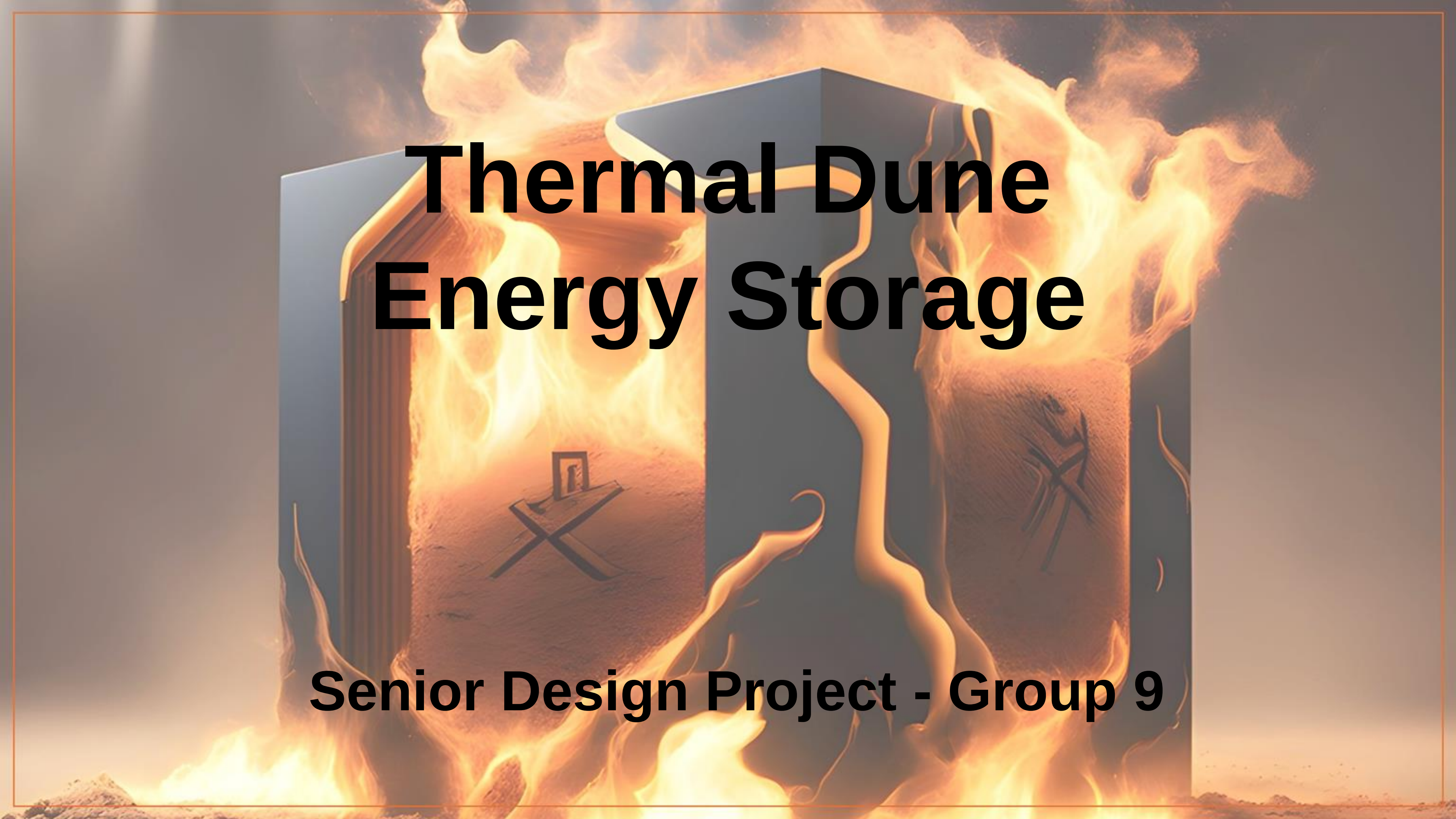


Thermal Dune Energy Storage

Senior Design Project - Group 9

Meet the team

Michael Hernandez
Electrical Engineering

Miguel Baca-Urteaga
Computer Engineering

Filipe Pestana Frances
Computer Engineering

Tanner Cyr
Electrical Engineering

Motivation and background

- ➔ Roughly 50% of energy used within the US is used for home heating.
- ➔ Widespread solar adoption has been causing dips in power spot price during peak production hours.
- ➔ Energy storage has slow commercial adoption due to high prices of lithium storage + installation.

Goals and objectives

- ➔ Provide a means of energy storage for low income consumers.
- ➔ Create a plug and play solution for mass residential energy storage without professional installation.
- ➔ Deliver thermal energy storage several orders of magnitude cheaper than equivalent lithium ion alternatives.

Goals and objectives

- ➔ Create a simple user interface
- ➔ User will be able to set desired room temperature, and charging times
- ➔ User will be able to override the preset settings
- ➔ Thermal Storage system will self regulate

Engineering Specifications

- ➔ Manual override for flexibility.
- ➔ Real-Time temperature display.
- ➔ Maximum power drawn.

Specification	Description	Range/number
Charging/Heating Time	User is able to set the charging / heating time.	0-24 hours
Discharge Duration	Duration for which the battery can maintain ambient warmth.	0-24 hours
User Interface	Interface allowing the user to set charging and discharge times.	LCD 3.5"
Battery	Shows the percentage of the battery on the screen.	0-100%
Turn on/off	User is able to turn on/off overriding the schedule time.	Less than 15 seconds
External Temperature Display	Display showing the current external temperature.	0°C to 50°C
Internal Temperature Display	Display showing the current internal temperature of the sand.	0°C to 500°C
Temperature Range (Internal)	Range of temperature the internal sand can reach.	0°C to 500°C
Energy Capacity	Amount of energy the battery can store.	8KWh
Power Input	Power is required for charging the battery.	120V, 60Hz
Maximum Power Drawn	Maximum power drawn at different energy storage states.	2.5W idle, 875W charging, and 35W heating

Hardware comparison and selection

MCU

- ➔ Strong components support and high performance.
- ➔ Scalability and future expansion.
- ➔ Development Ecosystem.

Specification	MSP430FR6989	ESP32	RP2040
Processor	16-bit RISC	32-bit Dual-core Xtensa LX6	Dual-core ARM Cortex-M0+
Clock Speed	Up to 16 MHz	Up to 240 MHz	Up to 133 MHz
RAM	2 KB SRAM	512 KB SRAM	264 KB SRAM
Flash Memory	128 KB FRAM	Up to 4 MB external	Up to 2 MB external
GPIO Pins	47	36	30
Development Ecosystem	TI CCS, Energia	Arduino, PlatformIO	Arduino, MicroPython
Price	$8.68	$3.35	$7.74
Best For	Battery-powered applications	IoT, Complex tasks	Versatile applications

Hardware comparison and selection

LCD display

- ➔ Power efficiency and voltage compatibility.
- ➔ Capacitive touchscreen with IPS quality.
- ➔ Cost-effective solution.
- ➔ Versatile I2C and SPI communication protocols.

Brand	Waveshare	Adafruit	Hosyond
Model	4.3inch DSI QLED	3.5inch TFT Touch	3.5inch IPS SPI
Resolution	800x480	480x320	480x320
Display Size	4.3 inches	3.5 inches	3.5 inches
Communication	DSI	SPI	I2C, SPI
Touchscreen	Capacitive	Capacitive	Capacitive
Power Consumption	1.2 watts	--	0.5 watts
Price	$45.99	$39.95	$18.99
Voltage	3.3-5V	3.3V	3.3-5V

Hardware comparison and selection

Thermocouple

- ➔ Accurate and sufficient temperature range.
- ➔ Cost-effective and flexible voltage supply.
- ➔ SPI compatibility and simplicity.

Brand	Maxim Integrated	Maxim Integrated	Maxim Integrated
Model	MAX6675	MAX31856	MAX31865
Price	$7.99	$26.99	$1.99
Type of thermocouple	K type	K, J, N, R, S, and T type	K, J, N, R, S, and T type
Temperature Range	-200ºC to 1024ºC	-210ºC to 1800ºC	-200ºC to 1024ºC
Digital Interface	SPI(Serial Peripheral Interface)	SPI(Serial Peripheral Interface)	SPI(Serial Peripheral Interface)
Power Supply Voltage	3.3 or 5V	3 to 3.6V	-0.3 to 4V
Resolution	0.25ºC / 0.45ºF	0.0078125ºC / 0.01283ºF	0.0078125ºC / 0.01283ºF

Hardware comparison and selection

Temperature sensor

➔ Cost-effective and versatile.

➔ Sufficient temperature and humidity ranges.

➔ Simple integration and low power consumption.

Model	Adafruit MCP9808	DHT11	DFROBOT SEN0497	Adafruit TMP235	Adafruit AHT20
Type	Digital Temperature Sensor	Digital Temperature / Humidity Sensor	Sensor Board (Analog)	Analog Temperature Sensor	Digital Temperature / Humidity Sensor
Price	$4.99	$9.99 per 5 pack	$17.99	$2.50	$4.50
Communication Interface	I2C	Single-Wire Digital	Analog Output	I2C	I2C
Temperature Range	-40ºF to 257ºF	32ºF to 122ºF	-40ºF to 185ºF	-40ºF to 257ºF	-40ºF to 185ºF
Temperature Resolution (Accuracy)	0.1125ºF	3.6ºF	Variable	0.18ºF	0.55ºF
Power Supply Voltage	2.7V to 5.5V	3.3V to 5.5V	3.3V to 5V	3.3V to 5V	1.8V to 3.6V
Humidity Range	N/A	20% to 95%	N/A	N/A	0% to 100%
Humidity Resolution	N/A	1%	N/A	N/A	3%

Hardware comparison and selection

Heating element

- ➔ Cost-effective and efficient.
- ➔ Effective heat distribution and high efficiency.
- ➔ Easy integration.

Model	Rheem Protect Copper	DERNORD Tri-Clamp Foldback	Char-Broil Universal electric	Camplux Cartridge Heater pipe fittings	Whirlpool Electric Range Stove Set
Price	$11.94	$34.99	$29.49	$11.99/ 3 elements	$29.56 / 4 elements
Metal Type	Copper	Stainless Steel	Stainless Steel	Stainless Steel	Nichrome inside Steel
Input Voltage	120V	120V	110V	110V	230V
Power Rating (W)	2000	1650	1500	100	1500
Resistance (ohms)	7.2	8.73	8	121	32 and 43
Dimensions	12 inches x 3 inches x 5 inches	15.1 inches x 2.4 inches x 2.6 inches	15.6 inches x 10.2 inches x 2 inches	1.6 inches x 0.32 inches	4 inches x 4.33 (or 6.33) inches x 0.5 inches

Hardware comparison and selection

Heat transfer conduit

- ➔ High heat conductivity.
- ➔ Temperature compatibility.
- ➔ Cost-effectiveness.

Type of Tubing	1 inch Metallic EMT Conduit	1 inch Copper Tubing	Stainless Steel 1 inch ThickWall Tubing	3/4 inch Aluminum Tubing
Material	Steel	Copper	Stainless Steel	Aluminum
Price	$17.47 per 10 feet	$6.37 per foot	$14.80 per foot	$4.75 per foot
Size (Diameter)	1 inch	1 inch	1 inch	3/4 inch
Corrosion Resistance	70%	60%	90%	90%
Flexibility	10%	40%	5%	80%
Advantages	Durability	High thermal Conductivity, High electrical conductivity	Corrosion Resistant, Strength	Lightweight, Corrosion Resistance
Strength	50%	70%	90%	20%
Intended Function(s)	Electrical Wiring protection	HVAC, Water Supply	Industrial Piping, Structural Component	Structural Component, Electrical Wiring

Software Specifications

ECAD Software

- ➔ 3D Design and Visualization.
- ➔ Schematic-to-Layout Integration.
- ➔ Cloud-Based collaboration and User-friendly interface.

Specification	Altium	Fusion360	KiCad
Flexibility	Highly adaptable, but may be too much for simple design	Less flexible than dedicated PCB tools	Flexible, but missing some advanced features
Complexity	Many features, but it can be too much	With 3D option will increase complexity	Less features than others
Features	Good set of features for advanced PCB design	Good selection of features for PCB design	Good set of features for a free software
Integration	Excellent integration with different tools	Strong integration with Autodesk tools	Effective integration with other EDA tools
Easy to Use	Intuitive interface, industry-standard UI	Intuitive interface, especially for 3D	User-friendly
Performance	Requires High-end hardware for max performance	Cloud-based nature, it may be slower	Efficient, and performs well on basic hardware
Updates	Frequently updates and new features	Improves regularly with updates and new features	Constantly improves by open-source community

Software Specifications

Integrated development environment

- ➔ Easy of use and quick setup.
- ➔ Built-in ESP32 support.
- ➔ Extensive libraries and resources.

Specification	Arduino IDE	Visual Studio Code	IntelliJ IDEA
Easy to Use	Beginner-friendly	Requires some setup	Complex
Resources	Many libraries available	Extensive resources and extensions	Extensive resources
Customization	Minimal	Highly customizable	Highly customizable
ESP 32 Support	Built-in	Platform IO extension	Via plugins
Initial Setup	Simple, quick setup	Requires configuration	Requires plugins and setup
Best For	Simple projects	Large projects	Complex projects

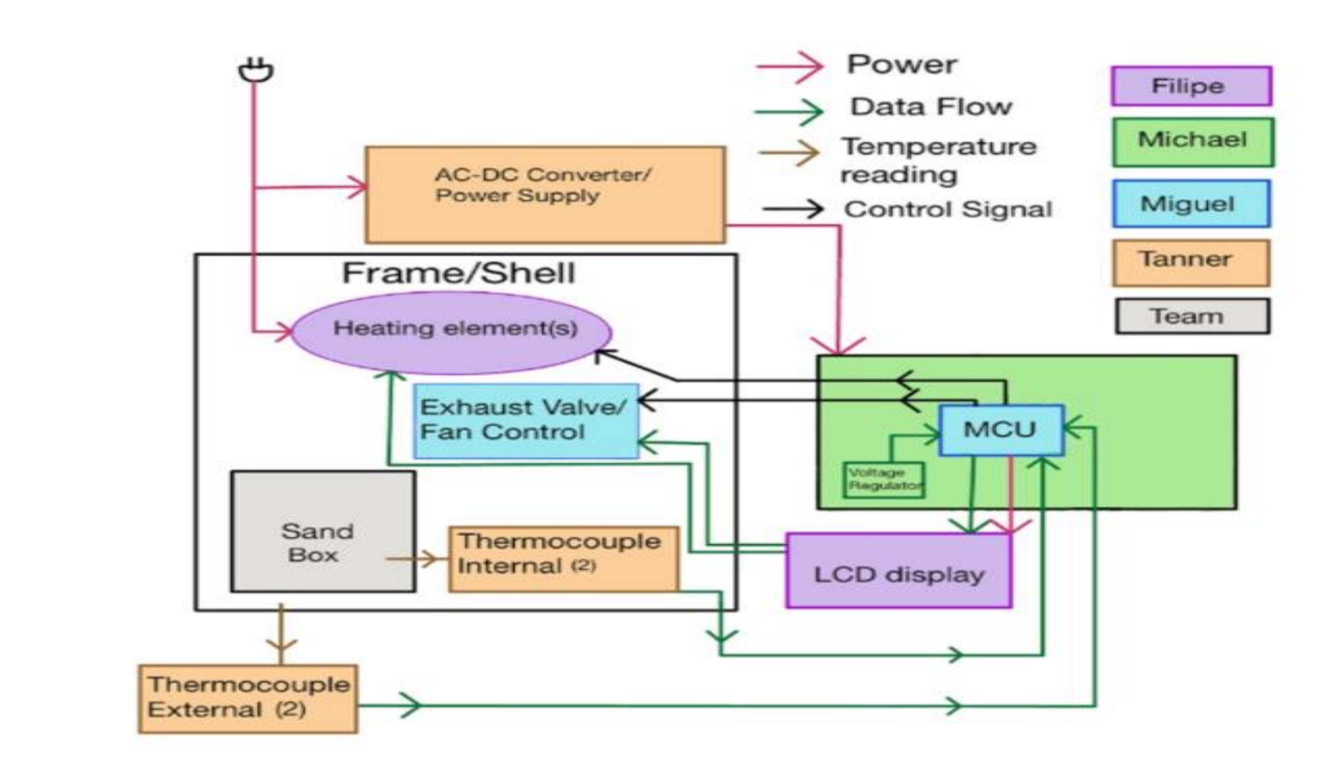
Software Specifications

Programming language

- ➔ Powerful features.
- ➔ Suitable for system development.
- ➔ Balancing efficiency and capabilities.

Criterion	Python	C	C++
Easy to Use	High, simple syntax	Moderate, simple syntax, procedural	Moderate, complex syntax, object-oriented
Library	Extensive for general programming	Moderate, but extensive for embedded systems	Extensive for general and system level
Performance	Low, interpreted language	High, compiled language	High, compiled language
Memory Usage	High, less efficient	Low, very efficient	Moderate, efficient
Control	Low, high-level abstractions	High, low-level access	High, OOP features
Development Speed	Fast, many libraries	Slow, requires detailed and specific coding	Moderate, requires more code than python
Suitable for Embedded Systems	Low, barely used for microcontrollers	High, widely used for microcontrollers	High, widely used for microcontrollers

Hardware Design



Hardware Design

Hardware Implementation

Peripheral Devices

Ambient Temperature

- Provides real time readings of the room’s ambient temperature
- Enables the MCU to calculate the amount of heat required to reach a desired room temperature

Internal Temperature

- Constantly monitors the internal temperature
- Alerts the MCU when the temperature falls below a set threshold, triggering a recharge of thermal energy
- Safety monitor system to shut off heating elements in case of overheating

Power/ Heat Control

- ZGT-25DD Solid State Relays
- Controls the power supply of the heating elements and regulates heat valves for release discharge
- The MCU turns on/off these relays when the condition to release heat or recharge has been met

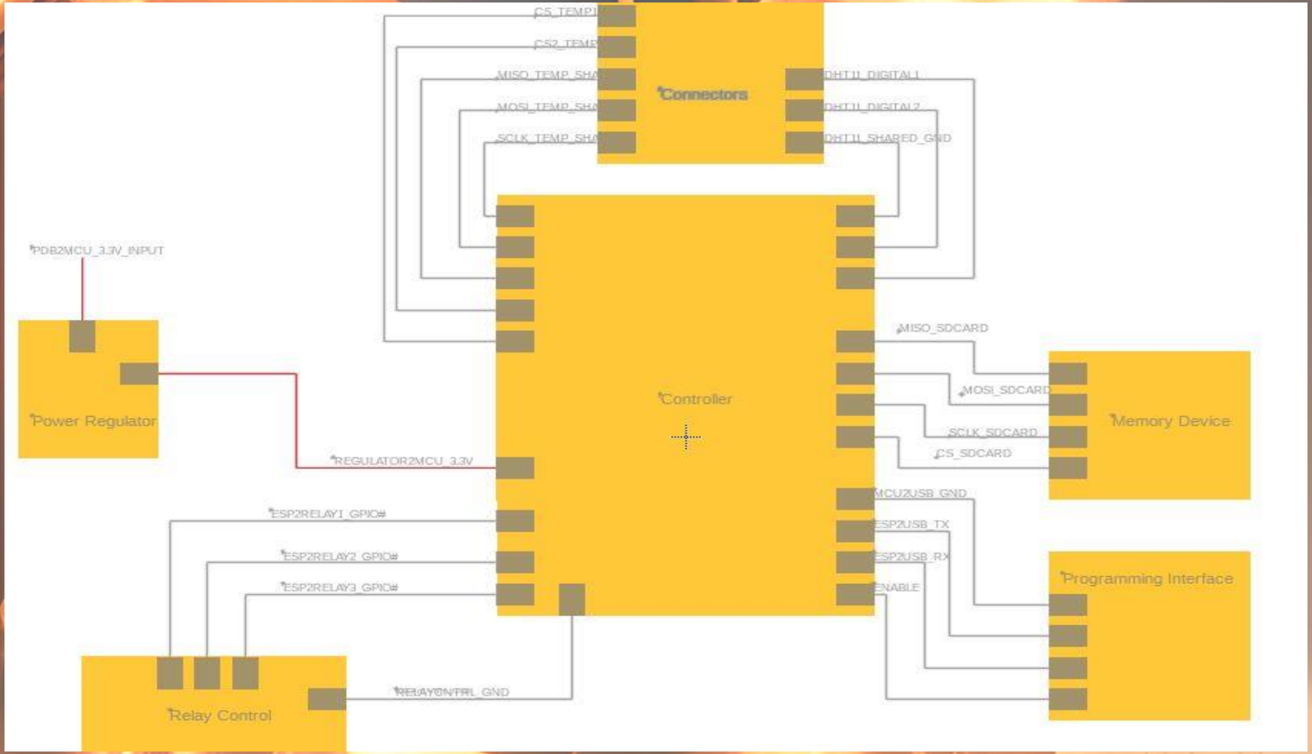
LCD Display

- Displays real time system status such as temp readings, heat modes, and safety alerts
- Allows user to interact with the system and control settings

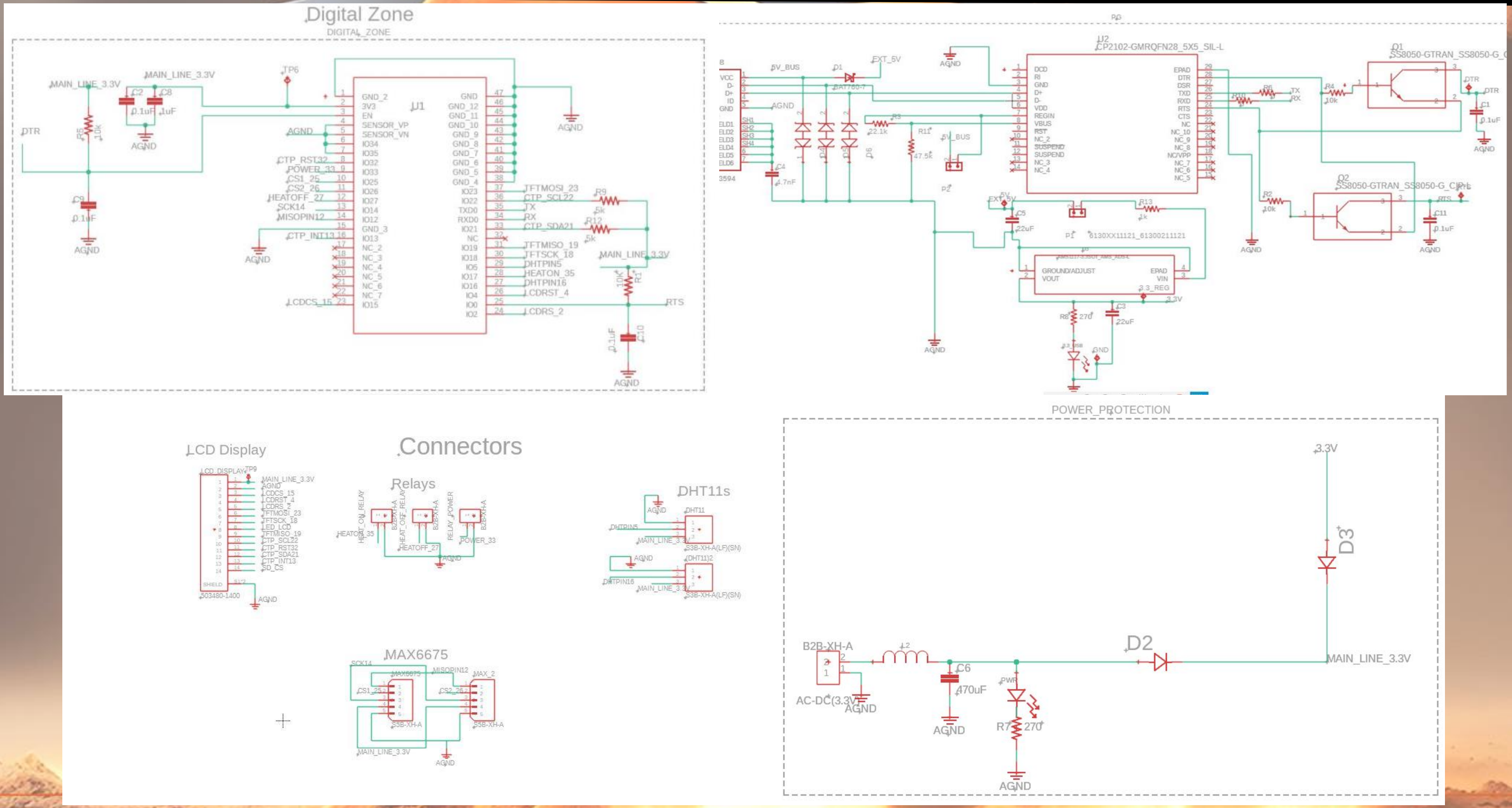
Hardware Block Diagram

MCU Board

- ➔ Main processor unit for our project
- ➔ Power and communication to peripherals
- ➔ Heat/ Low Power/ EMC



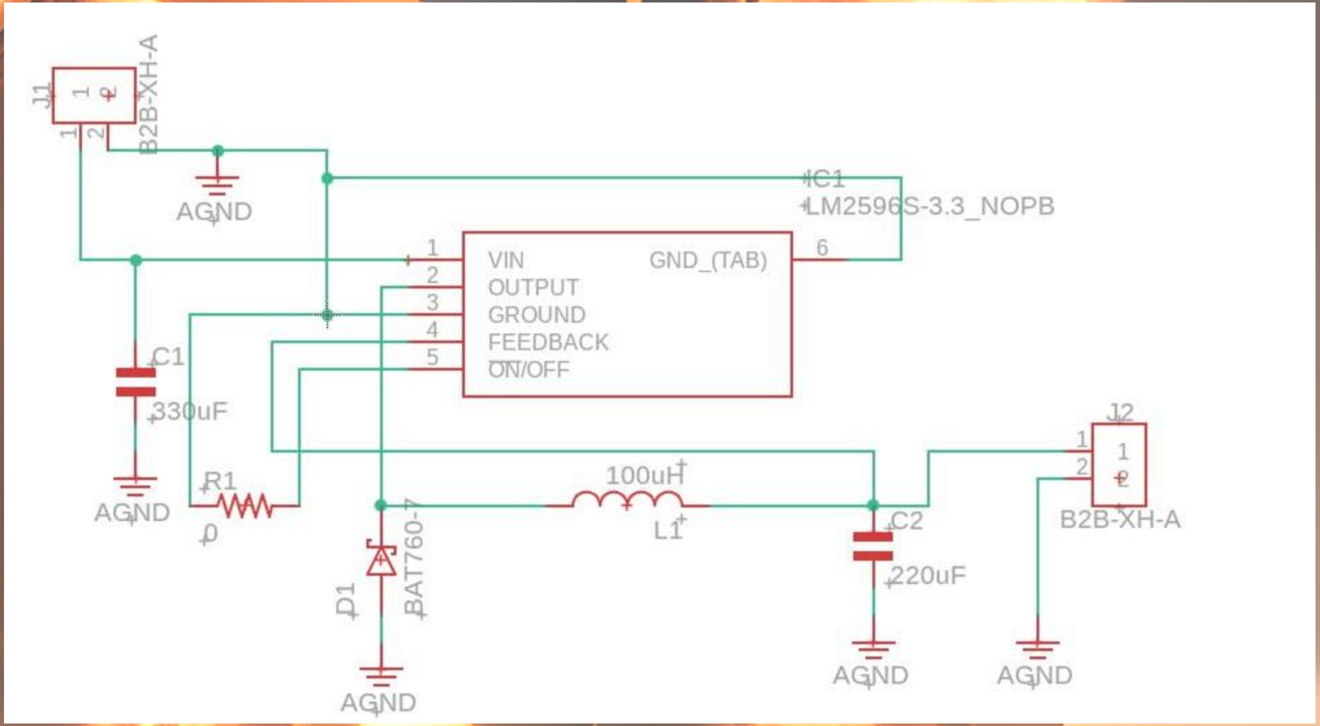
Overall Schematics (MCU)



Overall Schematics (DC-DC)

Custom Power Supply

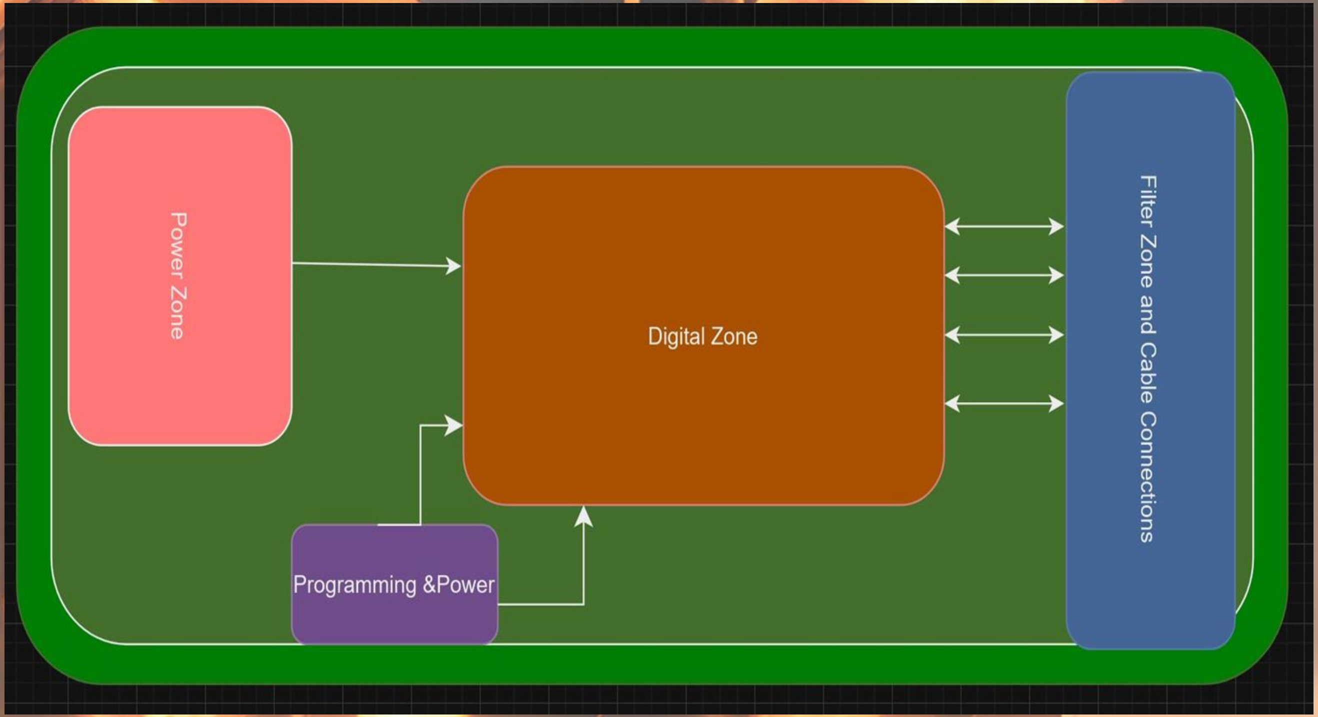
- ➔ 12/24 Input, 3.3V Simple Switcher Buck Regulator
- ➔ Continuous Mode of Operation
- ➔ Low ESR Capacitors and Inductors Required



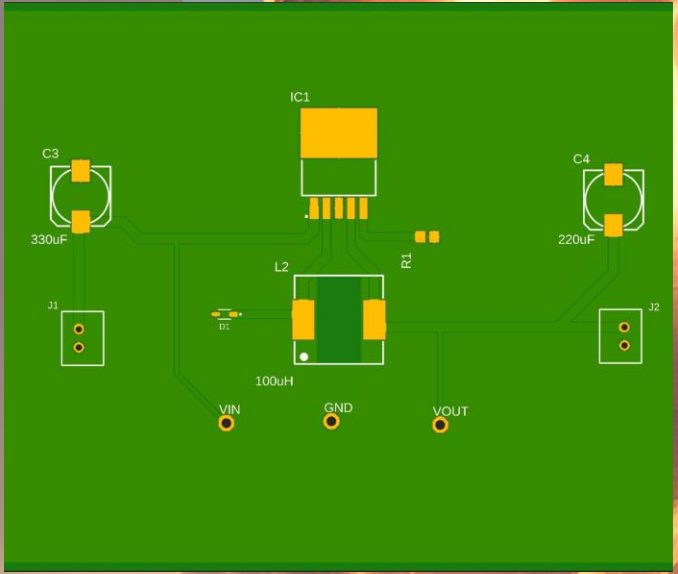
PCB Design

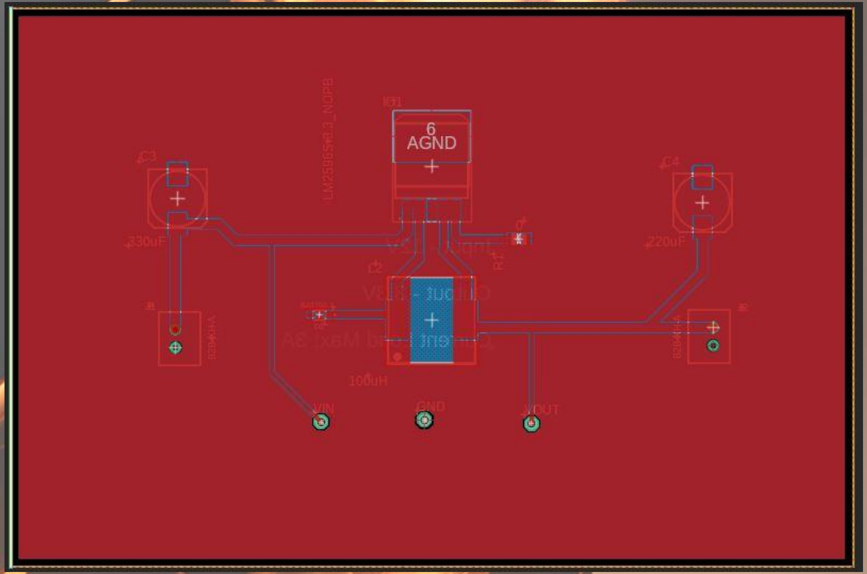
To Effectively Layout our PCB:

- ➔ Take into account EMC considerations
- ➔ Ensure signal/ power integrity
- ➔ Solution: PCB Zones

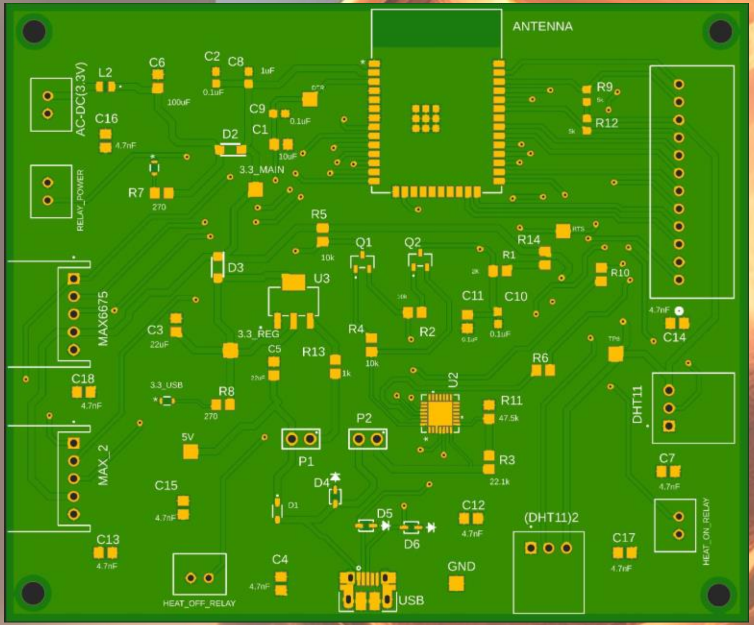


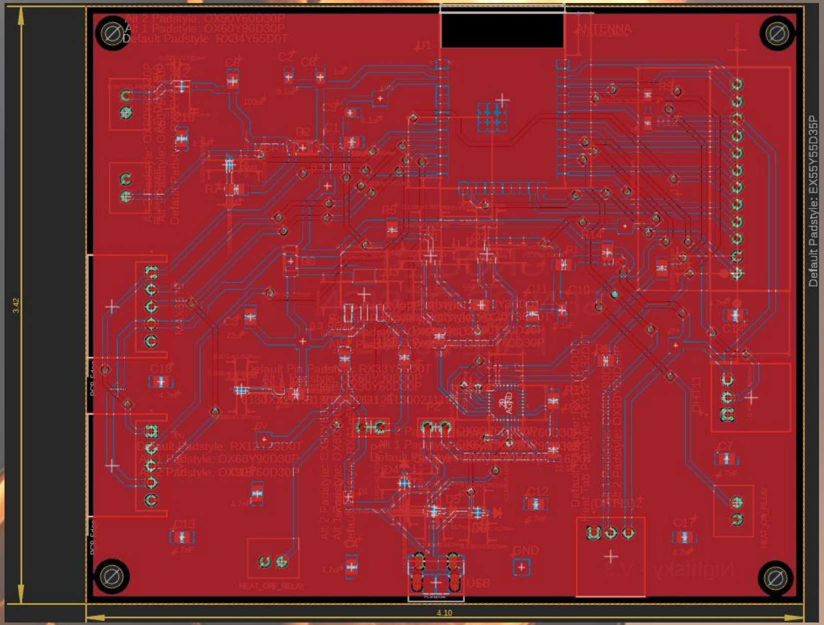
PCB Layout (DC-DC Converter)





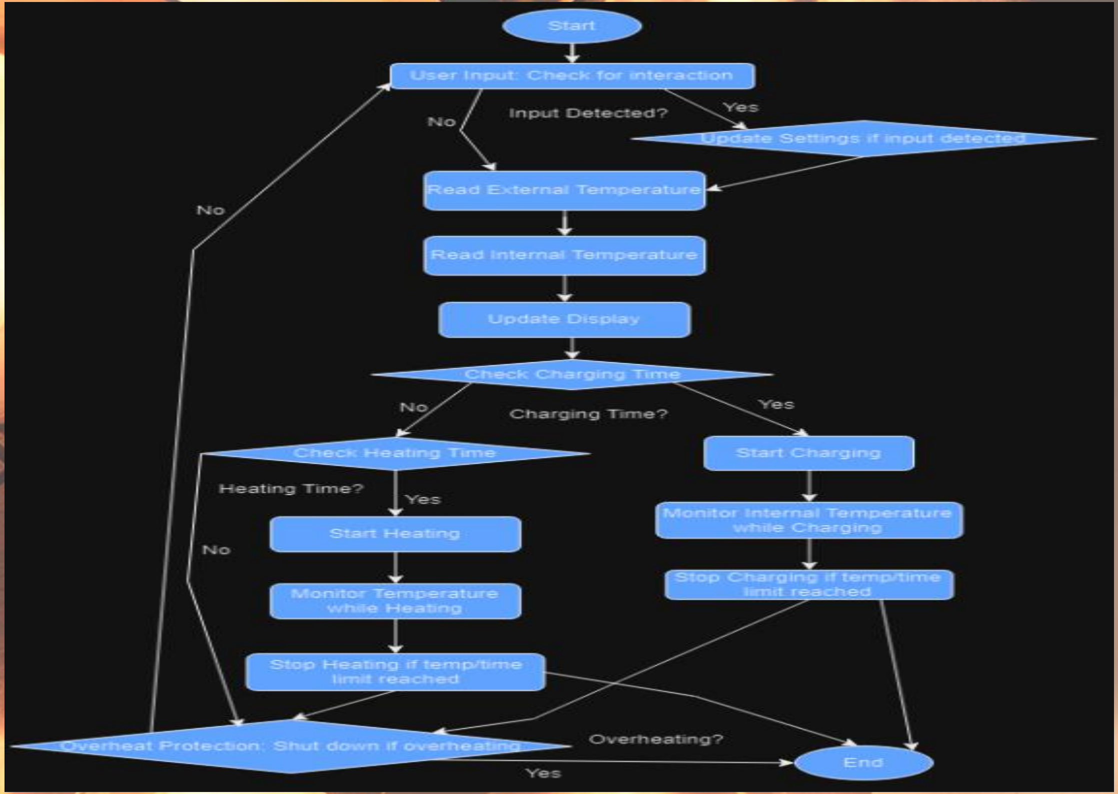
PCB Layout (MCU)





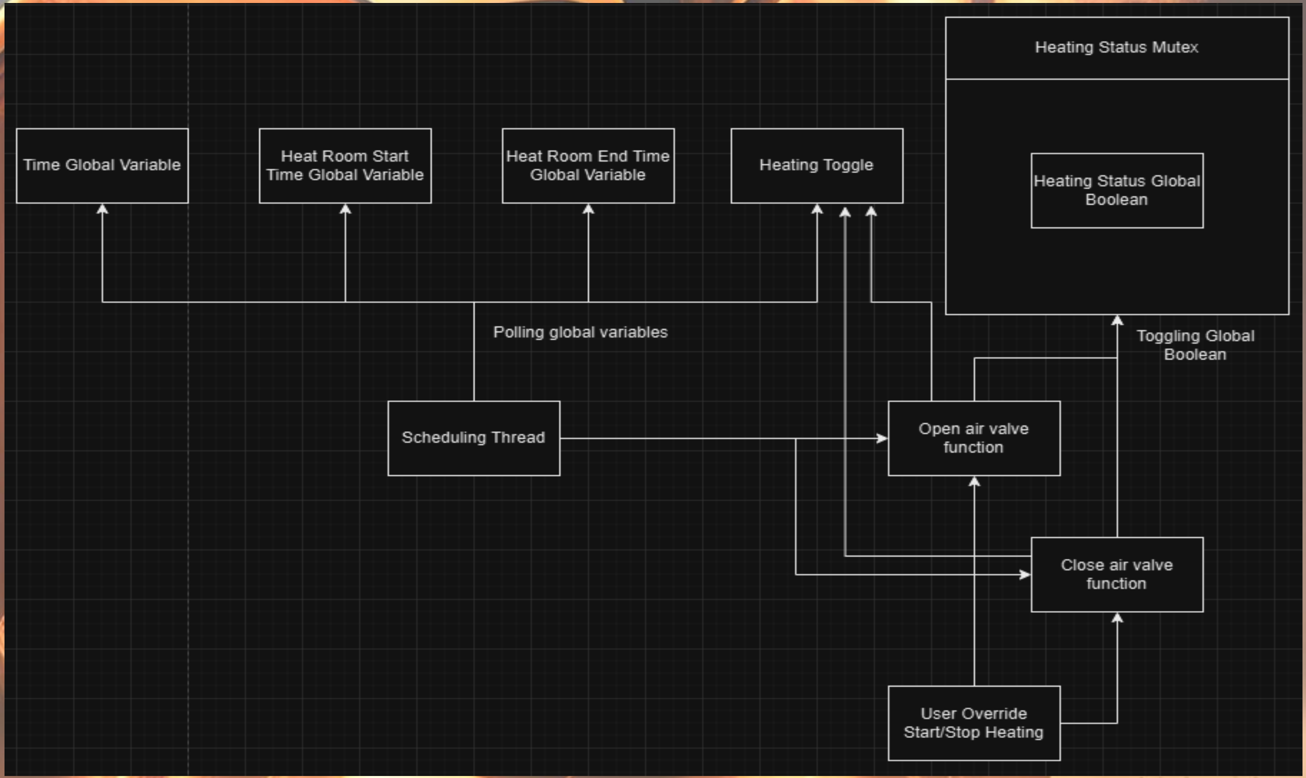
Software Flow Chart

- Front end display main and setting software flow chart



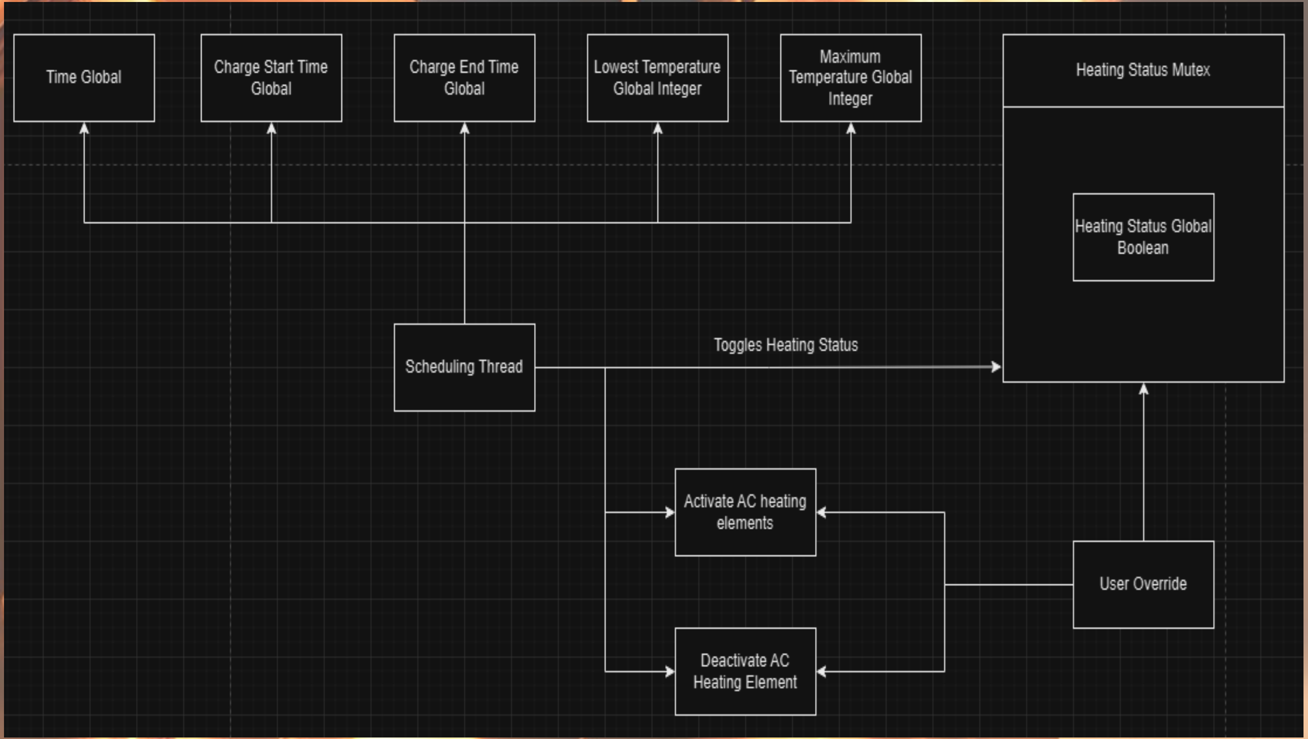
Software Flow Chart

- ➔ Heating Status Scheduling Thread



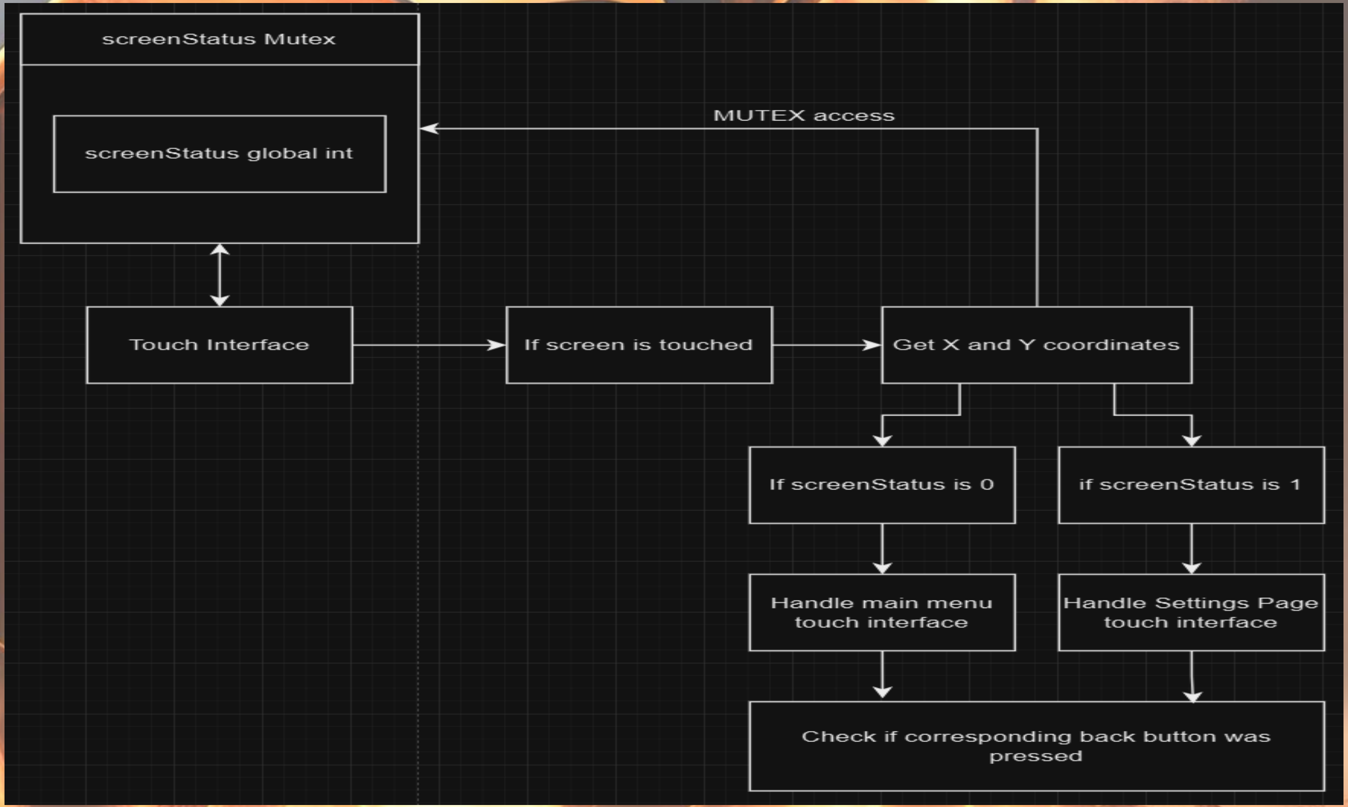
Software Flow Chart

- Charging Status Scheduling Thread



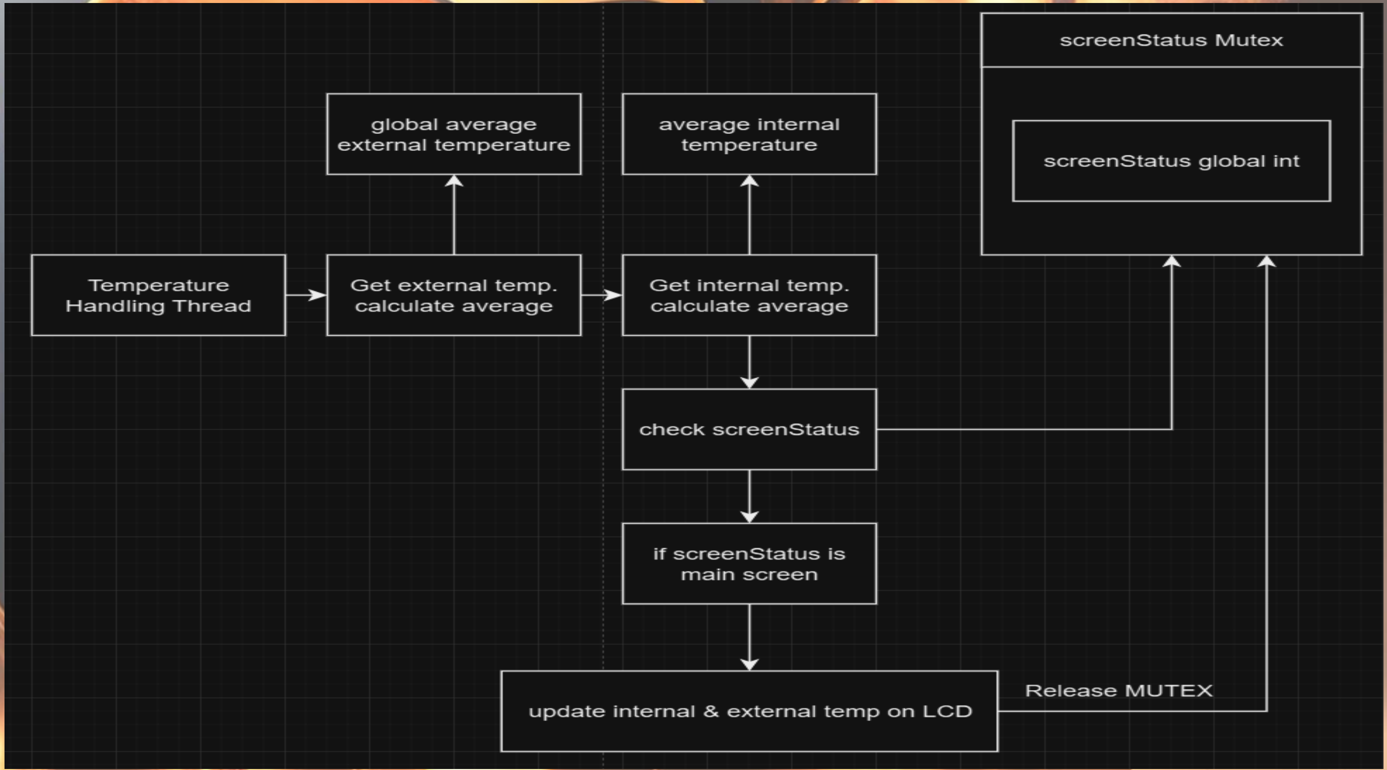
Software Flow Chart

- ➔ Touch Interface Thread



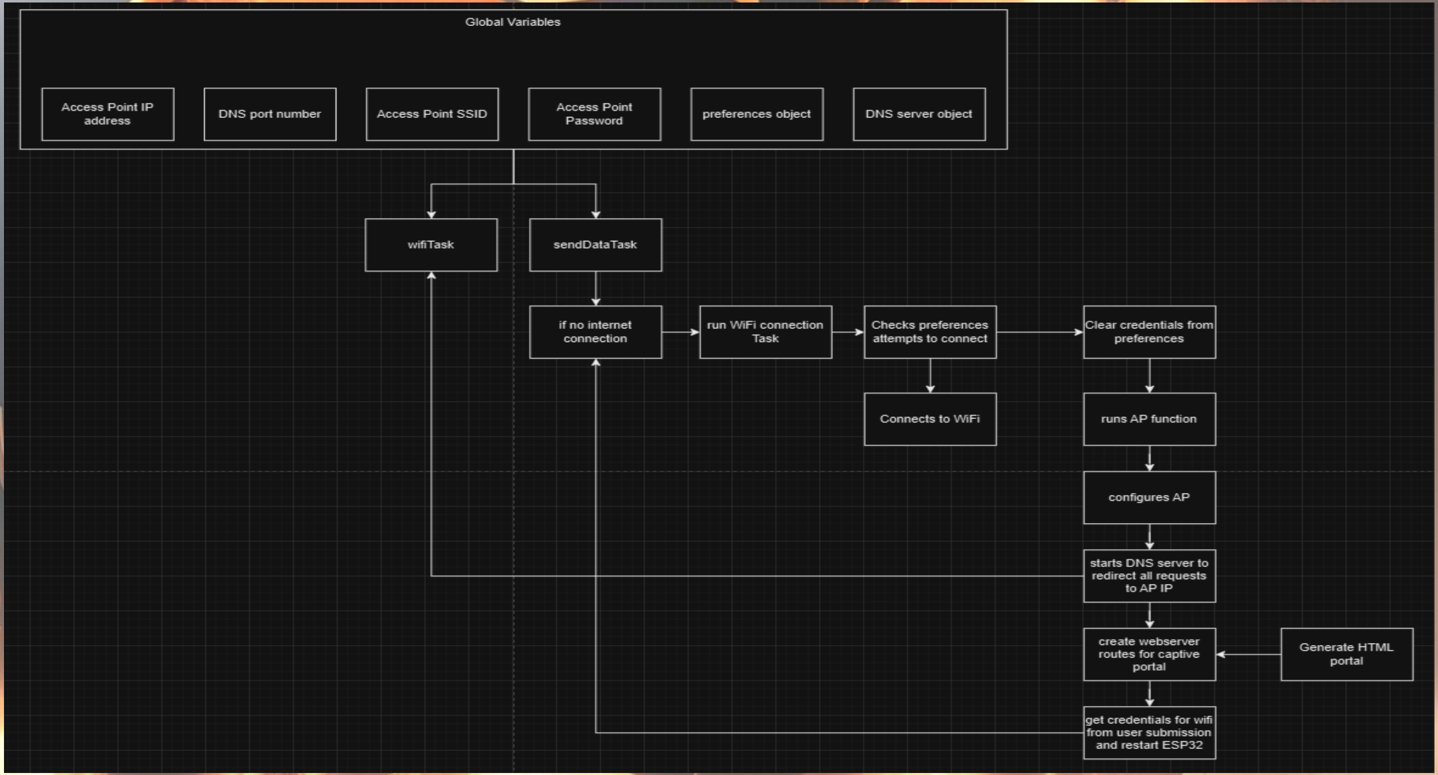
Software Flow Chart

- ➔ Temperature Readings



Software Flow Chart

- ➔ Wifi Connection Thread



Prototyping and Testing

- ➔ Testing DHT11’s
- ➔ K-Type Thermocouples
- ➔ LCD Display
- ➔ Wifi Connectivity
- ➔ Relay Control

Performance Evaluation

- ➔ Testing to see how long battery takes to reach full charge
- ➔ Testing to see how long battery takes to full discharge
- ➔ Test maximum overall system power draw

Prototyping and Testing

Hardware Test Procedure:

1. Preliminary:
   a. Visual Inspection
   b. Continuity Checks across critical power and ground points
   c. Power-Up Test
   d. Communication Verification to MCU
   e. Peripheral Testing

Prototyping and Testing

Hardware Test Procedure:

2. Functional Tests

- Verify that the PCB can read from all sensors and can accurately execute the code as intended
- Verify the LCD display can be integrated with touch capabilities
- Signal Lines will be probed to evaluate the integrity. Here we check for signal degradation, noise, rise and fall times
- Power Lines will be probed for accurate voltage and current draws

Prototyping and Testing

Hardware Test Procedure:

3. ESS Testing

- Unit Under Test (UUT) will be tested under a load similar to what is expected for demo
- UUT will then be tested to extended periods of time to observe any power & communication failures and/or overheating
- Data will be gathered to establish performance limits and trends

Successful Evaluation

To qualify as a success, the hardware must pass the following acceptance criteria:

- Correct functionality in reference to our stated goals
- Stable power outputs
- No communication failures
- Boards can effectively operate within safe operating temperatures. Thermal management devices were be added (heatsinks)

Administrative Content

Budget

- ➔ Final Budget: $910
- ➔ Goal: Provide a low-cost heating solution
- ➔ Beating the avg cost of a lithium battery per Kwh ($300)

Systems	Budget
Frame/Sand Storage	$200
MCU/Peripherals/Components	$400
DC-DC Converter/Heater	$150
Valves/Fans/Aesthetics	$160
TOTAL	$910

Work Distribution

Michael Hernandez	Miguel Baca-Urteaga	Filipe Pestana Frances	Tanner Cyr
- Schematic Capture/ PCB Design for MCU - Parts Selection for cable assemblies - Hardware Integration	- Sensor and Communication Protocols - Software Integration - Software Testing and Validation	- LCD communication for MCU - Graphic User Interface - Touch Display Capabilities	- Schematic Capture/PCB Design for AC-DC Converter - Structural and Mechanical Design - Welding and Manufacturing

All:

- Assembling PCBs -
  Mechanical and Electronic Integration
- Soldering/Troubleshooting - System Level
  Verification & Validation

Senior Design II Milestones