_{xhr} \quad (3)$$

Where,

$B_{tot} On_{xhr}$ = total boiler runtime for all boilers, per hour on x day

n_x = hour of day that fuel reading was taken on x day, with 0 = 12:00 a.m. to 12:59 a.m.

8. Calculate the number of run hours after the fuel reading is taken (Worksheet: “Step 3 Fuel Alloc”).

$$PostB_{tot} On_{xhr} = \sum_{n_x+1}^{23} B_{tot} On_{xhr} \quad (4)$$

Where,

$B_{tot} On_{xhr}$ = Total boiler runtime for all boilers, per hour on x day

$n_x + 1$ = hour after fuel reading was taken on x day

$Fuel_{xday}$ = fuel usage reading taken on x day

- Calculate the daily fuel consumption for each day (Worksheet: "Step 3 Fuel Alloc").

$$Fuel_{xtot} = \left(\left(\frac{PreB_{tot} On_{xhr}}{PreB_{tot} On_{xhr} + PostB_{x-1tot} On_{x-1hr}} \right) \times Fuel_{xday} \right) + \left(\left(\frac{PreB_{x-1tot} On_{x-1hr}}{PreB_{tot} On_{xhr} + PostB_{x-1tot} On_{x-1hr}} \right) \times Fuel_{xday} \right) \quad (5)$$

Where,

$Fuel_{xday}$ = fuel usage reading on taken on x day

$PostB_{x-1tot} On_{x-1hr}$ = total boiler runtime after fuel reading was taken on day $x - 1$ (i.e., the previous day)

$Fuel_{xday}$ = fuel usage reading on taken on x day

Estimate Annual Fuel Consumption

- Use a first order polynomial regression model to develop a relationship between daily fuel use and the measured OAT for weekdays and weekends (Worksheet: "Step 4 Fuel-OAT Regression").

$$Fuel_{Wd} = a_{Wd} * OAT_{Wd} + b_{Wd} \quad (6)$$

and

$$Fuel_{We} = a_{We} * OAT_{We} + b_{We} \quad (7)$$

Where,

$Fuel_{Wd}$ = OAT-dependent fuel use for each weekday

OAT_{Wd} = weekday-specific measured average daily OAT

$Fuel_{We}$ = OAT-dependent fuel use for each weekend day

OAT_{We} = weekend day-specific measured average OAT

a_x, b_x = regression coefficients for weekdays and weekend days

- Calculate daily weekday and weekend day fuel usage based on the NOAA CNY average daily OAT, where daily average OAT is below 65 °F (Worksheet: "Step 5 Annual Calc", "Step 6 Result").

$$Fuel_{ann} = \sum_1^{365} Fuel_{CNYWd < 65} + \sum_1^{365} Fuel_{CNYWe < 65} \quad (8)$$

Where,

$Fuel_{CNYWd < 65}$ = calculated fuel use on each weekday where the NOAA CNY daily average OAT is below 65°F

$Fuel_{CNYWe < 65}$ = calculated fuel use on each weekend day where the NOAA CNY daily average OAT is below 65 °F

A.15: Cooling Tower Fan Calculations

Constant Speed Fans Using an On/Off Logger

This calculation is for a cooling tower with constant-speed fans. Measured input data include spot measurements for true power and motor operational time per hour, as measured by motor on/off loggers on each fan in the tower.

1. Convert seconds on per hour to average energy per hour (Worksheet: "Step 2. Energy Calcs"). Repeat for all fans and then sum to get a total for the cooling tower. Note that since the data loggers cannot be perfectly synched, the time stamp for the dataset for each fan will be different. The workbook time-aligns the datasets.

$$\bar{E}_f(t) = \frac{On_f(t) * P_f}{3600} \quad (2)$$

$$\bar{E}(t) = \sum_{f=1}^F \bar{E}_f(t) \quad (3)$$

Where,

$\bar{E}_f(t)$ = average hourly fan motor energy on for each fan, f , kWh

t = time index

$On_f(t)$ = measured time that motor is on for each fan, f , seconds

P_f = one-time power measurement for each fan, f , kW

$\bar{E}(t)$ = total average energy of all fan motors, kWh

F = total number of fans

2. Wet-bulb temperature is calculated from the measured dry-bulb temperature and measured relative humidity with the following empirical equation (Worksheet: "Step 3 Wetbulb Calcs").³

$$T_{wb} = T_{db} \tan^{-1} \left[0.151977(RH + 8.313659)^{1/2} \right] + \tan^{-1}(T_{db} + RH) - \tan^{-1}(RH - 1.676331) + 0.00391838(RH)^{3/2} * \tan^{-1}(0.023101 * RH) - 4.686035 \quad (4)$$

Where,

T_{wb} = wet-bulb temperature, °C

T_{db} = dry-bulb temperature, °C

RH = relative humidity, %

³ Stull, R., "Wet-Bulb Temperature from Relative Humidity and Air Temperature", *J. of the American Meteorological Society*, Nov 2011, pp. 2267-2269.

- To model the total fan energy at different wet-bulb temperatures, a second-order polynomial regression model of total fan energy as a function wet-bulb temperature is fit (Worksheet: "Step 4 Regression").

$$E(T_{wb}) = a * T_{wb}^2 + b * T_{wb} + c \quad (5)$$

Where,

$E(T_{wb})$ = average hourly fan energy, kWh
 a, b, c = regression coefficients

- Calculate operating hours (Worksheet: "Step 5 Daily Op Hrs").

$$On(t) = \begin{cases} 1 & \text{if } \bar{E}(t) > 0 \\ 0 & \bar{E}(t) = 0 \end{cases} \quad (6)$$

$$\overline{On}_{d,h} = \begin{cases} 1 & \text{if } \bar{E}(n) > 0 \text{ for any } n \in N(d,h) \\ 0 & \end{cases} \quad (7)$$

Where,

$On(t)$ = cooling tower fans are on, binary

$\overline{On}_{d,h}$ = cooling tower is on for a given day of week, d , and hour of the day, h , binary

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$n \in N(d, h)$ = index for the subset of measured data points that fall on day of week, d , and hour of the day, h

- Calculate energy used for full year for each fan (Worksheet: "Step 6 Results").

$$E = \sum_{t=1}^{8760} \overline{On}_{d,h}(t) * CoolingSeason(t) * E(T_{wb}(t)) \quad (8)$$

Where,

E = annual energy, kWh

$CoolingSeason(t)$ = does the given hour, t , fall within the cooling season, binary

Constant Speed Fans Using a Data-Logging Power Meter

This calculation is for a cooling tower with constant-speed fans. Measured input data is average hourly power draw (in kW) as measured by a DENT power logger for each fan in the cooling tower.

- Total energy for each hour (Worksheet: "Step 2 Energy Calcs"). Since the measured power value (kW) is the average for an hour, it is equivalent to the energy for the hour (kWh).

$$\bar{E}(t) = \sum_{f=1}^F \bar{E}_f(t) \quad (9)$$

Where,

$\bar{E}_f(t)$ = average hourly fan motor energy on for each fan, f , kWh

\bar{E} = total average energy of all fan motors, kWh

F = total number of fans in the cooling tower

t = time index

2. The remainder of the workbook is the same as the on/off logger workbook, and hence uses Equations 3 through 8 to calculate the total annual energy.

Constant Speed Fans Using a Current Sensor

This calculation is for a cooling tower with constant-speed fans. Measured input data include hourly average current (in Amps) as directly measured by current sensors, and spot measurements for true power for each fan in the cooling tower.

1. Total energy for each hour (Worksheet: "Step 2 Energy Calcs"). Since the measured current (Amps) is the average for an hour, Equation 10 yields the average energy per hour (kWh) assuming voltage is constant.

$$\bar{E}_f(t) = \frac{i_f(t) * P_f}{I_f} \quad (10)$$

$$\bar{E}(t) = \sum_{f=1}^F \bar{E}_f(t) \quad (11)$$

Where,

$\bar{E}_f(t)$ = average hourly fan motor energy on for each fan, f , kWh

$i_f(t)$ = average hourly current for each fan, f , Amps

t = time index

P_f = one-time power measurement for each fan, f , kW

I_f = one-time current measurement for each fan, f , Amps

\bar{E} = total average energy of all fan motors, kWh

F = total number of fans in the cooling tower

2. The remainder of the workbook is the same as the on/off logger workbook, and hence uses Equations 3 through 8 to calculate the total annual energy.

Variable Speed Fans Using a Data-Logging Power Meter

This calculation is for a cooling tower with variable-speed fans. Measured input data is average hourly power draw (in kW) as measured by a DENT power logger for one fan in the cooling tower. It is assumed that all the remaining fans are run at the same speed.

1. Total energy for each hour (Worksheet: "Step 2 Energy Calcs"). Since the measured power value (kW) is the average for an hour, it is equivalent to the energy for the hour (kWh).

$$\bar{E}(t) = \bar{E}_1(t) * F \quad (12)$$

Where,

$\bar{E}_1(t)$ = average hourly fan motor energy for the measured fan, kWh

\bar{E} = total average energy of all fan motors, kWh

F = total number of fans in the cooling tower

t = time index

2. The remainder of the workbook is the same as the on/off logger workbook, and hence uses Equations 3 through 8 to calculate the total annual energy.

A.16: DCV Calculations

Energy Savings per AHU for constant AHU with fixed OAD position (Configuration 1) retrofitted to variable OAD position (Configuration 2):

$$\text{Energy Savings for Heating (kBtuh)} = Q_{\text{heating,before}} - Q_{\text{heating,after}}$$

Where,

$Q_{\text{heating,after}}$ = post-retrofit heating energy (kBtuh) for the constant AHU with variable OAD position is calculated using the heating season workbook of Workbook Set 1

$Q_{\text{heating,before}}$ = pre-retrofit heating energy (kBtuh) for the constant AHU with fixed OAD position is calculated using the heating season workbook of Workbook Set 1

$$\text{Energy Savings for Cooling (kWh)} = Q_{\text{cooling,before}} - Q_{\text{cooling,after}}$$

Where,

$Q_{\text{cooling,after}}$ = post-retrofit cooling energy (kWh) for the constant AHU with variable OAD position is calculated using the cooling season workbook of Workbook Set 1

$Q_{\text{cooling,before}}$ = pre-retrofit cooling energy (kWh) for the constant AHU with fixed OAD position is calculated using the cooling season workbook of Workbook Set 1

Energy Savings per AHU for constant AHU with fixed OAD position (Configuration 1) retrofitted to two-speed AHU with variable OAD position (Configuration 3):

$$\text{Energy Savings for Heating (kBtuh)} = Q_{\text{heating,before}} - Q_{\text{heating,after}}$$

Where,

$Q_{\text{heating,after}}$ = post-retrofit heating energy (kBtuh) for the two-speed AHU fans with variable OAD position is calculated using the heating season workbook of Workbook Set 2

$Q_{\text{heating,before}}$ = pre-retrofit heating energy (kBtuh) for the constant AHU with fixed OAD position is calculated using the heating season workbook of Workbook Set 1

$$\text{Energy Savings for Cooling (kWh)} = Q_{\text{cooling,before}} - Q_{\text{cooling,after}}$$

Where,

$Q_{\text{cooling,after}}$ = post-retrofit cooling energy (kWh) for the two-speed AHU fans with variable OAD position is calculated using the cooling season workbook of Workbook Set 2.

$Q_{\text{cooling,before}}$ = pre-retrofit cooling energy (kWh) for the constant AHU with fixed OAD position is calculated using the cooling season workbook of Workbook Set 1.

$$\text{Energy Savings for Fan (kWh)} = E_{\text{before}} - E_{\text{after}}$$

Where,

E_{after} = post-retrofit electrical energy (kWh) for the two-speed AHU fans using fan current data (Fan Workbook 1) or fan speed data (Fan Workbook 2)

E_{before} = pre-retrofit electrical energy (kWh) for the constant-speed AHU fans using fan motor on/off data (Fan Workbook 3) or fan power data (Fan Workbook 4).

Energy Savings per AHU for constant AHU with fixed OAD position (Configuration 1) retrofitted to continuously variable-speed AHU with variable OAD position (Configuration 4):

$$\text{Energy Savings for Heating (kBtuh)} = Q_{\text{heating,before}} - Q_{\text{heating,after}}$$

Where,

$Q_{\text{heating,after}}$ = post-retrofit heating energy (kBtuh) for the continuous variable-speed AHU fans with variable OAD position is calculated using the heating season workbook of Workbook Set 3.

$Q_{\text{heating,before}}$ = pre-retrofit heating energy (kBtuh) for the constant AHU with fixed OAD position is calculated using the heating season workbook of Workbook Set 1.

$$\text{Energy Savings for Cooling (kWh)} = Q_{\text{cooling,before}} - Q_{\text{cooling,after}}$$

Where,

$Q_{\text{cooling,after}}$ = post-retrofit cooling energy (kWh) for the continuous variable-speed AHU fans with variable OAD position is calculated using the cooling season workbook of Workbook Set 3.

$Q_{cooling,before}$ = pre-retrofit cooling energy (kWh) for the constant AHU with fixed OAD position is calculated using the cooling season workbook of Workbook Set 1.

$$Energy\ Savings\ for\ Fan\ (kWh) = E_{before} - E_{after}$$

Where,

E_{after} = post-retrofit electrical energy (kWh) for the continuous variable-speed AHU fans using fan power data (Fan Workbook 5)

E_{before} = pre-retrofit electrical energy (kWh) for the constant-speed AHU fans using fan motor on/off data (Fan Workbook 3) or fan power data (Fan Workbook 4).

Workbook Set 1: Heating Energy (Configuration 1 and 2: Constant-Speed AHU Fan with Fixed OAD position or Variable OAD position)

1. Calculate the average flow per hour delivered by the AHU supply fan; Equation 1a is used for the hourly discharge air flow if the fan runtime data are collected using the motor on/off logger; Equation 1b is used if the power is measured as a proxy of the supply fan runtime (Worksheet: "Step 2 Supply Fan Calcs").

$$\dot{V}(t) = \frac{On(t) * \dot{V}_{duct}}{3600} \quad (1a)$$

Or

$$\dot{V}(t) = \begin{cases} 100\% * \dot{V}_{duct} & \text{if } kW(t) > 0 \\ 0\% * \dot{V}_{duct} & \text{if } kW(t) = 0 \end{cases} \quad (1b)$$

Where,

$\dot{V}(t)$ = average hourly discharge air flow rate, CFM

t = time index

$On(t)$ = measured time that fan motor is on, seconds

\dot{V}_{duct} = discharge air flow rate as measured from duct transverse, CFM

$kW(t)$ = measured power draw by the supply fan motor, kW, the fan runtime is assumed to be 100% per hour if the measured power is above 0; otherwise, the supply fan is assumed to be shut down

2. Calculate the average discharge air flow rate for each day of the week and for each hour of the day (Worksheet: "Step 2.1 Avg Supply Fan Calcs").

$$\bar{\dot{V}}(d, h) = \frac{\sum_{n=1}^{N(d,h)} \dot{V}(n)}{N(d, h)} \quad (2)$$

Where,

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$n \in N(d, h)$ = index for the subset of measured data points that fall on day of week, d , and hour of the day, h

$\bar{V}(d, h)$ = average discharge air flow rate for a given day, d , and a given hour, h , on that day, CFM

3. Calculate the outdoor air damper fraction, OAF (Worksheet: "Step 3 OAF").

$$OAF(t) = \frac{(MAT(t) - RAT(t))}{(OAT(t) - RAT(t))} * 100\% \quad (3)$$

Where,

$OAF(t)$ = outdoor air fraction in % of total AHU air flow

$MAT(t)$ = measured mixed air temperature, °F

$RAT(t)$ = measured return air temperature, °F

$OAT(t)$ = measured outdoor air temperature, °F

4. Calculate the average OAF for each day of the week and for each hour of the day (Worksheet: "Step 3.1 Avg OAF"). This calculation is for characterizing the occupancy throughout a given week.

$$\overline{OAF}(d, h) = \frac{\sum_{n=1}^{N(d,h)} OAF(n)}{N(d, h)} \quad (4)$$

Where,

$\overline{OAF}(d, h)$ = average outdoor air fraction for a given day, d , and a given hour, h , on that day, %

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$n \in N(d, h)$ = index for the subset of measured data points that fall on day of week, d , and hour of the day, h

5. Calculate the average RAT and DAT for each day of the week and for each hour of the day (Worksheet: "Step 3.1 Avg OAF").

$$\overline{RAT}(d, h) = \frac{\sum_{n=1}^{N(d,h)} RAT(n)}{N(d, h)} \quad (5)$$

$$\overline{DAT}(d, h) = \frac{\sum_{n=1}^{N(d,h)} DAT(n)}{N(d, h)} \quad (6)$$

Where,

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$n \in N(d, h)$ = index for the subset of measured data points that fall on day of week, d , and hour of the day, h

$\overline{RAT}(d, h)$ = average return air temperature for a given day, d , and a given hour, h , on that day, °F

$\overline{DAT}(d, h)$ = average discharge air temperature for a given day, d , and a given hour, h , on that day, °F

6. Calculate the sensible heat rate for heating season (Worksheet: "Step 4 Annual Calcs").

$$MAT'(t) = \overline{OAF}(d, h) * (OAT_{norm}(t) - \overline{RAT}(d, h)) + \overline{RAT}(d, h) \quad (7)$$

$$Q_s(t) = 1.08 * \overline{V}(d, h) * [\overline{DAT}(d, h) - MAT'(t)] \quad (8)$$

Where,

$MAT'(t)$ = mixed air temperature based on climate normal OAT, °F

t = hourly time index for whole year

$\overline{OAF}(d, h)$ = average outdoor air fraction for a given day, d , and a given hour, h , on that day, %

$OAT_{norm}(t)$ = hourly outdoor air temperature for climate normal data at LaGuardia, °F

$\overline{RAT}(d, h)$ = average return air temperature for a given day, d , and a given hour, h , on that day, °F

$Q_s(t)$ = Sensible heat, Btu/hr

$\overline{DAT}(d, h)$ = average discharge air temperature for a given day, d , and a given hour, h , on that day, °F

1.08 = constant representing is the specific heat (Btu/lb/ °F) times the density of air (lb/ft³) times 60 minutes per hour

$\overline{V}(d, h)$ = average discharge air flow rate for a given day, d , and a given hour, h , on that day, CFM

7. Calculate the total annual energy for heating (Worksheet: "Step 5 Results").

$$Q_s = \sum_{t=1}^{8760} Q_s(t) * \frac{1 \text{ kBtu}}{1000 \text{ Btu}} * \frac{1}{\eta_{boiler}} \quad (9)$$

$$Q_{heating} = Q_s \quad (10)$$

Where,

η_{boiler} = boiler efficiency

Q_s = total annual sensible heat energy for heating, kBtuh

$Q_{heating}$ = annual heat energy for heating season, kBtuh

Workbook Set 1: Cooling Energy (Configuration 1 and 2: Constant-Speed AHU Fan with Fixed OAD position or Variable OAD position)

1. Calculate the average flow per hour delivered by the AHU supply fan; Equation 1a is used for the hourly discharge air flow if the fan runtime is measured using the motor on/off logger; Equation 1b is used if the power data are collected as a proxy of supply fan runtime (Worksheet: "Step 2 Supply Fan Calcs").
2. Calculate the average discharge air flow rate for each day of the week and for each hour of the day using Equation 2 (Worksheet: "Step 2.1 Avg Supply Fan Calcs").
3. Calculate the outdoor air fraction using Equation 3 (Worksheet: "Step 3 OAF").
4. Calculate the average OAF for each day of the week and for each hour of the day using Equation 4 (Worksheet: "Step 3.1 Avg OAF"). This calculation is to characterize the occupancy throughout a given week.
5. Calculate the average RAT and DAT for each day of the week and for each hour of the day using Equation 5 and 6 (Worksheet: "Step 3.1 Avg OAF").
6. Calculate the sensible heat rate for cooling season (Worksheet: "Step 4 Annual Calcs").

$$Q_s(t) = 1.08 * \bar{V}(d, h) * [MAT'(t) - \overline{DAT}(d, h)] \quad (11)$$

Where,

$MAT'(t)$ = mixed air temperature based on climate normal OAT, °F calculated by Equation 7

t = hourly time index for whole year

$Q_s(t)$ = Sensible heat, Btu/hr

$\overline{DAT}(d, h)$ = average discharge air temperature for a given day, d , and a given hour, h , on that day, °F

1.08 = constant representing is the specific heat (Btu/lb/ oF) times the density of air (lb/ft³) times 60 minutes per hour

$\bar{V}(d, h)$ = average discharge air flow rate for a given day, d , and a given hour, h , on that day, CFM

7. Calculate the total sensible heat energy for cooling (Worksheet: "Step 5 Results").

$$Q_s = \sum_{t=1}^{8760} Q_s(t) * \frac{1 \text{ ton}}{12000 \frac{\text{Btu}}{\text{hr}}} * \eta_{chiller} \quad (12)$$

Where,

Q_s = total annual sensible heat energy for cooling, kWh

$Q_s(t)$ = Sensible heat, Btu/hr

$\eta_{chiller}$ = electric chiller efficiency, kW/ton

8. Calculate the latent heat (Worksheet: "Step 4 Annual Calcs"). Latent heat is removed when the moisture in the mixed air condenses on the cooling coils. Hence, the change in latent heat is

proportional to the difference between the mixed air water content minus the discharge air water content (Equation 19). The water content is determined from third-order polynomial regressions of the psychrometric chart where the independent variable is dry-bulb temperature. There are six separate curves for relative humidity levels of 30%, 40%, 50%, 60%, 70%, and 80% (Table 3), and a linear interpolation is evaluated between two of the curves (Equation 13, 14, and 15) to obtain a more accurate value. The mixed air water content is determined from the outdoor air damper position, outdoor air water content, and the return air water content, which is assumed to be at a constant relative humidity of 50% (Equation 16 and 17). The discharge air water content is assumed to be at a constant relative humidity of 75% (Equation 18). Please refer to “Quantification of Energy Savings from Implementing Building Re-tuning Recommendations” (CUNY BPL, 2019) for more details on this model and its assumptions.

Table 1. Humidity ratio 3rd-order polynomial regression equations, where T is the dry-bulb temperature

RH%	Humidity Ratio (grains/lb of air)
30≤RH<40	$0.0001126T^3 - 0.0066310T^2 + 0.4050469T - 1.9071429$
40≤RH<50	$0.0001530T^3 - 0.0091548T^2 + 0.5507684T - 2.6595238$
50≤RH<60	$0.0001970T^3 - 0.0121548T^2 + 0.7163745T - 3.6595238$
60≤RH<70	$0.0002407T^3 - 0.0151310T^2 + 0.8841486T - 4.7119048$
70≤RH<80	$0.0002826T^3 - 0.0176905T^2 + 1.0265043T - 5.3857143$
80≤RH<90	$0.0003303T^3 - 0.0211429T^2 + 1.2117316T - 6.6047619$
90≤RH<100	$0.0003785T^3 - 0.0245833T^2 + 1.3932179T - 7.7880952$

$$W_{LB}(OAT_{norm}(t)) = \text{Choose from Table 3 the equation that matches the RH,} \quad (13)$$

evaluate with OAT

$$W_{UB}(OAT_{norm}(t)) = \text{Choose from Table 3 the equation in the next higher RH band,} \quad (14)$$

evaluate with OAT

$$W_{OA}(t) = W_{LB}(t) + \frac{(RH_{norm}(t) - \text{Rounddown}(RH(t)))}{10} * (W_{UB}(t) - W_{LB}(t)) \quad (15)^4$$

$$W_{RA}(t) = 0.0001970 * \overline{RAT}(d, h)^3 - 0.0121548 * \overline{RAT}(d, h)^2 + 0.7163745 * \overline{RAT}(d, h) - 3.6595238 \quad (16)$$

$$W_{MA}(t) = \overline{OAF}(d, h) * W_{OA}(t) + (1 - \overline{OAF}(d, h)) * W_{RA}(t) \quad (17)$$

$$W_{DA}(t) = 0.0003058 * \overline{DAT}(d, h)^3 - 0.0193333 * \overline{DAT}(d, h)^2 + 1.1148954 * \overline{DAT}(d, h) - 5.8928571 \quad (18)$$

⁴ In this equation, the Microsoft Excel ROUNDOWN() function rounds down the RH value to the tens value (e.g., 37.2% is rounded down to 30%).

$$Q_l(t) = 0.68 * \bar{V}(d, h) * (W_{MA}(t) - W_{DA}(t)) \quad (19)$$

Where,

$RH_{norm}(t)$ = hourly relative humidity for climate normal data at the NOAA site closest to the facility, %

$W_{LB}(t)$ = lower bound of outdoor air humidity ratio, grains/lb of air

$W_{UB}(t)$ = upper bound of outdoor air humidity ratio, grains/lb of air

$W_{OA}(t)$ = outdoor air humidity ratio, grains/lb of air

$\overline{RAT}(d, h)$ = average return air temperature for a given day, d, and a given hour, h, on that day, °F

$\overline{DAT}(d, h)$ = average discharge air temperature for a given day, d, and a given hour, h, on that day, °F

$W_{DA}(t)$ = discharge air humidity ratio, grains/lb of air

$Q_l(t)$ = change in latent heat, Btu/hr

$\bar{V}(d, h)$ = average discharge air flow rate for a given day, d, and a given hour, h, on that day, CFM

9. Calculate the total annual energy for cooling (Worksheet: "Step 5 Results").

$$Q_l = \sum_{t=1}^{8760} Q_l(t) * \frac{1 \text{ ton}}{12000 \frac{\text{Btu}}{\text{hr}}} * \eta_{chiller} \quad (20)$$

$$Q_{cooling} = Q_l + Q_s \quad (21)$$

Where,

Q_l = total annual latent heat energy for cooling, kWh

$\eta_{chiller}$ = electric chiller efficiency, $\frac{\text{kW}}{\text{ton}}$

Q_s = total annual sensible heat energy for cooling, kWh

$Q_{cooling}$ = annual heat energy for cooling season, kWh

Workbook Set 2: Heating Energy (Configuration 3: Dual-Speed AHU Fan with Variable OAD Position)

1. Calculate the runtime percent when the supply fan is on and operated at high speed using Equation 22a or Equation 22b; if the supply fan is operated at low speed, Equation 23a or 23b is used to calculate the runtime percent; Equation 22a and 23a are used if current is measured as a proxy of supply fan runtime; Equation 22b and 23b are used if fan speed is measured as a proxy of supply fan runtime (Worksheet: "Step 2 Supply Fan Calcs").

$$\%FanOn_{high,f}(t) = \begin{cases} 100\% & \text{if } I_{high,f} * (1 - \varepsilon_I) < I_f(t) \\ \frac{I_f(t) - I_{low,f}}{I_{high,f} - I_{low,f}} & \text{if } I_{low,f} * (1 + \varepsilon_I) < I_f(t) < I_{high,f} * (1 - \varepsilon_I) \\ 0\% & \text{if } I_f(t) < I_{low,f} * (1 + \varepsilon_I) \end{cases} \quad (22a)$$

Or

$$\%FanOn_{high,f}(t) = \begin{cases} 100\% & \text{if } S_{high,f} * (1 - \varepsilon_{rpm}) < S_f(t) \\ \frac{S_f(t) - S_{low,f}}{S_{high,f} - S_{low,f}} & \text{if } S_{low,f} * (1 + \varepsilon_{rpm}) < S_f(t) < S_{high,f} * (1 - \varepsilon_{rpm}) \\ 0\% & \text{if } S_f(t) < S_{low,f} * (1 + \varepsilon_{rpm}) \end{cases} \quad (22b)$$

$$\%FanOn_{low,f}(t) = \begin{cases} \frac{I_f(t)}{I_{low,f}} & \text{if } I_f(t) < I_{low,f} * (1 - \varepsilon_I) \\ 100\% & \text{if } I_{low,f} * (1 - \varepsilon_I) < I_f(t) < I_{low,f} * (1 + \varepsilon_I) \\ 1 - \left(\frac{I_f(t) - I_{low,f}}{I_{high,f} - I_{low,f}} \right) & \text{if } I_{low,f} * (1 + \varepsilon_I) < I_f(t) < I_{high,f} * (1 - \varepsilon_I) \\ 0\% & \text{if } I_{high,f} * (1 - \varepsilon_I) < I_f(t) \end{cases} \quad (23a)$$

Or

$$\%FanOn_{low,f}(t) = \begin{cases} \frac{S_f(t)}{S_{low,f}} & \text{if } S_f(t) < S_{low,f} * (1 - \varepsilon_{rpm}) \\ 100\% & \text{if } S_{low,f} * (1 - \varepsilon_{rpm}) < S_f(t) < S_{low,f} * (1 + \varepsilon_{rpm}) \\ 1 - \left(\frac{S_f(t) - S_{low,f}}{S_{high,f} - S_{low,f}} \right) & \text{if } S_{low,f} * (1 + \varepsilon_{rpm}) < S_f(t) < S_{high,f} * (1 - \varepsilon_{rpm}) \\ 0\% & \text{if } S_{high,f} * (1 - \varepsilon_{rpm}) < S_f(t) \end{cases} \quad (23b)$$

Where,

$\%FanOn_{high,f}(t)$ = percent of an hour that supply fan is running at high speed, f, %

$\%FanOn_{low,f}(t)$ = percent of an hour that supply fan is running at low speed, f, %

$I_f(t)$ = measured current for supply fans, Amps

$S_f(t)$ = measured speed from VFD for supply fans, rpm

$I_{high,f}$ = high-speed setpoint for supply fans, Amps

$I_{low,f}$ = low-speed setpoint for supply fans, Amps

t = time index for each measured data point for supply fans

$S_{high,f}$ = high-speed setpoint for supply fans, rpm

$S_{low,f}$ = low-speed setpoint for supply fans, rpm

ε_I = error tolerance to classify current as representing high-speed or low-speed operation

ε_{rpm} = error tolerance to classify fan speed as representing high-speed or low-speed operation

2. Calculate average hourly discharge air flow (Worksheet: “Step 2 Supply Fan Calcs”).

$$\dot{V}_{high}(t) = \%FanOn_{high,f}(t) * \dot{V}_{duct,high} \quad (24)$$

$$\dot{V}_{high,hourly}(t) = \dot{V}_{high}(t) * 60 \frac{min}{hour} \quad (25)$$

$$\dot{V}_{low}(t) = \%FanOn_{low,f}(t) * \dot{V}_{duct,low} \quad (26)$$

$$\dot{V}_{low,hourly}(t) = \dot{V}_{low}(t) * 60 \frac{min}{hour} \quad (27)$$

$$\dot{V}(t) = \dot{V}_{high}(t) + \dot{V}_{low}(t) \quad (28)$$

Where,

$\dot{V}_{high}(t)$ = average hourly discharge air flow rate at the high speed, CFM

$\%FanOn_{high,f}(t)$ = percent of an hour that motor is running at high speed for supply fans, %

$\dot{V}_{duct,high}$ = measured discharge air flow rate at the high speed, CFM

$\dot{V}_{high,hourly}(t)$ = average hourly discharge air flow rate at the high speed, $\frac{ft^3}{hr}$

$\dot{V}_{low}(t)$ = average hourly discharge air flow rate at the low speed, CFM

$\%FanOn_{low,f}(t)$ = percent of an hour that motor is running at low speed for supply fans, %

$\dot{V}_{duct,low}$ = measured discharge air flow rate at the low speed, CFM

$\dot{V}_{low,hourly}(t)$ = average hourly discharge air flow rate at the low speed, $\frac{ft^3}{hr}$

$\dot{V}(t)$ = average hourly discharge air flow rate, CFM

t = time index for each measured data point for supply fans

3. Calculate the average discharge air flow rate for each day of the week and for each hour of the day (Worksheet: “Step 2.1 Avg Supply Fan Calcs”).

$$\bar{\dot{V}}(d, h) = \frac{\sum_{t=1}^{N(d,h)} \dot{V}(t)}{N(d, h)} \quad (29)$$

Where,

$N(d, h)$ = total number of measured data points that fall on day of week, d, and hour of the day, h

$t \in N(d, h)$ = time index for the subset of measured data points that fall on day of week, d, and hour of the day, h

$\bar{\dot{V}}(d, h)$ = average discharge air flow rate for a given day, d, and a given hour, h, on that day, CFM

4. Calculate the outdoor air fraction using Equation 3 (Worksheet: "Step 3 OAF & OA Air Flow").
5. Calculate the hourly outdoor air flow delivered by the AHU supply fans (Worksheet: "Step 3 OAF & OA Air Flow").

$$\dot{V}_{high,OA}(t) = \dot{V}_{high,hourly}(t) * OAF(t) \quad (30)$$

$$\dot{V}_{low,OA}(t) = \dot{V}_{low,hourly}(t) * OAF(t) \quad (31)$$

Where,

$\dot{V}_{high,OA}(t)$ = outdoor air flow delivered by the supply fan operated at high speed for a given day, d , and a given hour, h , on that day, $\frac{ft^3}{hr}$

$\dot{V}_{low,OA}(t)$ = outdoor air flow delivered by the supply fan operated at low speed for a given day, d , and a given hour, h , on that day, $\frac{ft^3}{hr}$

$OAF(t)$ = outdoor air fraction in % of total AHU air flow

6. Calculate average OAF for each day of the week and for each hour of the day using Equation 4 (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").
7. Calculate average hourly outdoor air flow for each day of the week and for each hour of the day (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").

$$\overline{\dot{V}_{high,OA}}(d, h) = \frac{\sum_{t=1}^{N(d,h)} \dot{V}_{high,OA}(t)}{N(d, h)} \quad (32)$$

$$\overline{\dot{V}_{low,OA}}(d, h) = \frac{\sum_{t=1}^{N(d,h)} \dot{V}_{low,OA}(t)}{N(d, h)} \quad (33)$$

Where,

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$t \in N(d, h)$ = time index for the subset of measured data points that fall on day of week, d , and hour of the day, h

$\overline{\dot{V}_{low,OA}}(d, h)$ = average discharge air flow delivered by the supply fan operated at low speed for a given day, d , and a given hour, h , on that day, $\frac{ft^3}{hr}$

$\overline{\dot{V}_{high,OA}}(d, h)$ = average discharge air flow delivered by the supply fan operated at high speed for a given day, d , and a given hour, h , on that day, $\frac{ft^3}{hr}$

8. Calculate the average RAT and DAT for each day of the week and for each hour of the day using Equation 5 and 6 (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").
9. Calculate sensible heat rate for heating season using Equation 7 and 8 (Worksheet: "Step 4 Annual Calcs").

- Calculate total annual energy (kBtuh) for heating using Equation 9 and 10 (Worksheet: “Step 5 Results”).

Workbook Set 2: Cooling Energy (Configuration 3: Dual-Speed AHU Fan with Variable OAD position)

- Calculate the runtime percent when the supply fan is on and operated at high speed using Equation 22a or Equation 22b; if the supply fan is operated at low speed, Equation 23a or 23b is used to calculate the runtime percent; Equation 22a and 23a are used if current is measured as a proxy of supply fan runtime; Equation 22b and 23b are used if fan speed is measured as a proxy of supply fan runtime (Worksheet: “Step 2 Supply Fan Calcs”).
- Calculate the average hourly discharge air flow in CFM operated at high speed using Equation 24 to 28 (Worksheet: “Step 2 Supply Fan Calcs”).
- Calculate the average discharge air flow rate for each day of the week and for each hour of the day using Equation 29 (Worksheet: “Step 2.1 Avg Supply Fan Calcs”).
- Calculate the outdoor air fraction using Equation 3 (Worksheet: “Step 3 OAF & OA Air Flow”).
- Calculate the hourly outdoor air flow delivered by the AHU supply fan using Equation 30 and 31 (Worksheet: “Step 3 OAF & OA Air Flow”).
- Calculate average OAF for each day of the week and for each hour of the day using Equation 4 (Worksheet: “Step 3.1 Avg OAF & OA Air Flow”).
- Calculate average hourly outdoor air flow for each day of the week and for each hour of the day using Equation 32 and 33 (Worksheet: “Step 3.1 Avg OAF & OA Air Flow”).
- Calculate the average RAT and DAT for each day of the week and for each hour of the day using Equation 5 and 6 (Worksheet: “Step 3.1 Avg OAF & OA Air Flow”).
- Calculate sensible heat rate for cooling season using Equation 11 (Worksheet: “Step 4 Annual Calcs”).
- Calculate total sensible heat (kWh) for cooling season using Equation 12 (Worksheet: “Step 5 Results”).
- Calculate latent heat rate for cooling season using Equation 13 to 19 (Worksheet: “Step 4 Annual Calcs”).
- Calculate total latent heat (kWh) for cooling season using Equation 20 (Worksheet: “Step 5 Results”).
- Calculate total annual energy (kWh) for cooling using Equation 21 (Worksheet: “Step 5 Results”).

Workbook Set 3: Heating Energy (Configuration 4: Continuously Variable-Speed AHU Fan with Variable OAD position)

- Calculate hourly discharge air flow (Worksheet: “Step 2 Supply Fan Calcs”).

$$\dot{V}(t) = \frac{kW_f(t)^{\frac{1}{2.5}}}{kW_{max,f}} * \dot{V}_{duct} \quad (34)$$

$$\dot{V}_{hourly}(t) = \dot{V}(t) * 60 \frac{min}{hour} \quad (35)$$

Where,

$\dot{V}(t)$ = hourly discharge air flow rate, CFM

$kW_f(t)$ = measured power for supply fans, kW

t = time index for each measured data point for supply fans

$kW_{max,f}$ = power reading for supply fans measured at the maximum speed, kW

\dot{V}_{duct} = AHU air flow rate as measured from duct transverse, CFM

$\dot{V}_{hourly}(t)$ = hourly discharge air flow rate, $\frac{ft^3}{hr}$

2. Calculate the average discharge air flow rate for each day of the week and for each hour of the day (Worksheet: "Step 2.1 Avg Supply Fan Calcs").

$$\bar{\dot{V}}(d, h) = \frac{\sum_{t=1}^{N(d,h)} \dot{V}(t)}{N(d, h)} \quad (36)$$

Where,

$N(d, h)$ = total number of measured data points that fall on day of week, d, and hour of the day, h

$t \in N(d, h)$ = time index for the subset of measured data points that fall on day of week, d, and hour of the day, h

$\bar{\dot{V}}(d, h)$ = average discharge air flow rate for a given day, d, and a given hour, h, on that day, CFM

3. Calculate the outdoor air fraction using Equation 3 (Worksheet: "Step 3 OAF & OA Air Flow").
4. Calculate the hourly outdoor air flow delivered by the AHU supply fans (Worksheet: "Step 3 OAF & OA Air Flow").

$$\dot{V}_{OA}(t) = \dot{V}_{hourly}(t) * OAF(t) \quad (37)$$

Where,

$\dot{V}_{OA}(t)$ = the amount of outdoor air delivered by the AHU supply fans per hour, $\frac{ft^3}{hr}$

$\dot{V}_{hourly}(t)$ = the hourly discharge air flow rate, $\frac{ft^3}{hr}$

$OAF(t)$ = the outdoor air fraction, %

5. Calculate average OAF for each day of the week and for each hour of the day using Equation 4 (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").
6. Calculate the average hourly outdoor air flow delivered by the AHU supply fans (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").

$$\bar{V}_{OA}(d, h) = \frac{\sum_{t=1}^{N(d,h)} \dot{V}_{OA}(t)}{N(d, h)} \quad (38)$$

Where,

$\bar{V}_{OA}(d, h)$ = average discharge outdoor air flow rate for a given day, d , and a given hour, h , on that day, $\frac{ft^3}{hr}$

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$t \in N(d, h)$ = time index for the subset of measured data points that fall on day of week, d , and hour of the day, h

7. Calculate the average RAT and DAT for each day of the week and for each hour of the day using Equation 5 and 6 (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").
8. Calculate sensible heat rate for heating season using Equation 7 and 8 (Worksheet: "Step 4 Annual Calcs").
9. Calculate total annual energy (kBtuh) for heating using Equation 9 and 10 (Worksheet: "Step 5 Results").

Workbook Set 3: Cooling Energy (Configuration 4: Continuously Variable-Speed AHU Fan with Variable OAD position)

1. Calculate the average hourly discharge air flow using Equation 34 and 35 (Worksheet: "Step 2 Supply Fan Calcs").
2. Calculate the average discharge air flow rate for each day of the week and for each hour of the day using Equation 36 (Worksheet: "Step 2.1 Avg Supply Fan Calcs").
3. Calculate the outdoor air fraction using Equation 3 (Worksheet: "Step 3 OAF & OA Air Flow").
4. Calculate the hourly outdoor air flow delivered by the AHU supply fans (Worksheet: "Step 3 OAF & OA Air Flow") using Equation 37.
5. Calculate average outdoor air fraction for each day of the week and for each hour of the day using Equation 4 (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").
6. Calculate average hourly outdoor air flow delivered by the AHU supply fans for each day of the week and for each hour of the day using Equation 38 (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").
7. Calculate the average RAT and DAT for each day of the week and for each hour of the day using Equation 5 and 6 (Worksheet: "Step 3.1 Avg OAF & OA Air Flow").
8. Calculate sensible heat rate for cooling season using Equation 11 (Worksheet: "Step 4 Annual Calcs").
9. Calculate total sensible heat (kWh) for cooling season using Equation 12 (Worksheet: "Step 5 Results").
10. Calculate latent heat rate for cooling season using Equation 13 to 19 (Worksheet: "Step 4 Annual Calcs").

11. Calculate total latent heat (kWh) for cooling season using Equation 20 (Worksheet: “Step 5 Results”).
12. Calculate total annual energy (kWh) for cooling using Equation 21 (Worksheet: “Step 5 Results”).

A.17: Air-Cooled Chiller Calculations

1. Convert raw temperature values of the chilled water (return and supply) and OAT from Fahrenheit to Rankine scale (Worksheet: “Step 2. Aggregate Data”).

$$^{\circ}Ra = ^{\circ}F + 459.67 \quad (2)$$

Where,

$^{\circ}Ra$ = Temperature value in Rankine, $^{\circ}Ra$
 $^{\circ}F$ = Temperature value in Fahrenheit, $^{\circ}F$

2. Find the difference between the chilled water temperatures (Worksheet: “Step 2. Aggregate Data”).

$$\Delta T (^{\circ}Ra) = (T_{chwST} (^{\circ}Ra) - T_{chwRT} (^{\circ}Ra)) \quad (3)$$

Where,

ΔT = chilled water temperature difference, $^{\circ}Ra$
 T_{chwST} = chilled water supply temperature, $^{\circ}Ra$
 T_{chwRT} = chilled water return temperature, $^{\circ}Ra$

3. Calculate the thermal load based on the temperature difference (“Worksheet: “Step 2. Aggregate Data”).

$$Q_{evap} \left(\frac{Btu}{hr} \right) = cp_{water} \left(\frac{Btu}{lbm \cdot ^{\circ}Ra} \right) * \rho_{water} \left(\frac{lbm}{gal} \right) * q_{evap} (GPM) * 60 \left(\frac{min}{hr} \right) * (\Delta T (^{\circ}Ra)) \quad (4)$$

Where,

Q_{evap} = thermal load of the evaporator, Btu/hr
 cp_{water} = specific heat of water = 1.000 Btu/lbm* $^{\circ}Ra$
 ρ_{water} = density of water = 8.342 lbm/gal
 q_{evap} = average flow rate of chilled water, gpm
 ΔT = chilled water temperature difference, $^{\circ}Ra$

4. Determine empirical COP based on measured data (Worksheet: “Step 2. Aggregate Data”).

$$COP = \frac{Q_{evap} \left(\frac{Btu}{hr} \right)}{P \left(\frac{Btu}{hr} \right)} \quad (5)$$

Where,

COP = coefficient of performance

Q_{evap} = thermal load of the evaporator, Btu/hr

P = energy consumption of chiller, Btu/hr

5. Use a second order polynomial regression model to develop a relationship between chilled water supply temperature and the measured OAT. Repeat with thermal load of the evaporator (Worksheet: "Step 3. Variable Regression").

$$T_{chwST}(OA(t)) = a_{chwST} * OAT^2 + b_{chwST} * OAT + c_{chwST} \quad (6)$$

$$Q_{evap}(OA(t)) = a_Q * OAT^2 + b_Q * OAT + c_Q \quad (7)$$

Where,

T_{chwST} = chilled water supply temperature, °Ra

Q_{evap} = thermal load of the evaporator, Btu/hr

a, b, c = respective regression coefficients

$OAT(t)$ = measured outdoor air temperature, °Ra

6. Fitting the COP model (Worksheet: "Step 4. COP Regression"). This model, developed by Gordon-Ng (2000), is a semi-empirical representation of the entropy changes in a chiller⁵. Wei and Reddy (2003) recommended an alternative linear regression technique to fit their model, which is employed here using the "LINEST" function in MS Excel⁶.

$$\left(\frac{1}{COP} + 1 \right) \frac{T_{chwST}}{OAT} - 1 = a_0 \frac{T_{chwST}}{Q_{evap}} + a_1 \frac{(OAT - T_{chwST})}{OAT * Q_{evap}} + a_2 \frac{\left(\frac{1}{COP} + 1 \right) Q_{evap}}{OAT} \quad (8)$$

OR

⁵ Gordon, J.M., & Ng, K.C. (2000). Cool thermodynamics: The engineering and physics of predictive, diagnostic and optimization methods for cooling systems. (pp. 159-177)

⁶ Wei, J., & Reddy, T.A. (2003). Reevaluation of the Gordon-Ng Performance Models for Water-Cooled Chillers.

$$y = a_0x_0 + a_1x_1 + a_2x_2 \quad (9)$$

Where,

$a_0 = \Delta S$ = total internal entropy production rate in the chiller due to internal irreversibility's

$a_1 = Q_{leak}$ = rate of heat losses (or gains) from (or into) the chiller

$a_2 = R$ = total heat exchanger thermal resistance, which represent irreversibility due to finite-rate heat exchange

The coefficients x_0 , x_1 , x_2 , and y can be rearranged:

$$x_0 = \frac{T_{chwST}}{Q_{evap}} \quad (10)$$

$$x_1 = \frac{OAT - T_{chwST}}{OAT * Q_{evap}} \quad (11)$$

$$x_2 = -\frac{\left(\frac{1}{COP} + 1\right) * Q_{evap}}{OAT} \quad (12)$$

$$y = \left(\frac{1}{COP} + 1\right) \frac{T_{chwST}}{OAT} - 1 \quad (13)$$

7. Calculate predicted COP for the raw dataset (Worksheet: "Step 4.1. COP Model Verification").

$$COP(Q_{evap}) = \frac{1}{-1 + \frac{(1 + a_0x_0 + a_1x_1)}{\frac{T_{chwST}}{OAT} - a_3 \frac{Q_{evap}}{OAT}}} \quad (14)$$

8. Average percent operational time per hour for each hour of each day of the week (Worksheets: "Step 5. Daily Schedule" and "Step 5.1. Avg Daily Schedule").

$$On(t) = \begin{cases} 1 & \text{if } P(t) > 0 \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

$$\overline{\%ChlrOn}_{d,h} = \frac{\sum_{n=1}^{N(d,h)} On(t)}{N(d,h)} \quad (16)$$

Where,

$P(t)$ = measured power, kW

$On(t)$ = motor is on at time, t , binary

$\overline{\%ChlrOn}_{d,h}$ = average % time chiller is on per hour for given day of week, d , and hour of the day, h , %

$N_f(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$n \in t(d, h)$ = index for subset of measured data points that fall on day of week, d , and hour of the day, h

9. Using the variable coefficients found in Step 5, calculate the chilled water supply temperature with respect to NOAA CNY OAT. Repeat with thermal load of the evaporator (Worksheet: "Step 6. Annual Energy").

$$T_{chwST}(OAT'(t)) = a_{chwST} * OAT'^2 + b_{chwST} * OAT' + c_{chwST} \quad (17)$$

$$Q_{evap}(OAT'(t)) = a_Q * OAT'^2 + b_Q * OAT' + c_Q \quad (18)$$

Where,

$OAT'(t)$ = Climate normal outdoor air temperature from National Weather Service at station closest to site, °F

10. Calculate x_0 and x_1 with respect to the NOAA CNY temperature parameters found in Step 9 (Worksheet: "Step 6. Annual Energy").

$$x_0 = \frac{T_{chwST}(OAT'(t))}{Q_{evap}(OAT'(t))} \quad (19)$$

$$x_1 = \frac{OAT'(t) - T_{chwST}(OAT'(t))}{OAT'(t) * Q_{evap}(OAT'(t))} \quad (20)$$

11. Calculate predicted COP with respect to NOAA CNY temperature data (Worksheet: "Step 6. Annual Energy").

$$COP(Q_{evap}) = \frac{1}{-1 + \frac{(1 + a_0x_0 + a_1x_1)}{\frac{T_{chwST}(OAT'(t))}{OAT'(t)} - a_3 \frac{Q_{evap}(OAT'(t))}{OAT'(t)}}} \quad (21)$$

12. Estimate annual energy consumption (Worksheet: “Step 6. Annual Energy”).

$$E = \sum_{i=1}^{8760} \frac{Q_{evap}(OAT'(t))}{COP(Q_{evap})} * \overline{\%FanOn}_{d,h}(t) * \frac{1}{3412.192} \left(\frac{BTU}{kWh} \right) \quad (22)$$

Where,

E = estimated annual energy usage for the chiller, kWh

COP = predicted coefficient of performance

Q_{evap} = thermal load of the evaporator, Btu/hr

$OAT'(t)$ = climate normal outside air temperature from National Weather Service at station closest to site, °F

A.18: Secondary Chilled Water Pump Calculations

Constant Speed, Constant Volume Pumps Using Motor On/-Off Loggers

This calculation tool is for a constant speed, constant volume system. Measured input data include spot measurements for true power and motor operational time per hour, as measured by motor on/off loggers.

4. Convert seconds on per hour to percent on per hour (Worksheet: “Step 2. Percent Runtime Calcs”).

$$\%On(t) = \frac{On(t)}{3600} \quad (2)$$

Where,

$\%On(t)$ = percent of an hour that the pump motor is on, %

$On(t)$ = measured time that pump motor is on, seconds

t = index for each measured data point

2. Average % hour motor is on for each hour of each day of the week (Worksheet: “Step 3. Daily Avg Runtime Calcs”).

$$\overline{\%On}_{d,h} = \frac{\sum_{n=1}^{N(d,h)} \%On(n)}{N(d,h)} \quad (3)$$

Where,

$\overline{\%On}_{d,h}$ = average % time motor is on per hour for given day of week, d , and hour of the day, h , %

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$n \in t(d, h)$ = index for the subset of measured data points that fall on day of week, d , and hour of the day, h

3. Find the average hours per day pump is on (Worksheet: “Step 4. Results”).

$$\overline{HrsOn}_d = \sum_{h=1}^{24} \%On_{d,h} \quad (4)$$

Where,

\overline{HrsOn}_d = average hours per day for given day of week, d , hours

4. Calculate energy used for full year (Worksheet: “Step 4. Results”).

$$\begin{aligned} WeeksChillerOn &= (DayOfYear(CoolingSeasonEndDate) \\ &- DayOfYear(CoolingSeasonStartDate)) * \frac{WeeksPerYear}{DaysPerYear} \end{aligned} \quad (5)$$

$$E = WeeksChillerOn * P \sum_{d=1}^7 \overline{HrsOn}_d \quad (6)$$

Where,

E = annual pump energy, kWh

$DayOfYear$ = function to convert a date to the n^{th} day of the year

$CoolingSeasonEndDate$ = cooling season end date, mm/dd/yyyy

$CoolingSeasonStartDate$ = cooling season start date, mm/dd/yyyy

$WeeksChillerOn$ = length of cooling season, weeks

$WeeksPerYear$ = 52

$DaysPerYear$ = 365.24

P = measured pump power, kW

Constant Speed, Constant Volume Pumps Using Data Logging Power Meters

This calculation tool is for a constant speed, constant volume pump. Measured input data is average hourly power draw (in kW) as measured by a DENT power logger.

5. Average % hour motor is on for each hour of each day of the week (Worksheet: “Step 3. Avg Day of Week Calcs”).

$$\bar{P}_{d,h} = \frac{\sum_{n=1}^{N(d,h)} P(t)}{N(d,h)} \quad (7)$$

Where,

$\bar{P}_{d,h}$ = average motor power for given day of week, d , and hour of the day, h , kW

$P(t)$ = measured motor power, kW

t = index for measured data points

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$n \in t(d, h)$ = index for subset of measured data points that fall on day of week, d , and hour of the day, h

6. Calculate energy used for full year (Worksheet: "Step 4. Results"). *WeeksChillerOn* is from Equation 5.

$$E = WeeksChillerOn * \sum_{d=1}^7 \sum_{h=1}^{24} \bar{P}_{d,h} \quad (8)$$

Where,

E = annual pump energy, kWh

$WeeksPerYear = 52$

Constant Speed, Constant Volume Pumps Using Current Sensors

This calculation tool is for a constant speed, constant volume pump. Measured input data include hourly average current (in Amps) as directly measured by current sensors, and spot measurements for true power.

7. Convert average hourly current to percent on per hour (Worksheet: "Step 2. Percent Runtime Calcs").

$$\%On(t) = \begin{cases} \frac{I(t)}{I_{max}} & \text{if } I(t) < I_{max} \\ 100\% & \text{o.w.} \end{cases} \quad (9)$$

Where,

$\%On(t)$ = percent of an hour that the pump motor is on, %

$I(t)$ = measured time that pump motor is on, seconds

t = index for each measured data point

I_{max} = current measured at the maximum constant speed, Amps

8. Equations 3 to 6 are used to calculate the annual pump energy.

Variable Speed, Variable Volume Pumps Using Data Logging Power Meters

This calculation tool is for VFD-controlled pumps that are operated at speeds proportional to the heating/cooling load as represented by proxy with OAT. Measured input data include average hourly power draw (kW) as measured by a DENT power logger, and the average hourly OAT as measured by a temperature/RH logger.

9. Fit a second-order polynomial regression model of true RMS power as a function OAT. (Worksheet: "Step 3. Regression").

$$P(OAT) = a * OAT^2 + b * OAT + c \quad (10)$$

Where,

P = average hourly true RMS power, kW

a, b, c = regression coefficients

OAT = outdoor air temperature, °F

10. Average % hour motor is on for each hour of each day of the week (Worksheets: “Step 4. Schedule Calcs” and “Step 5. Daily Avg Schedule Calc”).

$$On(t) = \begin{cases} 1 & \text{if } P(t) > 0 \\ 0 & \text{otherwise} \end{cases} \quad (11)$$

$$\overline{\%On}_{d,h} = \frac{\sum_{n=1}^{N(d,h)} On(t)}{N(d,h)} \quad (12)$$

Where,

$P(t)$ = measured power, kW

$On(t)$ = motor is on at time, t , binary

$\overline{\%On}_{d,h}$ = average % time motor is on per hour for given day of week, d , and hour of the day, h , %

$N(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

$n \in t(d, h)$ = index for subset of measured data points that fall on day of week, d , and hour of the day, h

11. Total annual pump energy (Worksheets: “Step 6. Energy Calcs” and “Step 7. Results”).

$$E = WeeksChillerOn * \sum_{t=1}^{8760} P(OAT'(t)) * \overline{\%On}_{d,h}(t) \quad (13)$$

Where,

E = annual energy usage, kWh

$OAT'(t)$ = hourly climate normal outside air temperature from National Weather Service at station closest to site, °F

$WeeksChillerOn$ = cooling season (see Equation 5), weeks

Variable Speed, Variable Volume Pumps Using Speed Data From BAS or VFD

This calculation tool is for VFD-controlled pumps using hourly average motor speed (in RPM) as downloaded from a BAS or VFD, and spot measurements for true power.

12. Convert the speed data from the BAS or VFD to power (Worksheet: “Step 2. Aggregate Data”)

$$P(t) = P_{max} \left(\frac{\omega(t)}{\omega_{max}} \right)^{2.5} \quad (14)$$

Where,

$P(t)$ = average hourly true RMS power, kW

P_{max} = full speed true RMS power, kW

ω_{max} = maximum motor speed, rpm

$\omega(t)$ = motor speed, rpm

This equation represents the pump affinity law, where theoretically the exponent is 3. To represent the motor losses, the Consortium for Energy Efficiency recommends using a value of 2.5.⁷

13. Equations 10 to 13 are used to calculate the annual pump energy.

A.19: Lighting on Dedicated Panelboards Without Automatic Controls Calculations

Long-term True Power Measurements Using a Power Logger

This calculation is used to measure the total power of a lighting system at the panel or at the feed to groups of panels at the switchgear. The data-logging power meter (e.g., DENT ELITEpro XC) collects average true RMS power in kWh data for each hour. Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and are then extrapolated to an annual estimate of lighting energy consumption.

14. Find hourly average energy use for each hour of each day of the week (Worksheet: “Step 2. Avg Energy Calcs”).

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{h,n}}{N_f(d,h)} \quad (2)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week

$kWh_{h,n}$ = measured energy usage at each hour of each day of each week

$N_f(d, h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

⁷ Consortium for Energy Efficiency. *Motor Efficiency, Selection, and Management: A Guidebook for Industrial Efficiency Programs* (May 2011).

15. Find average daily energy use (Worksheet: “Step 3. Results”, “Step 3a. Hourly Results”).

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (3)$$

Where,

$\overline{kWh}_{d,w}$ = sum of energy usage for each day of the week
 $\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week
 n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

16. Calculate the average energy use per day for weekdays (Worksheet: “Step 3. Results”).

$$\overline{kWh}_{wd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wd,n}}{5} \quad (4)$$

Where,

\overline{kWh}_{wd} = average energy usage for weekdays
 $\overline{kWh}_{wd,n}$ = average energy of each n weekday
 n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

17. Calculate the average energy use per day for weekend days (Worksheet: “Step 3. Results”).

$$\overline{kWh}_{we} = \sum_{n=7}^1 \overline{kWh}_{we,n} \quad (5)$$

Where,

\overline{kWh}_{we} = of average energy usage for each day of the week
 $\overline{kWh}_{we,n}$ = average energy of each n weekend day
 n = day of week: 7 = Saturday, 1 = Sunday

18. Calculate the total weekday energy consumption (Worksheet: “Step 3. Results”).

$$\overline{kWh}_{wdYr} = \overline{kWh}_{wd} * (261 \text{ weekdays per year} - X) \quad (6)$$

Where,

\overline{kWh}_{wdYr} = annual weekday energy usage
 \overline{kWh}_{wd} = average weekday energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

19. Calculate the total weekend day energy consumption (Worksheet: “Step 3. Results”).

$$\overline{kWh}_{WE dYr} = \overline{kWh}_{WE d} * (104 \text{ weekend days per year} + X) \quad (7)$$

Where,

$\overline{kWh}_{WE dYr}$ = annual weekend day energy usage

$\overline{kWh}_{WE d}$ = average weekend day energy usage

X = number of weekdays that are adjusted to use weekend day average energy usage

20. Calculate total annual estimated energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{ann} = \overline{kWh}_{W dYr} + \overline{kWh}_{WE dYr} \quad (8)$$

Where,

\overline{kWh}_{ann} = annual energy usage

$\overline{kWh}_{W dYr}$ = annual weekday energy usage

$\overline{kWh}_{WE dYr}$ = annual weekend day energy usage

21. If more than one electric panel that is measured, sum the total energy usage of all panels to find the total energy usage of the facility

$$\overline{kWh} = \overline{kWh}_1 + \overline{kWh}_2 + \dots \quad (9)$$

Where,

\overline{kWh} = total energy usage for the facility

\overline{kWh}_n = total energy usage for each panel

n = number of panels measured

AC Current Measurement at Main Feed with Current Sensors

This calculation is used to measure the average current of a lighting system at the panel or at the feed to groups of panels at the switchgear. The current sensor and logger (e.g., Onset CTV series and Onset HOBO UX120-006M logger) collect average current (in amperes) as directly measured by current sensors, and spot measurements for true power using a one-time clamp meter (e.g., Fluke 345). Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption. Fixture counts and nominal lamp and ballast wattages are used to estimate the percentage of the lighting system measured.

1. Calculate average energy for each hour interval (Worksheet: "Step 2. Hourly Energy Calcs").

$$\overline{kWh}_h = \frac{I_{AC} * V_{rms} * PF * \sqrt{3}}{1000} \quad (10)$$

Where,

\overline{kWh}_h = average hourly energy

I_{AC} = average hourly AC current

V_{rms} = measured one-time RMS voltage value

PF = measured one-time power factor value

2. Calculate average energy use for each hour of each day of the week (Worksheet: "Step 3. Avg Energy Calcs", "Step 4a. Hourly Results").

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{hour,n}}{N_f(d,h)} \quad (11)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week

$kWh_{h,n}$ = measured energy usage at each hour of each day of each week

$N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

3. Calculate average daily energy use (Worksheet: "Step 4. Results").

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (12)$$

Where,

$\overline{kWh}_{d,w}$ = sum of energy usage for each day of the week

$\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

4. Calculate the average energy use per day for weekdays (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wd,n}}{5} \quad (13)$$

Where,

\overline{kWh}_{wd} = average energy usage for weekdays

$\overline{kWh}_{wd,n}$ = average energy of each n weekday

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

5. Calculate the average energy use per day for weekend days (Worksheet: "Step 4. Results").

$$\overline{kWh}_{weD} = \frac{\sum_{n=7}^1 \overline{kWh}_{we,n}}{2} \quad (14)$$

Where,

\overline{kWh}_{WEd} = of average energy usage for a weekend day
 $\overline{kWh}_{we,n}$ = average energy of each n weekend day
 n = day of week: 7 = Saturday, 1 = Sunday

6. Calculate the total weekday energy consumption (Worksheet: “Step 4. Results”).

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (15)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekday energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

7. Calculate the total weekend day energy consumption (Worksheet: “Step 4. Results”).

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (16)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage
 \overline{kWh}_{WEd} = average weekend day energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

8. Calculate total annual estimated energy consumption

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (17)$$

Where,

\overline{kWh}_{ann} = annual energy usage
 \overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{WEdYr} = annual weekend day energy usage

AC Current Circuit Measurement with Current Sensors

This calculation is used to measure the average current of a lighting system in a single panel for a single or group of lighting circuits. The current sensor and logger (e.g., Onset CTV series and Onset HOBO UX120-006M logger) collect average current (in amperes) as directly measured by current sensors, and spot measurements for true power using a one-time clamp meter (e.g., Fluke 345). Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption. Fixture counts and nominal lamp and ballast wattages are used to estimate the percentage of the lighting system measured.

1. For each circuit or group of circuits measured, calculate average energy for each hour interval (Worksheet: “Step 2. Hourly Energy Calcs”).

$$\overline{kWh}_h = \frac{I_{AC} * V_{rms} * PF * \sqrt{3}}{1000} \quad (18)$$

Where,

\overline{kWh}_h = True power for each hour
 I_{AC} = average hourly AC current
 V_{rms} = measured one-time RMS voltage value
 PF = measured one-time power factor value

- For each circuit or group of circuits measured, calculate average energy use for each hour of each day of the week (Worksheet: "Step 3. Avg Energy Calcs").

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{hour,n}}{N_f(d,h)} \quad (19)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week
 $kWh_{h,n}$ = measured energy usage at each hour of each day of each week
 $N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

- For each circuit or group of circuits measured, calculate average daily energy use (Worksheet: "Step 4. Results").

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (20)$$

Where,

$\overline{kWh}_{d,w}$ = average energy usage for each day of the week
 $\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week
 n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

- Calculate the average energy use per day for weekdays for all circuits (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wacd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wdc1,n}}{5} + \frac{\sum_{n=2}^6 \overline{kWh}_{wdc2,n}}{5} + \dots \quad (21)$$

Where,

\overline{kWh}_{WdCt} = average energy usage for weekdays for all circuits
 $\overline{kWh}_{wdCn,n}$ = average energy of each circuit for each n weekday of the week
 n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

5. Calculate the average energy use per day for weekend days for all circuits (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdCT} = \frac{\sum_{n=7}^1 \overline{kWh}_{weC1,n}}{2} + \frac{\sum_{n=7}^1 \overline{kWh}_{weC2,n}}{2} + \dots \quad (22)$$

Where,

\overline{kWh}_{WEdCT} = average energy usage for weekend days for all circuits
 $\overline{kWh}_{weCn,n}$ = average energy of each circuit for each n weekend day
 n = day of week: 7= Saturday, 1 = Sunday

6. Calculate the total Weekday energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (23)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekly weekday energy usage
 X = number of weekdays that are considered holidays and adjusted to weekend day average energy usage

7. Calculate the total weekend day energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (24)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage
 \overline{kWh}_{WEd} = average weekly weekend day energy usage
 X = number of weekdays that are considered holidays and adjusted to weekend day average energy usage

8. Calculate total annual estimated energy consumption

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (25)$$

Where,

\overline{kWh}_{ann} = annual energy usage
 \overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{WEdYr} = annual weekend day energy usage

Fixture Inventory and Long-term Light On/Off Operation

This calculation tool is used for spaces that have manual controls that may be utilized by occupants. Inputs include the total number of fixtures and associated power draw in each space that is manually controlled. Measurement of the on/off status of lighting in each space is done with a lighting logger (e.g., Onset HOB0 UX90-002). If possible, measure the total connected load in each space or the total lighting load either at the main feed or each lighting circuit. Use a minimum of one light on/off logger for each space and focus measurement of hours of operation on the fixture types and spaces with the largest total. For more than two distinct spaces, use multiple workbooks and sum totals.

1. For each space use manufactures' specifications or site survey to determine wattage of fixtures. Determine fixture count and multiply to determine total wattage of that fixture, (Worksheet: "Step 1.1 Space #1 Raw Data" or "Step 1.2 Space #2 Raw Data").

$$kW_{fix1} = N \times W_{fix1} \quad (26)$$

Where,

kW_{fix1} = total power draw of single fixture type in each space i that is individually controlled
 W_{fix1} = wattage of a single fixture type 1
 N = number of fixtures with that wattage in the space being measured

2. Sum the total power draw of all fixture types for the space being measured (Worksheet: "Step 1.1 Space #1 Raw Data" or "Step 1.2 Space #2 Raw Data").

$$kW_{Spi} = kW_{fix1} + kW_{fix2} + \dots \quad (27)$$

Where,

kW_{Spi} = total power draw of all light fixtures in the space i being measured
 kW_{fix1} = total power draw of fixture type 1
 kW_{fix2} = total power draw of fixture type 2

3. Convert Lighting Runtime measurements in seconds on per hour to percent on per hour in space being measured (Worksheet: "Step 2. Percent Runtime Calcs").

$$\%_{int} = t_{int}/3600 \quad (28)$$

Where,

$\%_{int}$ = percentage of seconds the lights are on in each hour interval
 t_{int} = measured number of seconds the lights are on in each hour interval

4. Find the hourly average percentage for each day of the week that the lights are on in space being measured (Worksheet: "Step 3. Daily Avg Runtime Calcs").

$$\%_{hourly} = \frac{\sum_1^n \%_{int,n}}{n} \quad (29)$$

Where,

$\%_{hourly}$ = hourly average percentage the lights are on

$\%_{int}$ = percentage of seconds lights are on in each hour interval

n = number of data points that have the same hour of day and day of week

5. Sum the percentages for each day to determine the daily operating hours per day (in space being measured (Worksheet: "Step 4. Results").

$$\%_{daily} = \sum_{n=0}^{23} \%_{hourly,n} \quad (30)$$

Where,

$\%_{daily}$ = daily average hours in percent per day the lights are on

$\%_{hourly}$ = hourly average percentage lights were on

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

6. Convert percentage to hours to determine hours per day lights are on in space being measured (Worksheet: "Step 4. Results").

$$T_{daily} = \%_{daily}/100 \quad (31)$$

Where,

T_{daily} = Hours light are on

$\%_{daily}$ = daily average hours in percent per day the lights are on

7. Calculate the average energy use per day for weekdays in each space being measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wd} = \frac{\sum_{n=2}^6 T_{wd,n}}{5} \times kW_{Spi} \quad (32)$$

Where,

\overline{kWh}_{wd} = average energy usage for weekdays

kW_{Spi} = total lighting power draw in space i being measured from Eq. 27

$T_{wd,n}$ = average hours of operation of each n weekday in space being measured

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

8. Calculate the average energy use per day for weekend days in each space being measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{we} = \frac{\sum_{n=7}^1 T_{we,n}}{2} \times kW_{Spi} \quad (33)$$

Where,

- \overline{kWh}_{WEd} = of average energy usage for a weekend day
 kW_{sp1} = total lighting power draw in each space i being measured from Eq. 27
 $T_{we,n}$ = average energy of each n weekend day
 n = day of week: 7 = Saturday, 1 = Sunday

9. Calculate the total weekday energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{WdSpi} * (261 \text{ weekdays per year} - X) \quad (34)$$

Where,

- \overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{WdSpi} = average weekday energy usage for space i
 X = number of weekdays that are adjusted to use weekend day average energy usage

10. Calculate the total weekend day energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdYrSpi} = \overline{kWh}_{WEdSpi} * (104 \text{ weekend days per year} + X) \quad (35)$$

Where,

- $\overline{kWh}_{WEdYrSpi}$ = annual weekend day energy usage for space i
 \overline{kWh}_{WEdSpi} = average weekend day energy usage for space i
 X = number of weekdays that are adjusted to use weekend average energy usage

11. Calculate total annual estimated energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{annSpi} = \overline{kWh}_{WdYrSpi} + \overline{kWh}_{WEdYrSpi} \quad (36)$$

Where,

- \overline{kWh}_{annSpi} = annual energy usage for space i
 $\overline{kWh}_{WdYrSpi}$ = annual weekday energy usage for space i
 $\overline{kWh}_{WEdYrSpi}$ = annual weekend day energy usage for space i

12. Sum the annual estimated energy consumption for all spaces that have been measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{ann} = \sum_{n=1}^n \overline{kWh}_{annSpi} \quad (37)$$

Where,

\overline{kWh}_{ann} = total annual energy usage for spaces measured
 $\overline{kWh}_{WdYrSpi}$ = annual weekday energy usage for each space i
 n = number of spaces i measured

A.20: Lighting on Dedicated Panelboards With Automatic Controls Calculations

Long-term True Power Measurements Using a Power Logger

This calculation is used to measure the total power of a lighting system at the panel or at the feed to groups of panels at the switchgear. The power logger (e.g., DENT ELITEpro XC) collects average true RMS power in kWh data for each hour. Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption.

13. Find hourly average energy use for each hour of each day of the week (Worksheet: “Step 2. Avg Energy Calcs”).

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{h,n}}{N_f(d,h)} \quad (2)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week
 $\overline{kWh}_{h,n}$ = measured energy usage at each hour of each day of each week
 $N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

14. Find average daily energy use (Worksheet: “Step 3. Results”, “Step 3a. Hourly Results”).

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (3)$$

Where,

$\overline{kWh}_{d,w}$ = sum of energy usage for each day of the week
 $\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week
 n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

15. Calculate the average energy use per day for weekdays (Worksheet: “Step 3. Results”).

$$\overline{kWh}_{Wd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wd,n}}{5} \quad (4)$$

Where,

\overline{kWh}_{Wd} = average energy usage for weekdays

$\overline{kWh}_{wd,n}$ = average energy of each n weekday
 n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

16. Calculate the average energy use per day for weekend days. (Worksheet: "Step 3. Results").

$$\overline{kWh}_{WEd} = \sum_{n=7}^1 \overline{kWh}_{we,n} \quad (5)$$

Where,

\overline{kWh}_{WEd} = of average energy usage for each day of the week
 $\overline{kWh}_{we,n}$ = average energy of each n weekend day
 n = day of week: 7 = Saturday, 1 = Sunday

17. Calculate the total weekday energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (6)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekday energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

18. Calculate the total weekend day energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (7)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage
 \overline{kWh}_{WEd} = average weekend day energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

19. Calculate total annual estimated energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (8)$$

Where,

\overline{kWh}_{ann} = annual energy usage
 \overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{WEdYr} = annual weekend day energy usage

20. If more than one electric panel that is measured, sum the total energy usage of all panels to find the total energy usage of the facility

$$\overline{kWh} = \overline{kWh}_1 + \overline{kWh}_2 + \dots \quad (9)$$

Where,

$$\begin{aligned}\overline{kWh} &= \text{total energy usage for the facility} \\ \overline{kWh}_n &= \text{total energy usage for each panel}\end{aligned}$$

AC Current Measurement at Main Feed with Current Sensors

This calculation is used to measure the average current of a lighting system at the panel or at the feed to groups of panels at the switchgear. The current sensor and logger (e.g., Onset CTV series and HOBO UX120-006M logger) collects average current (in amperes), as directly measured by current sensors, and spot measurements for true power using a one-time clamp meter (e.g., Fluke 345). Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption. Fixture counts and nominal lamp and ballast wattages are used to estimate the percentage of the lighting system measured.

21. Calculate average energy for each hour interval (Worksheet: "Step 2. Hourly Energy Calcs").

$$\overline{kWh}_h = \frac{I_{AC} * V_{rms} * PF * \sqrt{3}}{1000} \quad (10)$$

Where,

$$\begin{aligned}\overline{kWh}_h &= \text{average hourly energy} \\ I_{AC} &= \text{average hourly AC current} \\ V_{rms} &= \text{measured one-time RMS voltage value} \\ PF &= \text{measured one-time power factor value}\end{aligned}$$

22. Calculate average energy use for each hour of each day of the week (Worksheet: "Step 3. Avg Energy Calcs", "Step 4a. Hourly Results").

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{hour,n}}{N_f(d,h)} \quad (11)$$

Where,

$$\begin{aligned}\overline{kWh}_{d,h} &= \text{average energy of each hour for each day of the week} \\ \overline{kWh}_{h,n} &= \text{measured energy usage at each hour of each day of each week} \\ N_f(d,h) &= \text{total number of measured data points that fall on day of week, } d, \text{ and hour of} \\ &\quad \text{the day, } h\end{aligned}$$

23. Calculate average daily energy use (Worksheet: "Step 4. Results").

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (12)$$

Where,

$$\overline{kWh}_{d,w} = \text{sum of energy usage for each day of the week}$$

$\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week
 n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

24. Calculate the average energy use per day for weekdays (Worksheet: "Step 4. Results").

$$\overline{kWh}_{Wd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wd,n}}{5} \quad (13)$$

Where,

\overline{kWh}_{Wd} = average energy usage for weekdays
 $\overline{kWh}_{wd,n}$ = average energy of each n weekday
 n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

25. Calculate the average energy use per day for weekend days. (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEd} = \frac{\sum_{n=7}^1 \overline{kWh}_{we,n}}{2} \quad (14)$$

Where,

\overline{kWh}_{WEd} = of average energy usage for a weekend day
 $\overline{kWh}_{we,n}$ = average energy of each n weekend day
 n = day of week: 7 = Saturday, 1 = Sunday

26. Calculate the total weekday energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (15)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekday energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

27. Calculate the total weekend day energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (16)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage
 \overline{kWh}_{WEd} = average weekend day energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

28. Calculate total annual estimated energy consumption

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (17)$$

Where,

\overline{kWh}_{ann} = annual energy usage
 \overline{kWh}_{wdayr} = annual weekday energy usage
 \overline{kWh}_{wedayr} = annual weekend day energy usage

AC Current Circuit Measurement with Current Sensors

This calculation is used to measure the average current of a lighting system in a single the panel for single or groups of lighting circuits. The current sensor and logger (e.g., Onset CTV series and HOBO UX120-006M logger) collects average current (in Amps), as directly measured by current sensors, and spot measurements for true power using a one-time clamp meter (e.g., Fluke 345). Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption. Fixture counts and nominal lamp and ballast wattages are used to estimate the percentage of the lighting system measured.

29. For each circuit or group of circuits measured, calculate average energy for each hour interval (Worksheet: "Step 2. Hourly Energy Calcs").

$$\overline{kWh}_h = \frac{I_{AC} * V_{rms} * PF * \sqrt{3}}{1000} \quad (18)$$

Where,

\overline{kWh}_h = True power for each hour
 I_{AC} = average hourly AC current
 V_{rms} = measured one-time RMS voltage value
 PF = measured one-time power factor value

30. For each circuit or group of circuits measured, calculate average energy use for each hour of each day of the week (Worksheet: "Step 3. Avg Energy Calcs").

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{hour,n}}{N_f(d,h)} \quad (19)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week
 $\overline{kWh}_{h,n}$ = measured energy usage at each hour of each day of each week
 $N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

31. For each circuit or group of circuits measured, calculate average daily energy use (Worksheet: "Step 4. Results").

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (20)$$

Where,

$\overline{kWh}_{d,w}$ = average energy usage for each day of the week
 $\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week
 n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

32. Calculate the average energy use per day for weekdays for all circuits (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdCT} = \frac{\sum_{n=2}^6 \overline{kWh}_{wdC1,n}}{5} + \frac{\sum_{n=2}^6 \overline{kWh}_{wdC2,n}}{5} + \dots \quad (21)$$

Where,

\overline{kWh}_{WdCT} = average energy usage for weekdays for all circuits
 $\overline{kWh}_{wdCn,n}$ = average energy of each circuit for each n weekday of the week
 n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

33. Calculate the average energy use per day for weekend days for all circuits (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WECT} = \frac{\sum_{n=7}^1 \overline{kWh}_{weC1,n}}{2} + \frac{\sum_{n=7}^1 \overline{kWh}_{weC2,n}}{2} + \dots \quad (22)$$

Where,

\overline{kWh}_{WECT} = average energy usage for weekend days for all circuits
 $\overline{kWh}_{weCn,n}$ = average energy of each circuit for each n weekend day
 n = day of week: 7= Saturday, 1 = Sunday

34. Calculate the total Weekday energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (23)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekly weekday energy usage
 X = number of weekdays that are considered holidays and adjusted to weekend day average energy usage

35. Calculate the total weekend day energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEYr} = \overline{kWh}_{WE} * (104 \text{ weekend days per year} + X) \quad (24)$$

Where,

\overline{kWh}_{WEYr} = annual weekend day energy usage
 \overline{kWh}_{WE} = average weekly weekend day energy usage

X = number of weekdays that are considered holidays and adjusted to weekend day average energy usage

36. Calculate total annual estimated energy consumption

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (25)$$

Where,

\overline{kWh}_{ann} = annual energy usage

\overline{kWh}_{WdYr} = annual weekday energy usage

\overline{kWh}_{WEdYr} = annual weekend day energy usage

Fixture Inventory and Long-term Light On/Off Operation

This calculation tool is used for spaces that have manual controls that may be utilized by occupants. Inputs include the total number of fixtures and associated power draw in each space that is manually controlled. Measurement of the on / off status of lighting in each space is done with a lighting logger (e.g., HOBO UX90-002). If possible, measure the total connected load in each space or the total lighting load either at the main feed or each lighting circuit. Use a minimum of one light on/off logger for each space and focus measurement of hours of operation on the fixture types and spaces with the largest total. For more than two distinct spaces, use multiple workbooks and sum totals.

37. For each space use manufactures' specifications or site survey to determine wattage of fixtures. Determine fixture count and multiply to determine total wattage of that fixture, (Worksheet: "Step 1.1 Space #1 Raw Data" or "Step 1.2 Space #2 Raw Data").

$$kW_{fix1} = N \times W_{fix1} \quad (26)$$

Where,

kW_{fix1} = total power draw of single fixture type in each space i that is individually controlled

W_{fix1} = wattage of a single fixture type 1

N = number of fixtures with that wattage in the space being measured

38. Sum the total power draw of all fixture types for the space being measured (Worksheet: "Step 1.1 Space #1 Raw Data" or "Step 1.2 Space #2 Raw Data").

$$kW_{Spi} = kW_{fix1} + kW_{fix2} + \dots \quad (27)$$

Where,

kW_{Spi} = total power draw of all light fixtures in the space i being measured

kW_{fix1} = total power draw of fixture type 1

kW_{fix2} = total power draw of fixture type 2

39. Convert Lighting Runtime measurements in seconds on per hour to percent on per hour in space being measured (Worksheet: “Step 2. Percent Runtime Calcs”).

$$\%_{int} = t_{int}/3600 \quad (28)$$

Where,

$\%_{int}$ = percentage of seconds the lights are on in each hour interval

t_{int} = measured number of seconds the lights are on in each hour interval

40. Find the hourly average percentage for each day of the week that the lights are on in space being measured (Worksheet: “Step 3. Daily Avg Runtime Calcs”).

$$\%_{hourly} = \frac{\sum_1^n \%_{int,n}}{n} \quad (29)$$

Where,

$\%_{hourly}$ = hourly average percentage the lights are on

$\%_{int}$ = percentage of seconds lights are on in each hour interval

n = number of data points that have the same hour of day and day of week

41. Sum the percentages for each day to determine the daily operating hours per day (in space being measured (Worksheet: “Step 4. Results”).

$$\%_{daily} = \sum_{n=0}^{23} \%_{hourly,n} \quad (30)$$

Where,

$\%_{daily}$ = daily average hours in percent per day the lights are on

$\%_{hourly}$ = hourly average percentage lights were on

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

42. Convert percentage to hours to determine hours per day lights are on in space being measured (Worksheet: “Step 4. Results”).

$$T_{daily} = \%_{daily}/100 \quad (31)$$

Where,

T_{daily} = Hours light are on

$\%_{daily}$ = daily average hours in percent per day the lights are on

43. Calculate the average energy use per day for weekdays in each space being measured (Worksheet: “Step 4. Results”).

$$\overline{kWh}_{Wd} = \frac{\sum_{n=2}^6 T_{wd,n}}{5} \times kW_{Spi} \quad (32)$$

Where,

\overline{kWh}_{Wd} = average energy usage for weekdays

kW_{Spi} = total lighting power draw in space i being measured from Eq. 27

$T_{wd,n}$ = average hours of operation of each n weekday in space being measured

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

44. Calculate the average energy use per day for weekend days in each space being measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEd} = \frac{\sum_{n=7}^1 T_{we,n}}{2} \times kW_{Spi} \quad (33)$$

Where,

\overline{kWh}_{WEd} = of average energy usage for a weekend day

kW_{sp1} = total lighting power draw in each space i being measured from Eq. 27

$T_{we,n}$ = average energy of each n weekend day

n = day of week: 7 = Saturday, 1 = Sunday

45. Calculate the total weekday energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{WdSpi} * (261 \text{ weekdays per year} - X) \quad (34)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage

\overline{kWh}_{WdSpi} = average weekday energy usage for space i

X = number of weekdays that are adjusted to use weekend day average energy usage

46. Calculate the total weekend day energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdYrSpi} = \overline{kWh}_{WEdSpi} * (104 \text{ weekend days per year} + X) \quad (35)$$

Where,

$\overline{kWh}_{WEdYrSpi}$ = annual weekend day energy usage for space i

\overline{kWh}_{WEdSpi} = average weekend day energy usage for space i

X = number of weekdays that are adjusted to use weekend average energy usage

47. Calculate total annual estimated energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{annSpi} = \overline{kWh}_{WdYrSpi} + \overline{kWh}_{WEdYrSpi} \quad (36)$$

Where,

$$\begin{aligned} \overline{kWh}_{annSpi} &= \text{annual energy usage for space } i \\ \overline{kWh}_{WdYrSpi} &= \text{annual weekday energy usage for space } i \\ \overline{kWh}_{WEdYrSpi} &= \text{annual weekend day energy usage for space } i \end{aligned}$$

48. Sum the annual estimated energy consumption for all spaces that have been measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{ann} = \sum_{n=1}^n \overline{kWh}_{annSpi} \quad (37)$$

Where,

$$\begin{aligned} \overline{kWh}_{ann} &= \text{total annual energy usage for spaces measured} \\ \overline{kWh}_{WdYrSpi} &= \text{annual weekday energy usage for each space } i \\ n &= \text{number of spaces } i \text{ measured} \end{aligned}$$

A.21: Lighting on Mixed Panelboards Without Automatic Controls Calculations

Long-term True Power Measurements Using a Power Logger

This calculation is used to measure the total power of a lighting system at the panel or at the feed to groups of panels at the switchgear. The power logger (e.g., DENT ELITEpro XC) collects average true RMS power in kWh data for each hour. Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and are then extrapolated to an annual estimate of lighting energy consumption.

49. Find hourly average energy use for each hour of each day of the week (Worksheet: "Step 2. Avg Energy Calcs").

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{h,n}}{N_f(d,h)} \quad (2)$$

Where,

$$\begin{aligned} \overline{kWh}_{d,h} &= \text{average energy of each hour for each day of the week} \\ \overline{kWh}_{h,n} &= \text{measured energy usage at each hour of each day of each week} \\ N_f(d,h) &= \text{total number of measured data points that fall on day of week, } d, \text{ and hour of the day, } h \end{aligned}$$

50. Find average daily energy use (Worksheet: "Step 3. Results", "Step 3a. Hourly Results").

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (3)$$

Where,

$\overline{kWh}_{d,w}$ = sum of energy usage for each day of the week
 $\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week
 n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

51. Calculate the average energy use per day for weekdays (Worksheet: "Step 3. Results").

$$\overline{kWh}_{Wd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wd,n}}{5} \quad (4)$$

Where,

\overline{kWh}_{Wd} = average energy usage for weekdays
 $\overline{kWh}_{wd,n}$ = average energy of each n weekday
 n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

52. Calculate the average energy use per day for weekend days (Worksheet: "Step 3. Results").

$$\overline{kWh}_{WEd} = \sum_{n=7}^1 \overline{kWh}_{we,n} \quad (5)$$

Where,

\overline{kWh}_{WEd} = of average energy usage for each day of the week
 $\overline{kWh}_{we,n}$ = average energy of each n weekend day
 n = day of week: 7 = Saturday, 1 = Sunday

53. Calculate the total weekday energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (6)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekday energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

54. Calculate the total weekend day energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (7)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage

\overline{kWh}_{WEd} = average weekend day energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

55. Calculate total annual estimated energy consumption (Worksheet: “Step 3. Results”).

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (8)$$

Where,

\overline{kWh}_{ann} = annual energy usage
 \overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{WEdYr} = annual weekend day energy usage

56. If more than one electric panel that is measured, sum the total energy usage of all panels to find the total energy usage of the facility

$$\overline{kWh} = \overline{kWh}_1 + \overline{kWh}_2 + \dots \quad (9)$$

Where,

\overline{kWh} = total energy usage for the facility
 \overline{kWh}_n = total energy usage for each panel

AC Current Measurement at Main Feed with Current Sensors

This calculation is used to measure the average current of a lighting system at the panel or at the feed to groups of panels at the switchgear. The current sensor and logger (e.g., Onset CTV series and HOBO UX120-006M logger) collect average current (in amperes) as directly measured by current sensors, and spot measurements for true power using a one-time clamp meter (e.g., Fluke 345). Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption. Fixture counts and nominal lamp and ballast wattages are used to estimate the percentage of the lighting system measured.

57. Calculate average energy for each hour interval (Worksheet: “Step 2. Hourly Energy Calcs”).

$$\overline{kWh}_h = \frac{I_{AC} * V_{rms} * PF * \sqrt{3}}{1000} \quad (10)$$

Where,

\overline{kWh}_h = average hourly energy
 I_{AC} = average hourly AC current
 V_{rms} = measured one-time RMS voltage value
 PF = measured one-time power factor value

58. Calculate average energy use for each hour of each day of the week (Worksheet: “Step 3. Avg Energy Calcs”, “Step 4a. Hourly Results”).

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{hour,n}}{N_f(d,h)} \quad (11)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week

$\overline{kWh}_{h,n}$ = measured energy usage at each hour of each day of each week

$N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

59. Calculate average daily energy use (Worksheet: "Step 4. Results").

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (12)$$

Where,

$\overline{kWh}_{d,w}$ = sum of energy usage for each day of the week

$\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

60. Calculate the average energy use per day for weekdays (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wd,n}}{5} \quad (13)$$

Where,

\overline{kWh}_{wd} = average energy usage for weekdays

$\overline{kWh}_{wd,n}$ = average energy of each n weekday

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

61. Calculate the average energy use per day for weekend days (Worksheet: "Step 4. Results").

$$\overline{kWh}_{weD} = \frac{\sum_{n=7}^1 \overline{kWh}_{we,n}}{2} \quad (14)$$

Where,

\overline{kWh}_{weD} = of average energy usage for a weekend day

$\overline{kWh}_{we,n}$ = average energy of each n weekend day

n = day of week: 7 = Saturday, 1 = Sunday

62. Calculate the total weekday energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wdYr} = \overline{kWh}_{wd} * (261 \text{ weekdays per year} - X) \quad (15)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekday energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

63. Calculate the total weekend day energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (16)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage
 \overline{kWh}_{WEd} = average weekend day energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

64. Calculate total annual estimated energy consumption

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (17)$$

Where,

\overline{kWh}_{ann} = annual energy usage
 \overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{WEdYr} = annual weekend day energy usage

AC Current Circuit Measurement with Current Sensors

This calculation is used to measure the average current of a lighting system in a single the panel for single or groups of lighting circuits. The current sensor and logger (e.g., Onset CTV series and HOBO UX120-006M logger) collect average current (in amperes) as directly measured by current sensors, and spot measurements for true power using a one-time clamp meter (e.g., Fluke 345). Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption. Fixture counts and nominal lamp and ballast wattages are used to estimate the percentage of the lighting system measured.

65. For each circuit or group of circuits measured, calculate average energy for each hour interval (Worksheet: "Step 2. Hourly Energy Calcs").

$$\overline{kWh}_h = \frac{I_{AC} * V_{rms} * PF * \sqrt{3}}{1000} \quad (18)$$

Where,

\overline{kWh}_h = True power for each hour
 I_{AC} = average hourly AC current
 V_{rms} = measured one-time RMS voltage value
 PF = measured one-time power factor value

66. For each circuit or group of circuits measured, calculate average energy use for each hour of each day of the week (Worksheet: "Step 3. Avg Energy Calcs").

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{hour,n}}{N_f(d,h)} \quad (19)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week

$\overline{kWh}_{h,n}$ = measured energy usage at each hour of each day of each week

$N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

67. For each circuit or group of circuits measured, calculate average daily energy use (Worksheet: "Step 4. Results").

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (20)$$

Where,

$\overline{kWh}_{d,w}$ = average energy usage for each day of the week

$\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

68. Calculate the average energy use per day for weekdays for all circuits (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wdCT} = \frac{\sum_{n=2}^6 \overline{kWh}_{wdC1,n}}{5} + \frac{\sum_{n=2}^6 \overline{kWh}_{wdC2,n}}{5} + \dots \quad (21)$$

Where,

\overline{kWh}_{wdCT} = average energy usage for weekdays for all circuits

$\overline{kWh}_{wdCn,n}$ = average energy of each circuit for each n weekday of the week

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

69. Calculate the average energy use per day for weekend days for all circuits (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WE dCT} = \frac{\sum_{n=7}^1 \overline{kWh}_{weC1,n}}{2} + \frac{\sum_{n=7}^1 \overline{kWh}_{weC2,n}}{2} + \dots \quad (22)$$

Where,

$\overline{kWh}_{WE dCT}$ = average energy usage for weekend days for all circuits

$\overline{kWh}_{weCn,n}$ = average energy of each circuit for each n weekend day

n = day of week: 7= Saturday, 1 = Sunday

70. Calculate the total Weekday energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wdayr} = \overline{kWh}_{wd} * (261 \text{ weekdays per year} - X) \quad (23)$$

Where,

\overline{kWh}_{wdayr} = annual weekday energy usage

\overline{kWh}_{wd} = average weekly weekday energy usage

X = number of weekdays that are considered holidays and adjusted to weekend day average energy usage

71. Calculate the total weekend day energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wedyr} = \overline{kWh}_{wed} * (104 \text{ weekend days per year} + X) \quad (24)$$

Where,

\overline{kWh}_{wedyr} = annual weekend day energy usage

\overline{kWh}_{wed} = average weekly weekend day energy usage

X = number of weekdays that are considered holidays and adjusted to weekend day average energy usage

72. Calculate total annual estimated energy consumption

$$\overline{kWh}_{ann} = \overline{kWh}_{wdayr} + \overline{kWh}_{wedyr} \quad (25)$$

Where,

\overline{kWh}_{ann} = annual energy usage

\overline{kWh}_{wdayr} = annual weekday energy usage

\overline{kWh}_{wedyr} = annual weekend day energy usage

Fixture Inventory and Long-term Light On/Off Operation

This calculation tool is used for spaces that have manual controls that may be utilized by occupants. Inputs include the total number of fixtures and associated power draw in each space that is manually controlled. Measurement of the on/off status of lighting in each space is done with a lighting logger (e.g., HOBO UX90-002). If possible, measure the total connected load in each space or the total lighting load either at the main feed or each lighting circuit. Use a minimum of one light on/off logger for each space and focus measurement of hours of operation on the fixture types and spaces with the largest total. For more than two distinct spaces, use multiple workbooks and sum totals.

73. For each space use manufactures' specifications or site survey to determine wattage of fixtures. Determine fixture count and multiply to determine total wattage of that fixture, (Worksheet: "Step 1.1 Space #1 Raw Data" or "Step 1.2 Space #2 Raw Data").

$$kW_{fix1} = N \times W_{fix1} \quad (26)$$

Where,

kW_{fix1} = total power draw of single fixture type in each space i that is individually controlled

W_{fix1} = wattage of a single fixture type 1

N = number of fixtures with that wattage in the space being measured

74. Sum the total power draw of all fixture types for the space being measured (Worksheet: "Step 1.1 Space #1 Raw Data" or "Step 1.2 Space #2 Raw Data").

$$kW_{Spi} = kW_{fix1} + kW_{fix2} + \dots \quad (27)$$

Where,

kW_{Spi} = total power draw of all light fixtures in the space i being measured

kW_{fix1} = total power draw of fixture type 1

kW_{fix2} = total power draw of fixture type 2

75. Convert Lighting Runtime measurements in seconds on per hour to percent on per hour in space being measured (Worksheet: "Step 2. Percent Runtime Calcs").

$$\%_{int} = t_{int}/3600 \quad (28)$$

Where,

$\%_{int}$ = percentage of seconds the lights are on in each hour interval

t_{int} = measured number of seconds the lights are on in each hour interval

76. Find the hourly average percentage for each day of the week that the lights are on in space being measured (Worksheet: "Step 3. Daily Avg Runtime Calcs").

$$\%_{hourly} = \frac{\sum_1^n \%_{int,n}}{n} \quad (29)$$

Where,

$\%_{hourly}$ = hourly average percentage the lights are on

$\%_{int}$ = percentage of seconds lights are on in each hour interval

n = number of data points that have the same hour of day and day of week

77. Sum the percentages for each day to determine the daily operating hours per day (in space being measured (Worksheet: "Step 4. Results").

$$\%_{daily} = \sum_{n=0}^{23} \%_{hourly,n} \quad (30)$$

Where,

$\%_{daily}$ = daily average hours in percent per day the lights are on

$\%_{hourly}$ = hourly average percentage lights were on

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

78. Convert percentage to hours to determine hours per day lights are on in space being measured (Worksheet: "Step 4. Results").

$$T_{daily} = \%_{daily}/100 \quad (31)$$

Where,

T_{daily} = Hours light are on

$\%_{daily}$ = daily average hours in percent per day the lights are on

79. Calculate the average energy use per day for weekdays in each space being measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{Wd} = \frac{\sum_{n=2}^6 T_{wd,n}}{5} \times kW_{Spi} \quad (32)$$

Where,

\overline{kWh}_{Wd} = average energy usage for weekdays

kW_{Spi} = total lighting power draw in space i being measured from Eq. 27

$T_{wd,n}$ = average hours of operation of each n weekday in space being measured

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

80. Calculate the average energy use per day for weekend days in each space being measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEd} = \frac{\sum_{n=7}^1 T_{we,n}}{2} \times kW_{Spi} \quad (33)$$

Where,

\overline{kWh}_{WEd} = of average energy usage for a weekend day

kW_{sp1} = total lighting power draw in each space i being measured from Eq. 27

$T_{we,n}$ = average energy of each n weekend day

n = day of week: 7 = Saturday, 1 = Sunday

81. Calculate the total weekday energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{WdSpi} * (261 \text{ weekdays per year} - X) \quad (34)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage

\overline{kWh}_{WdSpi} = average weekday energy usage for space i

X = number of weekdays that are adjusted to use weekend day average energy usage

82. Calculate the total weekend day energy consumption for each space (Worksheet: “Step 4. Results”).

$$\overline{kWh}_{WEDYrSpi} = \overline{kWh}_{WEdSpi} * (104 \text{ weekend days per year} + X) \quad (35)$$

Where,

$$\begin{aligned} \overline{kWh}_{WEDYrSpi} &= \text{annual weekend day energy usage for space } i \\ \overline{kWh}_{WEdSpi} &= \text{average weekend day energy usage for space } i \\ X &= \text{number of weekdays that are adjusted to use weekend average energy usage} \end{aligned}$$

83. Calculate total annual estimated energy consumption for each space (Worksheet: “Step 4. Results”).

$$\overline{kWh}_{annSpi} = \overline{kWh}_{WdYrSpi} + \overline{kWh}_{WEDYrSpi} \quad (36)$$

Where,

$$\begin{aligned} \overline{kWh}_{annSpi} &= \text{annual energy usage for space } i \\ \overline{kWh}_{WdYrSpi} &= \text{annual weekday energy usage for space } i \\ \overline{kWh}_{WEDYrSpi} &= \text{annual weekend day energy usage for space } i \end{aligned}$$

84. Sum the annual estimated energy consumption for all spaces that have been measured (Worksheet: “Step 4. Results”).

$$\overline{kWh}_{ann} = \sum_{n=1}^n \overline{kWh}_{annSpi} \quad (37)$$

Where,

$$\begin{aligned} \overline{kWh}_{ann} &= \text{total annual energy usage for spaces measured} \\ \overline{kWh}_{WdYrSpi} &= \text{annual weekday energy usage for each space } i \\ n &= \text{number of spaces } i \text{ measured} \end{aligned}$$

A.22: Lighting on Mixed Panelboards With Automatic Controls Calculations

Long-term True Power Measurements Using a Power Logger

This calculation is used to measure the total power of a lighting system at the panel or at the feed to groups of panels at the switchgear. The data-logging power meter (e.g., DENT ELITEpro XC) collects average true RMS power in kWh data for each hour. Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption.

85. Find hourly average energy use for each hour of each day of the week (Worksheet: “Step 2. Avg Energy Calcs”).

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{h,n}}{N_f(d,h)} \quad (2)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week

$kWh_{h,n}$ = measured energy usage at each hour of each day of each week

$N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

86. Find average daily energy use (Worksheet: “Step 3. Results”, “Step 3a. Hourly Results”).

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (3)$$

Where,

$\overline{kWh}_{d,w}$ = sum of energy usage for each day of the week

$\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

87. Calculate the average energy use per day for weekdays (Worksheet: “Step 3. Results”).

$$\overline{kWh}_{wd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wd,n}}{5} \quad (4)$$

Where,

\overline{kWh}_{wd} = average energy usage for weekdays

$\overline{kWh}_{wd,n}$ = average energy of each n weekday

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

88. Calculate the average energy use per day for weekend days. (Worksheet: “Step 3. Results”).

$$\overline{kWh}_{we} = \sum_{n=7}^1 \overline{kWh}_{we,n} \quad (5)$$

Where,

\overline{kWh}_{we} = of average energy usage for each day of the week

$\overline{kWh}_{we,n}$ = average energy of each n weekend day

n = day of week: 7 = Saturday, 1 = Sunday

89. Calculate the total weekday energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (6)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage

\overline{kWh}_{Wd} = average weekday energy usage

X = number of weekdays that are adjusted to use weekend day average energy usage

90. Calculate the total weekend day energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (7)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage

\overline{kWh}_{WEd} = average weekend day energy usage

X = number of weekdays that are adjusted to use weekend day average energy usage

91. Calculate total annual estimated energy consumption (Worksheet: "Step 3. Results").

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (8)$$

Where,

\overline{kWh}_{ann} = annual energy usage

\overline{kWh}_{WdYr} = annual weekday energy usage

\overline{kWh}_{WEdYr} = annual weekend day energy usage

92. If more than one electric panel that is measured, sum the total energy usage of all panels to find the total energy usage of the facility

$$\overline{kWh} = \overline{kWh}_1 + \overline{kWh}_2 + \dots + \overline{kWh}_n \quad (9)$$

Where,

\overline{kWh} = total energy usage

\overline{kWh}_n = total energy usage for each panel

n = number of panels measured

AC Current Measurement at Main Feed with Current Sensors

This calculation is used to measure the average current of a lighting system at the panel or at the feed to groups of panels at the switchgear. The current sensor and logger (e.g., Onset CTV series and Onset HOBO UX120-006M logger) collects average current (in amperes), as directly measured by current sensors, and spot measurements for true power using a one-time clamp meter (e.g., Fluke 345). Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy

consumption. Fixture counts and nominal lamp and ballast wattages are used to estimate the percentage of the lighting system measured.

93. Calculate average energy for each hour interval (Worksheet: “Step 2. Hourly Energy Calcs”).

$$\overline{kWh}_h = \frac{I_{AC} * V_{rms} * PF * \sqrt{3}}{1000} \quad (10)$$

Where,

\overline{kWh}_h = average hourly energy
 I_{AC} = average hourly AC current
 V_{rms} = measured one-time RMS voltage value
 PF = measured one-time power factor value

94. Calculate average energy use for each hour of each day of the week (Worksheet: “Step 3. Avg Energy Calcs”, “Step 4a. Hourly Results”).

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{hour,n}}{N_f(d,h)} \quad (11)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week
 $kWh_{h,n}$ = measured energy usage at each hour of each day of each week
 $N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

95. Calculate average daily energy use (Worksheet: “Step 4. Results”).

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (12)$$

Where,

$\overline{kWh}_{d,w}$ = sum of energy usage for each day of the week
 $\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week
 n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

96. Calculate the average energy use per day for weekdays (Worksheet: “Step 4. Results”).

$$\overline{kWh}_{wd} = \frac{\sum_{n=2}^6 \overline{kWh}_{wd,n}}{5} \quad (13)$$

Where,

\overline{kWh}_{Wd} = average energy usage for weekdays
 $\overline{kWh}_{wd,n}$ = average energy of each n weekday
 n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

97. Calculate the average energy use per day for weekend days. (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEd} = \frac{\sum_{n=7}^1 \overline{kWh}_{we,n}}{2} \quad (14)$$

Where,

\overline{kWh}_{WEd} = of average energy usage for a weekend day
 $\overline{kWh}_{we,n}$ = average energy of each n weekend day
 n = day of week: 7 = Saturday, 1 = Sunday

98. Calculate the total weekday energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (15)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekday energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

99. Calculate the total weekend day energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (16)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage
 \overline{kWh}_{WEd} = average weekend day energy usage
 X = number of weekdays that are adjusted to use weekend day average energy usage

100. Calculate total annual estimated energy consumption

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (17)$$

Where,

\overline{kWh}_{ann} = annual energy usage
 \overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{WEdYr} = annual weekend day energy usage

This calculation is used to measure the average current of a lighting system in a single panel for a single or group of lighting circuits. The current sensor and logger (e.g., Onset CTV series and Onset HOBO UX120-006M logger) collects average current (in Amps), as directly measured by current sensors, and spot measurements for true power using a one-time clamp meter (e.g., Fluke 345). Measurements over a two- to four-week period are used to develop an average hourly and daily operational schedule period and then extrapolated to an annual estimate of lighting energy consumption. Fixture counts and nominal lamp and ballast wattages are used to estimate the percentage of the lighting system measured.

101. For each circuit or group of circuits measured, calculate average energy for each hour interval (Worksheet: "Step 2. Hourly Energy Calcs").

$$\overline{kWh}_h = \frac{I_{AC} * V_{rms} * PF * \sqrt{3}}{1000} \quad (18)$$

Where,

\overline{kWh}_h = True power for each hour
 I_{AC} = average hourly AC current
 V_{rms} = measured one-time RMS voltage value
 PF = measured one-time power factor value

102. For each circuit or group of circuits measured, calculate average energy use for each hour of each day of the week (Worksheet: "Step 3. Avg Energy Calcs").

$$\overline{kWh}_{d,h} = \frac{\sum_1^{N_f(d,h)} kWh_{hour,n}}{N_f(d,h)} \quad (19)$$

Where,

$\overline{kWh}_{d,h}$ = average energy of each hour for each day of the week
 $\overline{kWh}_{h,n}$ = measured energy usage at each hour of each day of each week
 $N_f(d,h)$ = total number of measured data points that fall on day of week, d , and hour of the day, h

103. For each circuit or group of circuits measured, calculate average daily energy use (Worksheet: "Step 4. Results").

$$\overline{kWh}_{d,w} = \sum_{n=0}^{23} \overline{kWh}_{d,h,n} \quad (20)$$

Where,

$\overline{kWh}_{d,w}$ = average energy usage for each day of the week

$\overline{kWh}_{d,h,n}$ = average energy of each n hour for each day of the week

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

104. Calculate the average energy use per day for weekdays for all circuits (Worksheet: "Step 4. Results").

$$\overline{kWh}_{wDCT} = \frac{\sum_{n=2}^6 \overline{kWh}_{wdC1,n}}{5} + \frac{\sum_{n=2}^6 \overline{kWh}_{wdC2,n}}{5} + \dots \quad (21)$$

Where,

\overline{kWh}_{wDCT} = average energy usage for weekdays for all circuits

$\overline{kWh}_{wdCn,n}$ = average energy of each circuit for each n weekday of the week

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

105. Calculate the average energy use per day for weekend days for all circuits (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEEdCT} = \frac{\sum_{n=7}^1 \overline{kWh}_{weC1,n}}{2} + \frac{\sum_{n=7}^1 \overline{kWh}_{weC2,n}}{2} + \dots \quad (22)$$

Where,

\overline{kWh}_{WEEdCT} = average energy usage for weekend days for all circuits
 $\overline{kWh}_{weCn,n}$ = average energy of each circuit for each n weekend day
 n = day of week: 7= Saturday, 1 = Sunday

106. Calculate the total Weekday energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{Wd} * (261 \text{ weekdays per year} - X) \quad (23)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{Wd} = average weekly weekday energy usage
 X = number of weekdays that are considered holidays and adjusted to weekend day average energy usage

107. Calculate the total weekend day energy consumption (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdYr} = \overline{kWh}_{WEd} * (104 \text{ weekend days per year} + X) \quad (24)$$

Where,

\overline{kWh}_{WEdYr} = annual weekend day energy usage
 \overline{kWh}_{WEd} = average weekly weekend day energy usage
 X = number of weekdays that are considered holidays and adjusted to weekend day average energy usage

108. Calculate total annual estimated energy consumption

$$\overline{kWh}_{ann} = \overline{kWh}_{WdYr} + \overline{kWh}_{WEdYr} \quad (25)$$

Where,

\overline{kWh}_{ann} = annual energy usage
 \overline{kWh}_{WdYr} = annual weekday energy usage
 \overline{kWh}_{WEdYr} = annual weekend day energy usage

Fixture Inventory and Long-term Light On/Off Operation

This calculation tool is used for spaces that have manual controls that may be utilized by occupants. Inputs include the total number of fixtures and associated power draw in each space that is manually controlled. Measurement of the on/off status of lighting in each space is done with a lighting logger (e.g., Onset HOB0 UX90-002). If possible, measure the total connected load in each space or the total lighting load either at the main feed or each lighting circuit. Use a minimum of one light on/off logger for each space and focus measurement of hours of operation on the fixture types and spaces with the largest total. For more than two distinct spaces, use multiple workbooks and sum totals.

109. For each space use manufactures' specifications or site survey to determine wattage of fixtures. Determine fixture count and multiply to determine total wattage of that fixture, (Worksheet: "Step 1.1 Space #1 Raw Data" or "Step 1.2 Space #2 Raw Data").

$$kW_{fix1} = N \times W_{fix1} \quad (26)$$

Where,

kW_{fix1} = total power draw of single fixture type in each space, i , that is individually controlled

W_{fix1} = wattage of a single fixture type 1

N = number of fixtures with that wattage in the space being measured

110. Sum the total power draw of all fixture types for the space being measured (Worksheet: "Step 1.1 Space #1 Raw Data" or "Step 1.2 Space #2 Raw Data").

$$kW_{Spi} = kW_{fix1} + kW_{fix2} + \dots \quad (27)$$

Where,

kW_{Spi} = total power draw of all light fixtures in the space i being measured

kW_{fix1} = total power draw of fixture type 1

kW_{fix2} = total power draw of fixture type 2

111. Convert lighting runtime measurements in seconds on per hour to percent on per hour in space being measured (Worksheet: "Step 2. Percent Runtime Calcs").

$$\%_{int} = \frac{t_{int}}{3600} \quad (28)$$

Where,

$\%_{int}$ = percentage of seconds the lights are on in each hour interval

t_{int} = measured number of seconds the lights are on in each hour interval

112. Find the hourly average percentage for each day of the week that the lights are on in space being measured (Worksheet: "Step 3. Daily Avg Runtime Calcs").

$$\%_{hourly} = \frac{\sum_1^n \%_{int,n}}{n} \quad (29)$$

Where,

$\%_{hourly}$ = hourly average percentage the lights are on

$\%_{int}$ = percentage of seconds lights are on in each hour interval

n = number of data points that have the same hour of day and day of week

113. Sum the percentages for each day to determine the daily operating hours per day (in space being measured (Worksheet: "Step 4. Results").

$$\%_{daily} = \sum_{n=0}^{23} \%_{hourly,n} \quad (30)$$

Where,

$\%_{daily}$ = daily average hours in percent per day the lights are on

$\%_{hourly}$ = hourly average percentage lights were on

n = hour of the day where 0 is 12:00 a.m. to 12:59 a.m.

114. Convert percentage to hours to determine hours per day lights are on in space being measured (Worksheet: "Step 4. Results").

$$T_{daily} = \%_{daily}/100 \quad (31)$$

Where,

T_{daily} = Hours light are on

$\%_{daily}$ = daily average hours in percent per day the lights are on

115. Calculate the average energy use per day for weekdays in each space being measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{Wd} = \frac{\sum_{n=2}^6 T_{wd,n}}{5} \times kW_{Spi} \quad (32)$$

Where,

\overline{kWh}_{Wd} = average energy usage for weekdays

kW_{Spi} = total lighting power draw in space i being measured from Eq. 27

$T_{wd,n}$ = average hours of operation of each n weekday in space being measured

n = day of week: 2 = Monday, 3 = Tuesday...6 = Friday

116. Calculate the average energy use per day for weekend days in each space being measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEd} = \frac{\sum_{n=7}^1 T_{we,n}}{2} \times kW_{Spi} \quad (33)$$

Where,

\overline{kWh}_{WEd} = of average energy usage for a weekend day

kW_{Spi} = total lighting power draw in each space i being measured from Eq. 27

$T_{we,n}$ = average energy of each n weekend day

n = day of week: 7 = Saturday, 1 = Sunday

117. Calculate the total weekday energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WdYr} = \overline{kWh}_{WdSpi} * (261 \text{ weekdays per year} - X) \quad (34)$$

Where,

\overline{kWh}_{WdYr} = annual weekday energy usage

\overline{kWh}_{WdSpi} = average weekday energy usage for space i

X = number of weekdays that are adjusted to use weekend day average energy usage

118. Calculate the total weekend day energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{WEdYrSpi} = \overline{kWh}_{WEdSpi} * (104 \text{ weekend days per year} + X) \quad (35)$$

Where,

$\overline{kWh}_{WEdYrSpi}$ = annual weekend day energy usage for space i

\overline{kWh}_{WEdSpi} = average weekend day energy usage for space i

X = number of weekdays that are adjusted to use weekend average energy usage

119. Calculate total annual estimated energy consumption for each space (Worksheet: "Step 4. Results").

$$\overline{kWh}_{annSpi} = \overline{kWh}_{WdYrSpi} + \overline{kWh}_{WEdYrSpi} \quad (36)$$

Where,

\overline{kWh}_{annSpi} = annual energy usage for space i

$\overline{kWh}_{WdYrSpi}$ = annual weekday energy usage for space i

$\overline{kWh}_{WEdYrSpi}$ = annual weekend day energy usage for space i

120. Sum the annual estimated energy consumption for all spaces that have been measured (Worksheet: "Step 4. Results").

$$\overline{kWh}_{ann} = \sum_{n=1}^n \overline{kWh}_{annSpi} \quad (37)$$

Where,

\overline{kWh}_{ann} = total annual energy usage for spaces measured
 $\overline{kWh}_{WdYrSpi}$ = annual weekday energy usage for each space, i
 n = number of spaces i measured

A.23: Additional Resources

For more information on the different types of fans found in AHU systems, please read “Application of Fans in Commercial HVAC Equipment” from the Carrier Corporation: <https://www.utcccs-cdn.com/hvac/docs/1001/Public/0F/04-581070-01.pdf>

For more information of the different types of motors that can be used in an AHU retrofit, please read Chapter 7 (starts on page 91) of the Premium Efficiency Motor Selection and Application Guide from the U.S. Department of Energy: https://www.energy.gov/sites/prod/files/2014/04/f15/amo_motors_handbook_web.pdf#page=91

For general information on Option A M&V guides, please read section 4.2 (starts on page 23) of “M&V Guidelines: Measurement and Verification for Performance-Based Contracts Version 4.0” from the U.S. Department of Energy: https://www.energy.gov/sites/prod/files/2016/01/f28/mv_guide_4_0.pdf#page=23

A.24: Bibliography

5. *Fans and Blowers* 5. *FANS AND BLOWERS Syllabus Fans and Blowers*. This resource went over the different types of pressures (static, velocity, and total) on page 106 that are prevalent in an AHU duct. This resource also provided some figures on page 107 which illustrated how the static, total, and velocity pressures are measured.

A Quick Introduction to Air Handling Units. “A Quick Introduction to Air Handling Units - AirFixture.” *AirFixture*, 3 Jan. 2019, airfixture.com/blog/a-quick-introduction-to-air-handling-units.

admintheseverngr. “VAV vs VVT HVAC Systems - The Severn Group.” *The Severn Group*, Severn Group, 23 May 2019, <http://www.theseverngroup.com/vav-vs-vvt-hvac-systems/>. This resource provided a diagram of a VAV system, which was useful in helping to understand how a VAV system works in conjunction with an AHU.

ASHRAE. *ASHRAE Guideline 14 - 2014 : Measurement of Energy, Demand, and Water Savings*. ASHRAE, 18 Dec. 2014. Section A3.2 was used. This source also references AMCA Publication 203. For measuring fan performance, the source also references the following standards: ANSI/ASHRAE Standard 51-2007 is the Laboratory Methods of Testing Fans for Rating, AMCA Standard 803-02 (R2008), Site Performance Test Standard for Power Plant and Industrial Fans. AMCA Publication

203-90 (R2011), Field Performance Measurement of Fan Systems, and AMCA Publication 201-02 (R2011), Fans and Systems. ASME PTC 11-2008, ASME PTC 11 was also referenced in this source, which provided standard procedures for testing fans under actual operating conditions. Two approaches are included, one using mass flow rate and fan specific energy and the other (more common in HVAC applications) using volume flow rate and pressure. Section E-2 was also used for this M&V guide include Section 5.2.4.

Bonnerville Power Association. *Engineering Calculations with Verification Protocol*. May 2012. Has example of VFD M&V evaluation and reporting.

---. *Verification of Energy Use Indexing Protocol*. May 2012. This protocol has a useful example of documentation and reporting. Simple and clear. Report on the following topics: M&V approach, measurement boundary, baseline and post-installation measurement periods, data results, calculations, summary of annual savings.

Doty, Steve, and Wayne C Turner. *Energy Management Handbook*. Boca Raton, Fla. Crc Press/Taylor & Francis Lilburn, Ga Fairmont Press C, 2013. Section 10.9: HVAC System Distribution Energy - The equation for fan horsepower was used in this M&V guide.

Pacific Northwest National Laboratory. *Building Re-Tuning Training Guide: AHU Static Pressure Control*. This guide points out that static pressure and damper position should be measured to re-tune the static pressure operation of an AHU. The fan is modulated to meet static pressure set points, which ideally should vary through the day. When doing M&V for a fan retrofit, we should measure/record the static pressure set points. If the set points differ between the pre and post-retrofit conditions, then the change in power demand for the new fan will not be valid.

The Engineering Mindset. "How Air Handling Units Work AHU Working Principle Hvac Ventilation." *YouTube*, 17 Sept. 2018, <http://www.youtube.com/watch?v=KCiv8IAUkh8>. Accessed 6 Dec. 2019.

Titan. "Under Pressure: Is Building Air Pressure Really Important." *Titan-Air.Com*, 2019, <http://www.titan-air.com/under-pressure--is-building-air-pressure-really-important.html>. This resource was important in describing why it is important to control the pressure inside a building, which is important in AHU design.

Trane. "Direct-Drive Plenum Fans and Fan Arrays." 2010. Important notes obtained from this source include the following: Plenum fans have become more popular as direct drive VFD motors have replaced constant speed motors connected to belt driven centrifugal fans. More efficient, less vibration, quieter. Variable Air Volume control in an AHU is achieved by the VFD by changing the speed of the fan or the diameter of the fan blades. Fan arrays (smaller fans (sets of 2, 4, or 6) across the duct) are used when there are space constraints. The length of the AHU can be shortened. Side benefit is redundancy if one of the fans fail. Drawback is higher energy consumption and noisier. If AHU discharges into long straight duct, then housed airfoil fan requires less power. A plenum fan will be quieter. If the duct is bent or there is a filter at the end of the AHU, then a plenum fan will be more energy efficient and quieter. Plenum fans are also lower maintenance because the absence of a belt.

York. *Return Fan and Exhaust Fan Economizers and Building Pressurization*. This document discusses the types of fans found in the economizer sections of AHUs. Three types are barometric relief dampers (i.e., no fan), exhaust fan and return fans. Exhaust fans are downstream of the mixing zone (where exhaust air is mixed with supply air), while return fans are upstream of the mixing zone. Return fans run continuously and therefore might be run at constant speed. Exhaust fans are variable speed such that the air mixing is done to meet mixing air temperature set points.