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Biodegradable Automated Thermal Container Using Peltier Technology

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ABSTRACT

Logistics today has been an integral part of the world, responsible for major trades of goods, medicines, products, and services. However, logistics face a big problem when it comes to goods that require a constant or a near about temperature to be maintained while being on the road. Using a temperature control system can help largely reduce the problem, thus saving time, money, and resources. The proposed container can be used to store temperature sensitive items such as medicines or general purpose/day to day items or food and beverages. In this paper, we discuss a temperature-controlled container that can be used to transport such temperature sensitive items. The main technology being used in the container would be thermoelectric Peltier (TEC). The container shall be user controlled via a keypad accompanied with several safety features such as over temperature protection, emergency shutdown button, display to view the current/set temperatures and have a docked/portable power supply system. The power supply and power converter for the board has been made completely in-house using detailed PCB's. Calculations for the power requirement and its efficiency have been discussed in depth. Such a product shall provide great help to logistics and medical industry. Material of the box (HDPE) could sustain wide temperature changes and the efficiency of the overall system was 70 percent.

1. INTRODUCTION

Logistics today is a vital component of the global landscape, responsible for significant trade in goods, medicines, products, and services. Food items delivered from one place to another do not arrive at the correct temperature, similarly pharmaceutical items such as vaccine are temperature sensitive and sometimes are required in an emergency, hence requiring a need for a portable, manually controlled temperature box. The utilization of a temperature control system can substantially alleviate this issue, resulting in time, cost, and resource savings.

The proposed conceptualized container shall be completely user controlled i.e., temperature to be maintained inside the container depends completely upon the user. This feature will help to store items inside the container that are thermally sensitive and require a temperature range when being transferred from one place to another. The said container would consist of Peltier which perform the main function for cooling and heating, fans for accelerating the process, a temperature sensor for detecting the internal temperature, an LCD for displaying live temperatures and messages to the user and several other components. On comparison with existing work studied, some of the systems didn't have dual operation of cooling and heating [1], some didn't have external user control [2] and some didn't provide display support for viewing the live temperature [3]. The proposed container stands unique in such mentioned terms and uses a dual thermal system with user-based temperature control. The display has been included to provide visual support, and dual operation has been provided to have best of both worlds. Material for the container has been chosen as HDPE (high density polyethylene) because of its high melting point and has the capability to withstand a wide range of temperatures. HDPE is chosen for its benefits such as bio-degradable nature, wide temperature withstanding property and non-reactive nature. Emphasis is made on biodegradability as it is the need of hour. The overall power system of box has been designed in such a way to consume low power, keeping environmental factors in mind.

2. LITERATURE REVIEW

Esfe et al. [4] and Shilpa et al. [5] discussed the working of the thermoelectric Peltier devices which can work in the absence of the coolant and as well as refrigerants. Various equations and performance validations are also provided by the authors which can be used and implemented on the new system that is to be designed. This helped us in understanding the overall thermodynamic angle of the container and how the equations can be based on it.

In various works [6-8], researchers discussed the various applications of the PIC microcontroller and its architecture which have practically been demonstrated with the help of various projects. A simulation is also provided in the proteus software, and the programming is done in the MPLAB software which is an ideal software to program PIC microcontroller of any family. The insights from these papers will help in proper understanding of PIC architecture as well as its simulation before implementation. This reference helped us in discovering the software Proteus, where we have carried out our simulations to lessen any errors and smoothen the user experience and helped us choose PIC as the microcontroller for our container.

In previous papers, researchers [9-14] discussed about the concept of the DC-DC buck and boost converters and various equations as well as the validation graphs are also present in the papers for better understanding of the concept. These converters are extremely important for the safe operation of low voltage circuit in our system for proper regulated supply in the circuit. These papers give us an overall idea of how to understand the power requirements for a system and design a power supply for it. Patil [15] and Gupta et al. [16] talked about the design and development of SMPS that is switching mode power supply. Various design methodologies, circuits, simulations, and validation graphs are present for proper understanding of the concept. This paper will help us design a custom SMPS where we can supply the power in AC from the local supply and a regulated DC voltage will be supplied to our system.

Utomo et al. [17] and Nugroho et al. [18] discussed enclosed regions such as an incubator and a smart box respectively which is temperature controlled using the fuzzy PID controller. In the papers it is perfectly demonstrated that PID controller is implemented as well as various performance analysis are also provided to justify the effectiveness of the controller. This paper gave us an idea on how to implement a PID like controller in our system to counter the rapid switching of relays and fans when the difference between set and actual temperature becomes negligible.

Wani et al. [19] talked about properties of HDPE such as stronger material, harder, opaque and being more resistant to high temperatures. They also mention that HDPE is the material that is used for food packaging for it being safe and preventing any chemical reactions. It is further discussed how HDPE can be easily recycled into a concrete mixture thus decreasing landfill pollution. This paper thus helped us in choosing the material for our container having an additional benefit of being a recyclable item.

3. METHODOLOGY

3.1 Container

The container is made of HDPE due to its high rigidity, lightweight, and high melting point. Selection of the material has been done based on factors such as availability, rigidity, chemical compatibility, grease proofness, and permeability. The dimensions of the container measure 36cm in length, 38 cm in breadth and 40cm in height. Several cutouts have been made for the fans, Peltier's, PCB's and several other components to be placed. A 3D model of the container has been made using CAD. Figures 1-3 represent the front view, top view, and isometric view of the container respectively.

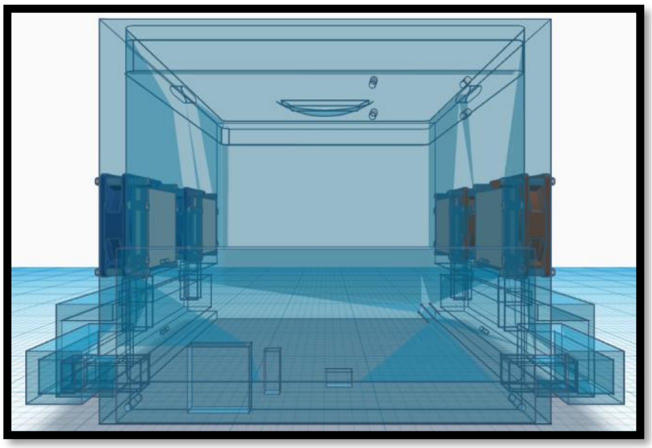

Figure 1. Front view

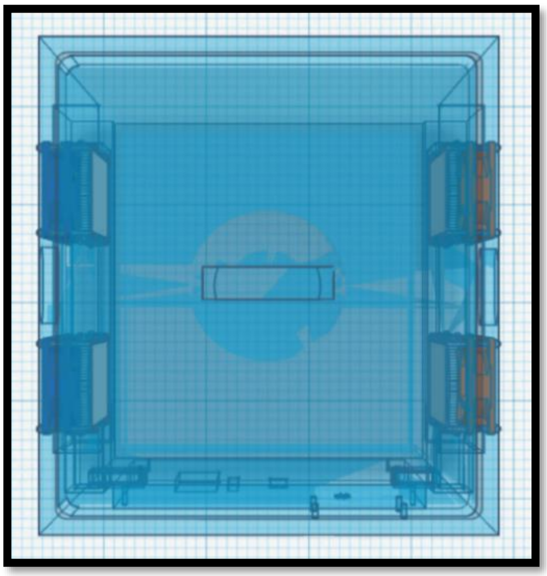

Figure 2. Top view

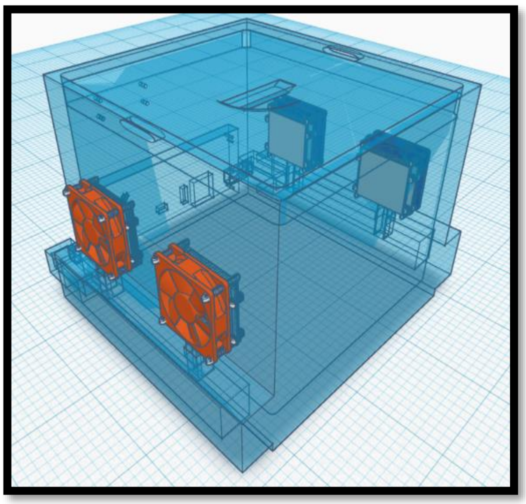

Figure 3. Isometric view

Grooves and handles have been made on the container so that it can be carried around easily. Screw holes are provided for the fans, PCBs, and other components to be attached onto the container. Pathways have been created for the electrical wires to junction at one meeting point.

3.2 Mechanical parts

3.2.1 Thermoelectric Peltier

These devices work based on the Peltier effect and are used in heating and cooling applications without the requirement of coolants and grills. The Peltier effect transfers heat between two electrical connections to produce a temperature differential. Heat is evacuated at one junction and cooling takes place when the current passes through the joints of the two conductors. At the opposite joint, heat is deposited. The two ceramic plates in the Peltier are separated by semiconductor pellets, which causes the temperature differential while current flows through it. Maximum power consumption for a single Peltier is rated at 36W. During the working of the box, only 2 Peltier's would be operable i.e., either the heating/cooling. These would be operated via relays by the PIC microcontroller. Figures 4 and 5 illustrate the Peltier that has been used for the container.

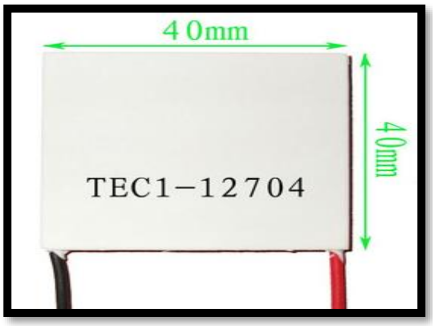

Figure 4. Thermoelectric Peltier

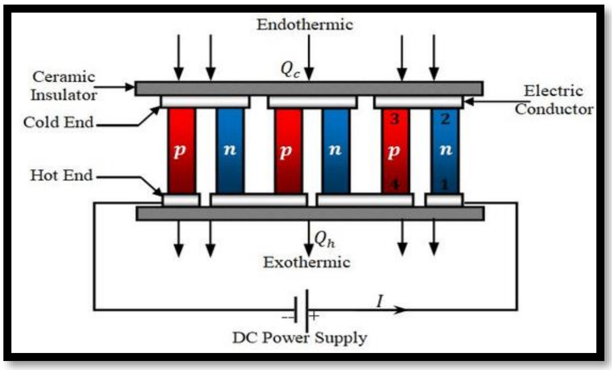

Figure 5. Diagrammatic representation

3.2.2 Heating/cooling fans

The Peltier's require heat to be removed off from one side to ensure proper cooling on the other and vice versa. To quicken and make the process more efficient, fans have been used to enable the operation. A total of 4 fans have been used with 2 on each side of the box. Similar to that of Peltier's, during the working of the box, only 2 fans would be operable i.e., either the heating/cooling fans. Each fan used consumes a total of 2.5W. Figure 6 illustrates the fan that has been used for the container.

Figure 6. Heating/cooling fan

3.3 Sensors and display

Temperature sensor LM35 has been used to detect the internal temperature of the container. The sensor sends the recorded data to the PIC microcontroller which then performs an analog to digital conversion and then displays it on the 16x2 LCD screen placed on the container. LM35 is chosen as the temperature sensor because of its low cost and easy to use nature, moreover, debugging it is easy too. The LCD screen is backlit and displays the set and internal temperature of the box. A 4×4 keypad is used to provide user input. In general, the proposed container should have an input and an output feature, hence the use of a display and a keypad, providing good feedback ability to the user.

3.3.1 Power supply

In order to understand the power supply first, we need to understand the overall framework of the container. Figure 7 shows the connection between the several components of the container.

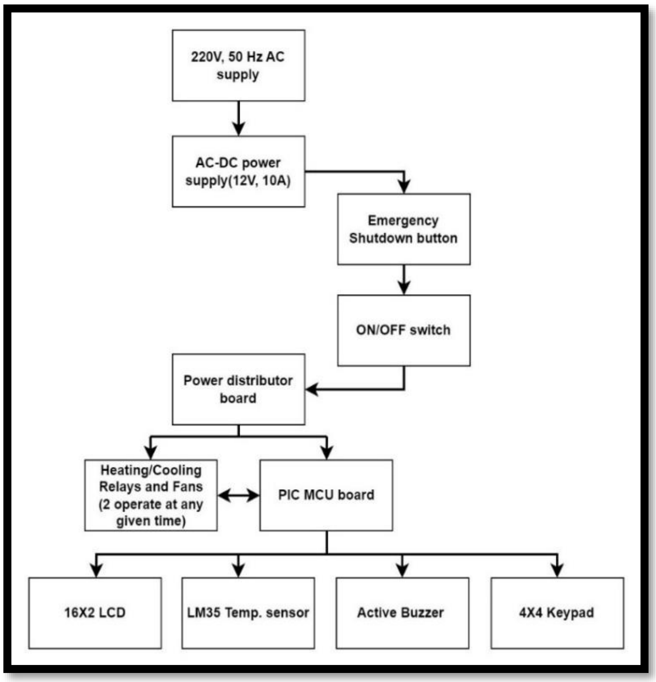

Figure 7. Power flow

Table 1. TEC 12704 datasheet

Room Temperature	25°C	50°C
Max. Power Consumption (W)	34	37
Max. Temp. Diff. (°C)	66	75
Max. Current (A)	3.3	3.3
Max. Voltage (VDC)	14	16
Int. Resistance (ohms)	3.1	3.6

Table 2. 12V DC fan datasheet

Rated Voltage (VDC)	12
Rated Current (mA) (Max.)	200
Rated Power Consumption (W) (Max.)	2.5
Operating Voltage Range (VDC)	4.5 to 13.8
Starting Voltage (VDC)	4.5
Operating Temp. Range (°C)	-10 to +70

The primary power-hungry component in the whole system is the Peltier's. Hence, while designing the power supply, their power consumption had to be kept in mind. Table 1 shows the datasheet values for the Peltier in use.

Coming to the secondary power-hungry component, the heating and cooling fans, Table 2 shows the datasheet values for the fans in use.

Thus, after obtaining the values from the datasheets, our calculations for the power requirement have been done as follows,

Total power consumed by Peltier's at a given point of time **=36×2=72W (max.)**

Total power consumed by fans at a given point of time=**2.5×2=5W (max.)**

Estimated power consumed by other miscellaneous components=**10-15W (max.)**

Therefore, total power consumed by container=**87-92W.**

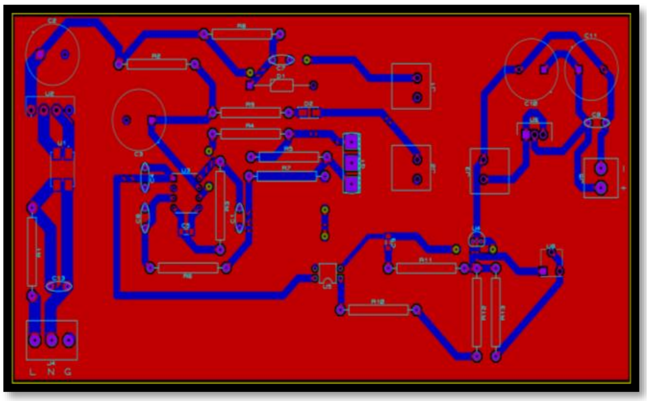

Figure 8. Power supply layout

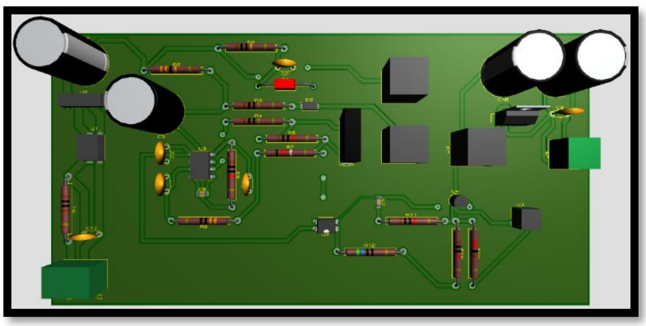

Figure 9. Power supply model

The power converter mentioned in the Figure 7 can provide up to 120W of power and has been made completely in-house. Several components such as input signal choke (1259CM), single phase bridge rectifier (KBP310G) and optocoupler (PC817) have been used. Main fuse has been used to prevent overcurrent scenario. For the DC-DC switching converter IC UC3843AN (having efficiency of 90 percent) has been used, capacitor and resistor values used are in accordance with the datasheet of the IC. The PCB of the power supply also has female connectors for the transformer to be placed. Two bulk and one decoupling capacitor have been used at the output stage. A diode array has also been placed at the output to prevent reverse flow of current. Potentiometer is kept for varying the output voltage. A 3-pin plug is used to provide AC supply input and an XT-60 connector is used to provide DC output. Figures 8 and 9 illustrate the layout and 3D model of the supply.

Coming to the power distributor board whose responsibility is, as the name suggests, to distribute power from the supply to all the electrical components of the container. The circuit consists of relay modules that would be used to control the Peltier's and fans via the PIC microcontroller, an emergency switch for cutting off power in times of malfunction/danger, a 7805 IC for the low voltage components, an XT-60 connector for input power and an ON/OFF switch. This distributor is mounted on the container and is a part of it. Figures 10 and 11 illustrate the layout and 3D model of the board.

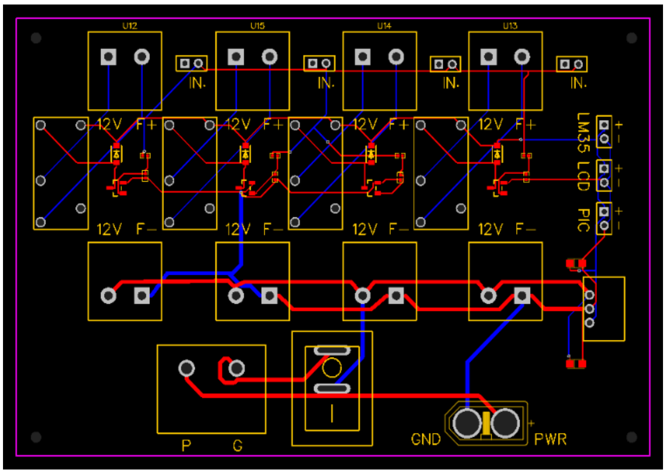

Figure 10. Power distributor layout

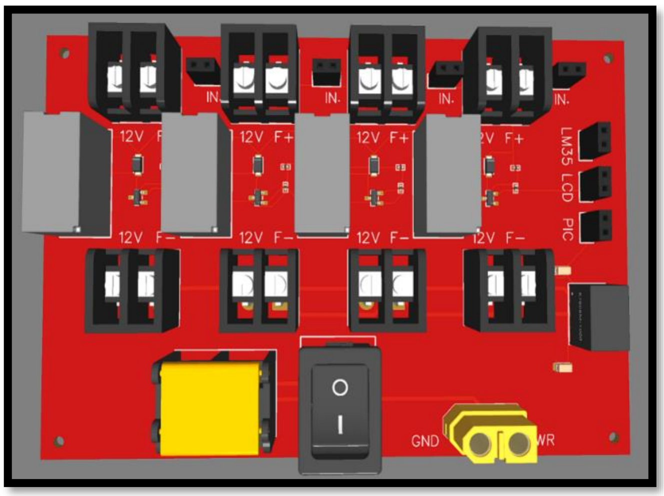

Figure 11. Power distributor model

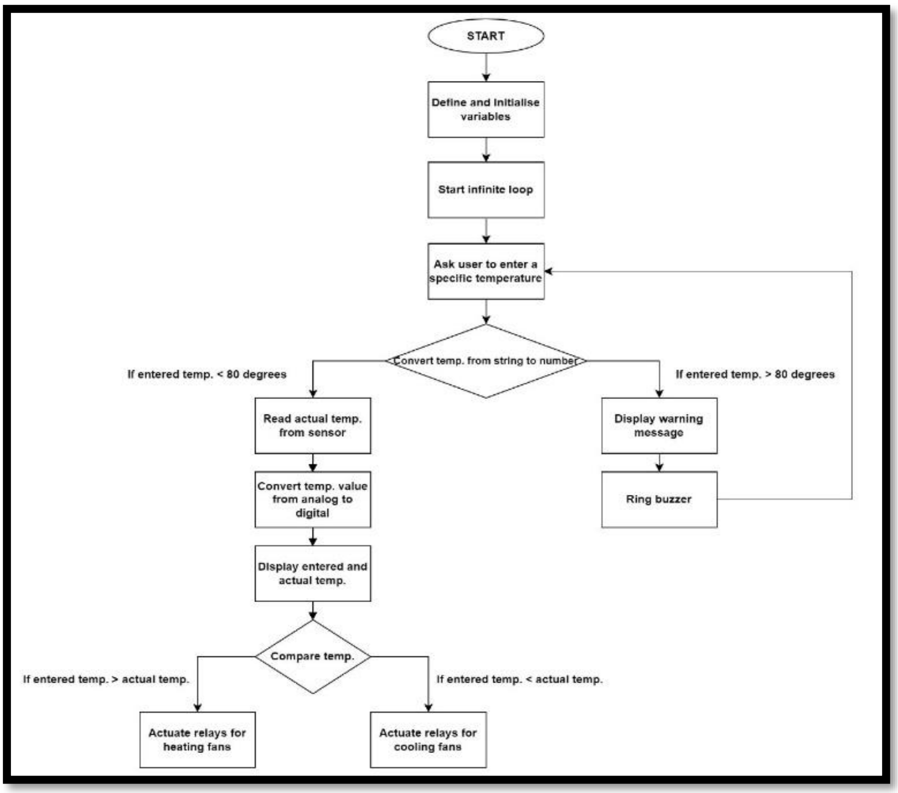

Figure 12. Flowchart of algorithm

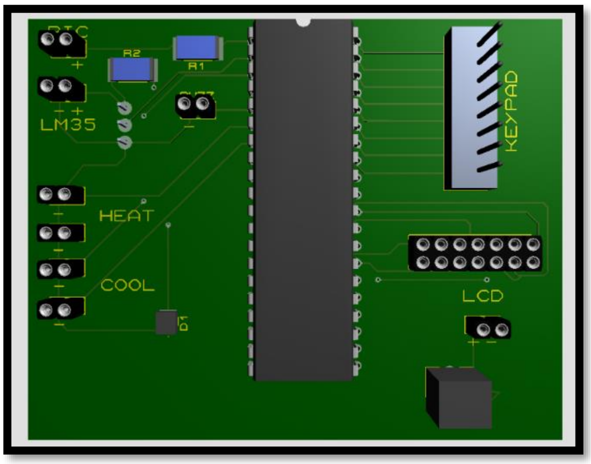

Figure 13. PIC board top view

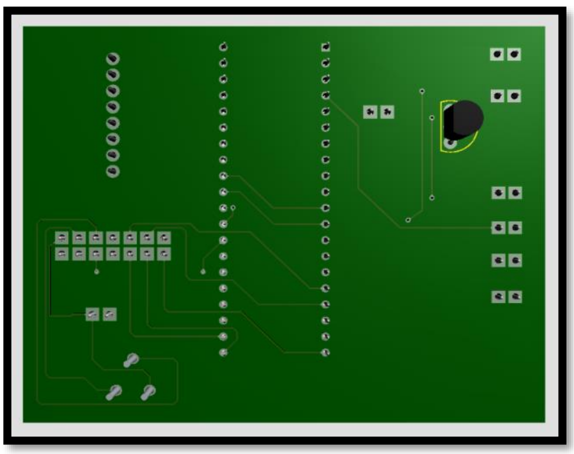

Figure 14. PIC board bottom view

3.3.2 Code algorithm

The flowchart depicted in Figure 12 represents the algorithm of the code that is programmed in the microcontroller. At first, the variables are defined and initialized after which the infinite loop starts. In the infinite loop, firstly the user is asked to enter a specific temperature which then is converted from string to number. Now if the entered is more than 80 degrees, a warning message is displayed followed by a ringing buzzer and the user is redirected to enter the temperature again. Now if the temperature entered is less than 80 degrees, current temperature data is obtained from the sensor, and it gets converted from analog to digital value and then entered value as well as actual value gets displayed on the screen. Lastly, temperature comparison is done and according to the requirement, the heating or cooling relay gets actuated. Figure 12 shows the flowchart of the described algorithm.

3.3.3 MCU

The MCU (microcontroller unit) for the container used is PIC16F. The 16-bit microcontroller enables low power and high-speed operation. We have used a PIC microcontroller as the processing power requirement is not high and a low power operation is favourable. A circuit has thus been made to connect the MCU with the other controllable components such as LCD, relays, and buzzer. Input connectors for LM35 and Keypad have been placed. A small LED is placed to indicate that the board is receiving power. Potentiometer is kept to vary the brightness of LCD. This board is also mounted on the container. Figures 13 and 14 illustrate the 3D model of the board.

3.4 Simulation and prototype

In order to test the code for its proper working, a simulation circuit was made on Proteus Design Suite, where code could be uploaded to the MCU and be simulated out. This simulation helped us greatly improve the overall user experience and provide counter measures for any dangers that might occur. Relays for the Peltier's have been replaced by LEDs for better understanding. Figure 15 shows the circuit created on Proteus.

Before the creation of the final product, we tested out the physical model by creating a prototype. The prototype consisted of the above said components except the MCU was replaced by an Arduino UNO for easy debugging [20]. The code for it had the same logic as already discussed. The container for the prototype is the same as discussed above and was bought. This prototype acted as a precursor for the final model. The final model is the same as that of the CAD model and hence is not shown. Figure 16 shows the prototype container made by us.

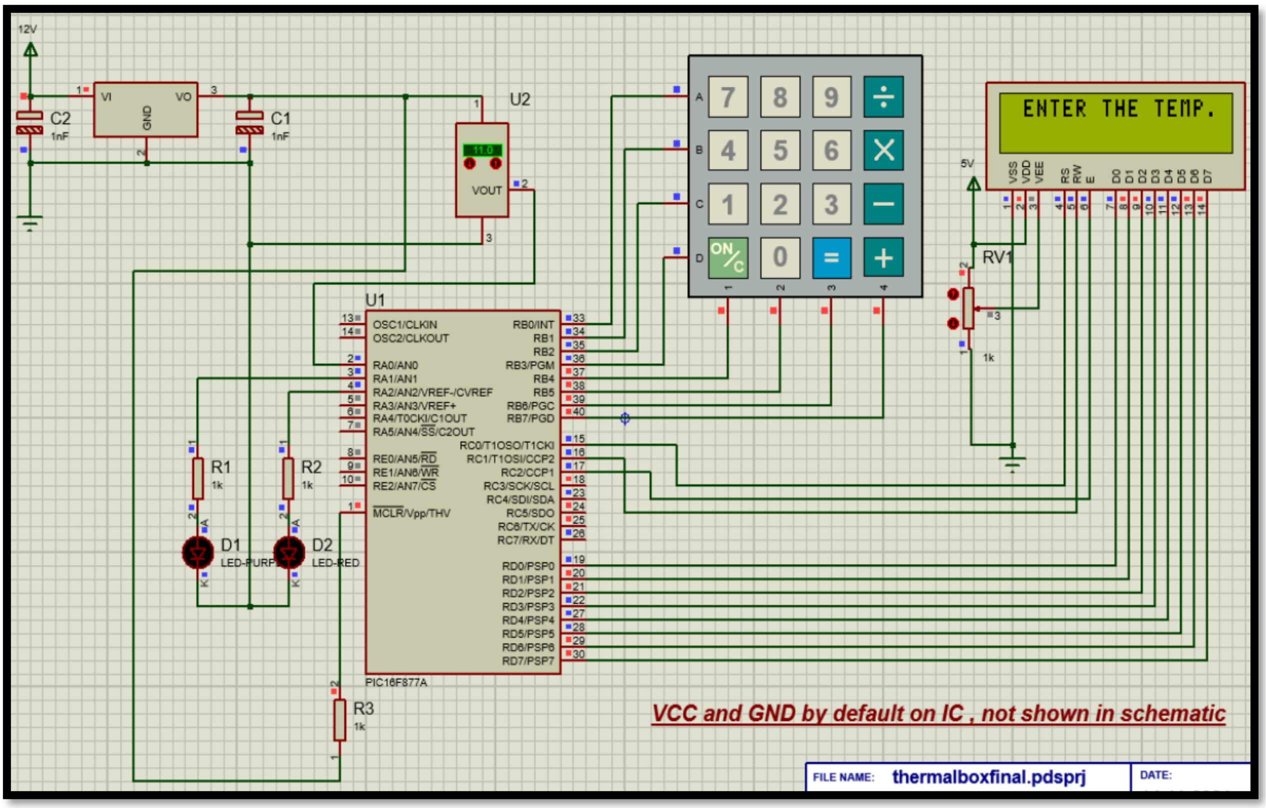

Figure 15. Simulation circuit schematic

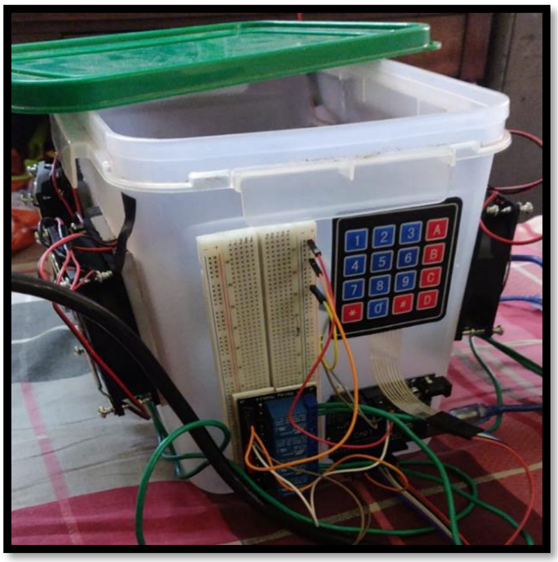

Figure 16. Prototype container

4. RESULTS

The following section shall represent the outcomes and results of the project in terms of pictures and output values. To start off, controlling the internal temperature of the container was well achieved by the fans. On testing the temperature sensor using a PIC debugger tool, the sensor showed stable, noiseless data. Figure 17 is a screenshot from the output window of the debugger tool.

The varying temperature was then noted on the LCD display at intervals of 30 seconds. Both heating and cooling operations were tested. The temperature sensor stood true to its accuracy and provided temperatures having a +/- error of 0.3 degree Celsius, as specified by the manufacturer. Figures 18 and 19 show graphs obtained of temperature vs. time. Time (in seconds) is kept on X axis and temperature on Y.

The average coefficient of performance for our Peltiers came to be in the range of 0.7 to 0.8. When compared to a commercial chilling refrigerator, whose CoP (coefficient of performance) is more than one, the value of CoP for the TEC is typically lower than one. Therefore, to provide efficient and quick cooling, the CoP for TEC value must be increased. The CoP of TEC may rise in the future because numerous researchers are working to boost it. Considering the current design, it was made sure that the components that were being selected consumes lowest possible power to make this more and more power efficient. As the efficiency of TEC increases in future, it will eventually bring the operational cost lower and lower.

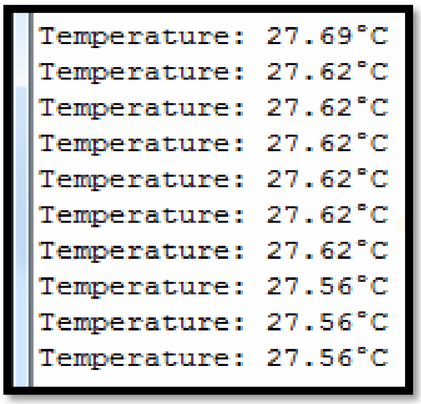

Figure 17. LM35 output

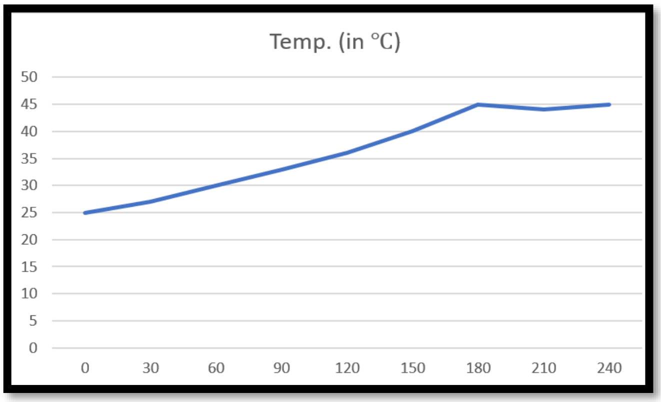

Figure 18. Heating operation when set to 45°C

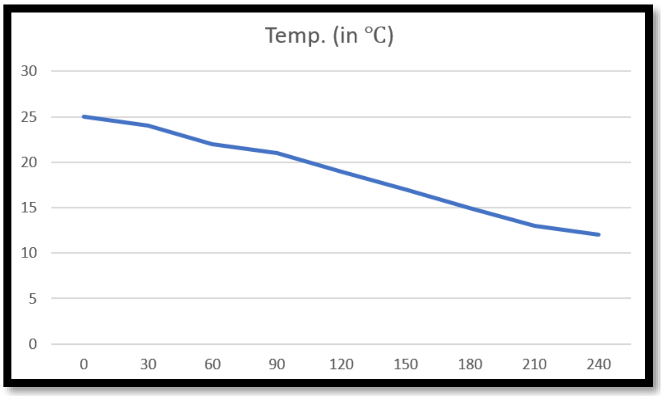

Figure 19. Cooling operation when set to 45°C

5. LIMITATIONS AND FUTURE SCOPE

Further development can be made on the container in terms of efficiency and connectivity. Here are some improvements that we suggest:

i. Provide a wireless connection with the container by providing an IOT option, where the user would be able to control and connect with it via an app on their phones. This would be possible by replacing the PIC MCU with Raspberry Pi Pico W.

ii. Design a portable and rechargeable Li-ion battery pack that could be used with the container, thus negating the use of docked power supply.

iii. Making a smoother and provide easier switching of the heating and cooling fans using a controller like that of PID. This would then increase its longevity and use, as it would avoid the rapid switching of the fans and would focus more on controlling its RPM, thus saving more power and increasing it's working efficiency.

iv. We plan to implement the mentioned changes/improvements in a phase wise manner, with each phase taking a maximum of 2-3 weeks, in the order mentioned.

6. CONCLUSIONS

By the completion of this project, we have been successful in maintaining a near constant temperature set from outside by the user. The sensors used have been able to give us a noiseless, stable temperature value. The power supply designed gave us a constant supply of voltage with minimal signal spikes. Switching of the fans and relays have been smooth as well, however it could be made much smoother by applying further complex techniques. As discussed, an app can be developed which would wirelessly connect with the box, helping user to control its temperature from phone itself. In conclusion, we have been thoroughly satisfied with the final product which would provide great help to the logistics and medical industry as these industries demand portability as well precision which are two main features that this project provides.

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