CHAPTER 3 – RESEARCH METHODS

3.1. Design Justification

3.1.1. Mechanical Design Improvement

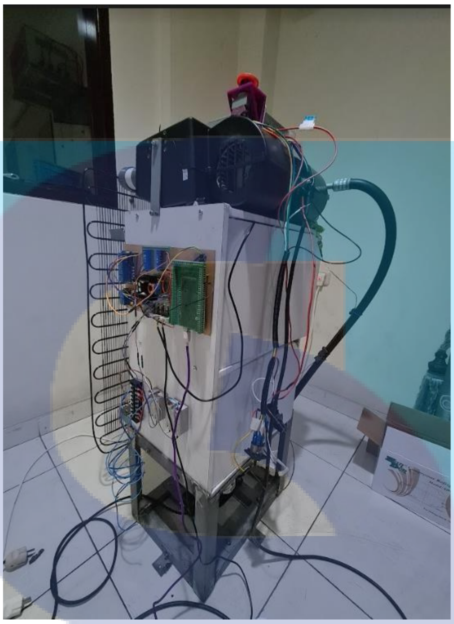

Figure 5. Previous Design

Figure 5 above illustrates the earlier model of the smart refrigerated locker model. In this previous design, the refrigeration system incorporated traditional components such as a compressor, condenser, and evaporator. The cooling process relied on the utilization of freon, a commonly used refrigerant, to lower the temperature within the locker's chamber. To achieve the desired cooling effect, the freon was circulated throughout the system using copper pipes and brass flared fittings. These components played a crucial role in ensuring the efficient transfer of heat and maintaining the overall functionality of the refrigeration system. In terms of component selection, the previous model opted for retrofitted parts. For instance, the compressor was sourced from a typical household air conditioner unit, which was repurposed to suit the requirements of the smart refrigerated locker. This retrofitting allowed for cost-effective implementation while still delivering the necessary compression capability for the system.

Figure 6. Previous Chamber Insulation Design

Figure 6 shows the previous model's chamber insulation design. In this design, aluminum foil insulation foam was chosen as the preferred material for all areas of the chamber. The selection of aluminum foil insulation foam was based on its notable characteristic of possessing high thermal conductivity, which makes it an excellent choice for effective insulation. The insulation has a crucial role in maintaining the desired temperature inside the locker's chamber. By utilizing aluminum foil insulation foam, it minimizes heat transfer between the interior of the chamber and its surroundings. This insulation material acts as a barrier, reducing the impact of external temperature fluctuations and helping to preserve the cool temperature within the locker. Furthermore, the high thermal conductivity of aluminum foil insulation foam allows for efficient heat dissipation. This means that any heat generated within the chamber, such as from the operation of the refrigeration system, can be effectively dispersed through the insulation material, aiding in maintaining the desired temperature.

Figure 7. New Smart Refrigerated Locker Design

Figure 7 shows the new smart refrigerated locker design. In this new model, a steel locker is employed as the primary structural material, offering enhanced durability and robustness. The utilization of steel contributes to the overall strength of the locker, ensuring the safe storage of items within. It also uses Peltier module to cool down the chamber temperature so the exterior is much simpler because Peltier module is small, and it only needs heatsink on the hot side and cold side. The Peltier module used in the new design measures 40mm x 40mm, with a thickness of 3.9mm. The compact size of the Peltier module, measuring 40mm x 40mm with a thickness of 3.9mm, not only facilitates efficient cooling but also simplifies the overall exterior structure of the locker. With the compact size of the Peltier module, the need for additional components and complex cooling systems is significantly reduced. To ensure proper insulation when the chamber is closed, the new model includes a hole on the right side of the locker. This hole allows for organized routing of the cables, ensuring a tight closure of the chamber door. By incorporating this cable management feature, the new model enhances the overall functionality and aesthetic appeal of the smart refrigerated locker.

It uses two power supply, one power supply for the heatsink fan of the hot side and cold side, and one power supply to power Peltier module.

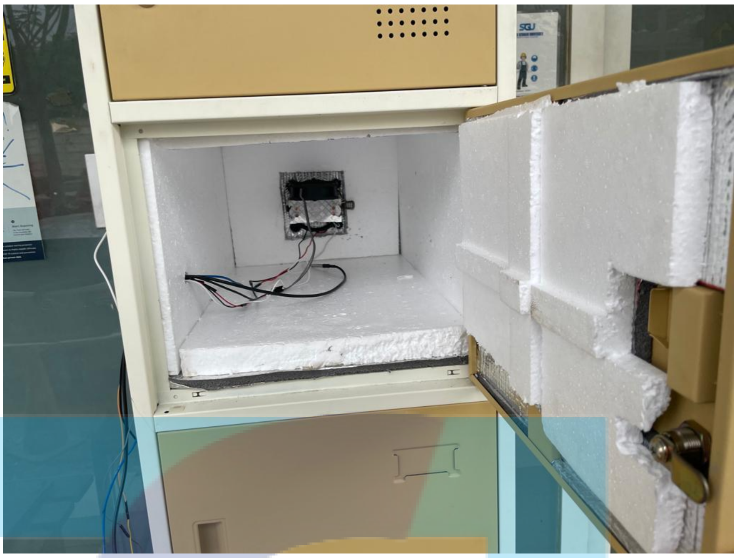

Figure 8. New Smart Refrigerated Locker Insulation Design

As seen on Figure 8, the new smart refrigerated locker insulation design incorporates two layers of insulator, which is aluminum foil insulation foam and Styrofoam. Aluminum foil insulation foam is chosen because the foam layer provides thermal resistance by limiting the heat transfer through conduction. Foam materials have low thermal conductivity, so this means that they are not efficient at conducting heat, preventing the heat from easily passing through. Combined with layer of aluminum foil which has excellent reflective properties that can effectively reflect radiant heat, the aluminum foil insulation foam adds the insulation performance by reducing heat. In addition, the Styrofoam is also an excellent insulator that helps maintain a stable temperature because it has low thermal conductivity. This means that the heat transfer between the chamber and the surroundings is minimized. The lightweight and customizability properties of Styrofoam also make it a good insulator because it is easy to customize to any shapes and sizes by cutting it. To ensure that there is no gap on the chamber, the combination of aluminum foil insulation foam and Styrofoam is fitted on all surface of the chamber, including the door. The small gap on the lower side of the door is needed so that the door can close and maintain the air-tight condition inside the chamber.

Figure 9. New model hot side heatsink

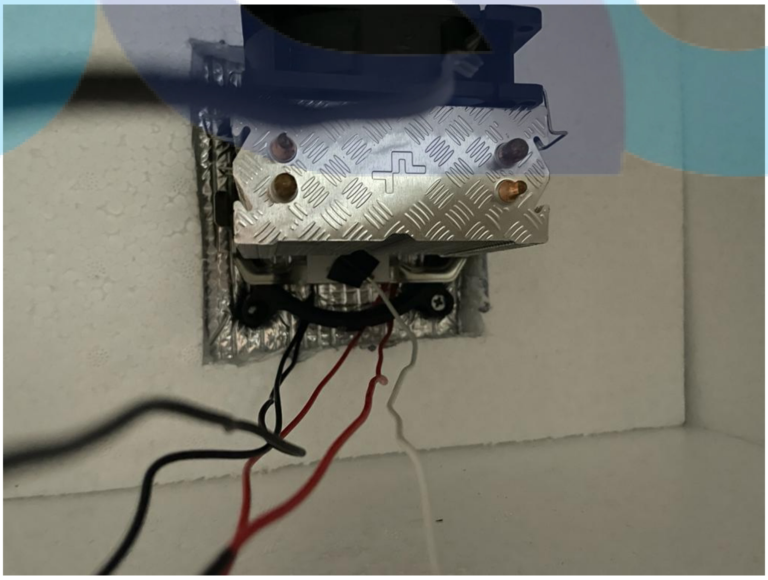

Figure 10. New model cold side heatsink

As seen on Figure 9 and Figure 10, the new model utilizes two separate heatsinks for the Peltier module, each serving a specific purpose in maintaining optimal cooling performance. In Figure 9, the larger heatsink is dedicated to the hot side of the Peltier module. This larger size is essential to ensure efficient heat dissipation from the hot side of the module. As the Peltier module absorbs heat from the chamber, it transfers this heat to the hot side. The larger heatsink maximizes the surface area available for dissipating this heat. Additionally, a fan is incorporated into the hot side heatsink to facilitate airflow and enhance heat dissipation. In Figure 10, the smaller heatsink is dedicated to the cold side of the Peltier module. This heatsink serves the crucial function of absorbing the heat present inside the chamber and transferring it to the cold side of the Peltier module. Similar to the hot side heatsink, a fan is incorporated into the cold side heatsink to facilitate airflow and aid in heat absorption.

3.1.2. Electrical Design

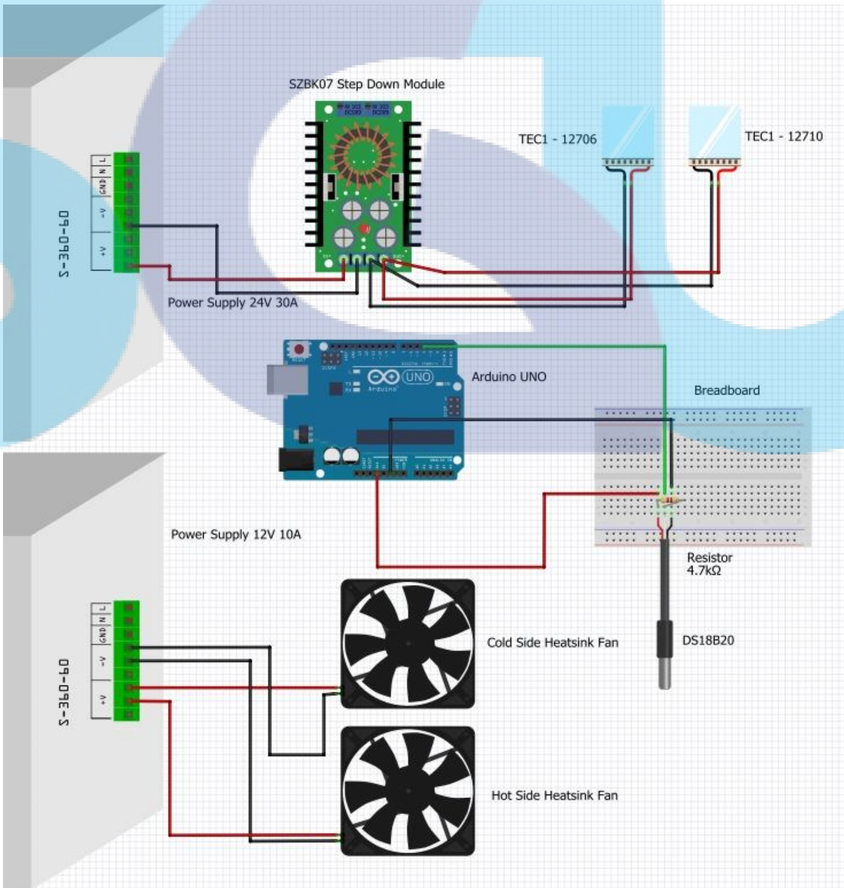

Figure 11. Fritzing Smart Refrigerated Locker

Figure 11 shows the power supply setup in the new smart refrigerated locker design. The Peltier module and the associated heatsink fans are connected to two separate power supplies, each serving a specific purpose. The first power supply is dedicated to powering the heatsink fans installed on both the hot side and cold side of the Peltier module. This power supply is a 12V 10A unit, specifically chosen to provide sufficient power for the fans' operation. The second power supply is responsible for providing the necessary power to operate the Peltier module itself. This power supply is a 24V 30A unit, selected to meet the power requirements of the Peltier module. To achieve the desired voltage output for the Peltier module, a step-down module, specifically the SZBK07 DC 6-40V to DC 1.2-36V, is integrated into the power supply setup. This step-down module serves the purpose of adjusting the voltage output of the 24V 30A power supply to a lower voltage level of either 15V or 12V. This voltage adjustment is necessary to align with the specific requirements of the Peltier module, ensuring optimal performance and maximizing the efficiency of the cooling process.

3.2. Materials and Equipment

3.2.1. Electrical Components

3.2.1.1. Power Supply

Figure 12. Power Supply

The power supply unit (PSU) is a vital component that is responsible for powering and facilitating the operation of the electrical components within this specific system. Its primary purpose is to convert the incoming Alternating Current (AC) power from an external source, such as a wall outlet, into the appropriate Direct Current (DC) power. This conversion is essential since all the electrical components in the system require

Direct Current (DC) voltage to function correctly. By converting the AC power to DC power, the power supply unit ensures compatibility between the power source and the components. It provides a steady and regulated supply of power, delivering the required voltage and current levels that each component needs to operate optimally.

For this model, two power supply are used with different specifications. The first power supply is a 24V 30A unit, while the second one is a 12V 10A unit. Both power supplies are designed to be connected to a power plug, utilizing the standard ground, neutral, and line pins for safe and reliable power connection. The 12V 10A power supply features two positive (+) pins and two negative (-) pins. These pins are utilized to deliver the required 12V DC power to the cooling fans in the system. By connecting the positive and negative pins to the respective terminals of the fans, the power supply ensures efficient cooling and proper airflow within the system. On the other hand, the 24V 30A power supply offers a slightly different configuration. It provides three positive (+) pins and three negative (-) pins. One of the positive pins and one of the negative pins from the 24V 30A power supply are connected to the SZBK07 DC 6-40V to DC 1.2-36V step-down module. This module serves the purpose of regulating the voltage between 12V and 15V, which is required for the operation of the two Peltier modules.

3.2.1.2. Arduino UNO

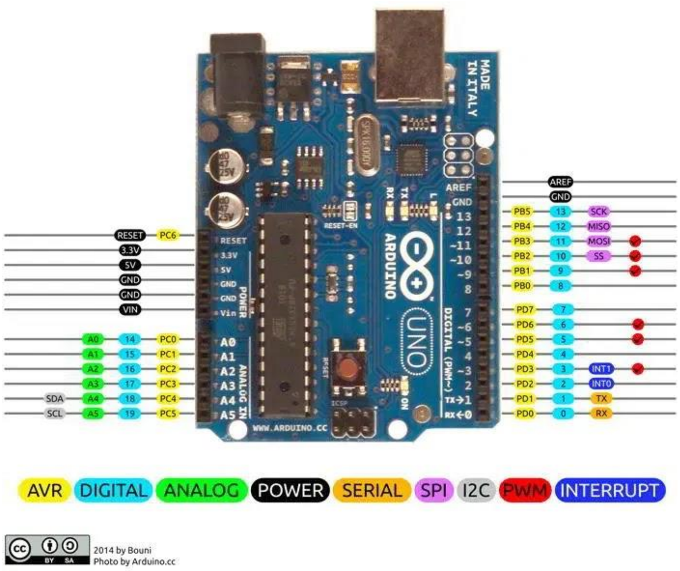

Figure 13. Arduino UNO pin layout

The chosen control unit for this project is Arduino Uno. It is a microcontroller board that has 14 digital input/output pins that can be configured as either inputs or outputs and used for tasks such as reading sensors or controlling actuators. Among these pins, 6 can be used for Pulse Width Modulation (PWM) output. The Arduino Uno is programmed using the Arduino IDE, which provides a user-friendly environment for writing, compiling, and uploading code to the board. The IDE is open-source and supports the C/C++ programming language, making it accessible for beginners. Using the Arduino Uno's programming capabilities, a dedicated code is developed to communicate with the DS18B20 temperature sensor and retrieve temperature readings at regular intervals. The code employs specific libraries and functions to read the sensor's digital output, convert it into a temperature value, and store or display the data as needed. The Arduino Uno's processing power and flexibility allow for real-time temperature monitoring and control of the smart refrigerated locker. It can execute custom logic and algorithms to trigger actions based on temperature thresholds, such as activating cooling systems or sending alerts when the temperature exceeds certain limits.

3.2.1.3. DS18B20 Temperature Sensor

Figure 14. DS18B20 Temperature Sensor pin layout

The DS18B20 temperature sensor has the function of accurately measuring the internal temperature of each locker. With a wide temperature range spanning from -55°C to 125°C, the DS18B20 temperature sensor give precise temperature readings across various operational conditions. This broad range allows for effective monitoring of temperature-sensitive items stored in the lockers, including perishable food, beverages, and ingredients. One notable advantage of the DS18B20 sensor is its waterproof capability. It adds an extra layer of reliability and safety when measuring the temperature in lockers that may contain liquids or require regular cleaning. The waterproof capability ensures that the sensor remains protected from moisture and contaminants, allowing for accurate and hygienic temperature measurements. It is connected to the Arduino UNO microcontroller. The Arduino UNO functions as the central control unit, responsible for receiving and processing the temperature data from the sensor. By interfacing with the sensor, the Arduino UNO can collect real-time temperature readings from each locker. In order to establish communication between the DS18B20 sensor and the Arduino UNO, One Wire Bus library is used. This library allows for simple and efficient data transmission over a single data line, reducing the complexity of the wiring and facilitating seamless communication. To ensure stable and reliable communication, a pull-up resistor is required. In this case, an additional 4700-ohm resistor is connected to DS18B20 temperature sensor from breadboard. The purpose of this resistor is to maintain a consistent voltage level on the One Wire Bus, enabling accurate data transfer between the sensor and the Arduino UNO. This pull-up resistor is an essential component for ensuring the integrity of the communication interface.

3.2.1.4. TEC1 – 12706 Peltier Module

Figure 15. TEC1 – 12706 Peltier Module

A Thermoelectric Cooler (TEC) module is an electronic component that harnesses the principles of thermoelectricity to provide efficient heating and cooling capabilities. Utilizing the Peltier effect, a TEC module can transfer heat from one side to the other when a direct current (DC) power source is applied. This functionality makes it a crucial component of the smart refrigerated locker system. TEC1 – 12706 is a specific type of TEC module that stands out for its simplicity and effectiveness. With the ability to cool and heat with remarkable efficiency, it presents a versatile solution for temperature control applications. The module is designed to handle temperature differentials of up to 90°C, enabling it to effectively cool one side while simultaneously heating the other. The TEC1 – 12706 module comprises 127 semiconductor couples, arranged in a 40x40mm configuration. These semiconductor couples consist of two dissimilar materials that exhibit the thermoelectric effect when subjected to an electrical current. As a result, one side of the module becomes the hot side, while the other side becomes the cold side.

The hot side of the TEC1 – 12706 Peltier module absorbs heat from the surrounding environment, while the cold side dissipates heat, creating a temperature gradient across the module. This temperature gradient enables heat transfer process of the temperature inside the smart refrigerated locker. To operate the TEC1 – 12706 Peltier module, a DC power source is required. By supplying the module with the appropriate voltage of 12V or 15V and current, it becomes an active heat pump, transferring heat from one side to the other. The TEC1 – 12706 module's compact size make it well-suited for the smart refrigerated locker system. Its relatively small size allows for easy placement and installation, maximizing space utilization within the lockers while delivering heat transfer capabilities.

3.2.1.5. TEC1 – 12710 Peltier Module

Figure 16. TEC1 – 12710 Peltier Module

The TEC1-12710 Peltier module is another type of thermoelectric cooler (TEC) or Peltier module that operates on the principles of the Peltier effect. It is an upgraded version compared to the TEC1-12706 module, offering improved performance and capabilities. The TEC1-12710 module is designed to provide efficient cooling and heating functionality in various applications. It consists of 127 semiconductor couples, similar to the TEC1-12706 module, but with a higher performance rating. The module measures 40x40mm, just like its counterpart. With the TEC1-12710 module, you can achieve greater cooling and heating capacity compared to the TEC1-12706 module. It can effectively create a larger temperature differential, allowing for more efficient heat transfer. The higher performance of the TEC1-12710 module makes it suitable for applications that require greater cooling power or precise temperature control. The TEC1-12710 module can handle temperature differentials of up to 100°C, making it capable of effectively cooling one side while heating the other.

In this model, the TEC1-12706 and TEC1-12710 Peltier modules are used in a cascade setup to enhance the cooling performance of the smart refrigerated locker's chamber. The cascade setup involves stacking both Peltier modules together, which results in increased heat transfer capabilities and ultimately enabling the smart refrigerated locker to attain lower temperatures inside the chamber. By utilizing the cascade setup, the cooling capacity of the system is significantly improved. The TEC1-12706 module is positioned as the first stage in the cascade. It extracts heat from the chamber, reducing the chamber's temperature. The heat extracted by the TEC1-12706 module is then transferred to the TEC1-12710 module, which acts as the second stage in the cascade. The TEC1-12710 module, being an upgraded and more powerful Peltier module, further cools the heat transferred from the first stage. Its enhanced cooling capacity enables the extraction of additional heat from the chamber, resulting in even lower temperatures. By combining the cooling capabilities of both modules, the cascade setup optimizes the cooling process and enhances the overall efficiency of the refrigeration system.

3.2.1.6. SZBK07 DC 6-40V to DC 1.2-36V Step-Down Module

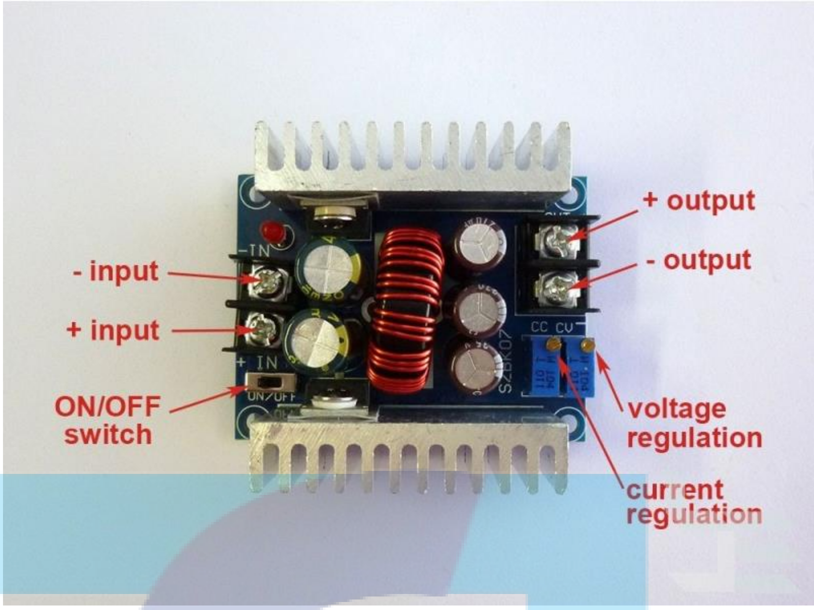

Figure 17. SZBK07 DC 6-40V to DC 1.2-36V step-down module

The SZBK07 step-down module is an electronic device used to regulate and convert higher DC voltage levels to lower DC voltage levels. The main function of the SZBK07 step-down module is to decrease the voltage from a higher input voltage source to a lower output voltage. This is achieved through the use of a switching regulator or buck converter circuitry. The module typically accepts a wide range of input voltages, such as 6-40V DC, and provides a regulated and adjustable output voltage within a specified range, such as 1.2-36V DC. The SZBK07 module incorporates various components and features to facilitate efficient voltage conversion. It includes a switching controller, power MOSFETs, inductors, capacitors, and feedback circuits. One of the key advantages of the SZBK07 step-down module is its ability to provide adjustable output voltage. It has a potentiometer or voltage and current adjustment module that allows the user to set the desired output voltage and ampere within the specified range. This adjustability makes it versatile for different model requirements.

The SZBK07 step-down module plays a crucial role in the overall functionality of the system by providing voltage regulation for the Peltier modules. It acts as a voltage converter, allowing the 24V 30A power supply to be adjusted to either 12V or 15V, depending on the requirements of the Peltier modules. To connect the SZBK07 module and the power supply, the (+) Input pin and (-) Input pin of the module are connected to the respective positive and negative pin of the 24V 30A power supply. This connection ensures that the module receives the necessary power input to perform its voltage conversion function. On the output side, the (+) Output pin and (-) Output pin of the SZBK07 module are connected to a terminal block. This terminal block serves as a convenient interface for connecting the Peltier modules. By routing the output voltage from the SZBK07 module through the terminal block, the desired voltage, either 12V or 15V, is supplied to both Peltier modules simultaneously.

3.2.1.7. Terminal Block TB – 2508L

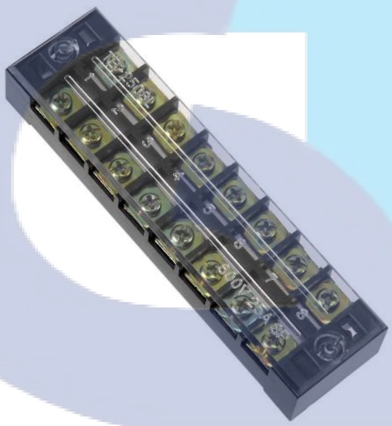

Figure 18. Terminal Block TB – 2508L

A terminal block, also known as a connection terminal or terminal strip, is a modular electrical connector used to secure and connect multiple electrical wires or cables. It provides a convenient and organized way to make electrical connections in various applications. The primary purpose of a terminal block is to establish secure and reliable electrical connections. It allows multiple wires to be connected or disconnected without the need for soldering or specialized tools. Terminal blocks are commonly used in industrial control panels, electrical distribution systems, HVAC systems, and various other applications where multiple electrical connections need to be made. The terminal block in this model functions as a secure and reliable connection of cables, thus making the wiring of the model become easier and neater. In addition, the terminal blocks provide convenience of maintenance to the electrical wiring such as the cable swapping is easy because there is no need of soldering. The terminal blocks that is used in this prototype is TB – 2508L with 600V 25A 8P, it means that it has eight poles, and each pole's maximum current is 25A. This prototype uses TB – 2508L to connect both Peltier module to the (+) Output pin and (-) Output pin of the SZBK07 step-down module. By using terminal block, this prototype can power up many Peltier modules just with using a single SZBK07 step-down module. With each pole being able to hold current up to 25A, the Peltier modules can be used up to its maximum power without worrying about the current.

3.2.2. Mechanical Components

3.2.2.1. Steel Locker

Figure 19. Krisbow 6 Stage Steel Locker

The steel locker is the central component of this project, serving as the primary structure that houses and maintains the desired temperature for the items stored within. To accommodate the thermoelectric cooling module and ensure effective cooling performance, certain modifications such as cutting holes to fit Peltier modules and holes to route the cables are made to the locker. By adapting the Krisbow steel locker and implementing the necessary modifications, this project aims to deliver a practical and efficient smart refrigerated locker solution that can safely store and preserve perishable items while maintaining optimal temperature control.

3.2.2.2. Heatsink

Figure 20. Cold Side Heatsink with fan

Figure 21. Hot Side Heatsink with Fan

In a Peltier cooling system, a heatsink is important in ensuring the effective transfer and dissipation of heat generated by the Peltier modules. To maintain efficient cooling, it is necessary to dissipate the heat generated by the hot side of the module. The heatsink provides a large surface area, allowing for effective heat dissipation into the surrounding environment. The performance and efficiency of Peltier modules are directly affected by the temperature gradient across their surfaces. Excessive heat buildup on the hot side of the module can lead to a reduction in cooling capacity and overall system efficiency. The heatsink helps regulate the temperature by providing a pathway for the heat to escape, preventing overheating and ensuring optimal performance of the Peltier modules.

In this model, the hot side heatsink is noticeably larger than the cold side heatsink. It is because for the hot side of Peltier module, A larger heatsink can absorb and distribute the heat more effectively, helping to maintain the temperature within the desired operating range. This helps to prevent localized hotspots and provides a more uniform cooling effect. The larger heatsink also provides a larger surface area, allowing for greater heat transfer to the surrounding environment and also provides better heat spreading capabilities. It allows for greater surface area contact with the Peltier module, ensuring that heat is spread more evenly across the heatsink

3.2.2.3. Aluminum thermal insulation

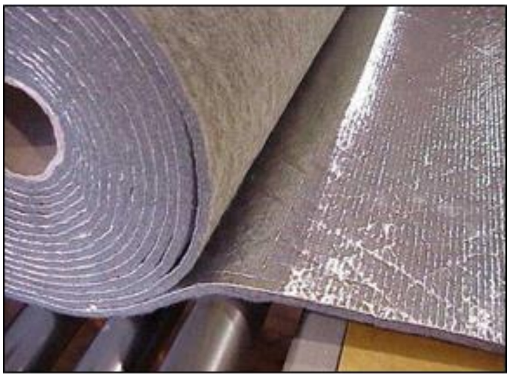

Figure 22. Aluminium thermal insulation

Aluminium foil insulation foam is used in the Peltier cooling system as a component to help maintain a cool temperature. The aluminium foil acts as a reflective barrier, preventing the transfer of heat through radiation. It reflects the heat back into the chamber, reducing heat gain from the surroundings. Additionally, the foil also provides a protective layer against moisture and other external elements. The foam material, on the other hand, acts as an insulator by trapping air pockets within its structure. These air pockets help to slow down the conduction of heat, effectively reducing heat transfer from the surroundings into the cooled chamber. By using aluminium foil insulation foam in the Peltier cooling system, it helps to minimize heat ingress, maintain a cooler temperature, and enhance the overall efficiency of the cooling process.

3.2.2.4. Thermal Paste

Figure 23. Thermal Paste

Thermal paste, also known as thermal compound or thermal grease, plays an important role in facilitating efficient heat transfer between the TEC1 – 12706 and TEC1 - 12710 Peltier modules and their respective heatsinks. When the Peltier modules generate heat during operation, it is important to have a reliable thermal interface to maximize heat dissipation. The thermal paste acts as a bridge between the surfaces of the Peltier modules and the heatsinks, filling in microscopic imperfections and air gaps that may exist between them. The primary function of the thermal paste is to improve thermal conductivity, enabling better heat transfer from the Peltier modules to the heatsinks. By ensuring optimal contact and eliminating air pockets, the thermal paste enhances the efficiency of heat dissipation by minimizing thermal resistance. In addition, the thermal paste helps to prevent uneven temperature distribution and hotspots, which can potentially damage the Peltier modules and compromise their performance. By providing a uniform interface between the modules and heatsinks, the thermal paste ensures that heat is evenly spread and dissipated, promoting more reliable and effective cooling.

3.2.2.5. Styrofoam

Figure 24. Styrofoam box

Styrofoam, also known as expanded polystyrene (EPS), is widely utilized in Peltier cooling systems as an insulator to help maintain a cool temperature. This material possesses several characteristics that make it well-suited for this purpose. One of the primary advantages of Styrofoam is its thermal insulation properties. The Styrofoam structure comprises countless small air pockets that are trapped within the material, and also possess low thermal conductivity, effectively slowing the transfer of heat. This insulation capability helps minimizing heat gain from the surrounding environment and prevents the intrusion of external heat into the cooled space. By creating a thermal barrier, Styrofoam ensures that the temperature inside the system remains cool and stable.

Additionally, Styrofoam is lightweight and easily malleable, allowing for easy customization and fitting into specific areas within the chamber. It can be readily cut or shaped to create barriers or enclosures, making sure that the smart refrigerated locker's chamber is properly insulated and shielded from external heat sources. Also, Styrofoam serves as a cost-effective insulation material compared to alternative options. It is readily available, affordable, and easy to work with, making it a practical choice for insulation in Peltier cooling systems.

3.3. Flowcharts

3.3.1. Refrigeration System

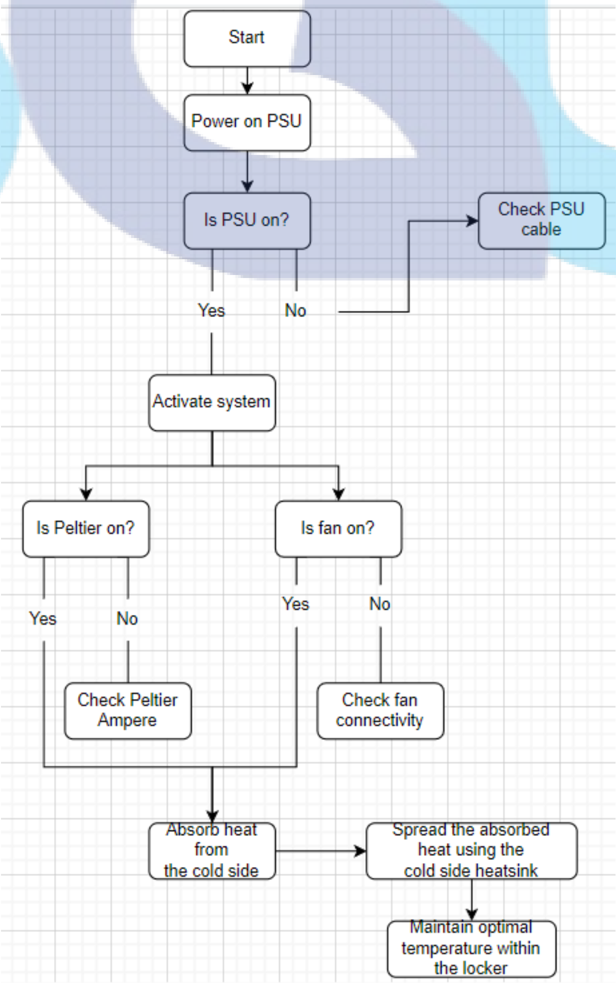

Figure 25. Refrigeration System Flowchart

The refrigeration system flowchart, depicted in Figure 25, illustrates the operation of the various components. First, power on the PSU. Check if the PSU is on. If it is not on, check the PSU cable and check the connection of the ground, neutral, and line. Upon powering on the PSU, check if the Peltier module and the CPU fan are activated. If the Peltier module is not on, check Peltier module ampere. If the ampere reads 0.1A, then the Peltier module is broken and needs to be replaced. if the fan is not on, check the connection of the fans to the PSU. if both Peltier module and fans are on, then the Peltier module will absorb the heat of the chamber from the Peltier module's cold side. The absorbed heat will be spread across cold side heatsink.

3.3.2. Locker Selection System

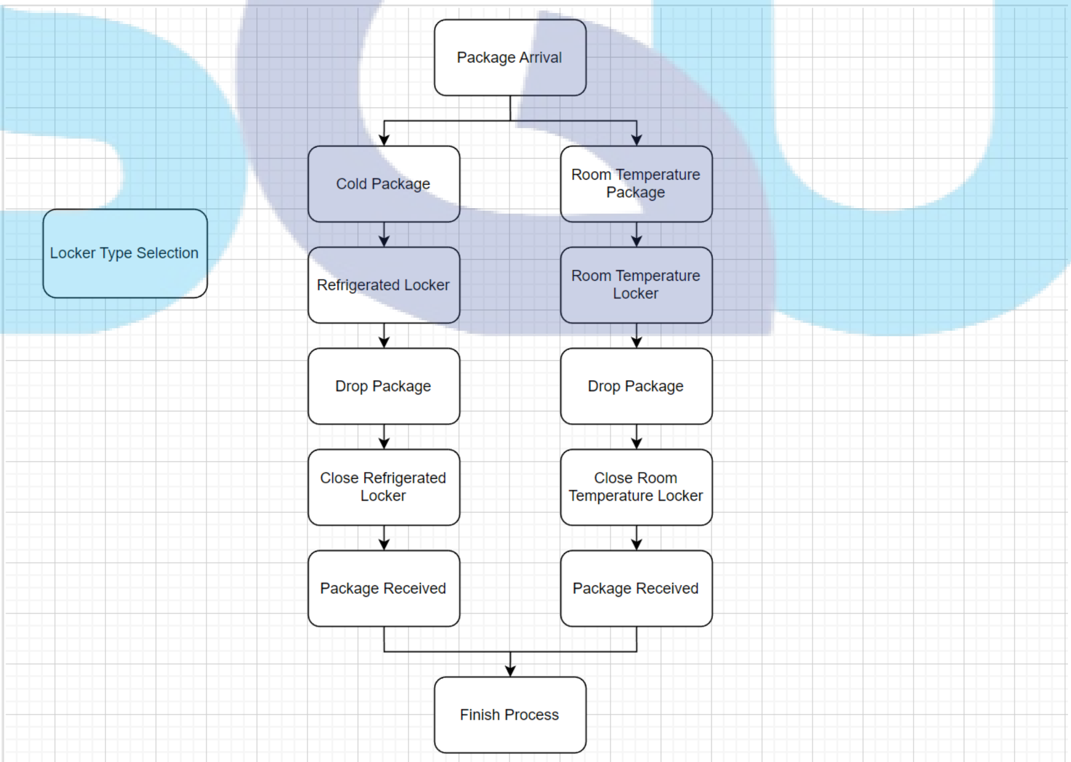

Figure 26. Locker Selection Flowchart

The flowchart shown in Figure 26 illustrates the decision-making process for selecting the appropriate locker based on the type of package being handled. It begins by deciding whether the package is classified as a cold package, indicating the need for refrigeration to maintain low temperatures. If it is a cold package, the flow directs towards using a refrigerated locker, which is specifically designed to preserve the freshness and quality of frozen food, beverages, or fresh meat. On the other hand, if the package is not categorized as cold items or fresh ingredients, it proceeds to a room temperature package. In this case, the flow leads to using a room temperature locker, which is suitable for storing items like bolts, screws, components, or gifts that do not require temperature control.

3.3.3. Program Flowchart

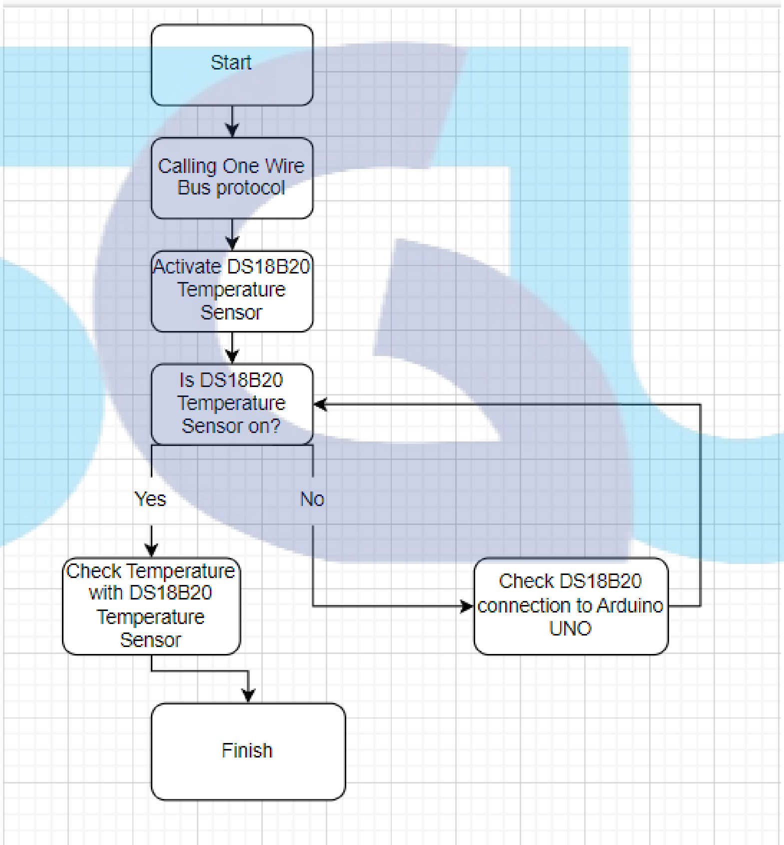

Figure 27. Program Flowchart

The flowchart depicted in Figure 27 outlines the steps involved in the temperature reading program within the smart locker system. The process starts with the Arduino UNO microcontroller activating the One Wire Bus, an important library required for the proper functioning of the DS18B20 temperature sensor. This step establishes the necessary connection between the sensor and the Arduino UNO, enabling the transmission of data from the DS18B20 temperature sensor to the microcontroller. Without the activation of the One Wire Bus, the DS18B20 temperature sensor would not be able to communicate with the Arduino UNO. Once the One Wire Bus is successfully called from the library, the DS18B20 temperature sensor is activated and ready to use. The program then proceeds to check the readings of the DS18B20 sensor. If it is powered on, the temperature readings detected by the sensor will be displayed on the serial monitor of the Arduino Integrated Development Environment (IDE). This real-time temperature feedback provides information about the internal temperature of the smart locker chamber, allowing for accurate monitoring and control. In the event that the DS18B20 temperature sensor fails to turn on, the flowchart directs the user to inspect the connection between the sensor and the Arduino UNO. This step ensures that the physical connection between the components is secure and properly established, as any loose or faulty connections affects the functionality of the temperature sensor.

3.4. Equation

3.4.1. Power Supply Justification

To power up many components in this model, power supply is needed. To check whether the power supply is enough to power up many components, the power supply can be calculated using the equation below.

Power formula: $P\ (\text{Watt}) = V\ (\text{Volt}) x\ I\ (\text{Ampere})$……………………………..*(eq.1)*

Based on the equation, each components power consumption that uses power supply to activate can be calculated. Below is the list of the components used and its power consumption.

12V 10A Power Supply components:

- DC fan hot side heatsink = $12V\ x\ 0{,}2A\ =\ 2{,}4W$

- DC fan cold side heatsink = $12V\ x\ 0{,}12A\ =\ 1{,}44W$

Total Power consumed: $2{,}4W\ +\ 1{,}44W\ =\ 3{,}84W$

24V 30A Power Supply components:

- Peltier module TEC1 – 12706 = $12V \ x \ 6A = 72W$

- Peltier module TEC1 – 12710 = $12V \ x \ 10A = 120W$

Total Power consumed: $72W + 120W = 192W$

Based on the provided calculation above for each component's power consumption, considering the Peltier module runs on its maximal ampere, total power consumption for power supply 12V 10A that provided 120W of power, only 3,84W is used. The power supply 12V 10A still has a margin of 116,16W power. As for power supply 24V 30A that provided 720W of power, 192W is used to power on both Peltier module in assumption that both Peltier module is running at its maximal capabilities. The power supply 24V 30A still has a margin of 528W power. Both power supply still has a big margin of power, allowing for safe usage and flexible power consumption.

3.4.2. Peltier Module Justification

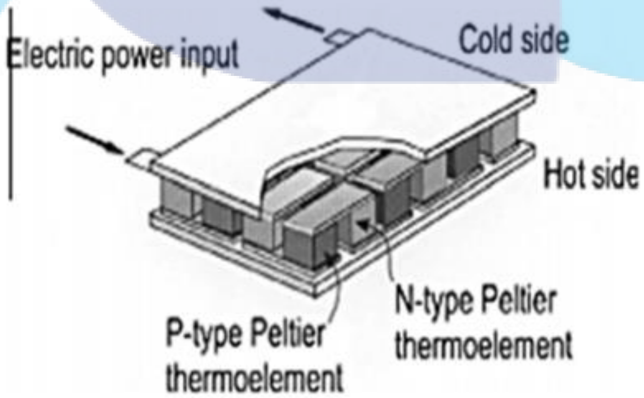

Figure 28. Peltier Module Diagram

According to Fairuz Remeli *et al*. (2020), Thermoelectric coolers are increasingly being used in a wide range of applications, spanning from small-scale heat removal in milliwatt-level devices to larger systems operating in the kilowatt range. These thermoelectric modules are compact and lightweight, making them suitable for various purposes, including outdoor and portable coolers, as well as cooling electronic components. The growing demand for computer and mobile components, as well as refrigeration and cooling systems, has further driven the adoption of thermoelectric coolers. In the field of computer technology, thermoelectric coolers are employed to effectively regulate the temperature of crucial components like CPUs, chipsets, and other parts, preventing them from overheating. Several cooling systems have been developed to address this requirement, with thermoelectric cooling emerging as a preferred solution. The key benefits of thermoelectric cooling include its small size, light weight, quiet and vibration-free operation, low maintenance needs, and compatibility with direct current (DC) power.

To determine the cooling power of the Peltier module, the cooling capacity, coefficient of performance (COP), and cooling rate must be calculated. the equation for cooling capacity and coefficient of performance (COP) can be seen below.

Cooling capacity formula: Qc (Joule) $= m\ x\ C\ x\ \Delta T$ ....(*2*)

Finding mass of air inside locker : $\rho = \frac{m}{v}$ ....(*3*)

Temperature difference: ΔT (°C) = $T2$ (°C) $- T1$ (°C)...................................(*4*)

Based on the formula above, the temperature difference (ΔT) can be calculated by subtracting final temperature (T2) with initial temperature (T1). The negative sign means that the temperature is cooling, while the positive sign means that the temperature is heating. The cooling capacity can be calculated by mass (m) multiplied by specific heat capacity (C) multiplied by temperature difference (ΔT). This formula helps estimate the actual cooling capacity of the Peltier module under specific temperature conditions. It provides a useful metric to determine the module's effectiveness in removing heat and cooling the desired system. It is also important to note that negative sign Qc indicates that heat is being absorbed by the Peltier module, and positive sign Qc indicates that the Peltier module is not absorbing heat but giving the heat back. The formula uses mass of air to calculate, so to determine the mass of air, (*eq.3*) is used. Below are the specifications for Peltier module TEC1 – 12706 and Peltier module TEC1 – 12710.

Figure 29. Peltier module TEC1 – 12706 specifications

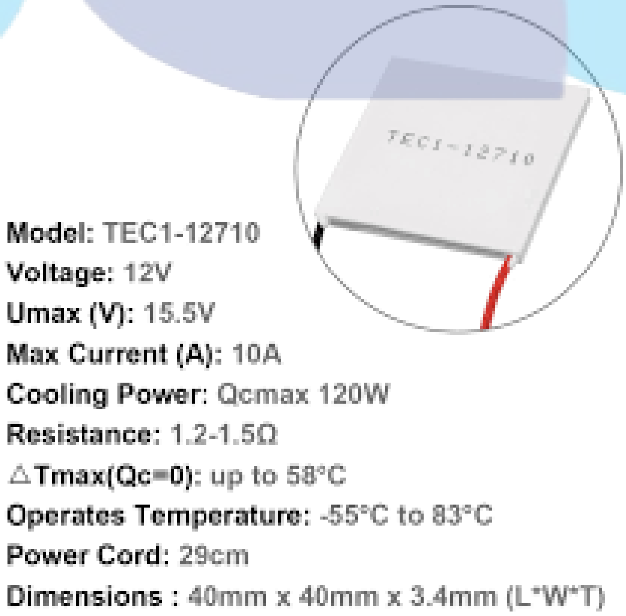

Figure 30. Peltier module TEC1 – 12710 Specifications

And for the coefficient of Performance formula can be seen below.

Coefficient of Performance formula: $COP = \frac{Qc}{Win}$ ……………………………..*(eq.5)*

To calculate the COP, the cooling capacity (Qc) is divided by the input power (Pin) that is supplied into the Peltier module. This provides a measure of how effectively the cooling system converts electrical power into cooling capacity. A higher COP value indicates a more efficient cooling system, as it achieves a greater cooling capacity per unit of input power. The COP is a useful metric for comparing the efficiency of different cooling systems and evaluating their performance in terms of cooling effectiveness and energy consumption. Based on the study conducted by Fairuz Remeli *et al*. (2020), The COP of thermoelectric cooling system ranges around 0,16 – 0,64 at operating temperature difference approximately ΔT=20°C

The cooling rate formula can be seen below.

Cooling Rate formula: $Cooling\ rate\ (°C/\text{min}) = \frac{(T2\ (°C) - T1\ (°C))}{t\ (\text{Min})}$ ……………….(*eq.6*)

To calculate the cooling rate formula, the temperature difference that occurred during the duration of cooling process(ΔT) is divided by the duration of cooling process (t) that are done by the Peltier module. This provides a measure of the speed of which the cooling process is taking place. The higher the temperature difference that occurred means that the cooling process is efficient. The cooling rate is used to measure how effective the Peltier module is in achieving the desired temperature. A higher cooling rate indicates that the temperature reduction is faster, and a lower cooling rate indicates that the temperature reduction is slower. The negative sign result of the cooling rate means that the system is cooling, while positive sign means that the system is heating.