Southern New Hampshire University | School of Engineering, Technology, and Aeronautics

Critical Design Review

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TEAM THERMOCLINE

Project Team & Roles

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Chief Test Engineer
(M.E.)

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(E.E.)

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Systems Engineer
(E.E.)

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Project Engineer
(M.E.)

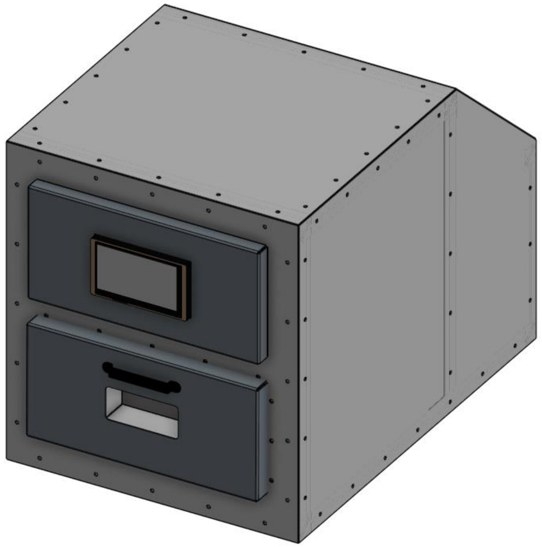
Agenda

- Overview
- Requirements Compliance
- Subsystems
  - Structural
  - Thermal-Fluid
  - Electrical
  - Control System
  - Safety
- Budget
- Open Design Items
- Data Acceptance Package Status

Follow or annotate on your device.

Context

- Thermally-controlled Printed Circuit Board (“PCB”) testing chamber
  - Table-top system
  - User-control & automatic operation
  - Spanning 0°C – 70°C commercial temperature range
- Purpose: evaluating operation, functionality, & performance of electronic components in an enclosure replicating environmental conditions.



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Requirements Compliance

Req. Num	Short Desc.	Status	Margin
STR-01	System Bounds	Current CAD and footprint overall fit in our maximum size.	10%
STR-03	Insulation and seal	Minimum thicknesses for insulation are within our requirements	<5%
THE-01	Min. Temperature	Pre-modification system reached 0, r410 boils at –43.	50%
THE-02	Sweep Speed	Heat rejection is 2-3 times larger than evaporator requirement	35%
CON-08	Log faults	RTOS logging setup as part of underlying structure	Met
SAF-05	Have a safe state	Implemented in underlying structure	Met

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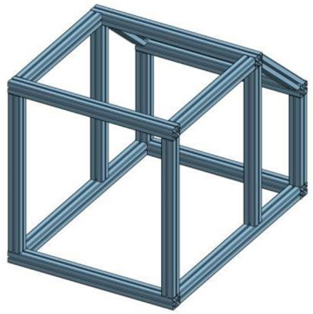
System Design

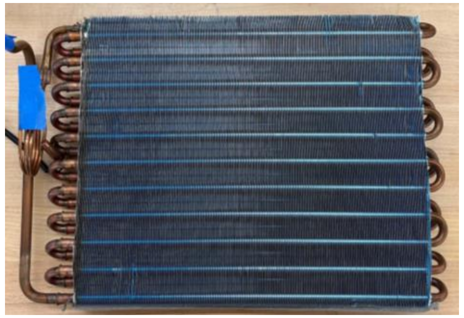
Holistic System

Structural



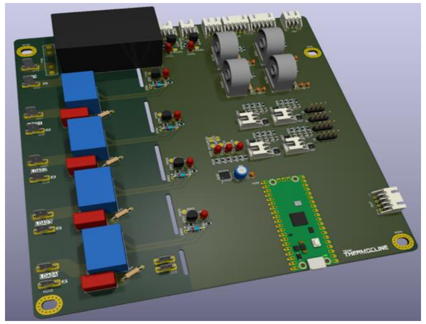
1.1 - The system shall accommodate a 12x12" PCB as a device to be tested.

Thermal-fluid



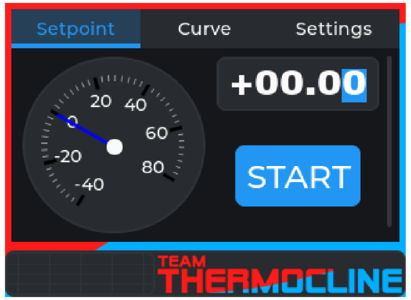
2.1.1 - The PCB shall be interfaceable while the system is running.

Electrical



3.2.1 - The system shall cover commercial temperature range (0-70°C)

Control System



3.2.4 - The system shall maintain a temperature ±3°C of setpoint.

Safety

3.4.5 - The system shall be capable of sweeping the temperature range in a 24-hour cycle.

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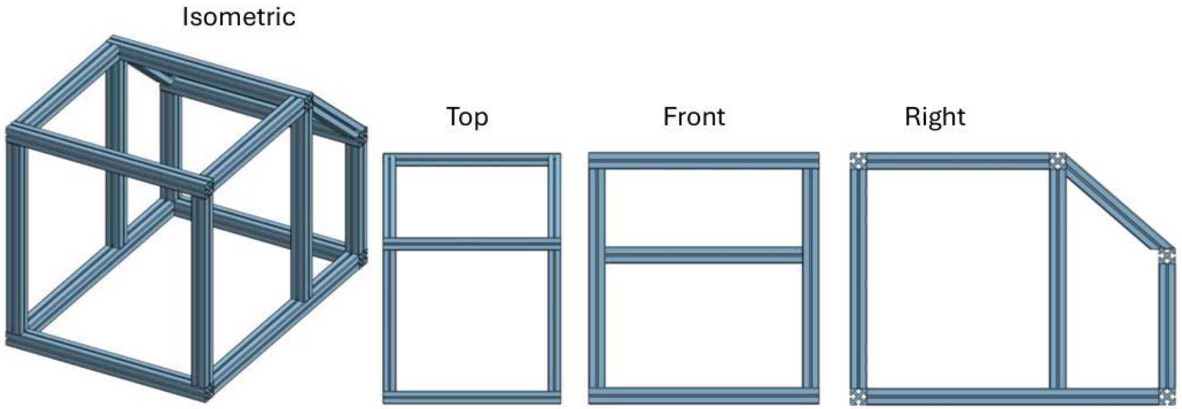
Subsystem Design: Structural



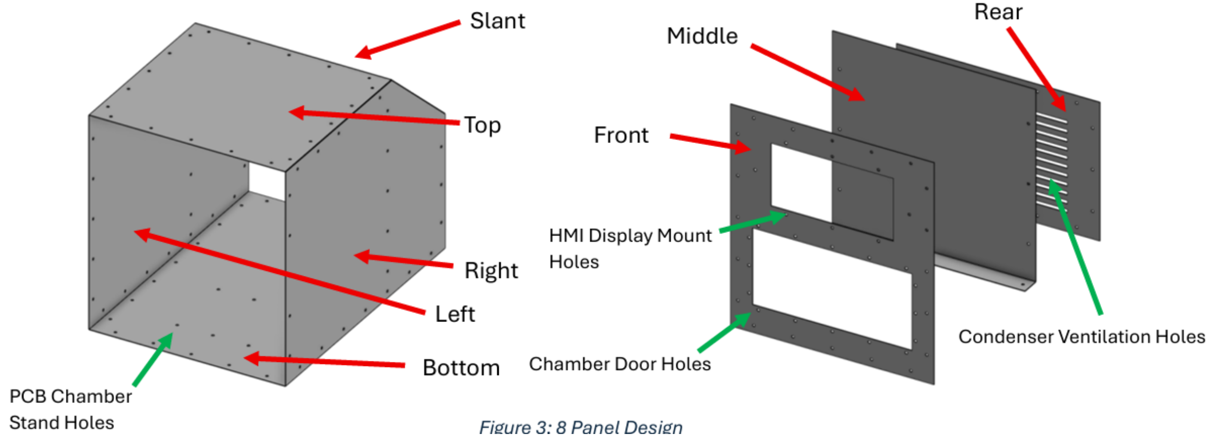


Figure 3: 8 Panel Design

Driving Requirements:

- **STR-01**: The system shall have external base dimensions of no more than 30x30 inches.
- **STR-03**: The chamber opening(s) shall include proper thermal sealing according to ASTM F1886.

Onshape Link (View Only)

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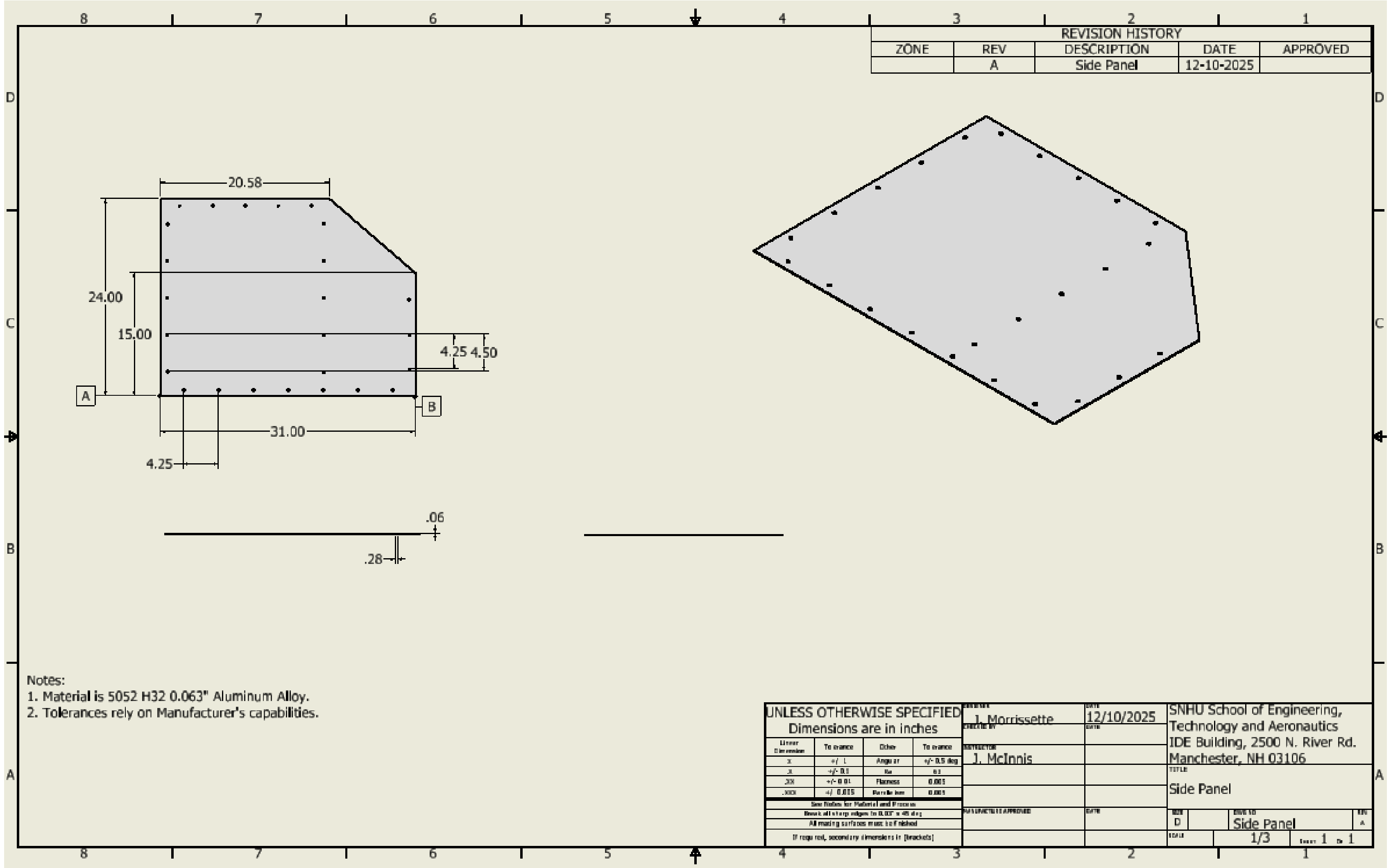
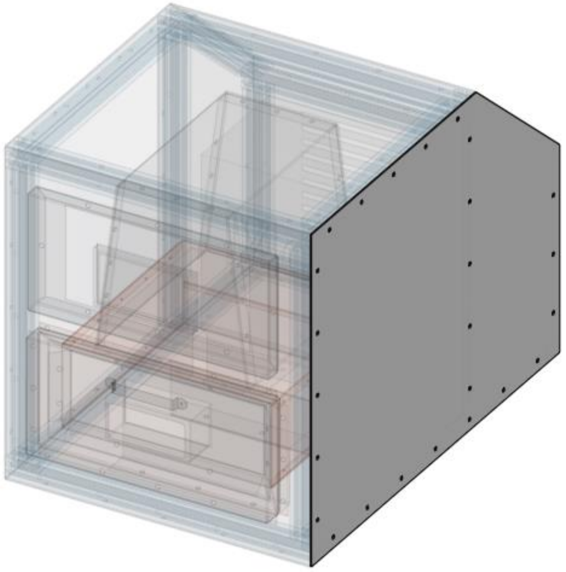
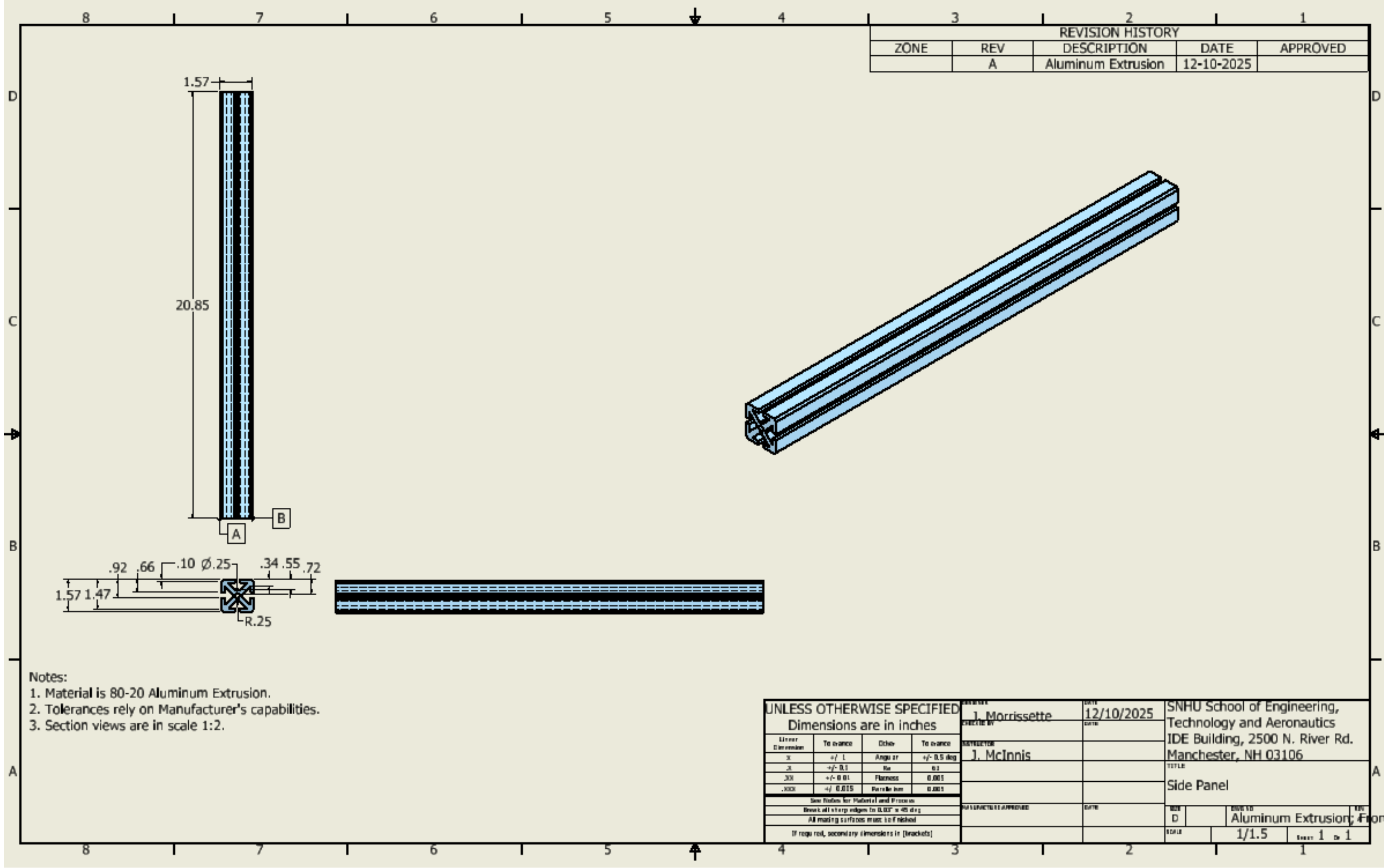
Subsystem Design: Structural



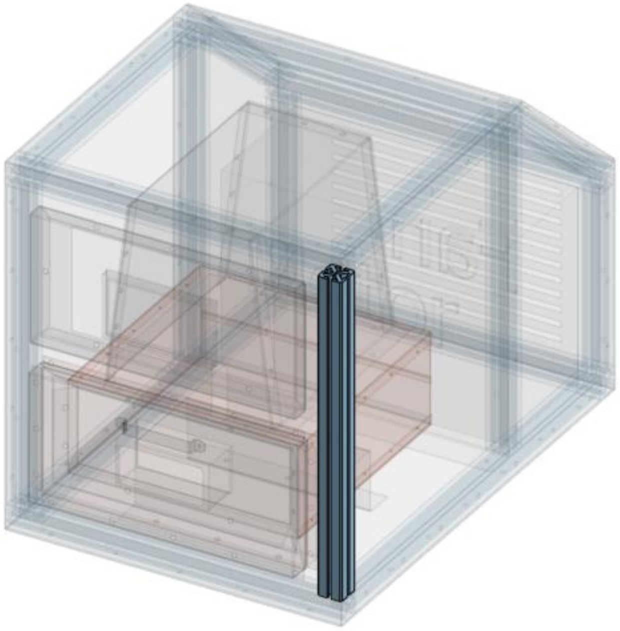
External Side Panel



Subsystem Design: Structural



Aluminum Extrusion Frame



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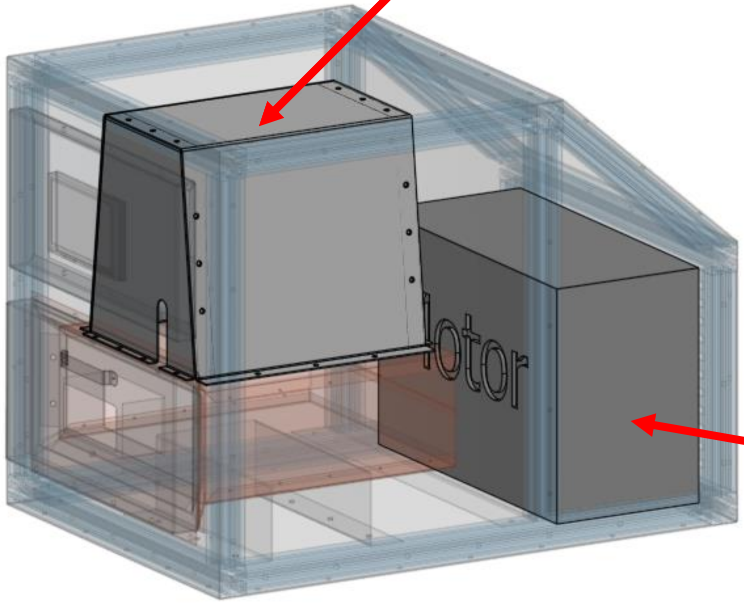
Subsystem Design: Thermo-fluid

R410a Recovery Tank

Airflow Management Chamber
(Heater, Evaporator, & Fan)



Heat Outlet Chamber
(Condenser & Fan)

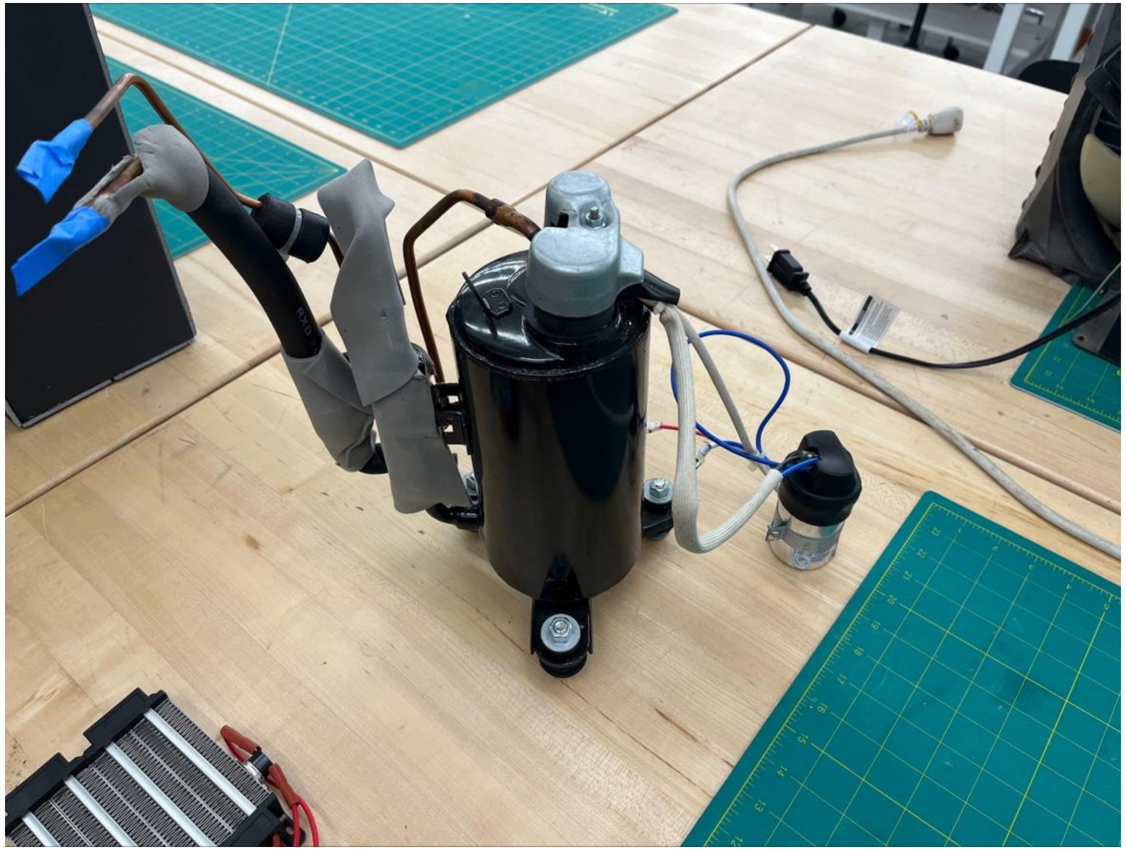
Driving Requirements:

- **THE-01**: The system shall cover *commercial* temperature range (0°C-70°C).
- **THE-02**: The system shall be capable of sweeping all temperature ranges within a 24-hour cycle.

Subsystem Design: Thermo-fluid

We tested our compressor prior to disassembly for verification of our minimum performance requirements.

- **Results:**
  - Condenser Temperature: **0°C (< 30min until steady)**
  - Compressor Temperature: **74°C (< 30min until steady)**
  - Current Draw: **5A (~ 2s until steady)**



Mechanical compressor

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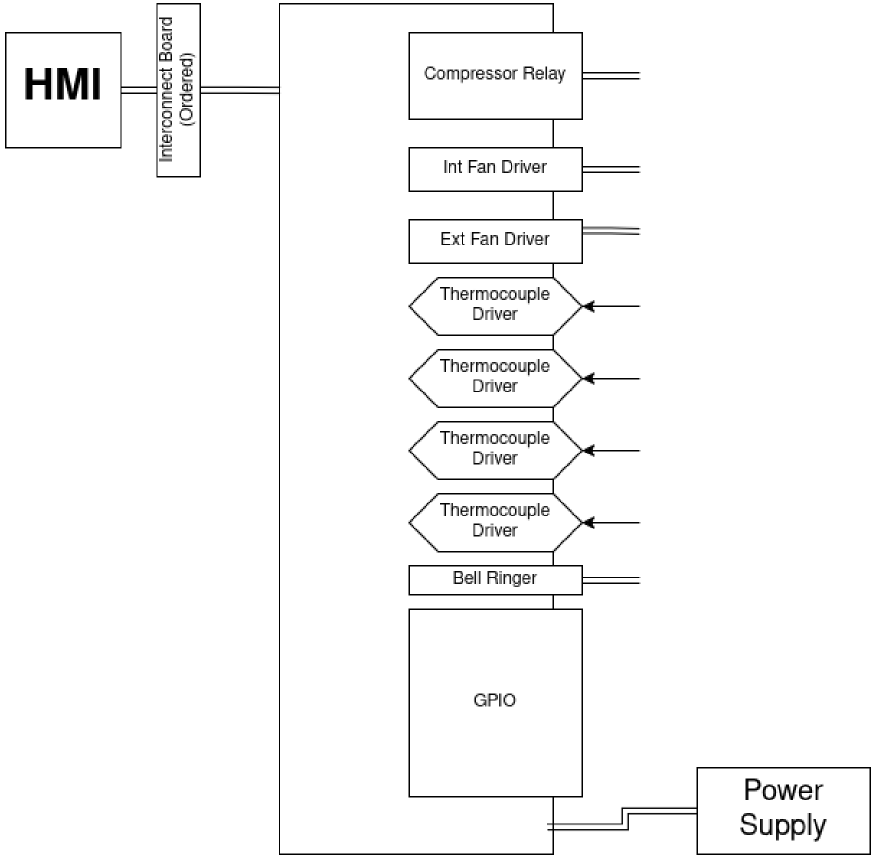
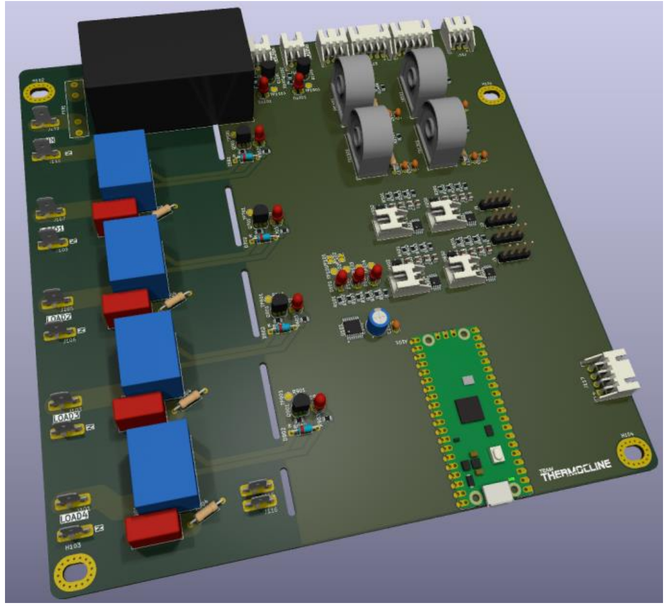
Subsystem Design: Electrical



High level overview

Driving Requirements:

- COM-03: The system shall adhere to UL 61010 for test and measurement equipment.



Mainboard PCB (current)

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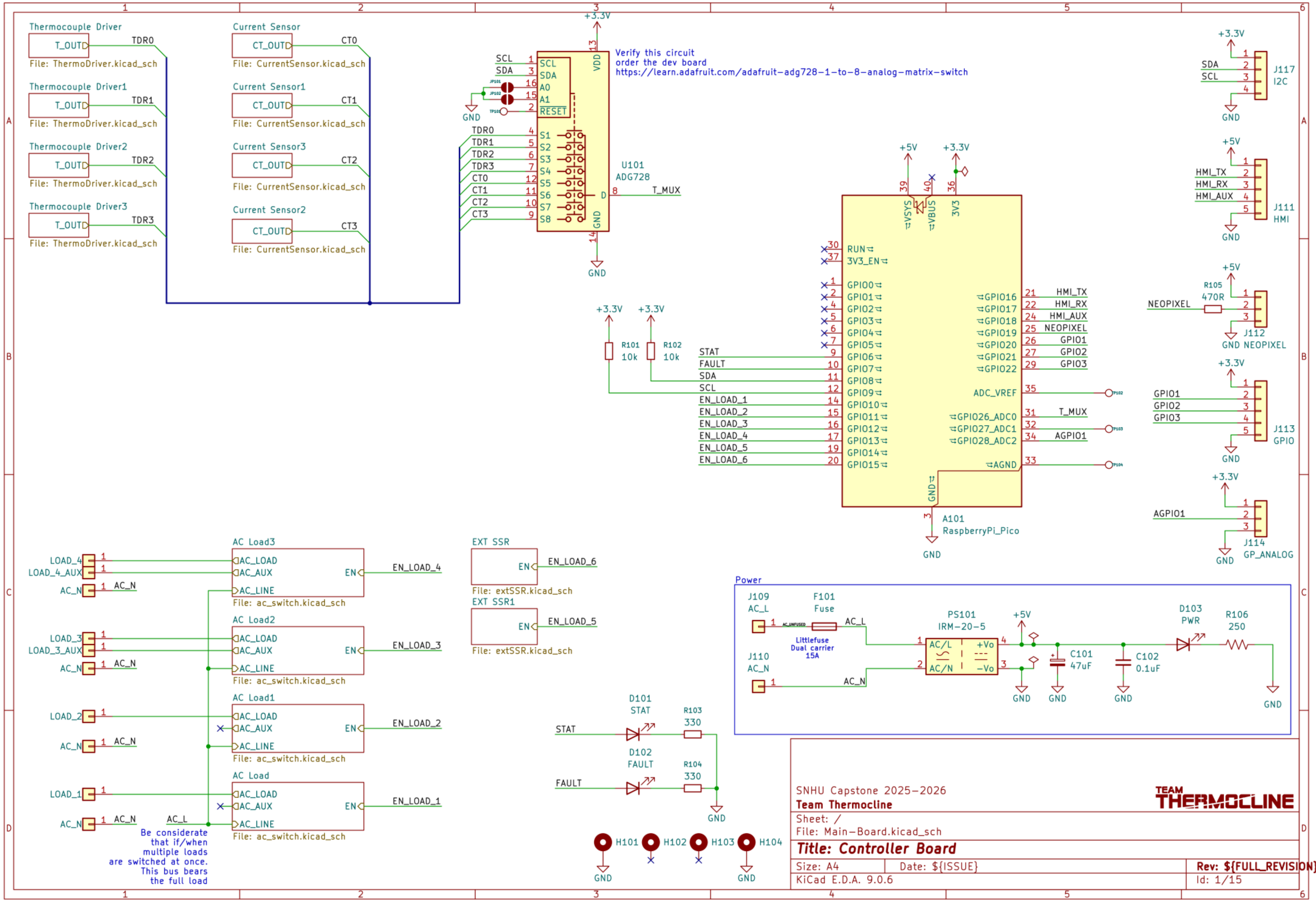
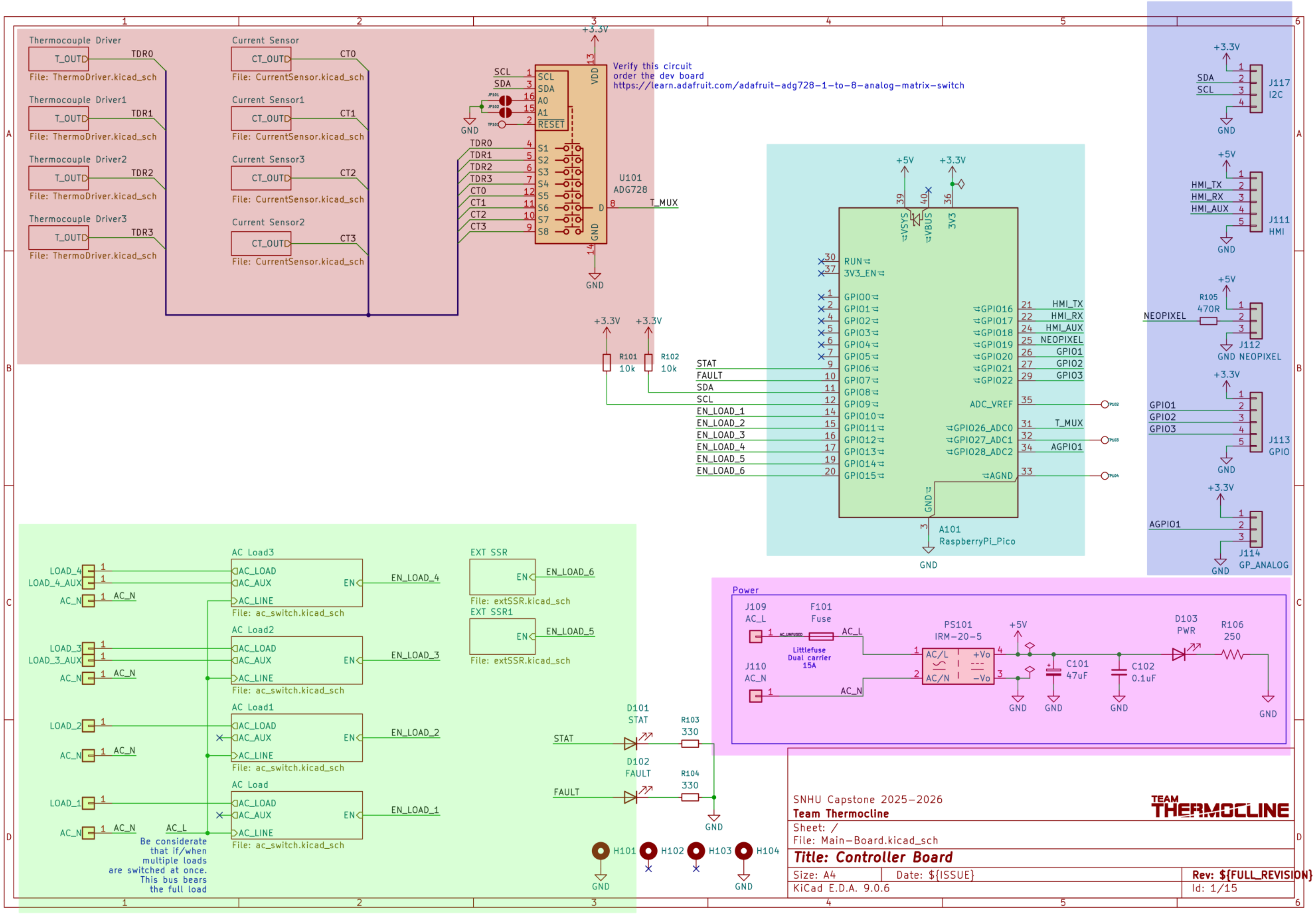
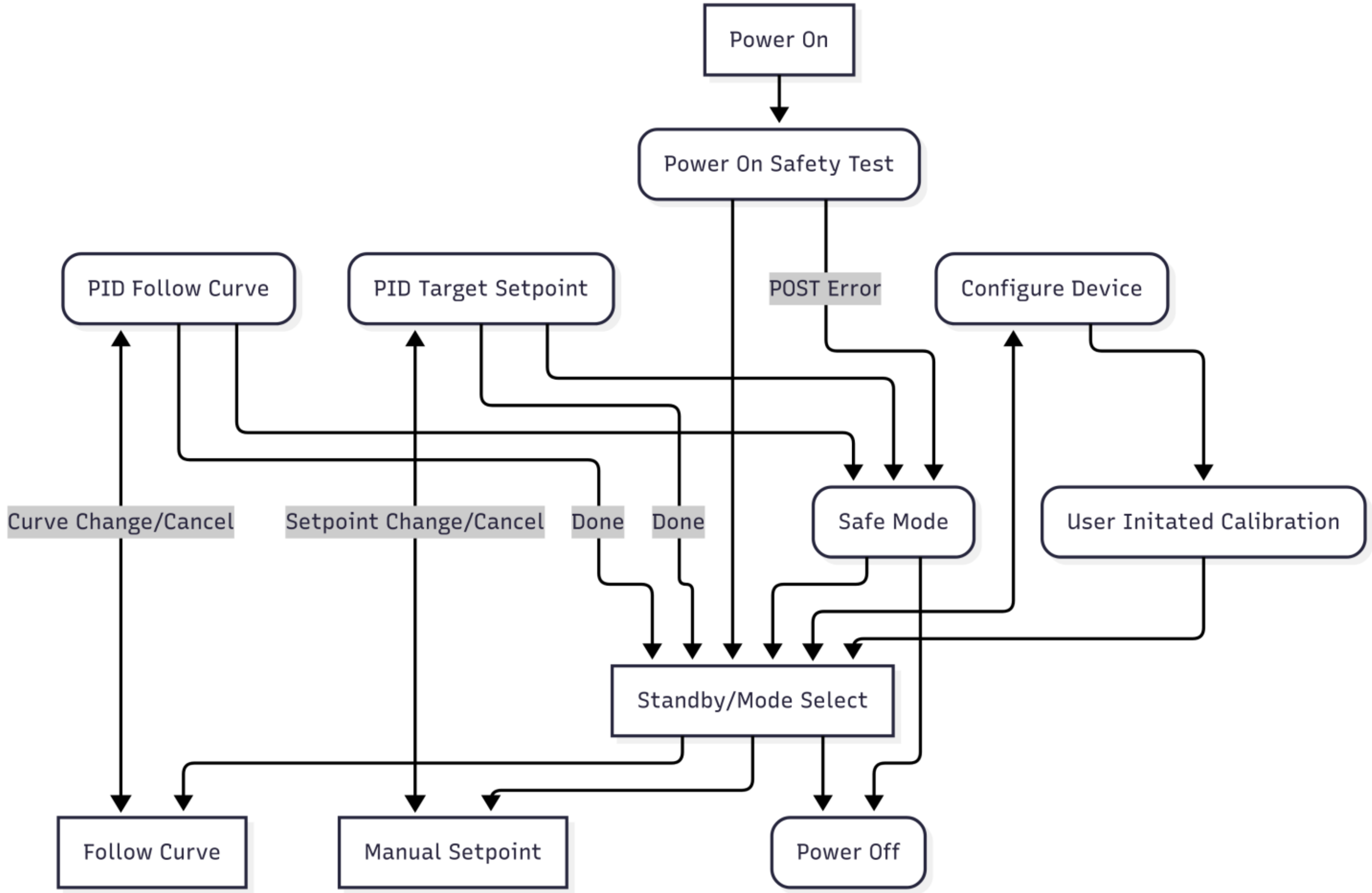

Thermocouple Driver
T_OUT
TDR0
File: ThermoDriver.kicad_sch
Thermocouple Driver1
TDR1
Thermocouple Driver2
TDR2
Thermocouple Driver3
TDR3
Current Sensor
CT_OUT
CT0
File: CurrentSensor.kicad_sch
Current Sensor1
CT1
Current Sensor3
CT2
Current Sensor2
CT3
+3.3V
Verify this circuit
order the dev board
https://adafruit.com/adafruit-adg728-1-to-8-analog-matrix-switch
SCL
SDA
A0
A1
RESET
VDD
S1 S2 S3 S4 S5 S6 S7 S8
D
T_MUX
U101
ADG728
GND
+5V
+3.3V
VSYS
VBUS
3V3
RUN
3V3_EN
GPIO0 GPIO1 GPIO2 GPIO3 GPIO4 GPIO5 GPIO6 GPIO7 GPIO8 GPIO9 GPIO10 GPIO11 GPIO12 GPIO13 GPIO14 GPIO15
GPIO16 GPIO17 GPIO18 GPIO19 GPIO20 GPIO21 GPIO22
ADC_VREF
GPIO26_ADC0
GPIO27_ADC1
GPIO28_ADC2
AGND
A101
RaspberryPi_Pico
R101 10k
R102 10k
STAT
FAULT
EN_LOAD_1
EN_LOAD_2
EN_LOAD_3
EN_LOAD_4
EN_LOAD_5
EN_LOAD_6
HMI_TX
HMI_RX
HMI_AUX
NEOPIXEL
GPIO1
GPIO2
GPIO3
AGPIO1
J117 I2C
J111 HMI
R105 470R
J112 NEOPIXEL
J113 GPIO
J114 GP_ANALOG
AC Load3
AC_LOAD
AC_AUX
AC_LINE
EN
File: ac_switch.kicad_sch
AC Load2
AC Load1
AC Load
LOAD_4
LOAD_4_AUX
AC_N
LOAD_3
LOAD_3_AUX
LOAD_2
LOAD_1
AC_L
Be considerate that if/when multiple loads are switched at once. This bus bears the full load
EXT SSR
File: extSSR.kicad_sch
EXT SSR1
D101 STAT
R103 330
D102 FAULT
R104 330
H101
H102
H103
H104
Power
J109 AC_L
F101 Fuse
Littlefuse Dual carrier 15A
J110 AC_N
PS101 IRM-20-5
AC/L
AC/N
+Vo
-Vo
C101 47uF
C102 0.1uF
D103 PWR
R106 250
SNHU Capstone 2025-2026
Team Thermocline
TEAM THERMOCLINE
Sheet: /
File: Main-Board.kicad_sch
Title: Controller Board
Size: A4
Date: ${ISSUE}
Rev: ${FULL_REVISION}
KiCad E.D.A. 9.0.6
Id: 1/15


Thermocouple Driver
T_OUT
TDR0
File: ThermoDriver.kicad_sch
Thermocouple Driver1
TDR1
Thermocouple Driver2
TDR2
Thermocouple Driver3
TDR3
Current Sensor
CT_OUT
CT0
File: CurrentSensor.kicad_sch
Current Sensor1
CT1
Current Sensor3
CT2
Current Sensor2
CT3
+3.3V
SCL
SDA
A0
A1
RESET
VDD
S1
S2
S3
S4
S5
S6
S7
S8
D
GND
U101
ADG728
T_MUX
Verify this circuit
order the dev board
https://learn.adafruit.com/adafruit-adg728-1-to-8-analog-matrix-switch
R101
10k
R102
10k
STAT
FAULT
EN_LOAD_1
EN_LOAD_2
EN_LOAD_3
EN_LOAD_4
EN_LOAD_5
EN_LOAD_6
+5V
VSYS
VBUS
3V3
RUN
3V3_EN
GPIO0
GPIO1
GPIO2
GPIO3
GPIO4
GPIO5
GPIO6
GPIO7
GPIO8
GPIO9
GPIO10
GPIO11
GPIO12
GPIO13
GPIO14
GPIO15
GPIO16
GPIO17
GPIO18
GPIO19
GPIO20
GPIO21
GPIO22
ADC_VREF
GPIO26_ADC0
GPIO27_ADC1
GPIO28_ADC2
AGND
HMI_TX
HMI_RX
HMI_AUX
NEOPIXEL
AGPIO1
A101
RaspberryPi_Pico
J117
I2C
J111
HMI
R105
470R
J112
GND NEOPIXEL
J113
GPIO
J114
GP_ANALOG
LOAD_4
LOAD_4_AUX
AC_N
LOAD_3
LOAD_3_AUX
LOAD_2
LOAD_1
AC_L
AC Load3
AC Load2
AC Load1
AC Load
AC_LOAD
AC_AUX
AC_LINE
EN
File: ac_switch.kicad_sch
Be considerate
that if/when
multiple loads
are switched at once.
This bus bears
the full load
EXT SSR
EXT SSR1
File: extSSR.kicad_sch
D101
STAT
D102
FAULT
R103
330
R104
330
H101
H102
H103
H104
Power
J109
AC_L
F101
Fuse
Littlefuse
Dual carrier
15A
J110
AC_N
PS101
IRM-20-5
AC/L
AC/N
+Vo
-Vo
C101
47uF
C102
0.1uF
D103
PWR
R106
250
SNHU Capstone 2025-2026
Team Thermocline
TEAM THERMOCLINE
Sheet: /
File: Main-Board.kicad_sch
Title: Controller Board
Size: A4
Date: ${ISSUE}
Rev: ${FULL_REVISION}
KiCad E.D.A. 9.0.6
Id: 1/15

Subsystem Design: Control System



Driving Requirements

CON-07: The system shall log humidity data.

CON-08: The system shall log faults for safety measures.

CON-09: The system shall have a ″shutdown″ state.

CON-10: The system shall have a ″standby″ mode.

CON-11: The system shall have a normal operating ″start″ mode.

CON-12: The system shall allow for manual switching between modes.

SAF-05: The system shall have a ″safe″ state.

Subsystem Design: Control System

```
/**
 * @brief Queueable command structure
 *
 * You can use almost anything in a FreeRTOS queue,
 * but this structure pretty much has everything we want.
 * Feel free to edit.
 * @author Joe
 */
struct Command {
  Interface interface;
  char command[64]; // Command name/type
  char data[512];   // JSON data/arguments as string

  /**
   * @brief Default constructor - initializes with empty values
   */
  Command() : interface(Interface::UNKNOWN) {
    command[0] = '\0';
    data[0] = '\0';
  }
```

- RTOS boilerplate and command structure is laid out.
- Communication already works solidly with the website https://team-thermocline.github.io/
- Connection to the HMI is the same language and format

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Subsystem Design: Safety

- **SAF-01**: The internal surfaces shall be safe for electronics according to ASTM D3874-20
- **SAF-02**: The system external surfaces shall not exceed the safe-touch temperature of 50 C according to ASTM C1055
- **SAF-03**: The System shall be able to operate in normal environment (external) conditions of 21 C
- **SAF-04**: The system shall include a safety measure if temperature range & tolerance is exceeded

Safety Warning Light

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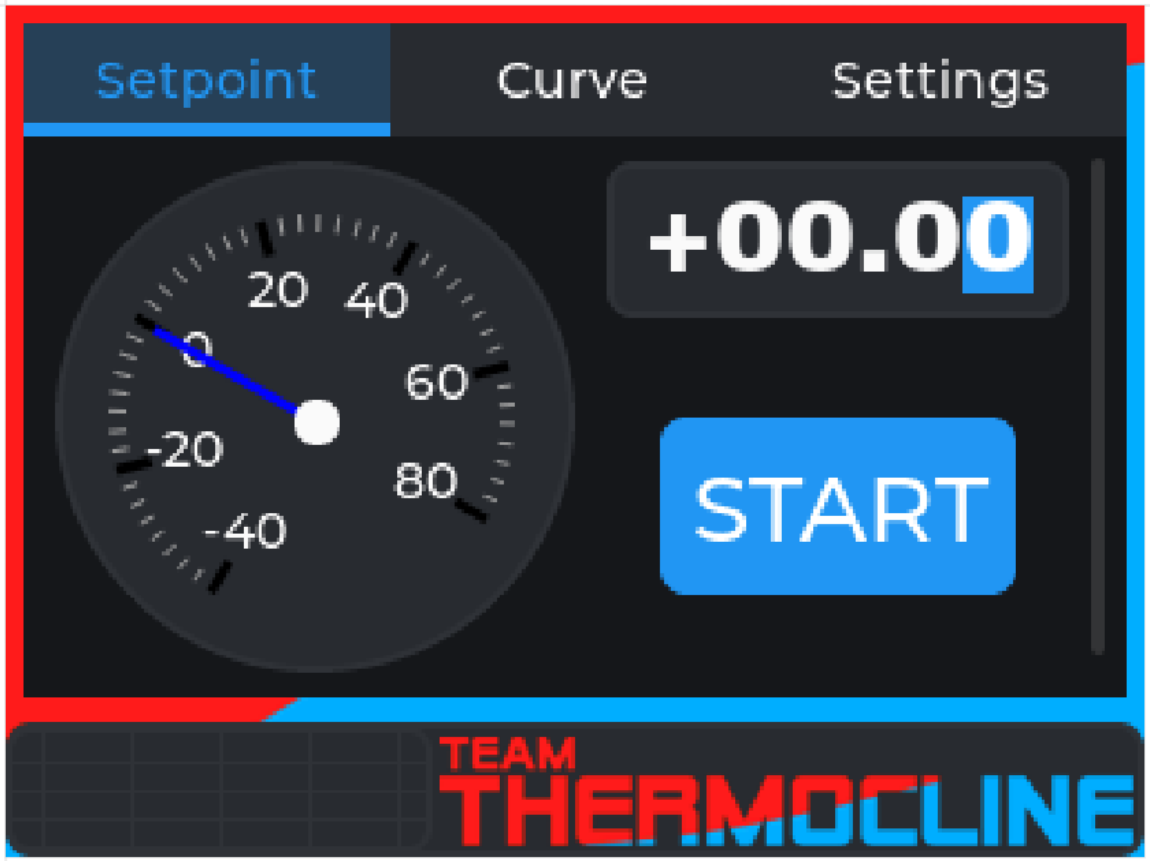
Subsystem Design: Control System

Control System HMI

The HMI (Human Machine Interface) is written in C with LVGL as the graphics backend.

Communicates to the MCU with the same JSON based communication language.

Meets requirements for presenting the state of the machine to the user as well as allowing user input.



UI in LVGL

Budget:

Overall Budget

#	Category	Original Budget ($	Spent ($)	Balance ($)
1	Materials	600	42.69	557.31
2	Hardware	600	87.72	512.28
3	Software	600	50	550
4	Management Reserve	600	0	600
5	Other	600	503	97
	Total ($):	3000	683.41	2316.59

We have spent 23% of our total budget.

Itemized Expenses

Item	% of Budget	Price
PCB	1%	$ 35.00
Compressor	0%	$ -
SendCutSend	1%	$ 30.00
HMI Screen	2%	$ 50.00
Recovery Pump	13%	$ 388.00
Manifold Gauge	2%	$ 49.00
Reciver Cylinder	2%	$ 66.00
Resistive Heater Core	1%	$ 29.55
9" Fan	1%	$ 23.17
Polycarb Square Sheet	0%	$ 12.69
Total Purchases	23%	$ 683.41
Total Budget	100%	3000
Total Budget Left	77%	$2,316.59

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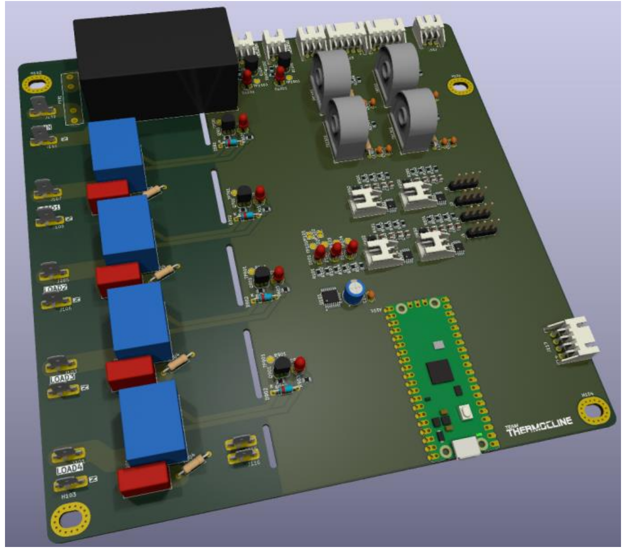
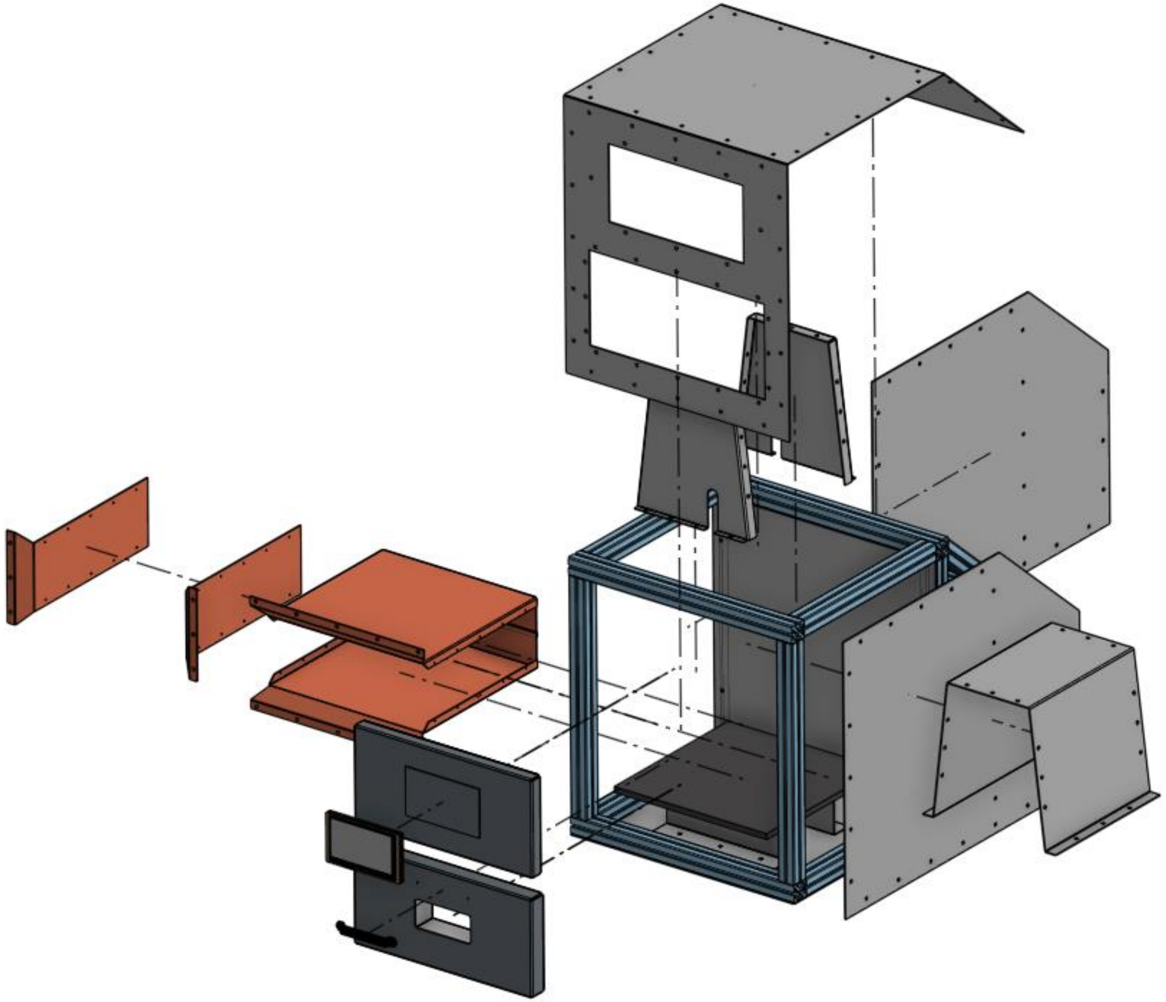
Open Design Items

- Chassis
- Shocks/Vibration Dampening
- Pre-Final Sheet Metal (Laser Cutter)
- Fans and Cooling (✓)
- Recovery and Logistics (✓)



Mainboard



Sheet Metal and Extrusion

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Data Acceptance Package

Deliverable	Status
CAD assembly & parts	☑
Drawings as PDF	◔
Assembly drawing as PDF	◔
Schematics	☑
PCB Layout (if relevant)	◔
Flowchart	☑
Pseudocode or preliminary code	☑
User interface design	◔
Final Report	◔

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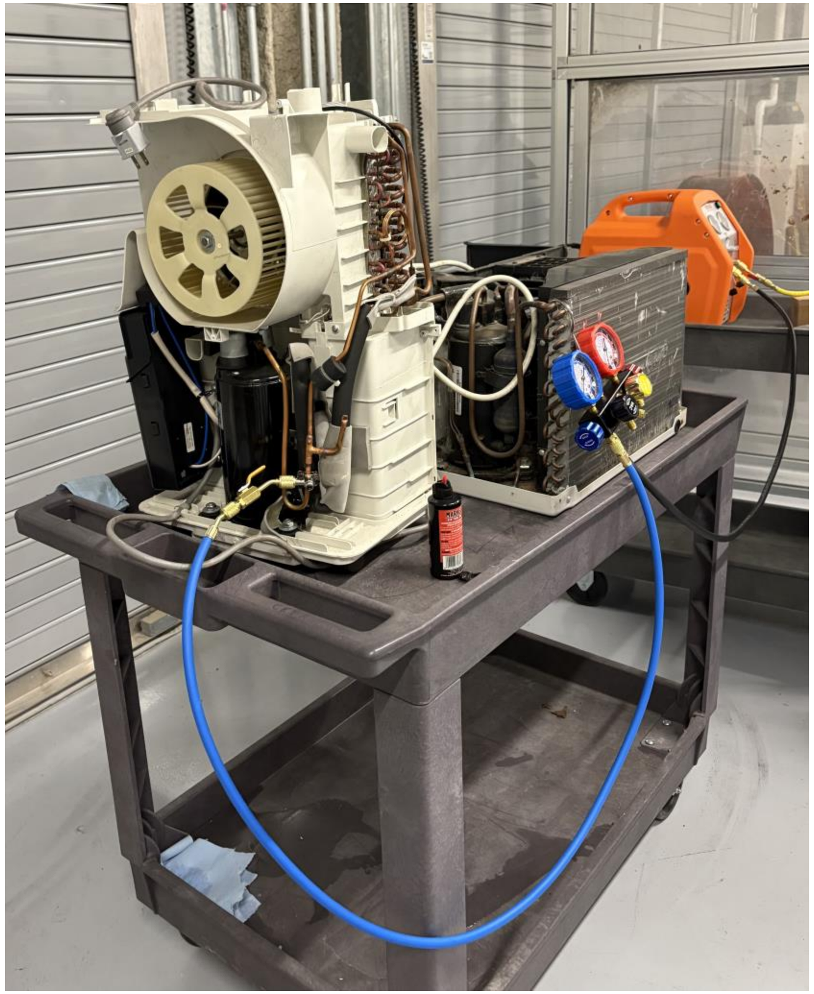
Questions?

BACKUP SLIDES

Refrigerant Recovery



- Refrigerant recovered and removed. Allowing safe work and CAD modeling of parts.

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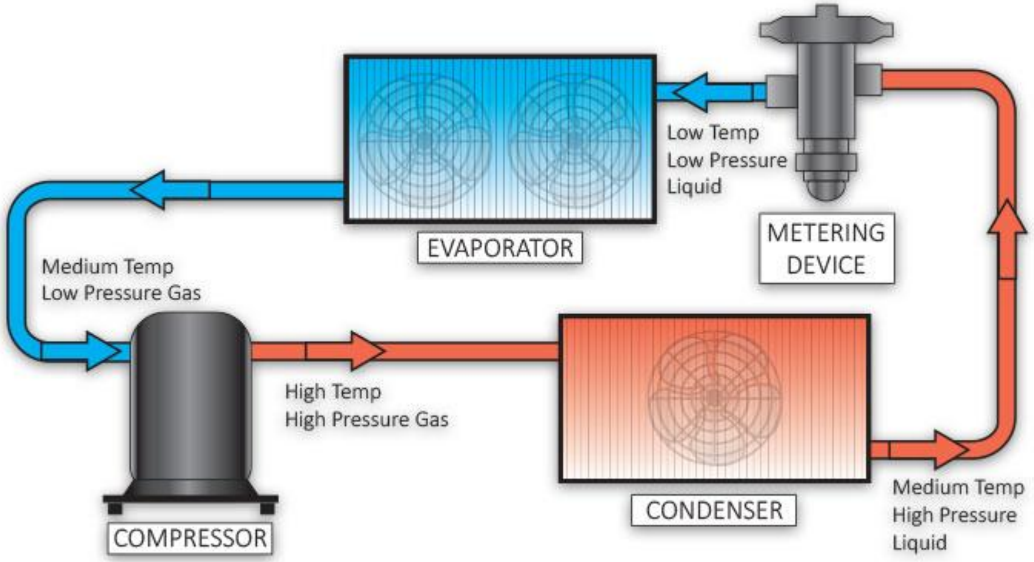
Control System Exploration

- Time Proportional PID (Duty Cycle PID)
- **Why cant you use normal PID?**
  - You can for **heat** but you cannot for cooling.
  - The reason is the head start problem. At max load, especially around where our system will operate at the –40 mark. The system head pressure ahead of the compressor will be VERY high as refrigerant struggles to boil in the cold environment behind. This is a common problem in HVAC where we cannot simply fast cycle. And must account for a **minimum off-time** to allow the pressure to drop.
- **Will This control method allow for our fine (3deg) control?**
  - Sorta, Kinda. When we charge the system, idealy, we use enough fluid to enable the cold side to **just boil** at our min temperature. This will leave us a **little overcharged at higher temperatures**. But will allow us greater, smoother control down low. And with our capilary metering, enable near cryo temperatures. Its complex to characterize but we may have a band especially at the **–5 to –10** mark where our minumum off time and desired cycle time are at odds.



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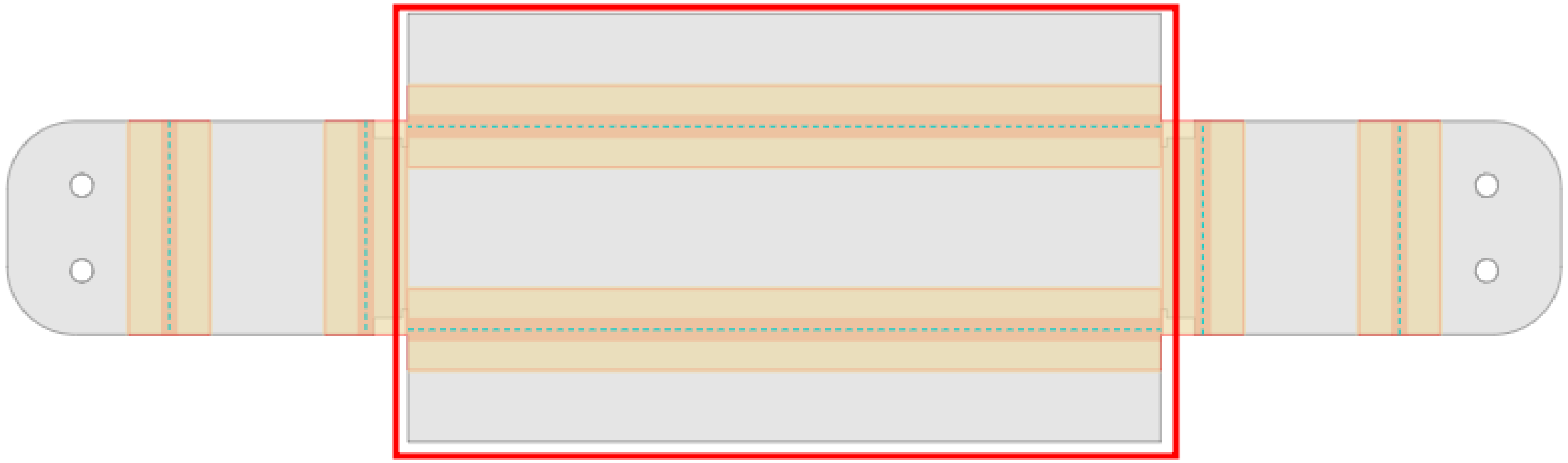
Hi Jason,

Thank you so much for your order! During our preproduction design checks, we noticed an issue that forced us to place **your order on hold**.

There are some limitations to what we can form in a "U" channel configuration before the bent part collides with the bending equipment. To avoid these collisions, we need the base-to-flange ratio to be at least 2:1.

2:1 RATIO FOR SHEET METAL

Tweaks_Repalcement_Body.step



We have your order on hold for now. Would you like to revise your design, or have the bending operation removed and the part shipped flat?

$L_{floor} := 13\ in \quad H_{wall} := 6\ in$

$$A_{internal} := 2 \cdot L_{floor}^{2} + 4 \cdot \left(L_{floor} \cdot H_{wall}\right) = 0.4194\ m^{2}$$

$t_{start} := 20\ °C \quad t_{end} := (-40)\ °C$

$$\Delta_t := t_{end} - t_{start} = -60\ K$$

$U := 5\ \frac{W}{m^{2}\ K}$ Overall heat transfer estimate

$$\boxed{Q_{cond} := U \cdot A_{internal} \cdot \Delta_t = -429.2686\ \frac{BTU}{hr}}$$

BTU just to maintain the condition.

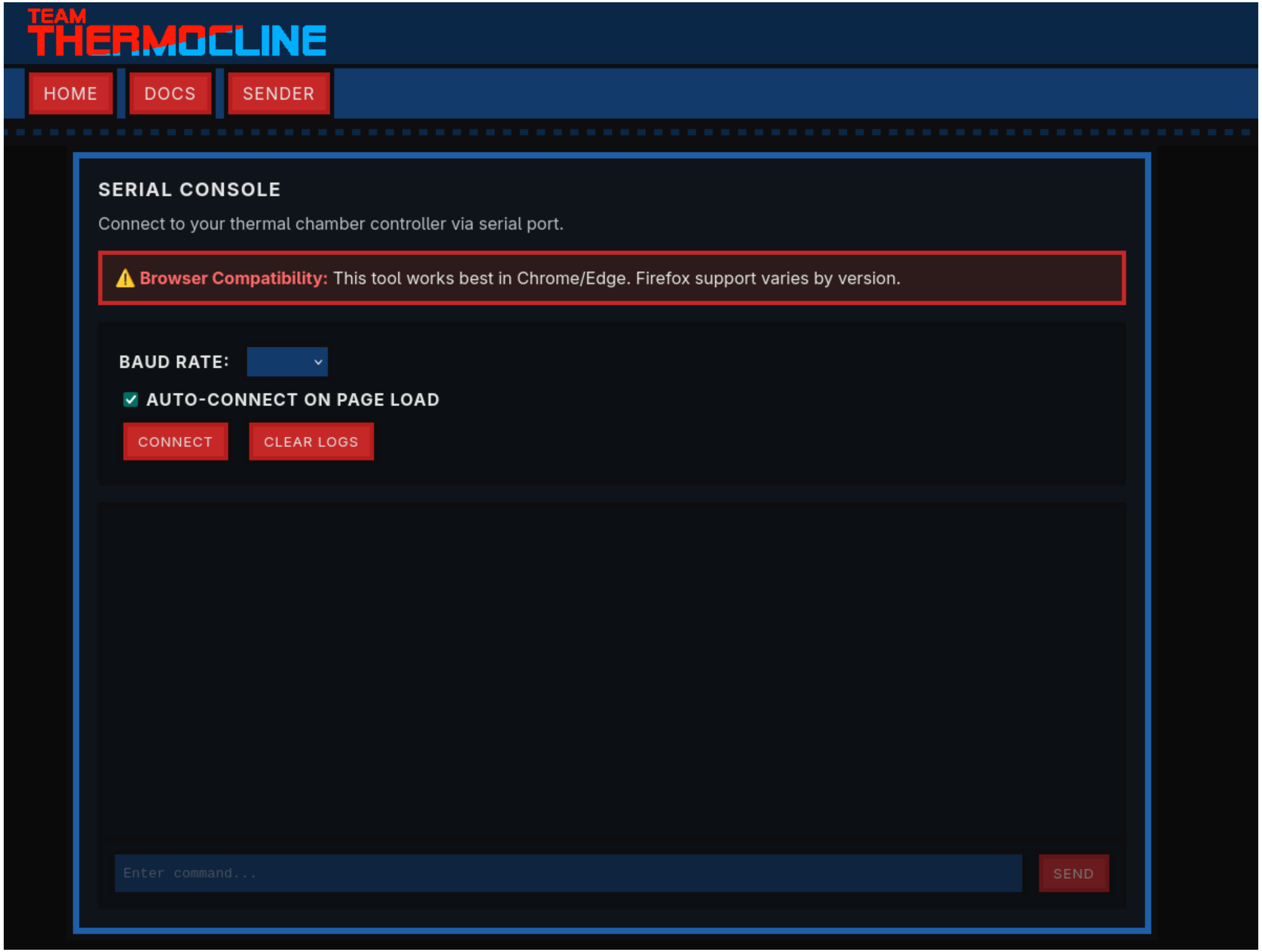
Not accounting for the density of air or anything just asuming contents of box and aluminum walls dominate.

$$c_{p\_aluminum} := 0.9 \ \frac{kJ}{kg \ K} \qquad m_{aluminum} := 1 \ kg$$

$$Q_{pull} := m_{aluminum} \cdot c_{p\_aluminum} \cdot \Delta_t = -51.1821 \ BTU$$

$$t_{time\_to\_cool} := 30 \ min$$

$$\boxed{Q_{total} := Q_{cond} + \frac{Q_{pull}}{t_{time\_to\_cool}} = -531.6328 \ \frac{BTU}{hr}}$$


TEAM THERMOCLINE
HOME
DOCS
SENDER
SERIAL CONSOLE
Connect to your thermal chamber controller via serial port.
⚠ Browser Compatibility: This tool works best in Chrome/Edge. Firefox support varies by version.
BAUD RATE:
AUTO-CONNECT ON PAGE LOAD
CONNECT
CLEAR LOGS
Enter command...
SEND

Requirements Database- Design

1.1	**The system shall accomodate a 12x12" PCB as device to be tested.**	Demonstration
1.1.1	The system shall have external base dimensions of maximum 30x30 inches.	Measure
1.2	**The system shall include insulation designed for external safety according to ASTM C1055.**	Inspection
1.2.1	The chamber opening(s) shall include proper thermal sealing.	Inspection
1.2.2	The internal thermal control components shall include proper thermal sealing.	Inspection
1.3	**The system's design shall be safe for continual operation.**	Measure
1.3.1	The internal surfaces shall be safe for electronics.	Analysis
1.3.2	The system external surfaces shall not exceed the safe-touch temperature of 50°C according to ASTM C1055.	Analysis
1.3.3	The system shall be able to operate in normal environmental (external) conditions of 21°C.	Demonstration

Requirements Database- System

2.1	**The system shall include a port to allow electrical cables to enter and leave for stimulus and measurement of the PCB.**	Inspection
2.1.1	The PCB shall be operatable while temperature is controlled.	Measure
2.2	**The system shall comply with electrical grounding requirements.**	Inspection
2.3	**The system shall be able to operate on a standard wall-outlet power of 120V (AC).**	Demonstration
2.4	**The system will comply with appropriate NEC and UL rules governing powered and plug in devices.**	Inspection
2.4.1	System will adhere to NEC rules on grounding.	Inspection
2.4.2	System will adhere to NEC rules on appropriate fuses and load wire sizes.	Inspection
2.4.3	System will adhere to UL 61010 for test and measurement equipment.	Inspection

Requirements Database- Functional

3.1	**The system shall monitor temperature inside the chamber.**	Demonstration
3.1.1	The sensors shall be properly rated to withstand internal environmental conditions.	Analysis
3.2	**The system shall control temperature inside the chamber.**	Demonstration
3.2.1	The system shall cover *commercial* temperature range (0_oC - 70_oC). [Optional]: cover *industrial* temperature range (-40_oC - 85_oC).	Measure
3.2.2	The system shall allow local temperature setpoint control.	Test
3.2.3	The system shall allow remote temperature setpoint control.	Test
3.2.4	The system shall maintain a toleranced temperature at $\pm 3^{\circ}C$ of setpoint.	Measure
3.2.5	The system shall prohibit thermal control when the chamber door is open.	Demonstration
3.2.6	The system shall prohibit thermal control when a user is handling the PCB.	Demonstration
3.2.7	The system shall include a safety measure if temperature range & tolerance is exceeded.	Demonstration
3.3	**The system shall remain within a specified humidity range (0% - 90%).**	Measure
3.4	**The system shall provide data output.**	Demonstration
3.4.1	The system shall support PC connection for datalogging.	Inspection
3.4.2	The system shall log temperature data.	Test
3.4.3	The system shall log humidity data.	Test
3.4.4	The system shall log faults for safety measures.	Measure
3.4.5	The system shall be capable of sweeping all temperature ranges within a 24-hr cycle.	Test

Requirements Database- Interface

4.1	**The system shall include an HMI for the control system.**	Inspection
4.2	**The system shall include separate operating/control modes.**	Demonstration
4.2.1	The system shall have a "shutdown" state.	Demonstration
4.2.2	The system shall have a "standby" mode.	Demonstration
4.2.3	The system shall have a normal operating "start" mode.	Demonstration
4.2.4	The system shall have a "safe" state.	Demonstration
4.2.5	The system shall allow for manual switching between modes.	Demonstration

Risk Assessment - List

A	Asset	Mechanical Failure of Components (worn, broken)
B	Asset	Insufficient Dimensions for PCB testing (internal, external, cable port, chamber door)
C	Asset, Human Safety	Internal System is Over Temperature Range (fire, melting components)
D	Asset, Human Safety	Internal System is Under Temperature Range (freezed components)
E	Asset, Performance	System's Safety Measure Fails If Outside Temperature Range
F	Asset, Performance	Internal Heating/Cooling System Can't Reach upper/lower boundaries (poor components, inefficient controller)
G	Asset, Performance	Inconsistent Temperature Control (poorly designed microcontroller or interface)
H	Asset, Performance	Failure to Maintain Toleranced Setpoint ($\pm^{o}3C$) (ineffective control system, poor insulation - internal & external)
I	Asset, Performance	Lack of Electronic Protection (excessive moisture buildup)
J	Cost	Spending Past Designated Budget for Equipment & Materials
K	Human Safety	Lack of Human Protection at Critical Temperature Ranges (burns)
L	Human Safety	System Fails to Meet Environmental/Engineering Codes
M	Human Safety	System Fails to Prohibit Temperature Control During Manual User Usage.
N	Human Safety, Performance	Chemical Leaking
O	Human Safety, Performance	Electrical Hazards (short circuits, improper connections)
P	Human Safety, Performance	System Fails to Operate Safely Under Normal Conditions
Q	Performance	Software/HMI Failure
R	Performance	Lack of Refrigerant Fluid in System
S	Performance	Controller not User Friendly (poor HMI design)
T	Performance	Sensor Reading Failure (miscalibration, component issue)
U	Performance	Improper Ventilation (pressure changes, fumes buildup)
V	Performance	Ineffective Insulation (poor materials or design)
W	Performance	Data Measuring, Collecting, and Logging Fail to Work Systematically
X	Performance	System Mode(s) Failures
Y	Schedule	Poor Scheduling for Fabricated Parts or Sourced Materials
Z	Schedule, Cost	Rework of Product (ineffective design from failed systems/components/materials)

Risk Assessment - Matrix

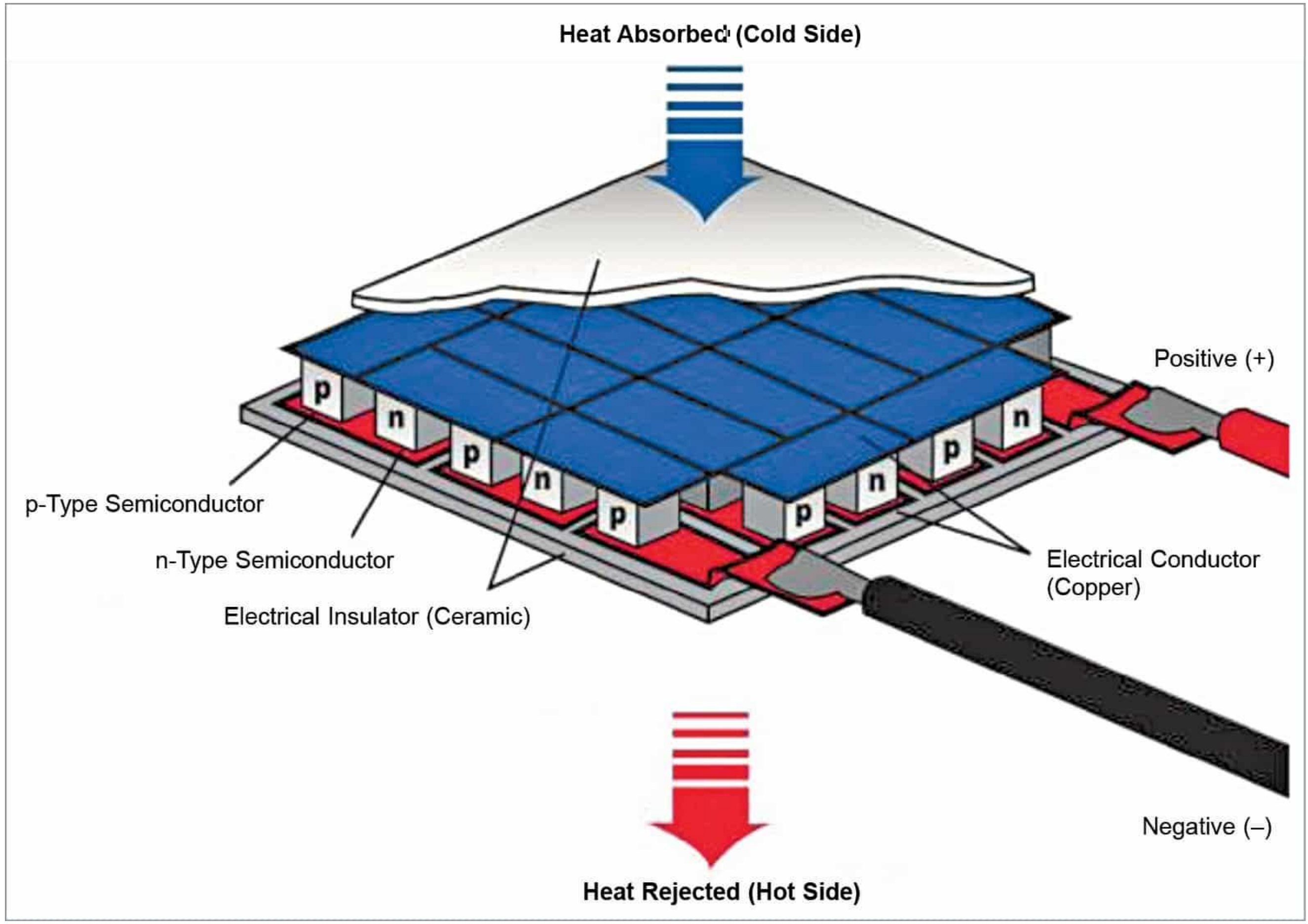
	5	B, L	A, E, P	K, M, O	Z	
	4		Y	N	I	Q, W
Consequence	3		F, G	T, U, X	V	
	2	R	J		C, D	H
	1	S				
		1	2	3	4	5
		Likelihood				
Notes:	Combined Risk Scores: 0-9 (**Green**) --> Minor 10-19 (**Yellow**) --> Moderate 20-29 (**Red**) --> Major					

Peltier Analysis

We explored using electric Peltier coolers. Which work by applying electrical current through a semiconductor, to move heat through a ceramic plate.

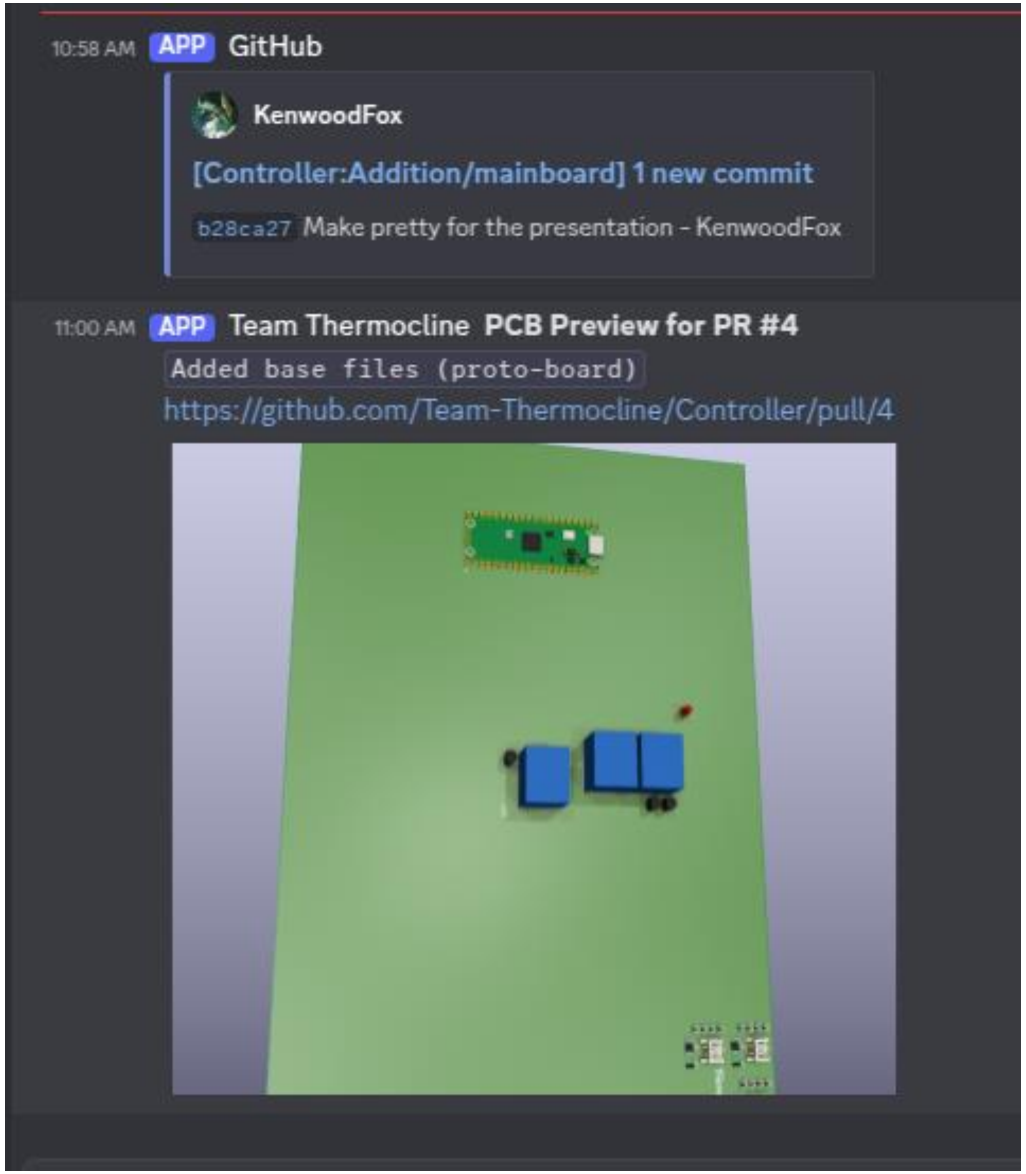
Our analysis found that a Peltier system that moves the thermal energy we expect to need, would require upwards of **400BTU/h to maintain temperature** and more than **500BTU/h** to change temperature at project requirement rates.

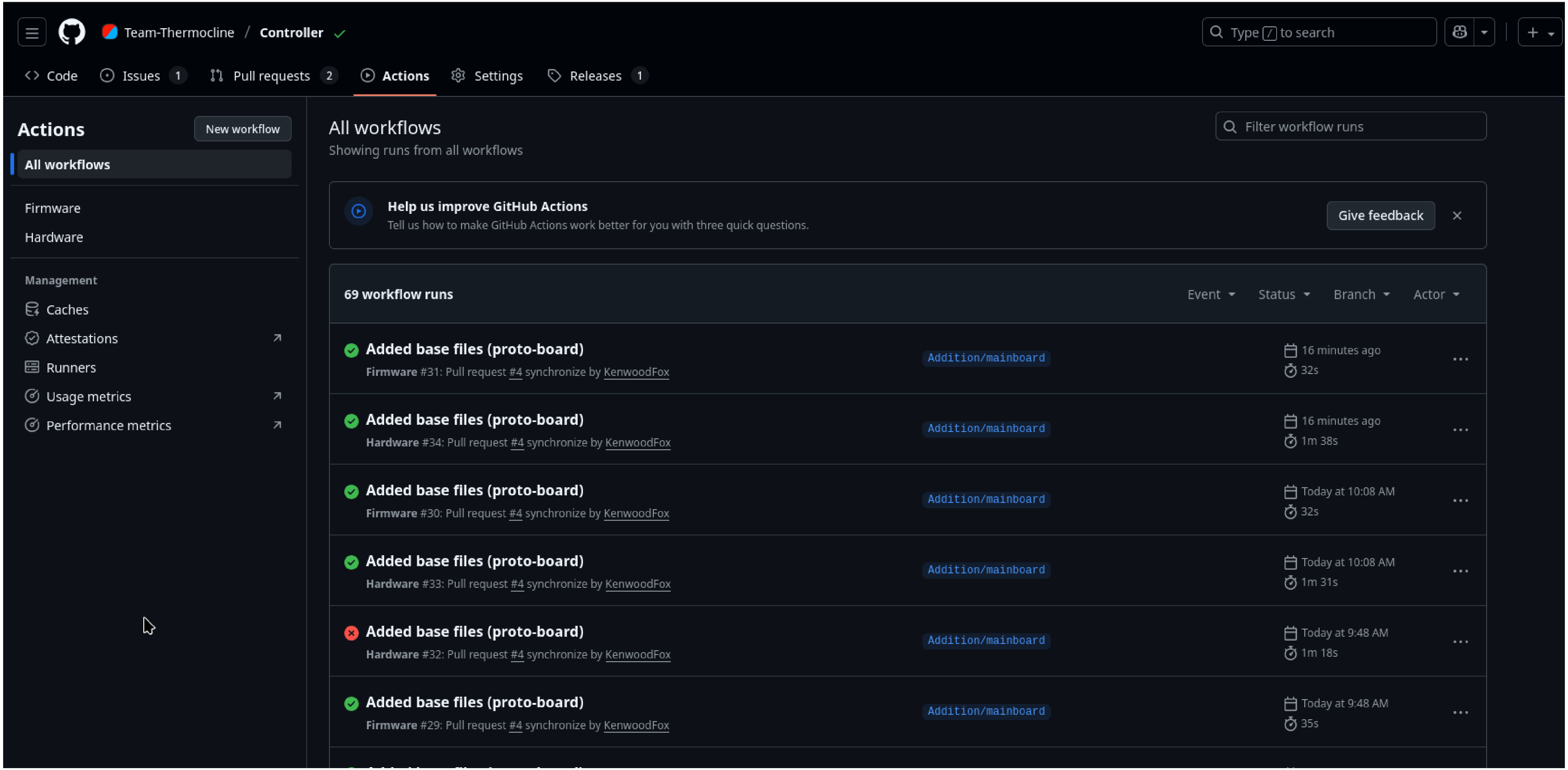
When weighed against our other avenues of heating and cooling we did not consider Peltier as a good fit for our design, specifically.

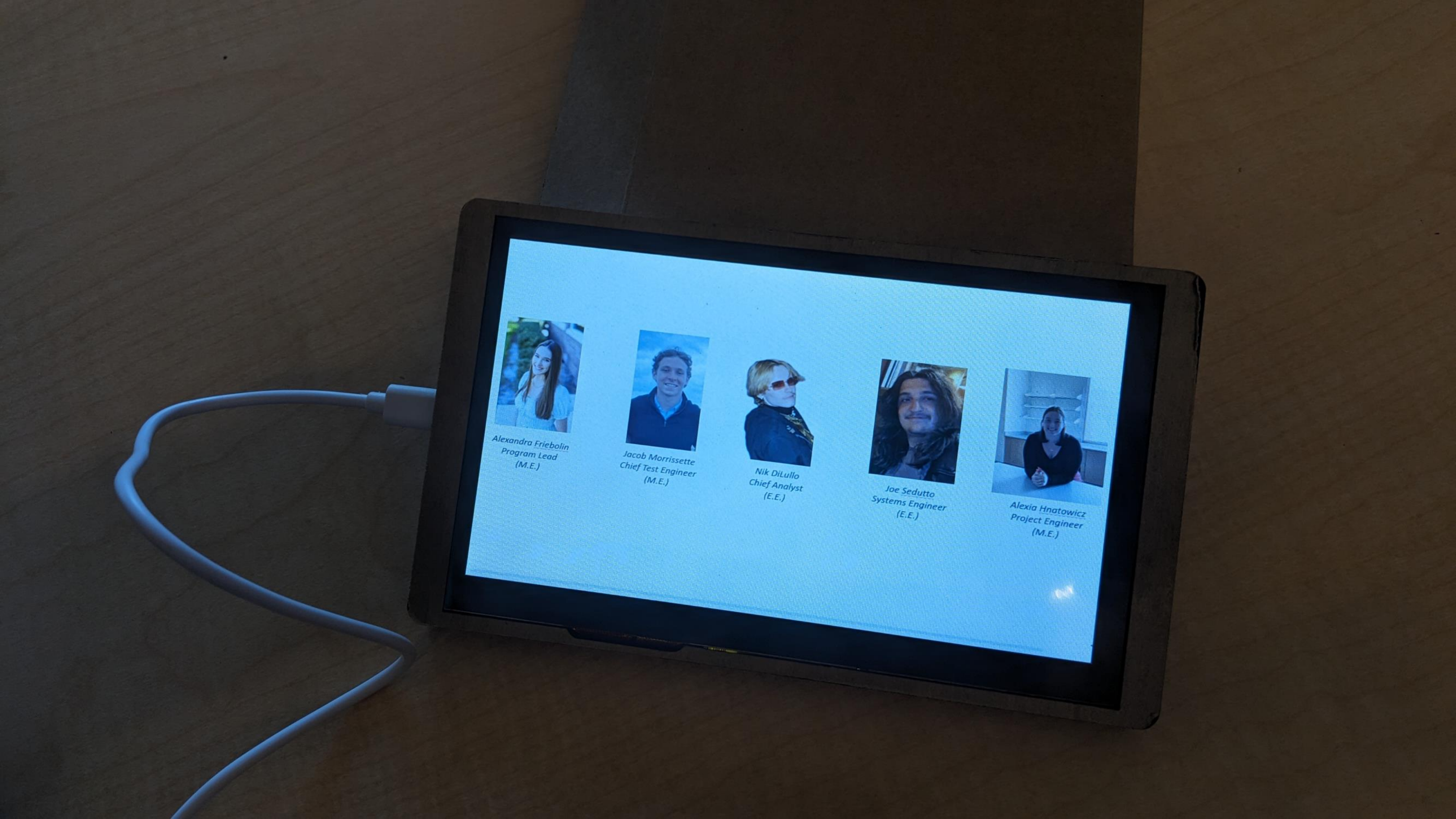


Sources on slides 28-29

Southern New Hampshire University


10:58 AM APP GitHub
KenwoodFox
[Controller:Addition/mainboard] 1 new commit
b28ca27 Make pretty for the presentation - KenwoodFox
11:00 AM APP Team Thermocline PCB Preview for PR #4
Added base files (proto-board)
https://github.com/Team-Thermocline/Controller/pull/4

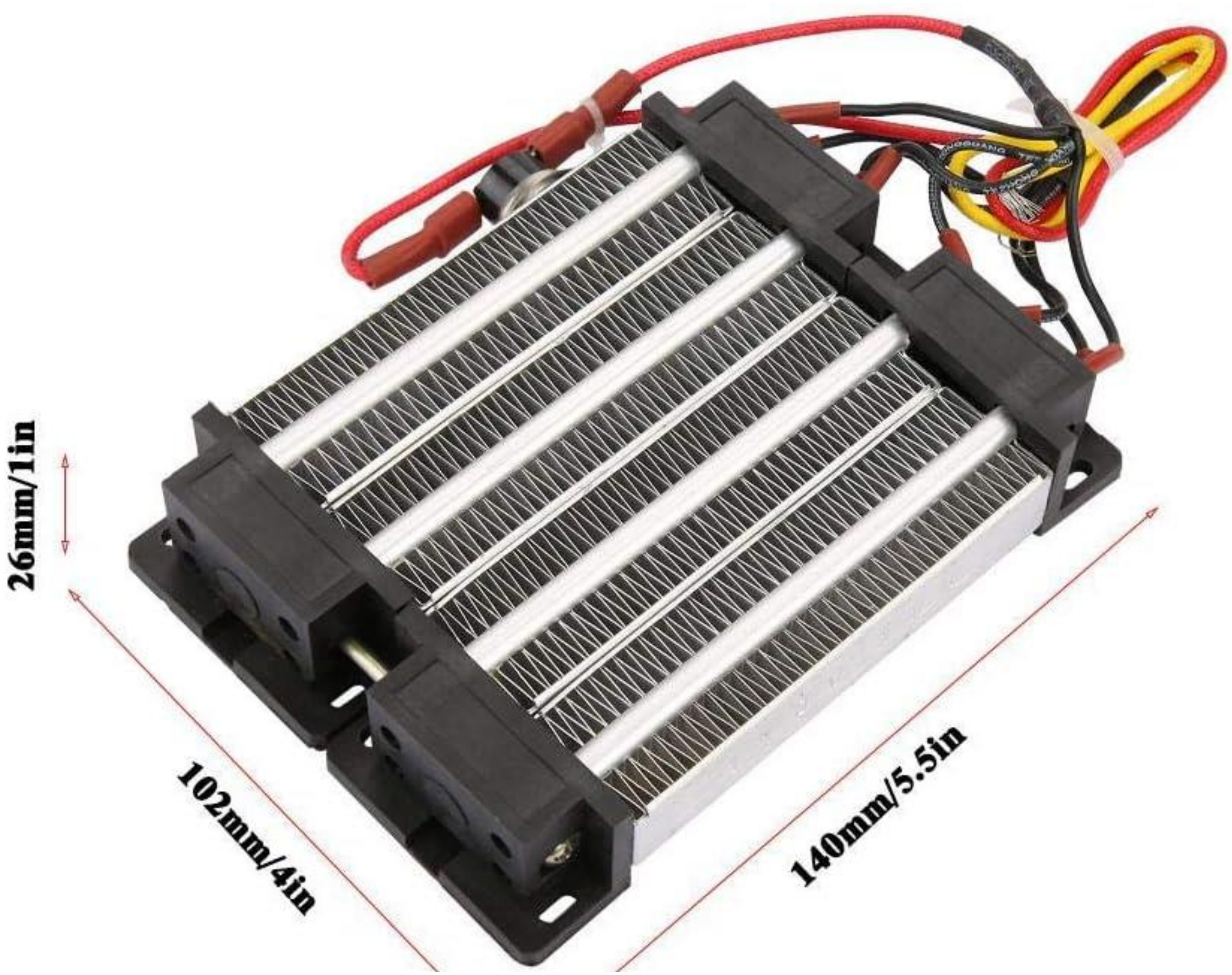

Team-Thermocline / Controller
Type / to search
Code
Issues 1
Pull requests 2
Actions
Settings
Releases 1
Actions
New workflow
All workflows
Firmware
Hardware
Management
Caches
Attestations
Runners
Usage metrics
Performance metrics
All workflows
Showing runs from all workflows
Filter workflow runs
Help us improve GitHub Actions
Tell us how to make GitHub Actions work better for you with three quick questions.
Give feedback
69 workflow runs
Event
Status
Branch
Actor
Added base files (proto-board)
Firmware #31: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
16 minutes ago
32s
Added base files (proto-board)
Hardware #34: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
16 minutes ago
1m 38s
Added base files (proto-board)
Firmware #30: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
Today at 10:08 AM
32s
Added base files (proto-board)
Hardware #33: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
Today at 10:08 AM
1m 31s
Added base files (proto-board)
Hardware #32: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
Today at 9:48 AM
1m 18s
Added base files (proto-board)
Firmware #29: Pull request #4 synchronize by KenwoodFox
Addition/mainboard
Today at 9:48 AM
35s


Alexandra Friebolin
Program Lead
(M.E.)
Jacob Morrissette
Chief Test Engineer
(M.E.)
Nik DiLullo
Chief Analyst
(E.E.)
Joe Sedutto
Systems Engineer
(E.E.)
Alexia Hnatowicz
Project Engineer
(M.E.)

- Amazon heater

Sub $50
Super easy to replace
Comes in every size we could want

Power from 800-1.2kw, easily in range



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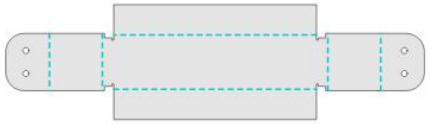

5052 H32 Aluminum (.063")
9.094" x 2.507"

TRACK ON UPS

PACKING SLIP 1

Shipping to:
Jason Crowell
Southern New Hampshire University
2500 North River Road

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