THE SOLAR COOLER

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Abstract

In this project we proposed, verified, designed, implemented and tested a whole new concept of cooling container. Our goal is to replace the use of traditional ice based cooler. Our proposed solution uses a solar panel which can provide endless energy used to cool the system and also incorporate four thermoelectric cooling modules to replace ice. The user can also have an accurate reading of the internal temperature from the temperature sensor. The result is that we have built a portable, yet more light weight solar cooler.

Contents

1. Introduction

1.1 Objective

During the summer, people usually bring a cooler for long drives or picnics to make their drinks stay cool, but the functionality of the cooler is highly depended on how often you can replace the ice. When the ice melts, the cooler just becomes a box filled with water. People must lift their cooler, despite the weight of the water, box and drink, pour the warm water out and replace with ice. The situation might be worse if you are going for a picnic. The sun just melts the ice much more quickly and even worse, it is very likely that you can't find a store to buy more ice, and you are forced to have a hot coke in the summer.

The project goal is to develop a cooler that actively cools the items within via solar power, also, store energy to be able to cool the interior without sunlight presence.

The idea and need for a solar powered cooler are simple: we reduce the weight of the typical cooler and ice, and thereby increase the amount of time the objects within the cooler are cooled for and increasing space within the cooler. Using a solar panel to power the system is the most optimal way to accomplish this because solar panels are lightweight and can charge the battery (or power the system) so long as there is incident light shining onto the panel's surface.

1.2 Background

The cooler is a very common appliance. The products on the market today is usually made with polyurethane insulation or vacuum insulation, both are very good insulation material, but they have one flaw in common: they can only absorb heat using ice, the cooler itself doesn't have the ability of removing heat. We plan to improve this product by replacing the ice with a thermoelectric cooling pad which is a more lightweight cooling agent, and power it with sustainable green energy: the solar power. The battery will be used to store the solar energy so that the cooler will work even without sunlight. The cooler is designed to be easy to use, anybody who can use a traditional cooler should be able to use our solar cooler, providing the user with a simple yet effective solution to heavy and ineffective traditional coolers.

1.3 High-level Requirement

- Must cool at least 20 °C below ambient temperature (to a minimum of 0 °C).
- Battery life must be able to power the system independently for at least 2 hours.
- The weight of the system must not exceed 10 kg, the lighter the better!

1.4 Functionality Overview

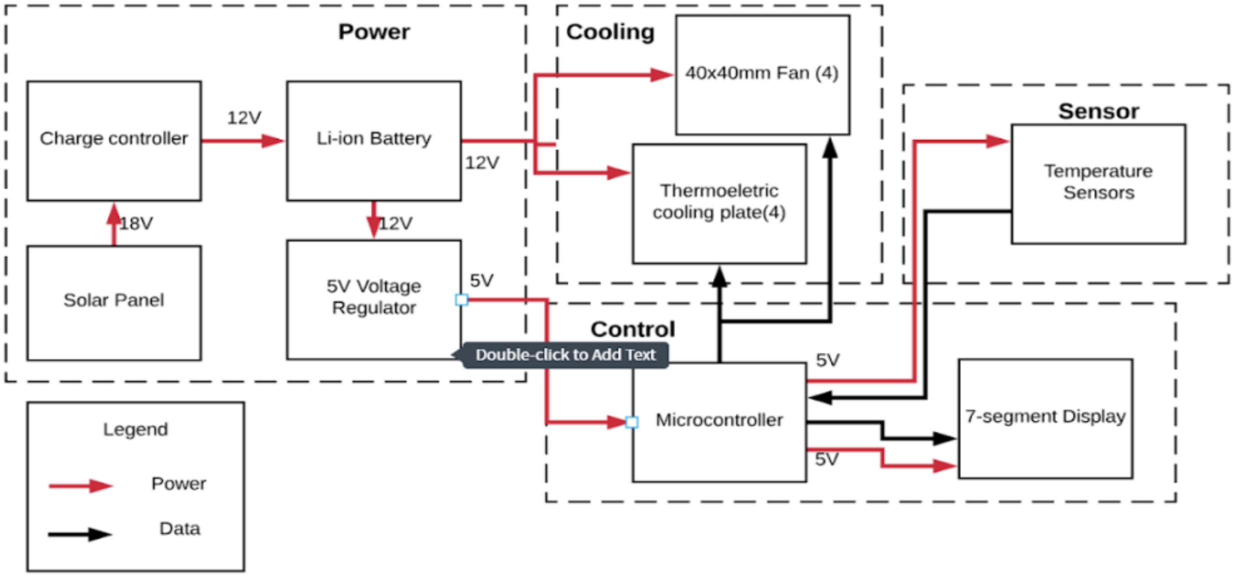

Figure 1: Solar Cooler Module Block Diagram

As Figure 1 show, there will be four major modules: power, control, cooling, and sensor. The power module will manage energy supply by the solar panel and store in Lithium battery. The power module will also power both the cooling module with 12V and microcontroller in the control module with 5V. Cooling module will be used to cool the internal of the cooler with relay control from microcontroller. The temperature sensors will be used to monitor the internal temperature of the cooler by the microcontroller to decide if the temperature is at target value.

This is actually different than our original plan, in our original plan, the cooling module are supposed to have only two cooling plate, however, that is not enough in our application, so we increased it to four. Also, cooling plates are supposed to be also power by the 5V voltage regulator. Due to increase in number of plates, the voltage regulator we have are not able to handle the load needed by the cooling module, so we had to power the cooling module directly from the 12V Lithium battery. So, the voltage regulator will be powering the microcontroller only. Lastly, fans are added to the cooling module because the cooling plate itself is not able to remove the heat from hot side of the plate fast enough. So, fans and heatsinks are attached to the hot side of the plate to help remove the heat extracted from interior of the cooler.

2 Design

2.1 Power Module

Purpose of the power module is to charge the 12V battery and power all other modules. The plan is to use charge controller design using *bq24650* chip [9] to take the energy output by the solar panel and safely charge the 12V battery. The 12V battery will then directly power the cooling module, and it will also power the control module by first going through a 5V voltage regulator.

2.1.1 Solar Panel

Solar panel will charge the system by converting light energy to electrical energy. We have selected a monocrystalline silicon panel module for a lightweight and robust component [1].

Since one of our requirements is to charge the 12V 10Ah battery in under 7h, we have selected a 25W solar panel such that this is feasible even under mildly cloudy conditions. Assume solar panel is running at its maximum power point with 18.0V and 1.39A[1], so it is outputting at 25 W. From Equation (1), it will charge the battery at 4.8 hours.

$$\frac{12V*10Ah}{25W} = 4.8\ hours \tag{1}$$

2.1.2 Charge Controller

The charge controller is responsible for controlling the flow of charge into the battery from the solar panel. We choose to use *bq24650* charge IC [9]. This component will be responsible for regulating input voltage into the battery and prevent overcharging, discharging and damage of the battery. It can take in 5V to 28V input solar panel which will be adequate for our solar panel since we want to run at maximum power point which is at 18.0 V. The IC has the ability to monitor the battery and stop charging when the battery is full. Another feature of *bq24650* is that there is maximum power point tracking capability so that battery can be efficiently charged [9].

The VIN in Figure 2 will be connect to the output of the solar panel and the arrow located at the bottom right of the figure will be connect to the Li-ion battery. The 3 MOSFETs in Figure 3 (Q1, Q2 and Q3), are dual N-channel MOSFETs. Q1 and Q2 will be using Si7288 with drain-source voltage rating of 40V [13]. Q3 will be using 2N7002 which has drain-source voltage rating of 60V [14].

To set the maximum power point which we want to be at 18.0V, we will set the resistor R3 and R4 according the equation (2). So $\frac{R3}{R4}$ need to be 14. To set the output voltage of the charge controller, we will need to charge the battery at 14V, so using equation (3), $\frac{R2}{R1}$ need to be $\frac{17}{3}$.

$$\text{Vbat} = 2.1 * (1 + \frac{R2}{R1}) \tag{2}$$

$$\text{Vmpp} = 1.2 * (1 + \frac{R3}{R4}) \tag{3}$$

Unfortunately, we were not able to get charge controller circuit work. The bq24650 chip is in RVA package, it is about 2mm x 2mm in dimension with pins flat under the chip [9]. When we solder the chip onto the circuit board, it is hard to know whether the connections under chip are connected or shorted. During verification of the circuit, we burned through couple boards and components. So in the actual testing, we had to use a commercially available charge controller to charge the battery.

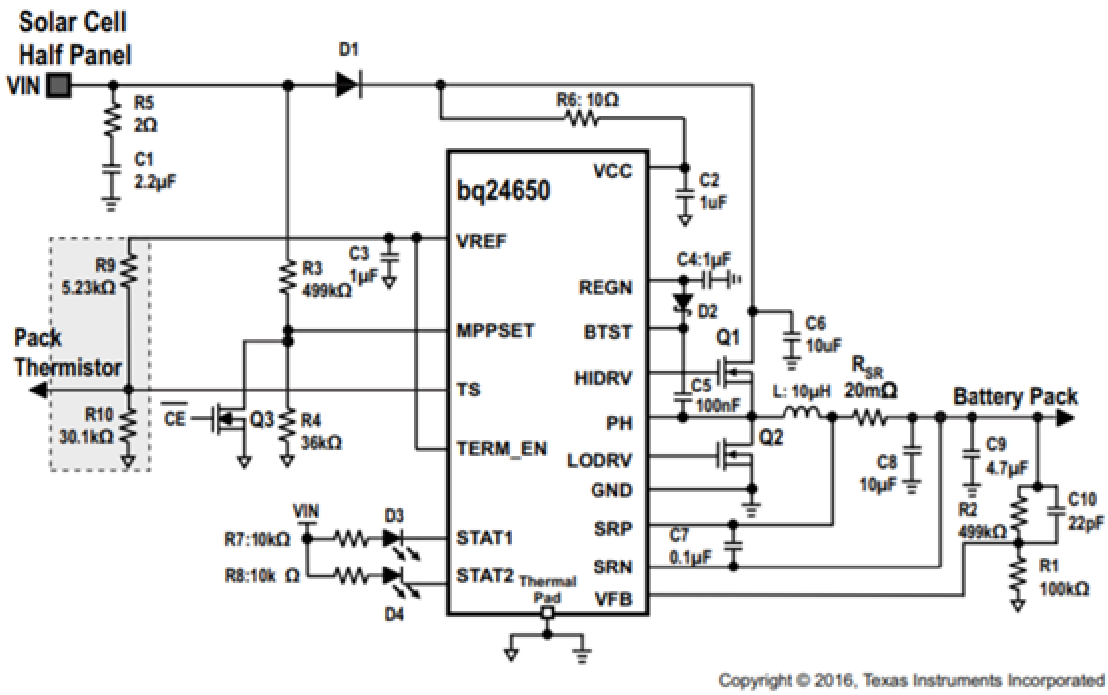

Figure 2: Schematic with Input from Solar Panel and Output to Battery [9]

2.1.3 Li-ion Battery

The Li-ion battery will store the power from the solar panel and supply the power to the rest of the system. We use a 12V Lithium battery with capacity of 10 Ah [4], the reason for Lithium-ion battery is because that it is lightweight comparing to other battery type such as lead acid. Ideally, the battery will be place at the bottom of the cooler so that the weight of the battery will not increase the center of mass and the cooler can be more stable. The original plan is to use two cooling pads drawing 20 W of power. Thus, it will be able to run for at least 6 hours from Equation (4).

$$\frac{12V * 10Ah}{20W} = 6 \text{ hours} \tag{4}$$

With the original plan, the capacity of the battery will be enough for our application. However, during testing, two cooling pads were not enough to cool the internal of the cooler, so we need to double up on the number of cooler pads to four. We also need to run it directly from 12V battery instead of from 5V voltage regulator, so total power consumption will be 72 W. From Equation (5), this will only run for 1.67 hours or 1 hour 40 minutes, which is 20 minutes under our requirement of 2 hours.

$$\frac{12V * 10Ah}{72W} = 1.67 \text{ hours} \tag{5}$$

2.1.4 Voltage Regulator

The voltage regulator will regulate voltage from battery to power rest of the system. The role of this component is to supply a constant operating voltage of each component. The voltage regulator will output a constant voltage of 5V with the input from the battery. We will use *LM1084* 5V voltage regulator, it will output at maximum current of 5A [10].

With original plan of two cooling pads, we will run them with 5V input from the voltage regulator. However, with four cooling plates, the voltage regulator we have was not able to provide the load, so we had to change our design such that the cooling pads will directly run from the 12V battery. Thus, the voltage regulator will only power the control module.

Figure 3 shows the implementation of the unit. The V_{in} will be connected to the output of the Li-ion battery and V_{out} will provide the power to the control module.

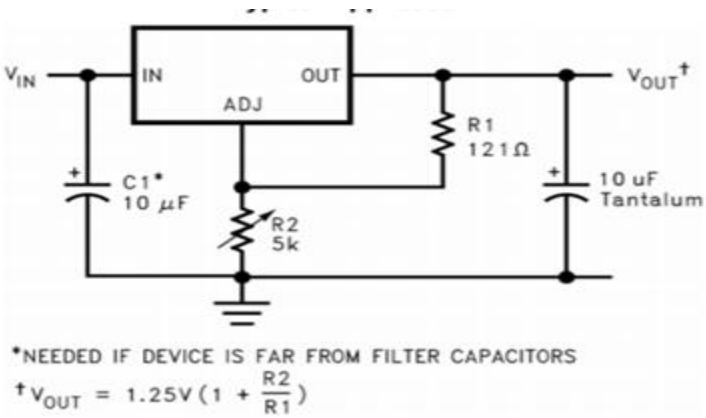

Figure 3: schematic diagram of Voltage Regulator [10]

The resistors R1 and R2 in Figure 3 should be chosen so that is match with equation (6). Thus, for V_{out} to be 5V we will need R2/R1 = 3.

$$\text{Vout} = 1.25 * (\,1 + \frac{R2}{R1}) \tag{6}$$

2.2 Control Module

Control module will be used to monitor the temperature from inside the cooler so that it can check if the temperature reaches target value. It will also have a seven-segment display that display the current temperature.

2.2.1 Microcontroller

We will use ATMEGA328-PU [11], Pin 28 is used to read the output voltage from the temperature sensor and map the result to a number from 0 to 1023. The maximum voltage it can read is 5V. A reading of 1023 means the voltage at Pin 28 is 5V, and a reading of 0 means the voltage at Pin 28 is 0 V. We then convert the number between 0 to 1023 to a temperature in Fahrenheit with code in Figure 5, and use the digital pins to display the temperature onto the seven-segments display as shown in Figure 4.

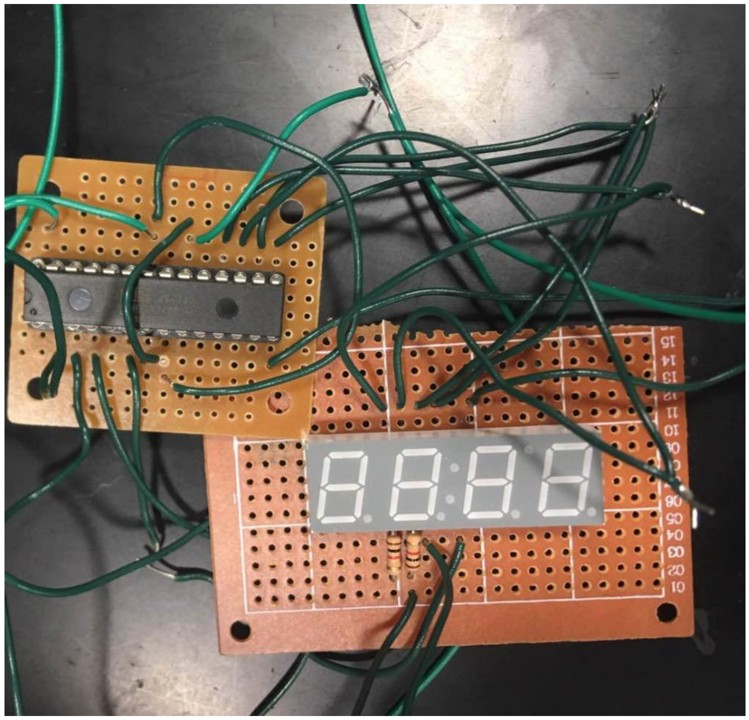

Figure 4: The Microcontroller with seven segment display attached

```
if(count == 0){
  sensorValue = analogRead(sensorPin);
  input_voltage = (sensorValue * 5.0) / 1024.0;
  newtemp=int(input_voltage*100-273);
}
count = (count + 1) % 500;

firstdigitnum=newtemp/10;
seconddigitnum=newtemp%10;
```

Figure 5: Code for Converting Voltage Reading to Temperature

2.2.2 Seven-Segment Display

The seven-segment display [6] will be the monitor for our solar cooler. This will display the internal temperature of the cooler in Fahrenheit. The temperature data will be provided by the temperature sensor located inside of the cooler which will be send to microcontroller. The microcontroller will control the display to display the correct value. We will be using the *LTC-4727JR* [6], it is a four-character LED display. We will use the Digit 1 for tens digit and Digit 2 for ones digit.

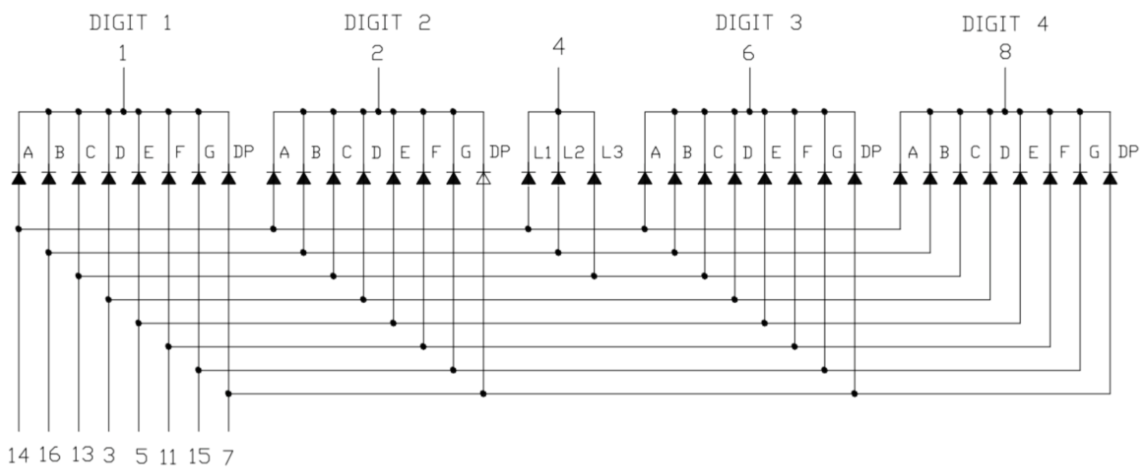

Figure 6: Internal layout of the display

According to Figure 6, all the segments of a digit control by the same pins with pins 1, 2,6,8 control which digit to show. Thus, microcontroller will need to cycle through each digit individually oppose to showing all four digits at the same time.

2.3 Sensor Module

2.3.1 Temperature Sensor

There will be two sensors, one will detect the internal temperature of the cooler, another will detect the temperature on the hot side of the cooling plate to prevent overheating. The sensors will provide feedback to the microcontroller which will control the cooling plate. We will be using LM335AH [12] as our temperature sensor. The sensor will provide 1 Celsius accuracy with wide operating temperature range from -40 to 100 Celsius [12]. The output of the sensor is linear, which makes reading the value easy without too much of calibration. For the sensor placed inside of the cooler, it will be wrapped with heat shrinkable tubing for waterproof.

We note that in the 3-pin configuration shown in Figure 7, we will need a Vcc and GND voltages which is provided by the voltage regulator, and output signal to the microcontroller. We expect temperatures between -5 to 30°C with an accuracy to +/- 1°C. With these requirements, using Equation (7), we expect the output voltage to be the range in Equation (8).

$$(273.15 - 5) * 10mV < Vout < (273.15 + 30) * 10mV \tag{7}$$

$$2.68 \text{ V} < \text{Vout} < 3.03 \text{ V} \tag{8}$$

Thus, the microcontroller must be able to identify a 5 mV difference in Vout to meet these requirements. With V^+ = 5V which is the voltage that voltage regulator provides, R1 should be chosen so that the current is 1 mA. So R1 will be 5000 Ω.

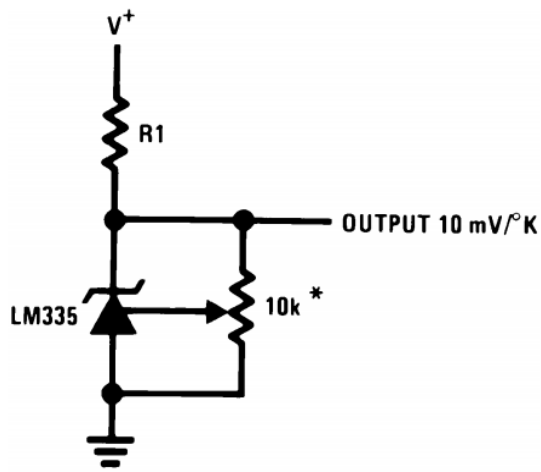

Figure 7: Schematic diagram for temperature sensor [12]

2.4 Cooling Module

2.4.1 Thermoelectric Cooling Plate

The decision for using thermoelectric cooling is because it is lightweight and have no moving parts. It will not add much weight to the cooler and we don't have to worry about the mechanical failures. The cooling plate will cool and maintain the internal temperature of the cooler. It will achieve this by transferring the heat from the cold side of the plate(internal) to hot side of the plate(external).

The cooling plate we selected is able to handle maximum of 4.56 V and 9.0 A [5]. Our original plan is to run each plate at 2.5V so we can connect two plates in series and power it with the 5V voltage regulator. Due to the fact that the 5V voltage regulator was not able to handle the load and we increase the number of plates to four, we had to run all four cooling plates in series with 12V. Since they power directly from 12V battery, each of the will run at 3 V and from Figure 9, it will draw 6.0 ± 0.5 A depending on the dT, the difference in temperature between hot side and cold side. We can see from Figure 8, that if as dT increases, more current will require to extract the same amount of heat. In our case, at 3V, we need to keep dT at least below 70 Celsius to start extraction of any heat. Preferably, we want dT to be at max 40 Celsius, so it could still counter the heat flow into the cooler when cooler is at target temperature.

In order for cooling plate to efficiently extract heat from the cold side, we will need to remove the heat from the hot side quickly. Thus, aluminum heatsink will be attached to the hot side of the plate with thermal conductive tape and also 12V fan will be install on the heatsink so that heat can escape properly to outside of the cooler to keep dT low.

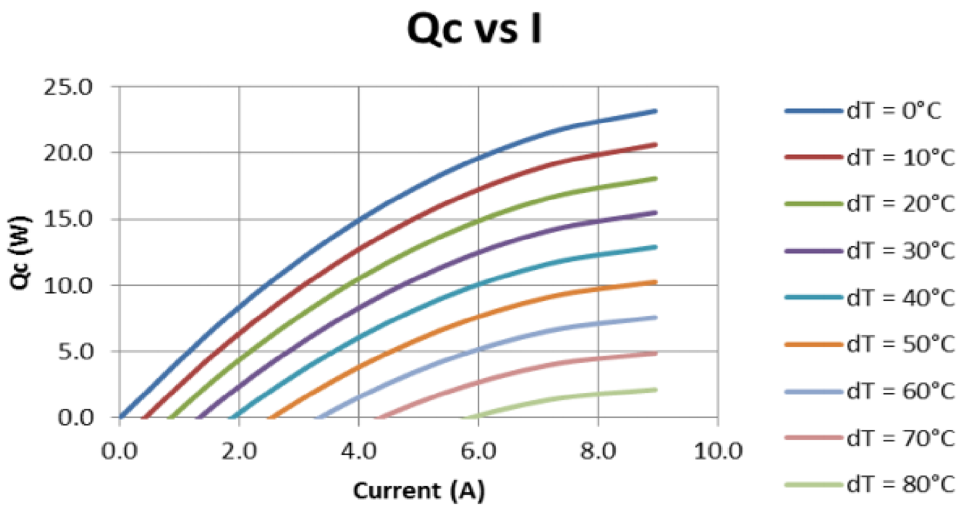

Figure 8: Heat extract vs input current at various temperature difference [5]

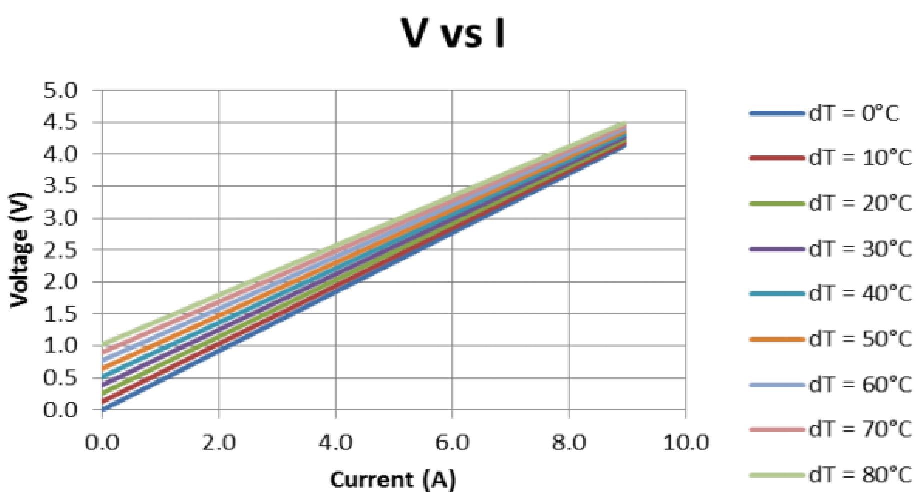

Figure 9: I-V curve of Thermoelectric cooling plate [5]

Here we will calculate length of time needed to cool 12 pack coke to simulate a common situation. First, we need to know how much heat is transferring from outside to inside. The weight of 12 cans of coke is around 4.5 kg, in room temperature to our desired temperature in a reasonable amount of time. We will use two cooling pads, and assume the room temperature is 20 degrees Celsius, outside temperature is 30 degrees Celsius, thus we have to cool the 12-pack coke from 20 degrees to 10 degrees. To make the calculation more fault tolerant, we assume the worst case of Qc = 8.5W per cooling pad and assume the internal dimension of the cooler is 21’’ x 16’’ x 21’’, note that this is an overestimation of the actual cooler. We assume the coke has the heat capacity of water which is 4186 joule/kg °C. We want to know the time to cool the items, which is given by the Equation (9).

$$T = Qdrink/(Qc\text{-}Wambient) \quad (9)$$

The key factor here is the Wambient, which is how much heat is transferring into the cooler. The Wambient, can be expressed with “Fourier’s Law” in Equation (10).

$$Wambient = k*A*\nabla T/d \quad (10)$$

Where k is the thermal conductivity value of the insulation material. The insulation material we chose is the Polyurethane foam, that has heat conductivity of 0.025W/mK. The **∇**T is the difference in temperature between outside of the cooler and inside of the cooler. d is the thickness of our material in meters, which we have chosen to be four inches. material and the thermal conductivity of our material. The thermoelectric cooler can remove up to 8.5 Watts of heat, and our inner layer of the cooler has dimension of 21’’ x 16’’ x 21”, thus the area is 1.45 m^2 shown in Equation (11).

$$(0.5374m * 0.4064m + 0.5374m * 0.5374m + 0.4064m * 0.5374m) * 2 = 1.45m^2 \quad (11)$$

All the variables above can be controlled, except the thermal conductivity, which is dependent on the temperature, the density and the moisture content of the material. For polyurethane, it could range from 0.02 W/mK to 0.028W/mk [8]. We will calculate the heat transferred in the worst case, when the foam has thermal conductivity of 0.028W/mk. The cooler temperature must be 20 Celsius lower than the ambient temperature, thus **∇**T is 20. Plug in the numbers to equation (12)

$$Wambient= (0.028\ W*(m^{-1})*(K^{-1}) * 1.45\ m^2 * 20C)/0.1016 \quad (12)$$

$$Wambient = 7.99Watt \quad (13)$$

The Wambient is 8 Watt calculated from equation (13), which is the heat flow from outside to inside, and Qdrink can be calculated with Equation (14).

$$Qdrink = weight*heat\ capacity*\Delta T \quad (14)$$

$$=4.5\ kg*4186\ joules/kg\ C*10 \quad (15)$$

$$=188370\ Joules \quad (16)$$

By making Qdrink a variable, we can make a graph in Figure 10 to show the relationship between the Qdrink and the time it takes to cool. We can see that the time to cool 12 cans of coke 10 degrees lower takes 2 hours.

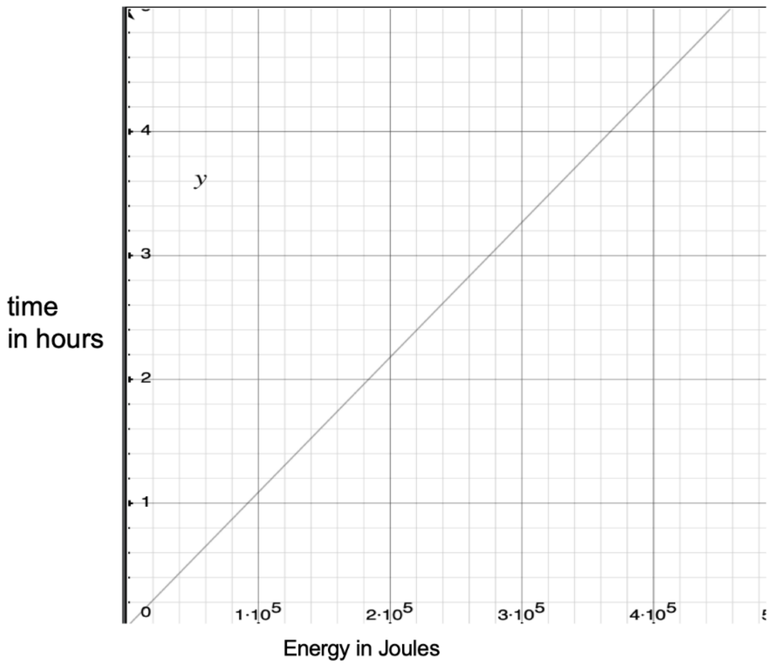

Figure 10: Time Takes to Cool vs Energy

3. Design Verification

3.1 Control Module

3.1.1 Microcontroller

The requirement for the microcontroller is that each pin is programmable when operated at 5V and is able to output 5V to the digital pins.

The plan was to write code to test each programmable pin, Figure 11 is a sample code to test the capability of digital write of pin 9. The result was that each pin is programmable and is able to output 5V.

```
void setup() {
  // initialize digital pin LED_BUILTIN as an output.
  pinMode(9, OUTPUT);
}

// the loop function runs over and over again forever
void loop() {
  digitalWrite(9, HIGH);   // turn the LED on (HIGH is the voltage level)
}
```

Figure11: Sample Code for Microcontroller

The next step is to check the capability of analogwrite of analog pins. The analogwrite can have values ranging from 0 to 255. 255 maps to 5 V while 0 maps to 0 V. We wrote a for loop ranging from 0 to 255 and increment each 1 seconds and monitor the AC voltage on the multimeter. The result was that the analog pins are programmable and is able to output analog voltages.

3.2 Display Module

3.2.1 Seven-segment Display

The requirement for the seven-segment display is that when supplied with 5 V. It can display numbers we desired.

To test the seven-segment display. We wired the display to the microcontroller as shown in Figure 13 and program the microcontroller to display numbers from 0 to 9. We have verified that the microcontroller is able to output 5 V to the digital pins, thus we have verified that the seven-segment display is functional at 5 V.

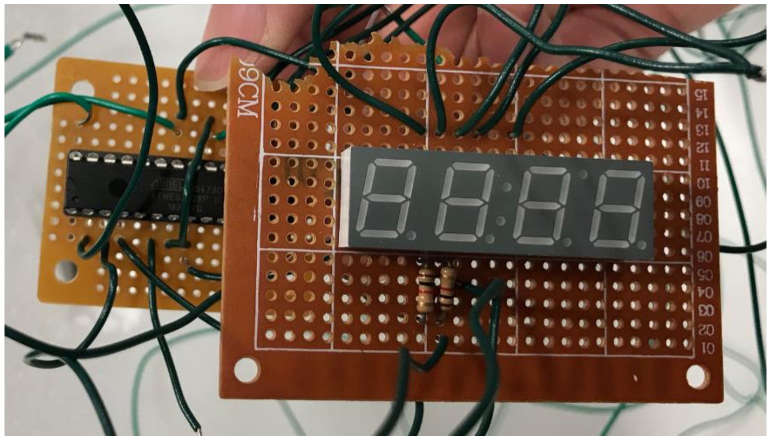

Figure 12: Circuit For 7 Segment Display

3.3 Power Module

3.3.1 Voltage Regulator

The requirement for the voltage regulator is that it should be able to output constant voltage of 5 V. We tested by wiring the regulator to a voltage supply and take the reading from the multimeter. The result is that when given any voltage from 7 V to 15 V, the output voltage is constant 5V.

3.3.2 Charge controller

The requirement for the charge controller is that it should stop charging battery when battery is fully charged, stop charging the battery when 3 A is exceeded and must provide 11V to 14V to the battery. We did not manage to get the charge controller to work.

3.3.3 Battery

The requirement for the battery is that fully charged battery should power the system for at least 2 hours with discharge voltage of 11V to 13V. To verify, we connected multimeter to the battery when the battery is half charged, the reading is 11.5V.

3.3.4 Solar Panel

The requirement for the solar panel is that it can provide 25.2 W. Our charge controller did not work; thus we bought another charge controller on amazon to replace the charge controller on board. The new charge controller comes with display. When connected to the solar panel under the sun, the solar panel generate 22.6 W of power. The result is lower than what the solar panel advertised, but is still acceptable since the power generated depends on the power of the sun.

3.4 Cooling Module

3.4.1 Cooling Plate

The requirement is that the cooling plate should reach lower than 10 Celsius, and the hot side of the cooling plate should never reach 80 Celsius, since the container we bought was cheap, and that is the temperature at which it will melt. To test, we wired the cooling plate to the voltage supply with constant voltage of 3V and constant current of 6A. We then monitor the temperature of the cold side and hot side with thermometer. The cold side of the cooling plate can reach a temperature of 1 Celsius while the hot side can reach a temperature of 67 Celsius. The result fits our requirement.

3.5 Sensor Module

3.5.1 Temperature Sensor

The requirement is that sensor should detect temperature with accuracy of at least 1°C in the range 0 to 30°C. To test this, first we calibrate the temperature sensor to the room temperature with a potentiometer, and then hold the temperature sensor with bare hand. The reading from the temperature sensor was 28.2 Celsius. We then tested the hand temperature; the temperature was 27.7 Celsius. The result is in range of the requirement and could be further calibrated with the potentiometer.

4. Costs

4.1 Parts

Table 1: Parts Costs

Part	Manufacturer	Retail Cost ($)	Bulk Purchase Cost ($)	Actual Cost ($)
25W Solar Panel	Newpowa	$39.97	$39.97	$39.97
Thermoelectric Pad	Laird Technology	$90.80	$80.08	$90.80
ATMEGA328-PU	Microchip Technology	$1.96	$1.63	$1.96
Lithium 12V battery	Dakota Lithium	$24.49	$24.49	$24.49
Temperature sensor	Texas Instrument	$1.13	$1.13	$1.13
Battery charge Controller	Texas Instrument	$5.52	$4.07	$5.52
5V Voltage Regulator	Texas Instrument	$7.80	$3.42	$7.80
7-segment Display	Lite-ON Inc	$3.96	$1.65	$3.96
PCB	PCBway	$0.00	$0.00	$0.00
Styrofoam box	Lifoam	$12.97	$12.97	$12.97
Aluminum Heatsink	EasyCargo	$8.99	$8.99	$8.99
Cooling Fan	SoundOriginal	$12.45	$12.45	$12.45
Total		**$210.04**	**$190.85**	**$210.04**

4.2 Labor

The national average salary for a BS ECE graduate is $96,518. The graduate tends to work 40 hours per week, and there are 52 weeks in a year. The ECE graduate earns about $46.4 per hour. We have three people and are planning to work on the project 12 hours for 16 weeks. The total is 16 weeks * 12 hours * 3 person * 2.5 * $46.4= $53452.8.

4.3 Schedule

Table 2: Schedule

Week	Hanfei	Karim	Kunjie	Group
2/25	Buy Parts and work on next week job if parts arrive early	Buy Parts and work on next week job if parts arrive early	Buy Parts and work on next week job if parts arrive early	Buy Parts
3/4	Burn Bootloader to microcontroller, test microcontroller	Parts Testing--Power	Parts Testing--Sensor,Display,Cooling	Soldering Assignment
3/11	Program microcontroller	Make sure battery and be charged with solar panel	Design PCB.	Order PCB
3/18	Meet up with Kunjie to integrate microcontroller into other components	Build the Cooler, integrate power component to the cooler	Meet up with Hanfei to integrate Sensor,Display,Cooling	Spring Break
3/25	Integrate control component to the cooler	Integrate power component to the cooler	Integrate control component to the cooler	Final Round PCB order
4/1	Debug	Debug	Debug	Debug
4/8	Verify the Cooler fits requirement	Verify the Cooler fits requirement	Verify the Cooler fits requirement	Prepare for Mocking Demo
4/15	Final Report	Final Report	Final Report	Prepare for Demo and Mock Presentation
4/22	Debug Control Component	Debug Power Component	Debug Cont	Prepare for Presentation
4/29	Prepare for Presentation	Prepare for Presentation	Prepare for Presentation	Prepare for Presentation

5. Conclusion

5.1 Accomplishments

Our project is a success in many submodules. The voltage regulator component is able to supply constant 5 V to the microcontroller. Our microcontroller circuit guarantees that the chip can work as on the original Arduino Uno board and is able to convert signals from the temperature sensor into temperature in Fahrenheit and display the temperature on the seven-segment display. The cooling component is able to extract heat from cold side and reach a surface temperature of 1 degree Celsius. The system worked together well despite the failure we had in charge controller.

5.2 Uncertainties

The charge controller at the end did not work. The charge controller was supposed to be responsible for regulating input voltage into the battery and prevent overcharging, discharging and damaging the battery. We bought a charge controller on amazon to replace our charge controller on board so our system can still operate.

5.3 Ethical considerations

There are two main safety issues that cause us concern. First, due to the nature of the device, the system must be robust. The circuitry and items inside the cooler must be contained separately. The system must be waterproof to avoid shocks and against the battery leakage. We chose lithium ion and not SLA (sealed lead acid) due to the toxicity of SLA. Second, we have to make sure the cooler door and parts are robust so that not sharp edges can be formed by wear and tear of cooler use. Third, the temperature sensor placed on the cooling plate will make sure there is no overheating during operation.

We have to make sure we don’t violate ACM Code of Ethics [2]and IEEE Code of Ethics[3] by avoiding injuring others. Through the use of our cooler, there is a chance that the cooler will malfunction, we will try to minimize the chance and mitigate the harm as much as possible. When release the product, we will follow the IEEE Code of Ethics [3] code number one by disclose promptly factors that might endanger the public or the environment.

Our project will very likely to accept help from many people, including TA, professor, friends, and people who have done similar projects in the past, we will follow IEEE Code of Ethics[3], seek, and accept criticism of technical work, improve our work base on the feedback and credit others properly.

5.4 Future work

In the future, we could add a user interface where the user can manually enter the internal temperature, and the cooler will try to achieve that temperature and automatically stops when the temperature is achieved. Another improvement we can make is that, we can convert the cooler into a heater that keeps food inside warm, since we are using a thermoelectric plate, it is very simple to swap the cold side and the hot side.

References

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Appendix A Requirement and Verification Table

Table 3: System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Control Unit Requirement a. Must be able to sense the voltage from temperature sensor with at least 10 mV increment. b. Microcontroller is able to output correct signal to the display to display correct value.	1. Verification a. Send the voltage to the microcontroller with function generator from 2.00V to 3.00V in 10mV increment. Check the readout on the microcontroller which will be setup to be display on the seven-segment display. Make sure it is able to detect difference in 10 mV. b. Program the microcontroller to display 0 - 9 on each of the four-character display. Verify that all segment is working correctly and the display does display the correct value.	Y
2. Seven Segment Display Requirement a. The 7-segment will operate at 4.8 - 5.1V. b. The display can successfully display the digit given by the microcontroller	2. Verification a. Using a DC power supply, with one end at cathode to GND and 5V at anthode of a segment. Measure the voltage with a multimeter. Verify the voltage is in 4.8-5.1V. b. Program the microcontroller to display 0 - 9 on each of the four character display. Verify that all segment is working correctly and the display does display the correct value.	Y
3. Temperature Sensor Requirement a. The sensor should detect temperature with accuracy of at least 1°C in the range 0 to 30°C.	3. Verification a. Using a DC power supply, with one end at cathode to GND and 5V at anthode of a segment. Measure the voltage with a multimeter. Verify the voltage is in 4.8-5.1V. b. Program the microcontroller to display 0 - 9 on each of the four character display. Verify that all segment are working correctly and the display does display the correct value.	Y
4. Cooling Requirement a. The cold side of plate should reach below 10 degrees. b. The hot side of the plate should not exceed 80 Celsius[5].	4. Verification a. Supply power with 3.5A to 2 plates connecting in series and monitor temperature changes via temperature sensor. b. While testing requirement 1, use a heat gun to check the temperature of the hot side of the cooling plate and verify it is under 80 Celsius during the operation.	Y

5. Voltage Regulator Requirement a. Output voltage should be in the range 4.8- 5.2V.	5. Verification a. Provide the voltage regulator with 11V from DC power supply. Measure output voltages using voltmeter. Verify the voltage is in the range 4.8- 5.2V.	Y
6. Battery Requirement a. Fully charged battery should power the system for at least 2 hours with discharge voltage of 9.0 - 11.0V.	6. Verification a. Measure the output voltage of the battery with a multimeter while the system is running. The multimeter should read in range 9.0 - 11.0V. b. Attach a 2A load battery tester and ensure the load is supplied for at least 2 hours via a voltmeter/ammeter.	Y
7. Charge Controller Requirement a. Must provide battery with 12 - 14V, when battery is not fully charged. b. Stop charging battery when battery is fully charged. c. Disconnect power from rest of the circuit if 3A is exceeded.	7. Verification a. With a DC power supply providing 18V and 1.2 A. Measure output voltage using voltmeter. Make sure it is between 12 - 14V. b. Measure power output (to battery) when a fully charged battery is connected. Make sure that there is no output from the charge controller. Also check the STAT1 and STAT2 to ensure they are HI and LOW respectively which shows charge is complete. c. Measure current using ammeter with an increasing current (up to 5A) from a DC power supply.	N
8. Solar Panel Requirement a. The panel can provide up to 25W, at 18V and 1.4A under maximum power delivery conditions. b. The solar panel charge the battery 120Wh (10Ah) fully in one day, or in other words, under 7 hours of sunlight.	8. Verification a. Obtain Solar panel I-V curve and find maximum power point. b. Verify maximum power point will fully charge battery in under 7 hours. The solar panel should provide power in the range 17.2 - 25 W.	N