

QL+ Body Temperature Regulating Vest

Project 43.a.01

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Table of Contents

Abstract.....	6
Chapter 1: Introduction.....	7
Stakeholders/Target Audience.....	7
Challenger background and needs.....	7
Purpose of the project	7
Project & Team Description	7
Chapter 2: Background	8
Existing Products.....	8
Ice-Pack Vest.....	8
Evaporative Cooling Vests.....	8
Phase Change Vests	8
Fluid Cooling	9
Air Cooling	9
Studies of Interest	9
Thermoelectric Cooling	9
Evaporative Cooling.....	9
Codes and Standards.....	9
Chapter 3: Design Development.....	11
Objectives.....	11
Customer Requirements	11
Project Requirements	11
Conceptual Models	14
Liquid Cooling Vest.....	14
Evaporative Cooling Vest.....	14
Conductive Material Vest	15
Concept Selection	15
Supporting Preliminary Analysis	16
Chapter 4: Description of the Final Prototype Design	22
Detailed Design Description	23
Schematics.....	23
Body to Vest Interface	25

Safety Considerations	29
Maintenance and Repair Considerations	29
Chapter 5: Product Realization	30
Chapter 6: Design Verification Plan (Testing).....	31
Test #1: Body to Vest Human Test while Exercising.....	31
Test # 2: Body to Vest Human Test while Stationary	32
Chapter 7: Conclusions & Recommendations.....	38
Chapter 8: Management Plan	39
References	41
Appendix A	42
Appendix B	44
Appendix C	45
Appendix D	46
Appendix E	53
Appendix F	55
Appendix G.....	57
Appendix H.....	69

Figure 1. Liquid Cooling Vest Configuration.	14
Figure 2. Evaporative Cooling Vest Configuration.	15
Figure 3. Conductive Material and Phase Change Cooling Vest.	15
Figure 4. Seven Stages of Heat Transfer Thermal Bock Diagram.	21
Figure 5. CAD Model of Thermal Vest.	22
Figure 6. Device System Block Diagram.	23
Figure 7. Body to Vest Interface Configuration.	25
Figure 8. Internal Fabric Layer.	25
Figure 9. Tubing Configuration.	26
Figure 10. External Layer Configuration.	27
Figure 11. Expanded View of Cooling Module.	27
Figure 12. Expanded View of Cooling Reservoir.	28
Figure 13. Heat Dissipation Assembly.	29
Figure 14.. Body to Vest Exercising Test Data.	31
Figure 15. Static Vest Temperature Data.	32
Figure 16. Body to Vest Insulative Layer Data	33
Figure 17. Body to Vest Aluminum Container Model Setup	34
Figure 18. Heat Exchanger Inlet and Outlet Temperatures.	34
Figure 19. Thermoelectric Performance Test Setup.	35
Figure 20. Thermoelectric Hot and Cold Plate Temperature Difference	36
Figure 21. System Model Configuration.	37
Figure 22. System Reservoir and Core Body Temperatures	37

Abstract

The purpose of this project is to design a thermal vest to be worn by individuals with spinal injuries to help regulate their core body temperature. Individuals with spinal injuries have impaired thermoregulation abilities which increase their susceptibility to succumbing to either heat stroke or hypothermia. This project focused on preventing heat stroke by inducing a cooling mechanism. To provide this cooling mechanism, a thermoelectric cooler was used to chill water in a reservoir. This water is then pumped through tubing sewn into the vest. The chilled water will absorb heat from the human body and return to the reservoir. At this point the water will then be re-chilled and recirculated. Testing regarding this method showed that 550 BTUs per hour of heat from the human body. This is almost half the amount of heat dissipated by the human body to maintain a core body temperature of 98.6°F. Further testing also verified that the chosen materials are biocompatible and capable of reducing body temperature.

Chapter 1: Introduction

Stakeholders/Target Audience

Individuals diagnosed with spinal injuries are oftentimes unable to regulate their body temperature below the site of injury. Unaffected individuals regulate their body temperature through conduction, evaporation and radiation methods. Conduction heat loss occurs when the body comes into contact with a cooler surface (i.e. the ground), but evaporation and radiation heat loss depends on signals from the body's control center. Individuals with spinal damage are unable to relay messages from their sensory neurons to the hypothalamus [1]. As a result, the hypothalamus is unable to stimulate vasodilation and sweating to induce heat loss.

When temperatures exceed 104°F, the inability to induce heat loss mechanisms poses threats to affected individuals. Specifically, elevated temperatures cause organ malfunctioning, cardiovascular problems and potentially death [2]. Therefore, the purpose of this project is to produce a vest that is capable of maintaining the core body temperature of individuals with spinal injuries at 98.6°F.

Challenger background and needs

The proposer of this project is Lisa Maddox. Maddox is a practicing doctor who works with multiple sclerosis patients. She has requested a design for a thermal vest that is capable of cooling and heating to maintain an average body temperature of 98°F. Ideally this device should regulate the core body temperature in environments that reach up to 110°F.

Purpose of the project

The purpose of this project is to design a vest capable of maintaining an individual's core temperature at 98°F. Current vest models exist that utilize ice packs that are inserted into vest pockets. However, once ice packs melt, the excess water increases the overall weight of the vest. In addition, these vests only cool the body for a limited amount of time. The overall purpose of this project is to create a battery-operated, light-weight, and functional vest that individuals will be inclined to use on a regular basis in warm environments.

Project & Team Description

This is a three-quarter long project that aims to design a body temperature regulated vest. The first quarter will be spent forming an initial design. The second quarter will be dedicated to testing and revising the initial design. The third quarter will be spent fabricating a proof-of-concept prototype.

The project team is composed of five members from biomedical, mechanical and materials engineering backgrounds. Melissa Goss will serve as the team lead to coordinate all correspondence with QL+, manage the project budget and submit project reports. Greg Olsen will serve as the lead communicator with the project challenger and faculty. Other members will be appointed various positions as the design process develops.

Chapter 2: Background

Existing Products

Currently, there are five leading types of thermal vests: Ice-pack, evaporative cooling, phase change, fluid cooling and air cooling. A detailed analysis of each vest type is included below. Further specifications for all devices are included in Appendix A.

Ice-Pack Vest

Ice-Pack vests insert frozen ice-packs into the pockets of jackets. Ice-Pack vests can last between two to four hours [3]. Ice-pack vests are low-cost, have a high cooling power and the ice packs can be reused. However, after melting, ice-pack vests can weigh between five and ten pounds. In addition the ice-packs require time to re-freeze. Another disadvantage is the fact that the vest is always in use, even when the body temperature is already at 98°F.

One current model is the kold-vest [4]. This device uses ice packs to induce cooling. This vest is light-weight, can last up to two hours and uses reusable ice-packs. The vest costs around \$150.00.

Evaporative Cooling Vests

Evaporative cooling devices use polymer materials soaked in water [5]. Over time, the water will evaporate from the vest in order to cool the body's surface. The device must be submerged in water for 1-3 minutes in order to operate for a period of 5-10 hours. These devices are often lightweight, low in cost, have high performance in dry climates, offer durability, operate without the use of ice packs and demonstrate a long performance time. However, these devices require soaking the garment in water which can be inconvenient for the user, have poor performance in high humidity climates and have the lowest overall cooling energy.

One current product is Gempler's Evaporative Cooling Vest [6]. The vest is composed of a polymer embedded fabric that is activated by water. This device must be submerged in water for 1-2 minutes and has an operating time of 5-10 hours. This design costs approximately \$36.15.

Phase Change Vests

Phase change vests use a polymer formula to help aid in cooling. Phase change materials are activated at a certain temperature between 0-30 °C [7]. In a thermal vest, the phase change material would become activated when the body reaches a certain temperature. At this point, the phase change material would begin to melt in order to cool the body primarily through conduction mechanisms. Common phase change materials include ice packs, dry ice, and the most commonly used: paraffin wax. Typically these vests range in cost between \$150 and \$300.

The phase change material is able to cool an individual between 2-3 hours [7]. This method is a passive process that offers a controlled release of a constant temperature which makes these devices easily customizable. They do not require the use of a freezer and they offer an effective cooling method in all climates. The disadvantages include high cost replacement parts and heavy weight after melting. However, these devices can only cool for approximately 3 hours, they weigh more than other cooling devices, they can have a higher cost and their total cooling power is less than cold pack systems.

A current model is the Cooling Vest of TST Sweden AB [8]. This model inserts PCM material into the pockets inside the vest. The PCM material melts at 28 °C and can cool the body for up to two hours. The vest can be recharged in an air conditioned room, a refrigerator or freezer. Another advantage is that the vest weighs only 2 kilograms.

Fluid Cooling

Active cooling vests pump coolant through a series of tubes embedded within the vest. The coolant can be activated by temperature sensors and the temperature of the coolant can be adjusted. This design can cost up to \$500. The advantages of this design include high efficiency, long cooling periods, can quickly remove a large amount of heat and no wetting is required. The disadvantages include high cost, high energy requirements, need for a water reservoir and the use of a pump. They are also heavier designs that limit the movement of the user.

Current models of this device include the Polar Active cooling vest [9]. This product circulates cool water through the vest. It comes in both fitted and adjustable versions. The vest uses a 15 quart wheeled cooler to provide water to the device. The device and cooler are connected by a retractable cord that can be disengaged when not in use. The product costs \$810 per vest.

Air Cooling

These devices direct compressed air around the body from an air supply system which allows excess sweat to be removed through evaporation. These devices are very comfortable, lightweight, and easily adjustable. However, these devices require more energy and therefore add expenses.

Current market products include the Kool-Vest [10]. Fresh air is distributed through small holes in the vest to provide evaporative cooling across the worker's back, chest, and face. The vest operates with only 10 - 20psi to accommodate a vortex cooling tube.

Another market product is the Personal Air Conditioner [11]. This device uses vortex tubes to separate compressed air into warm and cool streams. The advantage of this model is that it can heat and cool an individual. The disadvantages include high market price (approximately \$500+) and the requirement to be connected to compressed air.

Studies of Interest

Thermoelectric Cooling

These devices run electric current through the wires of the thermoelectric coolers which apply a voltage of constant polarity to a junction between two metals. This creates a hot and a cold side, with heat sinks that are responsible for transferring the thermal energy from the hot object, in this case the skin, to an object with a lower temperature, the environment.

This method is compact, inexpensive, and allow for the process to be reversed, presenting the option of the vest to not only cool, but to also heat. These systems are also inefficient when compared to alternative cooling methods, and they require a constant supply of power.

One study using this method incorporated a thermoelectric cooler into an evaporative cooling design [5].

Evaporative Cooling

Another study of interest is the "Personal-portable Cooling Garment Based on Adsorption Vacuum Membrane Evaporative Cooling" by Yifan Yang [12]. Yang designed a thermal vest that used evaporative cooling methods. Using the AVEC cooling method, a cooling capacity of 179 W/m² was obtained over a period of four hours.

Codes and Standards

The vest must not cause harm to the user. Specifically, the fabric and design must not cause skin burns, friction burns or pressure sores.

Regarding FDA standards, important codes to consider include 21CFR890.9, 21CFR890.5720, 21CFR890.5940 [11]. Code 890.9 addresses issues regarding premarket notification. Code 890.5720 addresses the issue of using circulating water in a cooling or heating pack. Depending on the final design

selection, additional FDA codes and standards may need to be considered. Specific FDA codes are included in Appendix B.

In regards to testing considerations, a model that accurately represents the conditions of an individual with a spinal cord injury is required. Other models used a torso replica that was capable of modeling evaporative, or sweating, cooling mechanisms [5]. In individuals with spinal injuries, sweating is often impaired below the site of injury. Therefore, a testing model with replicates this impairment should be used.

Chapter 3: Design Development

Objectives

The overall goals of this project are to design a lightweight, non-bulky jacket that uses thermal sensors to regulate an individual's core temperature.

Customer Requirements

The following list contains the proposed customer requirements. These requirements were chosen to create a user-friendly device that can be used on a regular basis.

- Durable
- Lightweight
- Non-insulating
- Functional for at least 8 hours
- Maintain core temperature of 98°F
- Moderated by a thermostat
- Can be worn under clothing
- Adjustable for different sizes
- No system failure
- User-friendly
- Reduced number of false alarms
- Lithium ion battery source
- Chemical based system

Project Requirements

Based on the proposed customer requirements, the following qualitative performance goals were proposed.

Performance Goals	
Durability	Must be able to with
Light Weight	Lightweight
Non-Insulating	Fabric must be breathable
Long Lasting	Use during a standard work day
Maintain Core Temp	Reduce temperature from 110 to 98 and regulate
Thin and compact design	Fit under a T-shirt
Reliability	Components must be durable and long-lasting
User Friendly	Comfortable and easy to use by individual
Washable	Must be water resistant
Cost	Must be inexpensive
Adjustable	Must be able to size from small to large shirt size
Safety	Must be able to operate without any impending danger to user

These qualitative performance goals were then transformed into quantitative functional goals.

Functional Requirements	
Durability	Withstand drop from 8 ft
Light Weight	Less than 5 lbs
Non-Insulating	more than 170 gram/(hour meter ²) of water permissibility
Long Lasting	Self contained operation 8 hours
Maintain Core Temp	Must expel 500 BTUs/hour
Thin and compact design	Vest must protrude off the body by no more than 1/4 inch
Reliability	All components must last 10 ⁶ cycles w/ 95% reliability
User Friendly	User fully Functional after 3 attempts
Washable	Must be able to function after being submerged in 5 PSI of water
Cost	Must cost less than \$2000 to build and test
Adjustable	30 inch chest to a 46 inch chest
Safety	All contact materials to be biocompatible

The functional goals were then compared using a rank order comparison shown in Appendix C. Based on the rank order comparison the top four goals were determined to be maintaining core body temperature, safety, light-weight design and non-insulating materials. Detailed explanations for these goals are included below.

- **Maintaining Core Body Temperature: Must expel 1000 BTUs/hour**
 - The main goal of this project is to regulate an individual's body temperature at 98 degrees. If this standard is not met, then ultimately the design does not achieve its overall purpose. In order to maintain an individual's body temperature, 1000 BTUs/hour must be expelled by the entire body. Assuming that half of the heat loss occurs from the torso then the vest must expel 500 BTUs/hour.
- **Safety: All contact materials to be biocompatible**

- This device must not be dangerous to use. In order to be FDA approved, certain standards must be met to ensure user safety. Furthermore, it is important that materials are selected that don't cause skin lesions or burns.
- **Light-weight: Less than 5 lbs**
 - In order to be used on a daily basis the design must be light-weight. This will ultimately increase the user's satisfaction and increase the device usage.
- **Non-insulating: more than 170 gram/(hour meter²) of water permissibility**
 - The material must be able to expel excess heat to prevent the user from overheating.

Other goals that ranked relatively high included a thin & compact design, reliability of device and long-lasting.

- **Thin & Compact Design: Vest must protrude off the body by no more than 1/4 inch**

This will allow the vest to lie below an individual's clothing.

- **Reliability: All components must last 10⁶ cycles w/ 95% reliability**

This device is responsible for regulating the body temperature in high temperature environments. It must be 95% reliable to ensure that the individual does not succumb to heat stroke.

- **Durability: Withstand drop from 8 ft**

Must be durable enough to withstand normal daily conditions. If the device can withstand an 8 foot drop, then it should be able to withstand daily activities.

- **Long Lasting: Self contained operation 8 hours**

This will allow the user to wear the vest during a standard eight hour work day.

The least important goals at this time are adjustability, washable and low-cost.

- **User-Friendly: User fully Functional after 3 attempts**

Must not be a difficult device for the user to operate. They must be able to use the device with minimal instructions.

- **Adjustability: 30 inch chest to a 46 inch chest**

These are the dimensions of average female and male chest sizes.

- **Washable: Must be able to function after being submerged in 5 PSI of water**

If the user is using the device on a daily basis, it must be washable.

- **Cost: Must cost less than \$2000 to build and test**

This is the cost for building and prototyping. Individual units may be more expensive than existing models. The rationale for a higher unit cost is dependent on the fact that this device will be used on a daily basis.

Conceptual Models

Based on the design requirements outlined above and preliminary background research, three top conceptual models were designed: the liquid cooling vest, the evaporative cooling vest and the conductive material and phase change vest. Each model is discussed in detail below.

Liquid Cooling Vest

The liquid cooling vest pumps liquid throughout the vest to produce a cooling effect. Liquid is stored in a fluid reservoir and is cooled by a thermoelectric cooler. Figure 1 shows the configuration of the liquid cooled vest design.

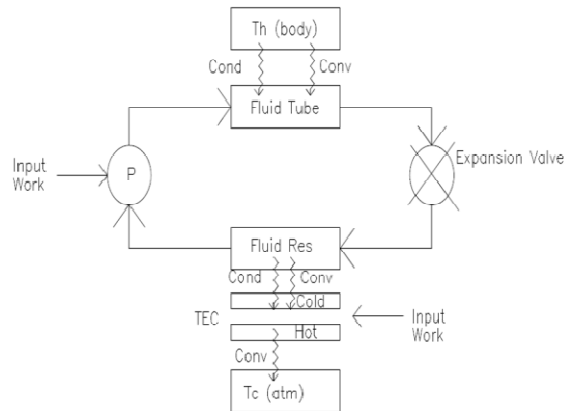


Figure 1. Liquid Cooling Vest Configuration.

As the liquid travels through the vest-lined tubing, it absorbs heat from the body. The fluid then enters the fluid reservoir, where the thermoelectric cooler (TEC) works to cool the water and remove the heat from the vest reservoir into the surrounding environment.

Benefits of this design include increased efficiency and high thermal conductivity. However, this design may also be bulky and heavy for the user. In addition, the current design must be continuously powered and has the potential to leak.

Evaporative Cooling Vest

The evaporative cooling vest uses an air pump in order to remove heat from the user. The vest material is slightly dampened to facilitate heat transfer reactions between the user's skin and the fluid tube.

Evaporative and convective forms of heat are emitted from the user's skin to the fluid tube. From here, heat enters the inlet and outlet where it is removed from the system through a TEC.

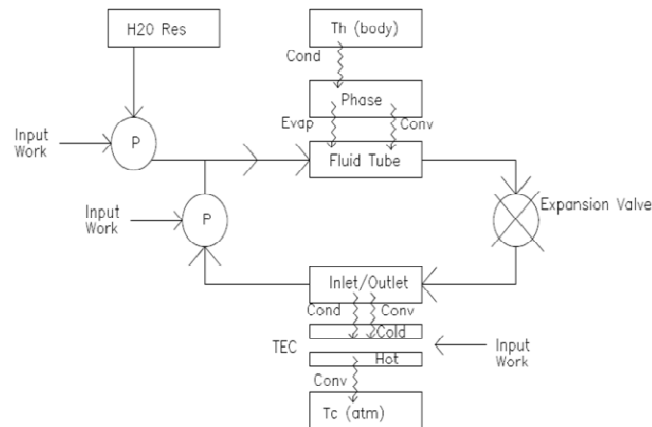


Figure 2. Evaporative Cooling Vest Configuration.

The benefits of this design include a passive form of cooling that is lightweight. The disadvantages of this design include the need for water components and a bulky design.

Conductive Material Vest

The conductive vest operates similar to a heating blanket. Heat from the body comes into contact with a conductive material and then a TEC in order to expel heat into the surrounding environment.

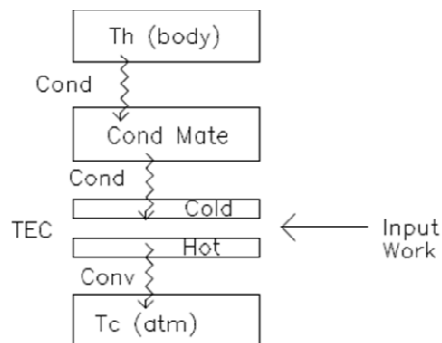


Figure 3. Conductive Material and Phase Change Cooling Vest.

Benefits of this design include a simple design schematic. However some disadvantages of this design include the need for extensive wiring. This may increase the likelihood of negative side effects to the user (i.e. increased likelihood of burns). Also, this is not an efficient design.

Concept Selection

To compare the three models a Pugh Matrix was created. The liquid cooling vest was selected as the datum since the most research has been conducted regarding this design.

Based on the Pugh Matrix included in Appendix C, both the evaporative and phase change vests only had one advantage over the liquid cooling vest. In addition, they each had several disadvantages compared to the liquid cooling vest and ranked the same in the remaining categories. Therefore, the liquid cooling vest was selected as the final design.

Supporting Preliminary Analysis

In order to determine the validity of the proposed design, MATLAB code was used to model heat transfer throughout the chosen model. First this model makes several assumptions:

- System and system components are operating at steady state
- The system is expelling heat from the body to the atmosphere

Heat transfer is modeled in seven stages as detailed below:

Stage 1: Heat transfer from the body to the conductive fabric (the internal layer of the vest/body interface)

Assumptions:

- Uniform torso temperature of the user
- Uniform internal layer temperature
- Surface area of the users torso is 5 ft²
- 1-D Conduction model

$$T_{i,f} = T_{skin} - \frac{(E_{gen} * t_{fab})}{(A_{f,cs} * K_{fab})} \quad (1)$$

$T_{i,f}$ = Temperature of the internal fabric layer (°F)

T_{skin} = Temperature of the user's torso (°F)

E_{gen} = Heat required for dissipation by the Thermal Vest (Btu/Hr)

t_{fab} = Thickness of the internal layer fabric (ft)

$A_{f,cs}$ = Surface area of the user's torso in contact with the internal layer (ft²)

K_{fab} = Internal layer thermal conductivity ((Btu/hr) / (ft*°F))

Stage 2: Heat transfer from the conductive fabric to the tubing material

Assumptions:

- Uniform tube temperature
- 1-D Conduction model

$$T_{tube} = T_{i,f} - \frac{(E_{gen} * t_{tube})}{(A_{t,cs} * K_{tube})} \quad (2)$$

T_{tube} = Temperature of the tubing material (°F)

t_{tube} = Thickness of the tubing (ft)

$A_{t,cs}$ = Contact area of the tubing to the conductive fabric (ft²)

K_{tube} = Thermal conductivity of the tubing material ((Btu/hr) / (ft*°F))

Stage 3: Heat transfer from the tubing material to the circulated cooling fluid

Assumptions:

- Turbulent fully developed flow through the tubing
- Forced convection internal flow model

$$Nu_{vest} = .023 * Re_{vest}^{(4/5)} * Pr * D_{tube} \quad (3)$$

$$Re_{vest} = \frac{\rho_f * V_f * D_{tube}}{\mu_f} \quad (4)$$

$$H_{vest} = \frac{Nu_{vest} * K_{fl}}{D_{tube}} \quad (5)$$

$$T_f = T_{tube} - \frac{(E_{gen})}{(A_{i,cs} * H_{vest})} \quad (6)$$

Nu_{vest} = Nusselt Number for the fluid in the vest

Re_{vest} = Reynolds Number for the fluid in the vest

ρ_f = Density of the fluid in the vest (lb/ft³)

μ_f = Dynamic viscosity of the Fluid in the vest (lb*s/ft²)

Pr = Prandlt Number of the fluid in the vest

D_{tube} = Internal diameter of the tubing (ft)

V_f = Velocity of the fluid in the vest (ft/s)

K_{fl} = Thermal conductivity of the fluid in the vest ((Btu/hr) / (ft*°F))

H_{vest} = Convection coefficient of the heat transfer in the tubing ((Btu/hr) / (ft²*°F))

T_f = Temperature of the fluid in the vest (°F)

$A_{i,cs}$ = Internal contact area of the tubing and the circulating fluid (ft²)

Stage 4: Heat transfer from the flowing fluid to the cooling reservoir

Assumptions:

- Turbulent full developed flow through cooling reservoir
- Forced convection internal flow model

$$Nu_{res} = .023 * Re_{res}^{(4/5)} * Pr * D_{res} \quad (7)$$

$$Re_{res} = \frac{\rho_f * V_f * D_{res}}{\mu_f} \quad (8)$$

$$H_{res} = \frac{Nu_{res} * K_{fl}}{D_{res}} \quad (9)$$

$$T_{res} = T_f - \frac{(E_{gen})}{(A_{res} * H_{res})} \quad (10)$$

Nu_{res} = Nusselt Number for the fluid in the cooling reservoir

Re_{res} = Reynolds Number for the fluid in the cooling reservoir

D_{res} = Internal diameter of the cooling reservoir (ft)

H_{res} = Convection coefficient of the heat transfer in the cooling reservoir ((Btu/hr) / (ft²*°F))

T_{res} = Temperature of the cooling reservoir (°F)

A_{res} = Internal contact area of the cooling reservoir and the circulating fluid (ft²)

Stage 5: Heat transfer from the cooling reservoir to thermoelectric modules

Assumptions:

- Cooling reservoir is at uniform temperature
- 2-D Conduction Model
- Thermoelectric model plate difference linearly and symmetrically about atmospheric temperature

$$T_{sp} = T_{res} - \frac{(E_{gen} * t_{res})}{K_{res} * q_{ss} * S * (S / (4 * \pi))} \quad (11)$$

$$T_{wp} = (T_{atm} - T_{sp}) + T_{atm} \quad (12)$$

T_{sp} = Temperature of the thermoelectric module supply plate (°F)

t_{res} = Thickness of the cooling reservoir (ft)

K_{res} = Thermal conductivity of the cooling reservoir ((Btu/hr) / (ft*°F))

q_{ss} = 2-D conduction heat transfer coefficient

S = 2-D conduction heat transfer shape factor

T_{atm} = Temperature of the atmosphere (°F)

T_{wp} = Temperature of the thermoelectric module waste plate (°F)

Stage 6: Heat transfer from the thermoelectric module waste plate to the heat sink

Assumptions:

- Uniform heat exchanger temperature
- Heat sink conduction in 2 parts, module to base and base to finned array
- 2-D Conduction model (part 1)
- 1-D Conduction model (part 2)

$$T_{hs,b} = T_{wp} - \frac{(E_{gen} * t_{hs,b})}{K_{hs} * q_{ss} * S * (S / (4 * \pi))} \quad (13)$$

$$T_{hs,f} = T_{hs,b} - \frac{(E_{gen} * t_{hs,f})}{(A_{hs,f} * K_{hs})} \quad (14)$$

$T_{hs,b}$ = Temperature of the heat sink base (°F)
 $t_{hs,b}$ = Thickness of the heat sink base (ft)
 K_{hs} = Thermal conductivity of the heat sink ((Btu/hr) / (ft*°F))
 $A_{hs,f}$ = Contact area of the finned array to heat sink base (ft^2)
 $T_{hs,f}$ = Temperature of the heat sink finned array (°F)
 $t_{hs,f}$ = Thickness of the heat sink finned array (ft)

Stage 7: Heat transfer from the heat sink to the atmospheric air

Assumptions:

- Turbulent fully developed flow through heat sink
- Internal forced convection model

$$Nu_{hs} = .023 * Re_{hs}^{(4/5)} * Pr * De_{hs} \quad (15)$$

$$Re_{hs} = \frac{\rho_a * V_a * De_{hs}}{\mu_a} \quad (14)$$

$$H_{hs} = \frac{Nu_{hs} * K_s}{De_{hs}} \quad (15)$$

$$T_{air} = T_{atm} - \frac{(E_{gen})}{(A_{a,i} * H_{hs})} \quad (16)$$

Nu_{hs} = Nusselt Number for the air in cooling the heat sink
 Re_{hs} = Reynolds Number for the air in cooling the heat sink
 De_{hs} = Effective diameter of the inlet area to the heat sink (ft)
 ρ_a = Density of the atmospheric air (lb/ft^3)
 V_a = Velocity of the air thorough the heat sink (ft/s)
 μ_a = Dynamic viscosity of the atmospheric air (lb*s/ft^2)
 K_s = Thermal conductivity of the atmospheric air ((Btu/hr) / (ft*°F))
 T_{air} = Temperature of the outlet air to the atmosphere (°F)
 $A_{a,i}$ = Inlet area to the heat sink (ft^2)
 H_{hs} = The air convection coefficient cooling the heat sink ((Btu/hr) / (ft^2*°F))

Detailed results are included in the description of the final design. An updated model of the heat flow was also created as shown in Figure 4.

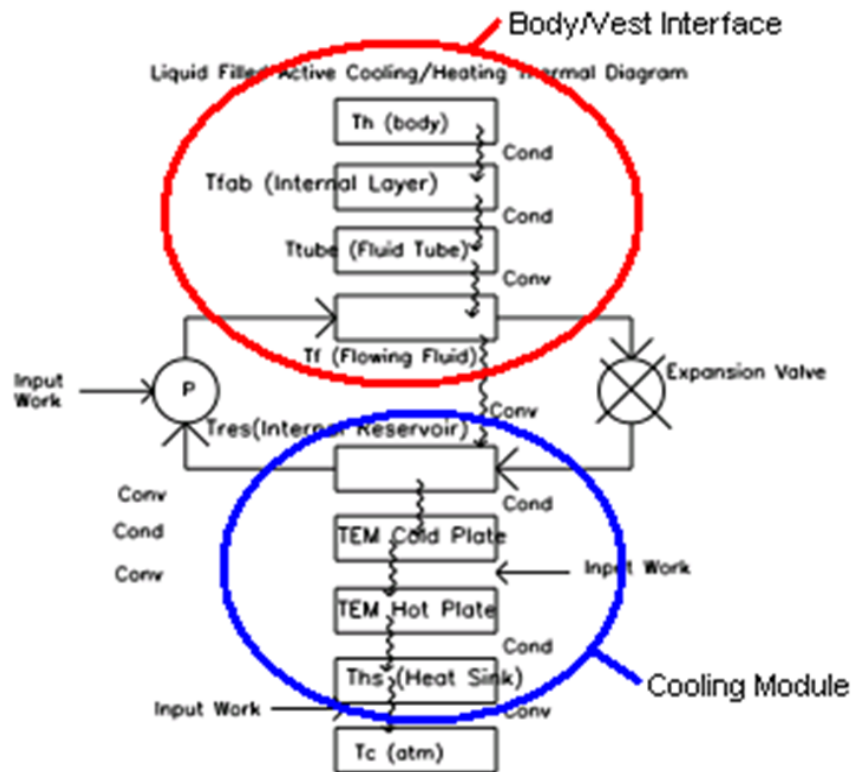


Figure 4. Seven Stages of Heat Transfer Thermal Block Diagram.

Chapter 4: Description of the Final Prototype Design

The liquid cooling vest was chosen as the final design. The liquid cooling vest is composed of two main components: a body to vest interface and a cooling module as shown in Figure 5. The body to vest interface is composed of a conductive fabric, an insulating fabric, and vest tubing. The vest tubing is responsible for circulating fluid to and from the cooling module. As fluid moves through the tubing, it extracts heat from the human body and transfers it back to the cooling module.

The cooling module is then responsible for cooling the returned water. Fluid is cooled by a thermoelectric cooler which absorbs heat from the water and returns it to the surrounding atmosphere. From here, the chilled water is then pumped out of the reservoir and through the vest tubing to repeat the process.

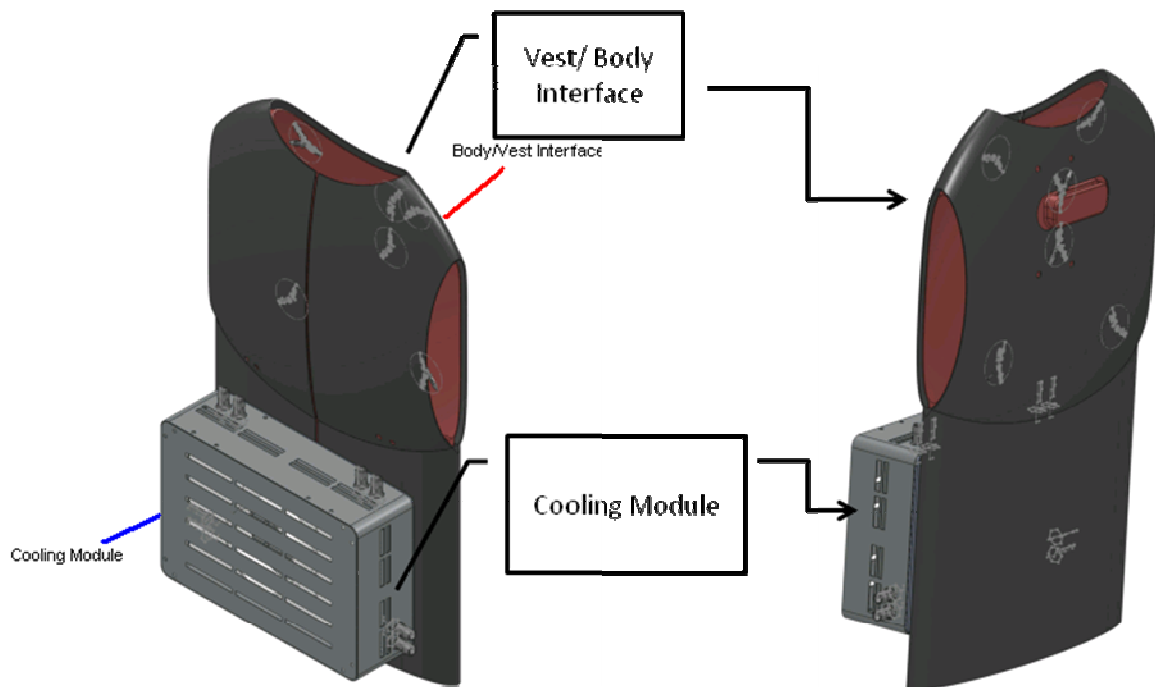


Figure 5. CAD Model of Thermal Vest.

Detailed Design Description

Schematics

Figure 6 shows the system diagram of the proposed design. Specific details of each component are detailed below.

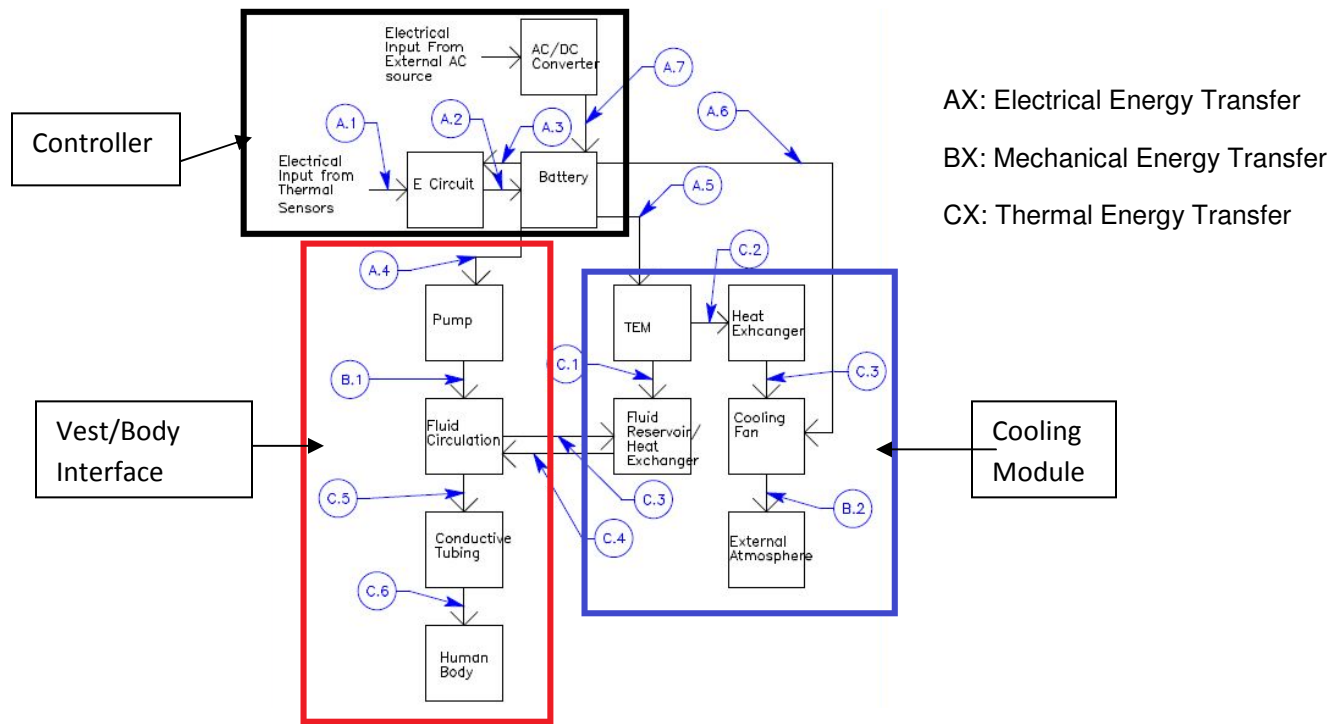


Figure 6. Device System Block Diagram.

- A.1:** Thermal sensors throughout the vest send a voltage potential to an electrical circuit which will activate the thermal vest system if the voltage potential is great enough.
- A.2:** The electrical circuit allows the battery to power the active cooling components of the vest. The cooling fan, the thermoelectric module, and the pump are activated.
- A.3:** Any operating power the system needs to maintain the off and on temperature sensing regulations is supplied by the battery power source.
- A.4:** The system activates the coolant pump at a fixed speed to circulate the cooling or heating fluid through the vest tubes.
- A.5:** The battery sends power to the thermoelectric module which converts the electrical potential into a temperature difference between two plates. The amount of supplied voltage depends on how much the wearer's core temperature deviates.
- A.6:** The battery supplies electrical power to the cooling fan to cool the heat exchanger on the waste side of the thermoelectric module.

- A.7:** The battery power source can be recharged from an external AC power source. Once the power source is depleted (approximately 8 hours) an indication light will illuminate on the battery to indicate the need to recharge.
- B.1:** The coolant pump converts the electrical energy into mechanical work to circulate the coolant through the cooling vest. The rate of fluid circulation is directly proportional to the amount of heat the vest can extract.
- B.2:** The cooling fan converts electrical energy into mechanical work to remove the hot air in the microclimate of the hot plate thermoelectric cooler heat exchanger. This fan will operate for as long as the vest is active.
- C.1:** The thermoelectric module cools or heats a heat exchanger/fluid reservoir. The fluid reservoir is designed to have excellent heat transfer with the thermoelectric module and the flowing fluid through the vest.
- C.2:** Thermoelectric module waste plate thermally exchanges energy with a heat exchanger. The waste heat exchanger is necessary to restrict the waste plate from being potentially dangerous to the user or the user's surroundings.
- C.3:** The fluid reservoir intakes coolant to thermally treat to operating temperature before recirculating. The coolant enters the reservoir and is subjected to a series of heat exchanger fins before being pumped out at operating temperature.
- C.4:** The fluid reservoir expels operating temperature fluid to be circulated through the vest. The fluid reaches the bottom of the reservoir and is pumped back to the vest to either extract or input heat.
- C.5:** Operating fluid thermally transfers energy to the conductive tubing throughout the vest. As the fluid flows through the conductive tubing the tubing changes temperature towards the operating temperature of the fluid.
- C.6:** The conductive tubing conducts heat with the surface of the body. The body is constantly attempting to maintain its core temperature and must either expel or extract heat from the environment.

Body to Vest Interface

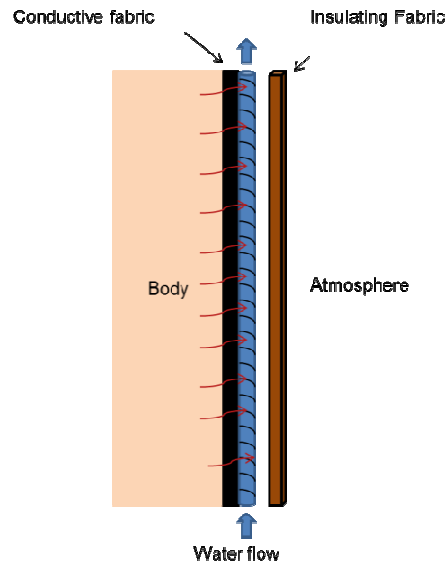


Figure 7. Body to Vest Interface Configuration.

The body to vest interface is comprised of only a few sub components and has the main function of providing the best compromise of thermal efficiency and comfort to the user. Contacting the skin, the first sub component is the conductive fabric (internal layer). Sewn directly to the internal layer is the tubing. In order to maintain high thermal efficiency, there needs to be a method of insulating the cooling mechanism from the atmosphere. This is achieved by securing an additional layer to the vest that has a looser fit than the internal layer. This allows the body-vest interface to create a microclimate between the two fabric layers.

Internal Layer



Figure 8. Internal Fabric Layer.

The first sub component of the body vest interface is the internal layer of the vest which has to keep a tight and comfortable fit to the user while supporting the major components of the entire vest to the torso of the user. A pouch on the back of the vest is sewn in to allow a place for the pump. The two hoops in the front of the vest are designed to secure the cooling module to the user.

The internal layer is sewn directly to the tubing, so it must be tight fitting to pull the tubing close to the body and maximize heat transfer. It must also be highly thermally conductive and breathable. For these reasons UnderArmor® Heat Gear® was selected, a blend of cationic polyester and elastane

Tubing

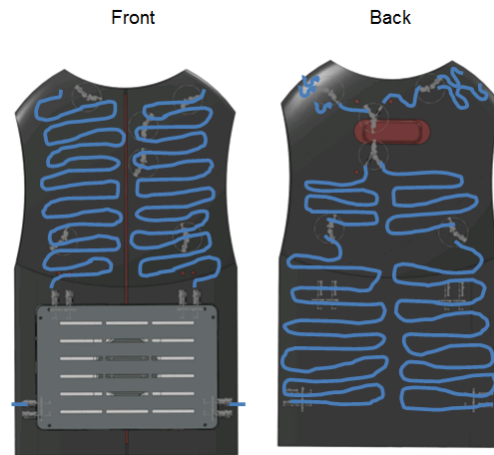


Figure 9. Tubing Configuration

The second sub component of the body vest interface and is essentially 50 feet of thermally conductive tubing to circulate the cool water throughout the body vest interface. The tubing will need to extract the heat from the body as quickly as possible with a practical flow rate and maintain integrity through the lifetime of the vest. Once the vest is assembled the tubing will not be able to be separated from the two fabric layers surrounding it. The ends of the tubing will be attached to fluid quick connects that attach directly to the cooling module.

The tubing in the vest must be highly thermally conductive to transfer body heat to the fluid moving through it. The tubing must also be highly flexible and not fatigue. The tubing selected was CoolPoly D8102, a thermoplastic elastomer.

External Layer

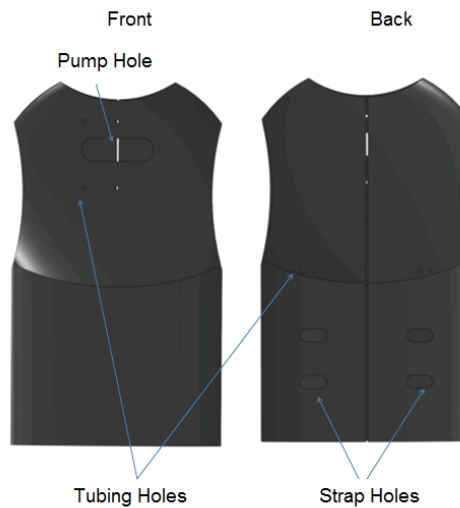


Figure 10. External Layer Configuration.

The final sub component of the body vest interface needs to provide insulation to the device and guide the tubing to and from the pump. The external layer (insulating fabric) must have a loose fit to the rest of the components with minimal contact. The layer must be lightweight and breathable. For these reasons PolarTec 300 fabric was selected, a synthetic fleece material.

Cooling Module

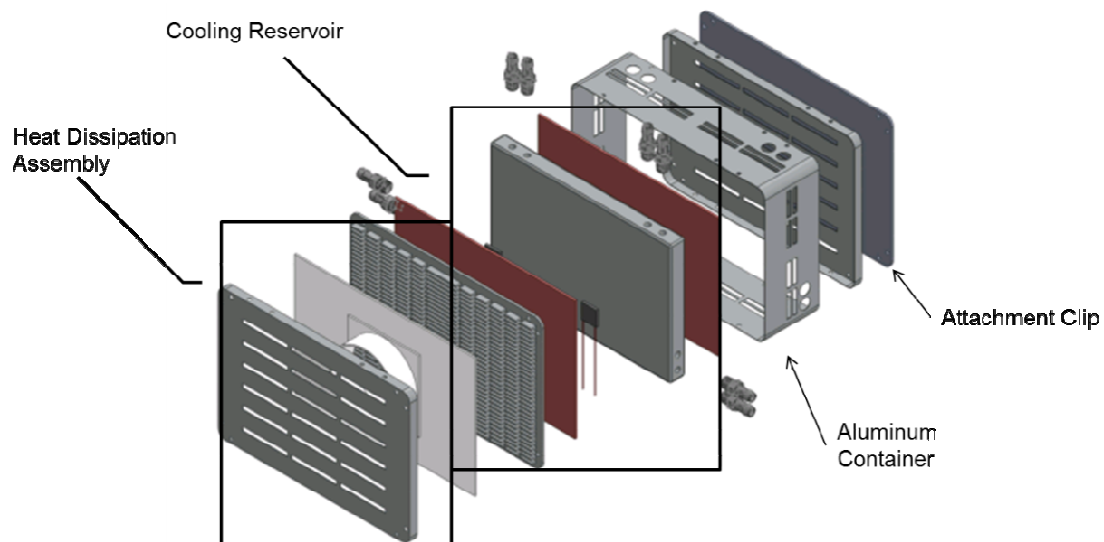


Figure 11. Expanded View of Cooling Module.

The cooling model is comprised of two major sub components, the heat dissipation assembly, and the cooling reservoir. Both of these assemblies are contained within a vented aluminum housing and attached to the thermal vest by an attachment clip. The geometry of the aluminum container and the attachment clip/mechanism is still in the development stage.

Cooling Reservoir

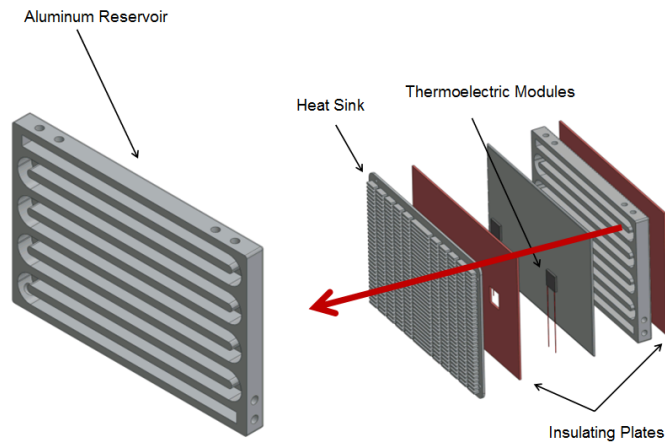


Figure 12. Expanded View of Cooling Reservoir.

The cooling reservoir is responsible for extracting heat from the circulating water to and from the body vest interface. The circulated water from the vest is circulated through an aluminum reservoir acting as a heat exchanger. The water enters at 4 inlets at the top of the reservoir and exits at 4 outlets on the sides. The heat is extracted with a use of two thermoelectric modules. With an electrical input into the thermoelectric module the heat flow is initiated (shown by the red arrow in the Figure 12 above). In order to improve the effectiveness of the thermoelectric module the reservoir is surrounded by a strong thermal insulating material. This will ensure that most of the heat transfer will occur between the thermoelectric modules and not with the environment. The heat will flow from the waste plate of the thermoelectric modules to an aluminum heat sink at the end of the cooling reservoir.

For the aluminum container, a 6061 aluminum sheet was selected. . 1100 aluminum was selected for the cooling reservoir because although it is not as thermally conductive as copper alloys, it is much less dense and reduces the overall weight of the module considerably. Finally, the insulating plates should be lightweight as well as insulating, so melamine foam sheet was selected.

Heat Dissipation Assembly

The heat dissipation assembly couples a DC powered fan to circulate atmospheric air into the cooling module. The fan draws atmospheric air in to cool the heat exchanger and send the hot air out back to the atmosphere. The figure above displays the circulation of the working fluids. The blue lines indicate water circulated to and from the body, the yellow lines indicate atmospheric air going into the cooling module heat dissipation assembly, and the red line indicates hot air leaving the cooling module. This represents the final stage of heat transfer modeled in the MATLAB analysis. To maximize thermal conductivity while maintaining low density in the heat sink, 1100 aluminum was selected.

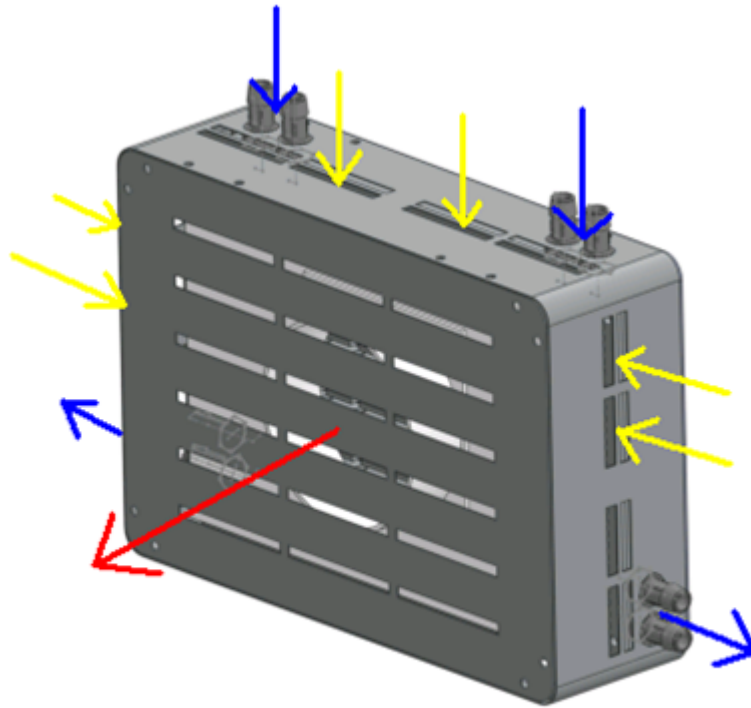


Figure 13. Heat Dissipation Assembly.

Analysis Results (MATLAB)

Based on the MATLAB program presented earlier, the following results were obtained.

The model provided recommendations for key parameters of the design including: component operating temperatures, number of batteries, thermoelectric modules and the hours of operation. This model determined that to expel 1000 BTUs per hour while operating for a continuous eight hours, five batteries, two thermoelectric modules, and an input power of 46 Watts are required. The total weight of the vest was estimated to be 18 pounds. A second iteration of the simulation was run as a comparison with the performance set to expel 500 BTUs per hour from the user.

Complete output results and comparison are contained in Appendix G.

Safety Considerations

When using this device, the user must not be harmed. This includes ensuring that the device does not cause burns or skin lesions. For this reason all heating elements must not be in direct contact with the user. In this design, the thermoelectric module is contained within an aluminum container to prevent skin from contacting either the hot or cold plates. While the tubing will not reach temperatures cold enough to cause cold temperature burns, it will be contained between two layers of fabric to prevent any excessive discomfort from colder temperatures. This design will increase user comfort while still allowing for effective heat transfer.

Maintenance and Repair Considerations

Since this device is designed to be used on a daily basis, it must be machine washable. The cooling module is easily detachable and body-vest interface can be hand-washed.

Chapter 5: Product Realization

Prototype

To create the initial prototype of this design, components from the Veskimo device will be used and custom parts will be ordered. Tubing from the veskimo will be reused. Local fabric professionals will be hired to sew both a conductive under armour material to the tubing. An insulating layer will also be attached.

Two custom thermoelectric modules will be ordered from Custom Thermoelectronics. The purchased modules will chill the water and recirculate the fluid to the veskimo tubing. Quick connect plugs will be purchased to connect the tubing to the reservoir.

Final Design

The final design will be composed entirely of custom parts. The same fabric materials will be used in the final design but different tubing will be purchased. The current prototype is an AC powered device with an infinite operation time. The final design will be battery powered and have a functional running time between two and eight hours. The final design may also be powered to work in a cyclic manner in which it is powered on for a designated amount of time followed by periods of time in which the device is powered off. Future iterations may also consider the addition of thermal sensors to power the device on when the skin temperature reaches a designated value.

Cost Estimate

The total cost of the vest component of the cooling was \$619.75. The batteries at this stage of design cost \$300 each. Future designs should focus on reducing the power requirements or finding alternate power options to reduce the vest cost. To construct the vest, including assembly and sewing, will require approximately \$50 worth of labor due to the fact that sewing has to be outsourced locally. Therefore including labor the total cost of the vest component would be \$669.75. As seen in the bill of materials (Appendix E), the other key costs are the tubing for \$100 and the water pump for \$100. These two items were specifically chosen because of their properties and thus cannot be replaced by a cheaper component without reducing the vest efficiency.

The cooling module resulted in a total cost of \$523.59. The highest cost components in the reservoir were the two aluminum bars used to create the reservoir and the heat sink. Labor costs for the cooling module will be approximately \$50. This is due to the need to machine the aluminum into the proper shape for use in the module; this includes labor and access to the resources necessary to machine the components. Including labor and material costs the total price for the cooling module is \$573.59. It was found that Aluminum 1100 was the only commercially available aluminum that suited the functional requirements and thus it cannot be substituted without substantial change to the cooling unit. The thermoelectric modules are also another necessary cost as the thermoelectric modules selected were chosen based on the functional requirements.

Chapter 6: Design Verification Plan (Testing)

To verify that the customer and engineering requirements could be met by this design, five tests were designed to analyze the performance and needs of each component of the design. The five tests modeled the modes of heat transfer present in the system as follows:

1. Body to Vest Human Test while exercising
2. Body to Vest Human Test while stationary
3. Body to Vest Aluminum Container Model
4. Thermoelectric Performance
5. System Test to determine the Core Body Temperature Change

Test #1: Body to Vest Human Test while Exercising

The first test conducted was designed to model the amount of heat the Veskimo thermal vest was capable of extracting from a person under stress. To simulate the stress experienced when a body overheats two individuals ran eight minute miles in a controlled environment. One temperature probe was placed in the water reservoir and two temperature probes were placed on the body, specifically the upper front of the torso. Initially, each person ran an 8 minute mile without the vest to serve as the control. The individual then rested for 30 minutes before running a second eight minute mile while wearing the cooling vest. The change in body temperature between the control and experimental body temperatures were then compared to calculate how much heat the vest was able to extract from the human body.

Based on the data collected, Figure 10 shows the average skin temperature during the control and experimental tests, as well as the average water reservoir temperature.

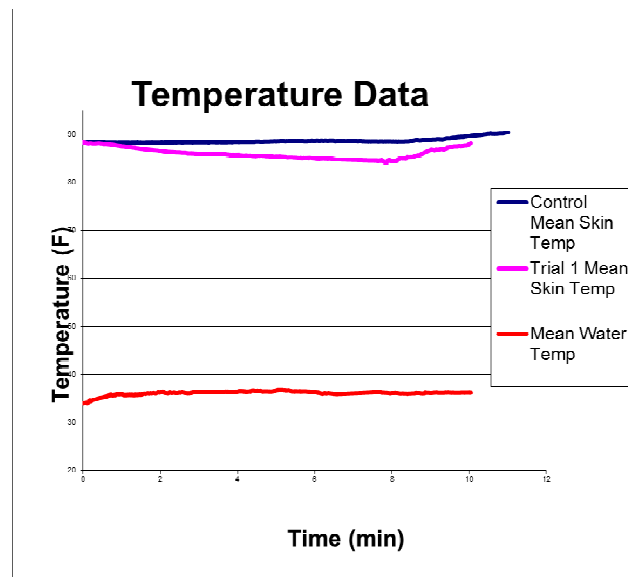


Figure 14.. Body to Vest Exercising Test Data

Figure 10 shows that the cooling vest was able to lower the average skin temperature during exercise. This data combined with the following equations allowed the amount of heat removed from the system to be calculated.

Governing Equation

$$\dot{Q} = h * A * (\Delta T)$$

Based on the difference in skin temperature from the control run and the vest run, the approximate surface area of the user's torso, and the convection coefficient of the fluid in the Veskimo tubing which was calculated to be 35 ((BTUs/hr)/ft²*F). This data showed that the Veskimo vest was capable of removing 730 BTU/hour from the human body. This showed that a liquid cooled vest is capable of producing a cooling effect in the user.

Test # 2: Body to Vest Human Test while Stationary

The second test focused on testing the ability of the Veskimo vest to extract heat from an individual at rest. To set up the experiment one temperature probe was placed into the water reservoir and two temperature probes were placed on the upper torso. The test subject then wore the vest for three hours while remaining seated. Midway through the testing period an insulating layer, in the form of a sweatshirt, was added to prevent the user from becoming too chilled.

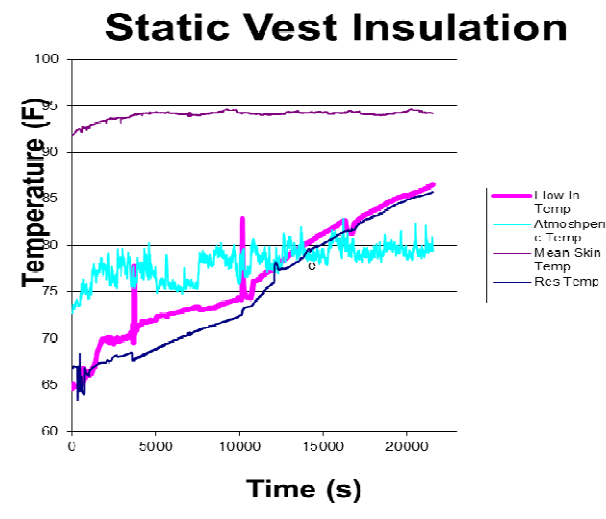


Figure 15. Static Vest Temperature Data

Figure 15 shows the skin and reservoir temperature over a period of three hours. While wearing the cooling vest, the average skin temperature remained relatively constant around 94°F. Since, the water was not cooled over the testing period, the reservoir temperature increased as heat was being extracted from the human body. Around 10,000 seconds, an insulating layer (sweatshirt) was added to prevent the sensation of excessive cooling. The addition of this layer resulted in a smaller temperature increase over a longer period of time (i.e. a steeper slope after $t=10,000s$). This indicated that the addition of an insulating layer resulted in increased heat transfer from the liquid to the reservoir.

Based on the results of the first iteration of test #2, a second iteration was repeated with the subject wearing an external insulating layer of fabric over the vest throughout the entire 3 hour testing period. This was done to validate the assumption made during the design process that the addition of an insulating layer would allow for the system to have a more effective heat transfer overall.

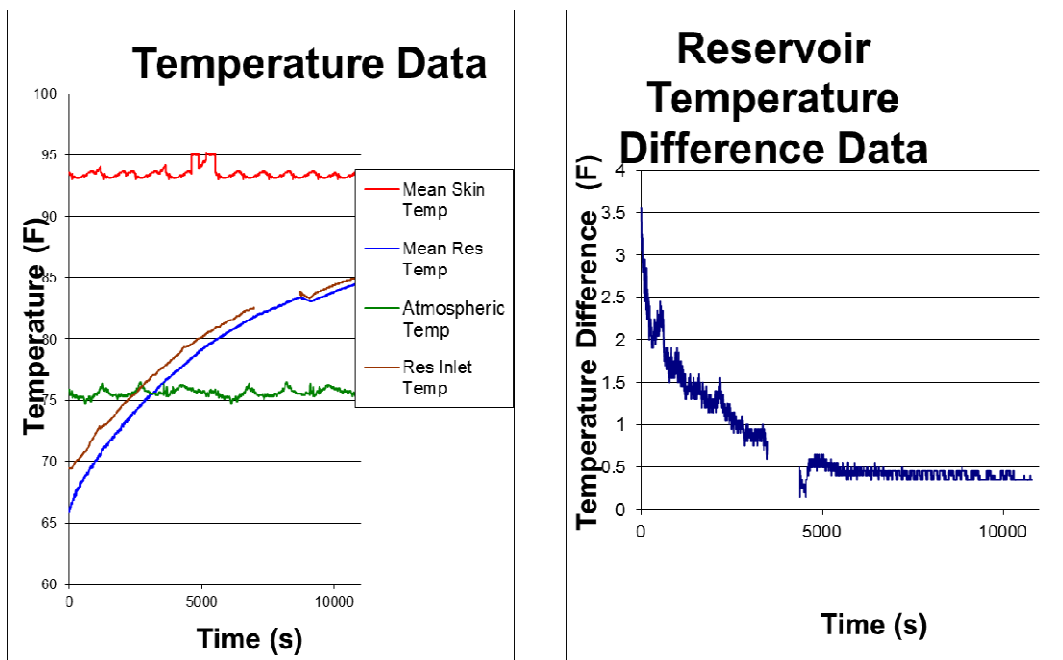


Figure 16. Body to Vest Insulative Layer Data

Figure 16a shows that the vest was able to maintain a relatively constant average temperature around 93°F. In addition Figure 16a shows that the water was cooled within the reservoir. Figure 16b calculates the temperature difference between the inlet and outlet of the reservoir. Based on this data at steady-state conditions, the temperature difference between the inlet and outlet is 0.5°F. In order to remove 750 BTUs/hour of heat, the reservoir temperature difference must be at least 0.5°F.

Test #3: Body to Vest Aluminum Container Model

The third test was designed to evaluate the performance of the heat exchange within the design. In this test an aluminum cylinder was placed onto a hot plate, filled half-way with water and was heated to a uniform temperature. Using pumps at designated flow rates, water was pumped from one large plastic bucket filled with cold water, into the aluminum cylinder and then into an initially empty bucket. The test setup is shown in Figure 17. Temperature probes were placed into each bucket, on the bottom of the aluminum cylinder and on the sides of the aluminum cylinder to measure the temperatures throughout the entire test. This data was then used to compute the difference between the reservoir inlet and outlet temperatures. The temperature difference could then be used to calculate the amount of heat removed by the proposed design.

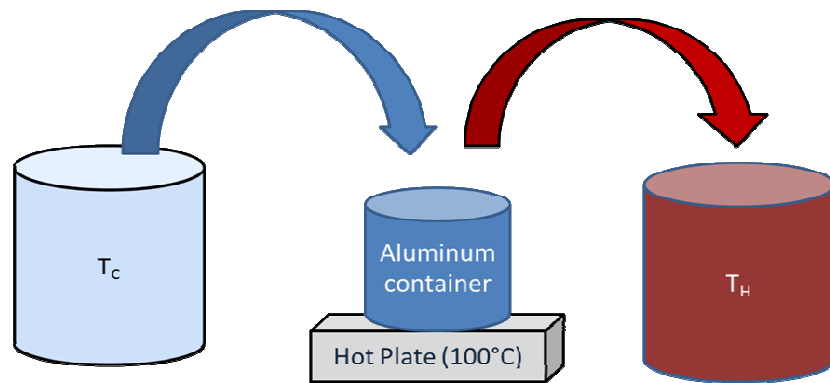


Figure 17. Body to Vest Aluminum Container Model Setup

Figure 18 displays plots of both the inlet (T_H) and the outlet (T_c) reservoir temperatures throughout the test. The difference between the inlet and outlet remains relatively constant at 1°F.

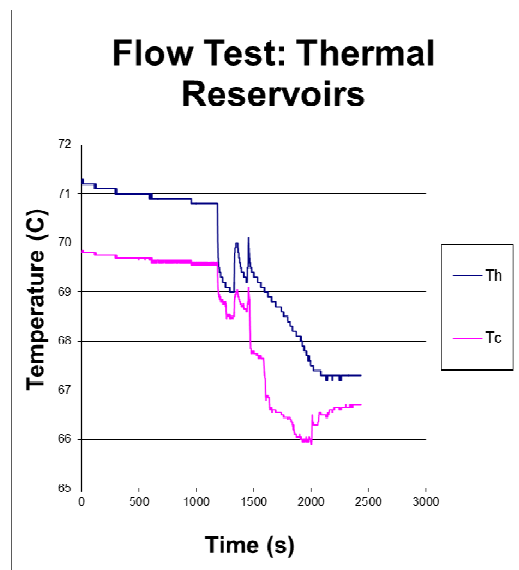


Figure 18. Heat Exchanger Inlet and Outlet Temperatures

Using the following governing and derived equations, the heat transfer from the system was calculated:

Governing Equation:

$$Q_{conv} = HA(T_{al} - T_{H2O})$$

Derived Equations:

$$\pi_1 = \frac{(D * v)}{V} * \Delta T$$

$$\left(\frac{(D * v)}{V} * \Delta T \right)_{Test} = \beta * \left(\frac{(D * v)}{V} * \Delta T \right)_{Simulation}$$

By deriving a Buckingham Pi correlation for the internal flow forced convection, an equivalence ratio of 1/191 was determined for the scaled model. With the correlation we calculate that the system could remove 560 BTUs per hour of heat. This includes the cooling reservoir component of the system only.

Test #4: Thermoelectric Performance

Test four was designed to evaluate the performance of the thermoelectric module incorporated into the design. This simulation allowed for a better understanding of the energy conversion of the module and the amount of electrical energy required to establish the desired temperature difference. To set up the test the thermoelectric module was placed onto an aluminum plate with foam boards placed on either side. With the hot side of the module facing upwards a second aluminum plate was placed on top of the system. The setup is shown in Figure 19.

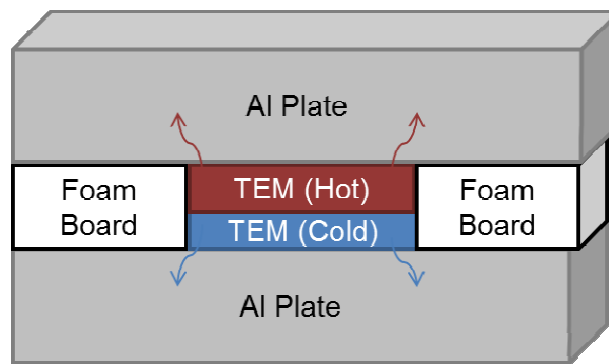


Figure 19. Thermoelectric Performance Test Setup

According to the MATLAB model, to power and cool the system for a period of 8 hours, the temperature difference between the hot plate and the cold plate of thermoelectric module must be 46°C. Figure X shows the temperatures of both the hot and cold plates in test #4.

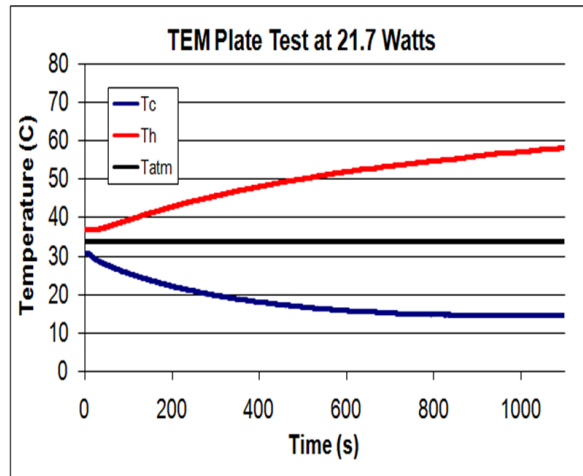


Figure 20. Thermoelectric Hot and Cold Plate Temperature Difference

This test was run at 2/3 of the maximum power and after approximately fifteen minutes, the temperature difference was approximately 45.6°C. This test showed that the actual temperature difference matched the theoretical value.

Test #5: System Model

Test five was designed to evaluate the response of the body's core temperature to convective heat transfer. The human torso was modeled by a technique taken from a study conducted at Worcester Polytechnic Institute. An inner layer of conductive fabric was placed over an aluminum cylinder. The tubing used in the vest design was then wrapped around the fabric and an outer layer of insulative fabric was placed over the tubing. In this test, a sample of under armour material was used as the conductive internal material and a towel was used as the external insulating layer. A heater core was then placed into the aluminum cylinder filled with water that was heated to a constant, uniform temperature of 116°F.

Ice water was then pumped from an initial bucket through the tubing and into a second bucket. The initial bucket represented the reservoir outlet and the final bucket represented the reservoir inlet. Temperature probes were placed in both buckets and inside the aluminum cylinder. The system configuration is shown in Figure 21.

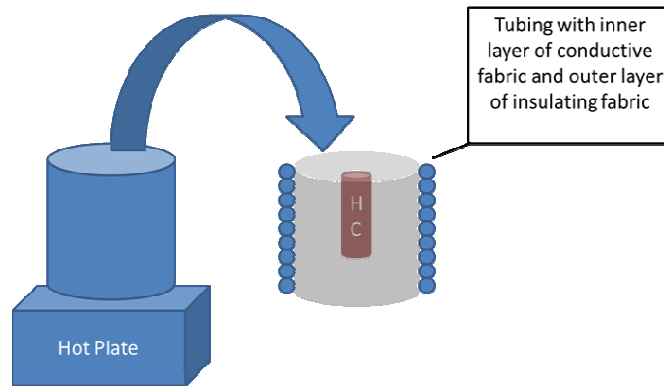


Figure 21. System Model Configuration.

Figure 21 displays the average core temperature and the reservoir temperatures throughout the test. Initially the core temperature was 116°F at steady-state conditions. Once the pump was turned on and ice water was pumped through the tubing the core temperature steadily decreased until it reached 103°F at 2500 seconds.

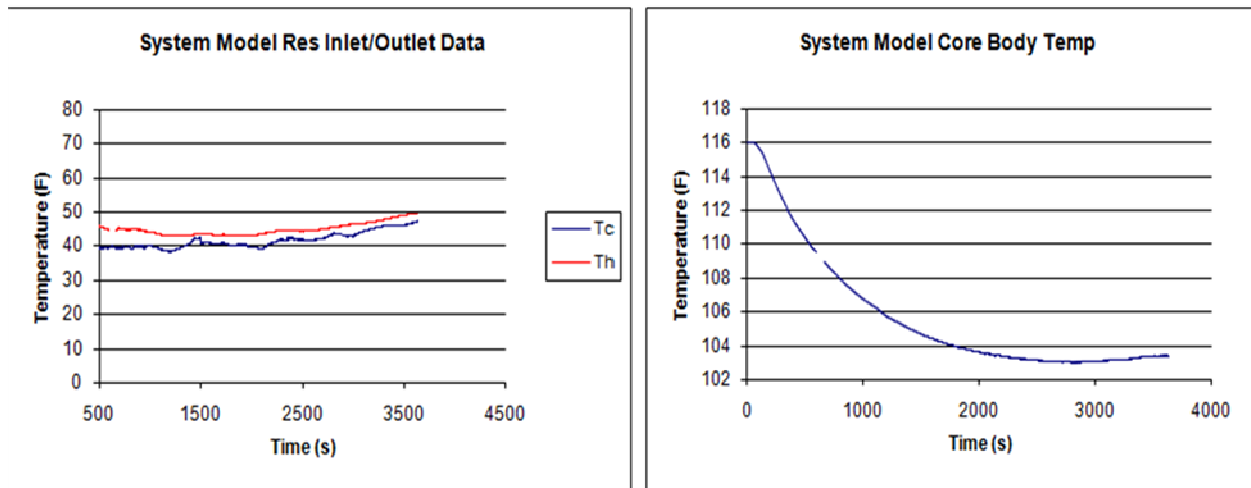


Figure 22. System Reservoir and Core Body Temperatures

Figure 22 also shows the temperature difference between the inlet and outlet conditions to cool the core temperature. Initially, when the temperature drop was the greatest the reservoir inlet and outlet changes changed by as much as 5°F. Towards the end of the test, when the core temperature was relatively constant, the temperature difference was on the range of 1°F.

Overall, this test showed that if a temperature difference of 1°F is maintained, the core body temperature can decrease by as much as 13°F

Chapter 7: Conclusions & Recommendations

The MATLAB model showed that theoretically this design is capable of removing up to 1000 BTUs/hour of heat from the human body. However, there are certain limitations and requirements that must be met to fulfill this requirement.

Bench tests verified that this cooling mechanism is capable of extracting over 500 BTUs per hour from the human body. While the initial requirements stated that 1000 BTUs per hour needed to be extracted by the device, 500 BTUs per hour should be a sufficient amount of heat. The torso composes approximately half of the human body surface area; as a result additional heat is lost from the extremities, head, etc. Based on this assumption, the vest only needs to extract half the total heat.

Additionally, bench tests allowed for adjustments in certain design features. After optimizing testing features, the pump flow rate was increased from 500 ml per minute to 2000 ml per minute. This allowed for more efficient heat transfer throughout the device.

Lastly, one of the original design requirements for this project was the need to power the device for eight continuous hours. To meet this specification, the device would need five batteries that cost \$300 each. Since one of the goals of this project is to produce a device that is reasonable priced, this requirement is quite excessive. Instead, either the device run time requirement may need to be reevaluated or ways to minimize battery usage need to be found. Most likely the device would not need to run for more than two hours to obtain the desired cooling results.

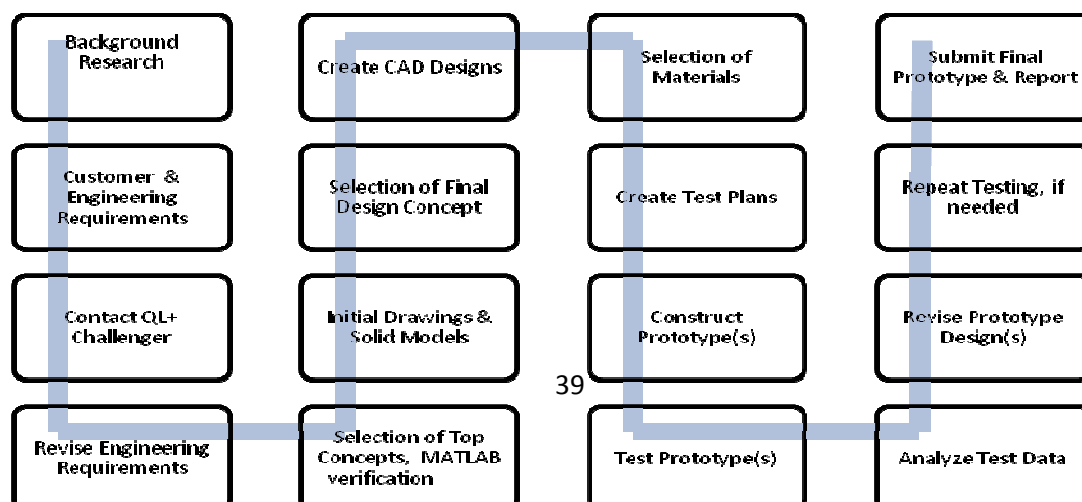
Chapter 8: Management Plan

Method of Approach

This project will be three quarters long. The first quarter will be dedicated to background research, formation of design requirements, determination of top conceptual models and the selection of the final design. The first quarter will also include the creation of CAD models and the selection of final product materials. The second quarter will be dedicated to testing and modifying the final design. Revisions will be made based on the test results. The third quarter will consist of the fabrication of an initial prototype and the presentation of the project findings. This project should be completed by Wednesday, May 30th, 2012. The following table details the reports to be submitted to QL+ and project milestones.

Date	Deliverable or Milestone
Monday October 3 rd	Team Contract Statement of Work
Monday October 10 th	Project Planning (Gantt Chart)
Monday October 31 st	Design Review Preliminary Project Report
Monday November 14 th	CAD Design Drawings
Monday November 21 st	Design Review Bill of Materials
Monday December 5 th	Concept Design Report Final Materials Selection
Monday January 2 nd	Prototype Manufacturing
Monday January 16 th	Prototype Initial Testing
Monday March 6 th	Interim Design Report
Monday, April 9 th	Completion of Design Revision
Monday, May 7th	Completion of Prototype Fabrication
Monday, May 14th	Prototype Testing Completed
Monday, May 28th	Prototype Revisions Completed
Wednesday, May 30th 2012	Project Poster Due Final Project Report Design Notebooks Due Proof-of-Concept Prototype
Thursday, May 31st, 2012	Senior Project Expo

The following flow chart diagrams the general process that will be utilized to complete this project.



At this point, the problem has been defined and background research conducted. Based on this research the initial design requirements were formed. After meetings with the QL+ Challenger and Sponsors, these requirements were further redefined. The top conceptual models were verified in MATLAB to determine the maximum power input. A Pugh comparison showed that the fluid cooling vest was the best design.

In addition, bench tests have been conducted to verify that the desired results can be obtained. Device components have also been modified to produce improved heat transfer mechanisms. The next quarter will be dedicated to producing an AC-powered proof-of-concept prototype and the recruitment of students to continue this project during the 2012-2013 school year.

A detailed Gantt chart is included in Appendix H to measure project progression.

Budget Allocation

The budge was broken into two areas: vest and test materials. Based on cost estimates from online vendors and local stores the total cost for the vest and tests totaled \$1,419.43.

	Cost (\$)
Vest	699
Test #1	452.34
Test #2	238
Test #3	170
Test #4	409.3
Total Cost	1968.64

Table 1. Vest and Test Materials Costs

Specific breakdowns for the vest and test materials are included in Appendix E.

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Appendix A

Evaporative Cooling Properties

Cooling Time	5-10 hours
Vest Sizes	<i>S, M, L, XL, 2XL or 3XL</i>
Material	Nylon outer with polymer embedded fabric inner. Black poly-cotton trim.
Price	\$36.15

Phase Change Cooling Properties

Vest Weight:	Approximately 2 kilograms								
Vest Size:	<table> <tr> <td>Size</td><td>Chest Circumference</td></tr> <tr> <td>S-M</td><td>84-100cm</td></tr> <tr> <td>L-XL</td><td>100-116cm</td></tr> <tr> <td>XXL-XXXL</td><td>116-132cm</td></tr> </table>	Size	Chest Circumference	S-M	84-100cm	L-XL	100-116cm	XXL-XXXL	116-132cm
Size	Chest Circumference								
S-M	84-100cm								
L-XL	100-116cm								
XXL-XXXL	116-132cm								
Vest Types:	Two types; PCM melting point of 28°C and 32°C								
Vest Material:	Polyester								
PCM Material:	Mixed salt (interior), Valeron coating aluminum (exterior)								

Fluid Cooling Properties

Sizes	Adjustable S, M/L, L/XL
Design	9 foot of insulated water lines from the cooler, optional 5 ft length instead of 9 ft or additional 4 foot lengths are also available.
Cooling system	15 quart wheeled cooler with retractable handle
Price	\$810

Air Cooling (Kool Vest) Properties

Material	Double coated PVC on nylon scrim material with Velcro front closures and sewn-in adjustable belt
Add ons	vortex adapter or Air Systems' unique Cool-Box™
Cooling method	Small holes on interior of vest direct air to complete upper torso, front and rear
Layout/Design	Specially designed plenum directs air to a neck ring for cool air distribution to the neck and face. A rear Velcro strip controls the air volume to the neck ring

Air Cooling (Personal Air Conditioner) Properties

Item #	Description	Cooling Capacity	Price (\$)
22815	Vortex Air Conditioner with Belt 900 BTUH	900 Btu/hr	114
22825	Vortex Air Conditioner with Belt 1500 BTUH	1500 BTU/hr	114
22835	Vortex Air Conditioner with Belt 2500 BTUH	2500 Btu/hr	114
220	Hot/Cold Air Conditioner with Belt 1500 BTUH	1500 Btu/hr	302
855	Diffuse Air Vest with unfolding Lapels		199

Thermoelectric Cooling Properties

TEC temperature	hot side temp is 27°C, 50°C, maximum watts range between 20 and 22
Power Supply	ATX 300 Watt power supply
Material	mesh lined vest, wicking material was a sheet of Shamwow

Appendix B

FDA Codes & Standards

PART 890 -- PHYSICAL MEDICINE DEVICES

Subpart A--General Provisions

Sec. 890.9 Limitations of exemptions from section 510(k) of the Federal Food, Drug, and Cosmetic Act (the act).

Sec. 890.5720 Water circulating hot or cold pack.

Appendix C

QFD, Decision Matrices

Design Objects Rank Order Comparison

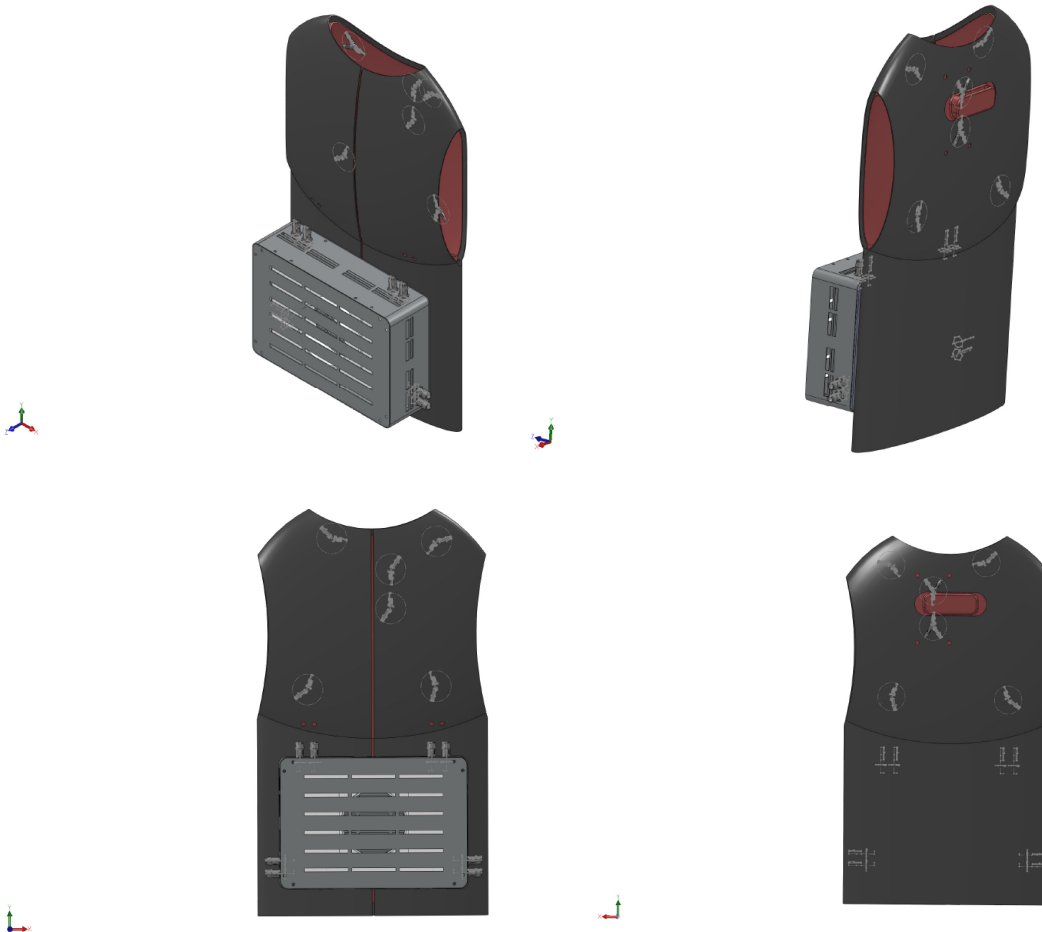
	Maintain Core Temp	Safety	LightWeight	Non-Insulating	Thin and compact design	Reliability	Durability	Long Lasting	User Friendly	Adjustable	Washable	Cost
Durability	1	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0
LightWeight	1	1	**	0.5	0.5	0.5	0	0	0	0	0	0
Non-Insulating	1	1	0.5	**	0.5	0.5	0	0	0	0	0	0
Long Lasting	1	1	1	1	0.5	0.5	0.5	**	0.5	0.5	0	0
Maintain Core Temp	**	0.5	0	0	0	0	0	0	0	0	0	0
Thin and compact design	1	1	0.5	0.5	**	0.5	0	0.5	0	0	0	0
Reliability	1	1	0.5	0.5	0.5	**	0	0.5	0	0	0	0
User Friendly	1	1	1	1	1	1	0.5	0.5	**	0.5	0	0.5
Washable	1	1	1	1	1	1	0.5	1	1	0.5	**	0.5
Cost	1	1	1	1	1	1	1	1	0.5	0.5	0.5	**
Adjustable	1	1	1	1	1	1	0.5	0.5	0.5	**	0.5	0.5
Safety	0.5	**	0	0	0	0	0	0	0	0	0	0
Sum	10.5	10.5	7.5	7.5	7	7	3	4.5	3	2.5	1.5	1.5
Percentage	15.91	15.91	11.36	11.36	10.61	10.61	4.55	6.82	4.55	3.79	2.27	2.27

Conceptual Model Pugh Matrix

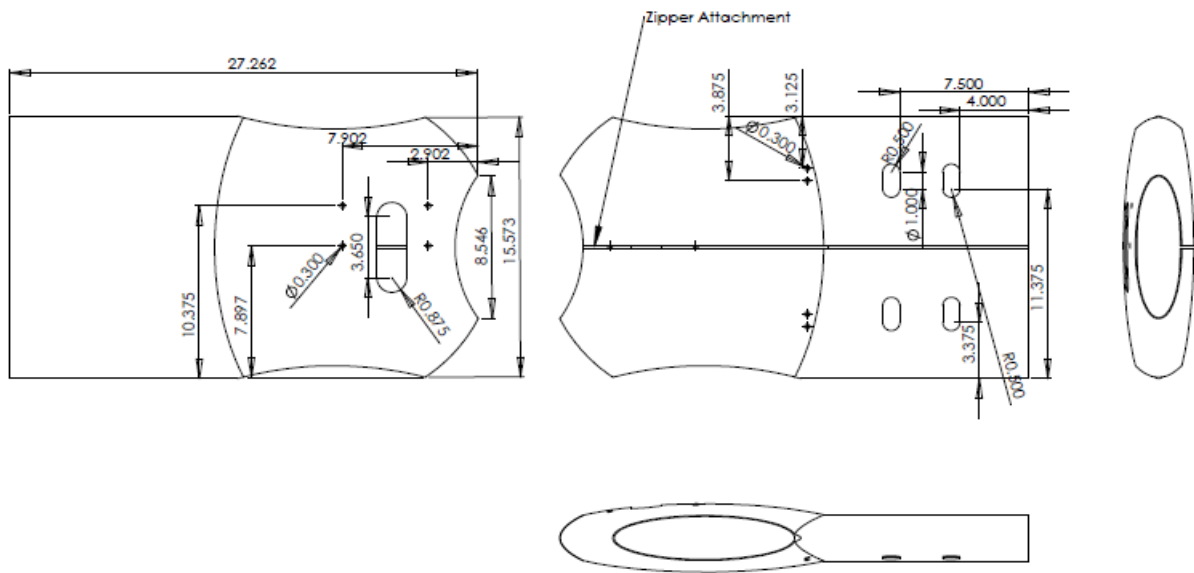
	Liquid	Evaporative	Conductive
Durability	D	S	S
Lightweight		+	+
Non-Insulating	A	S	S
Long Lasting		S	-
Maintain Core Temp	T	S	S
Thin and compact design		-	-
Reliability	U	S	S
User Friendly		-	-
Washable	M	S	S
Cost		S	S
Adjustable		S	S
Safety		S	S
Ó+		1	1
Ó-		2	3
ÓS		9	8

Appendix D Final Drawings

Prototype Assembly



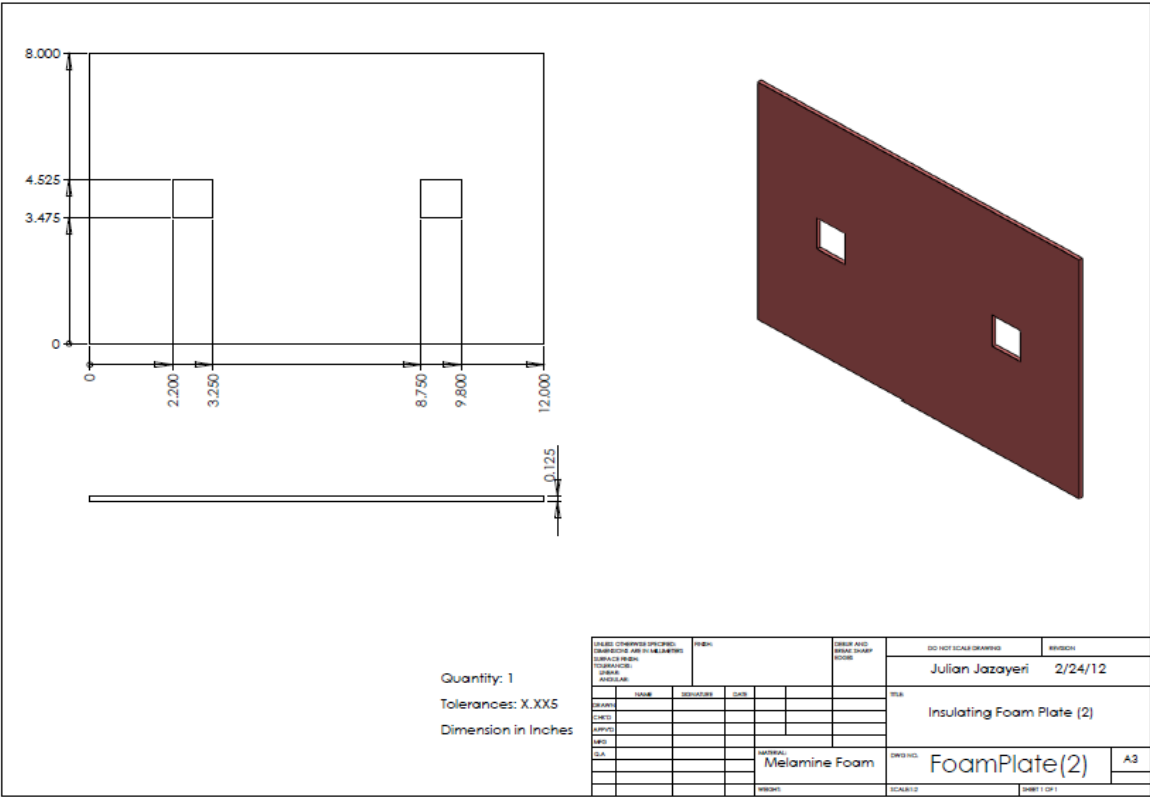
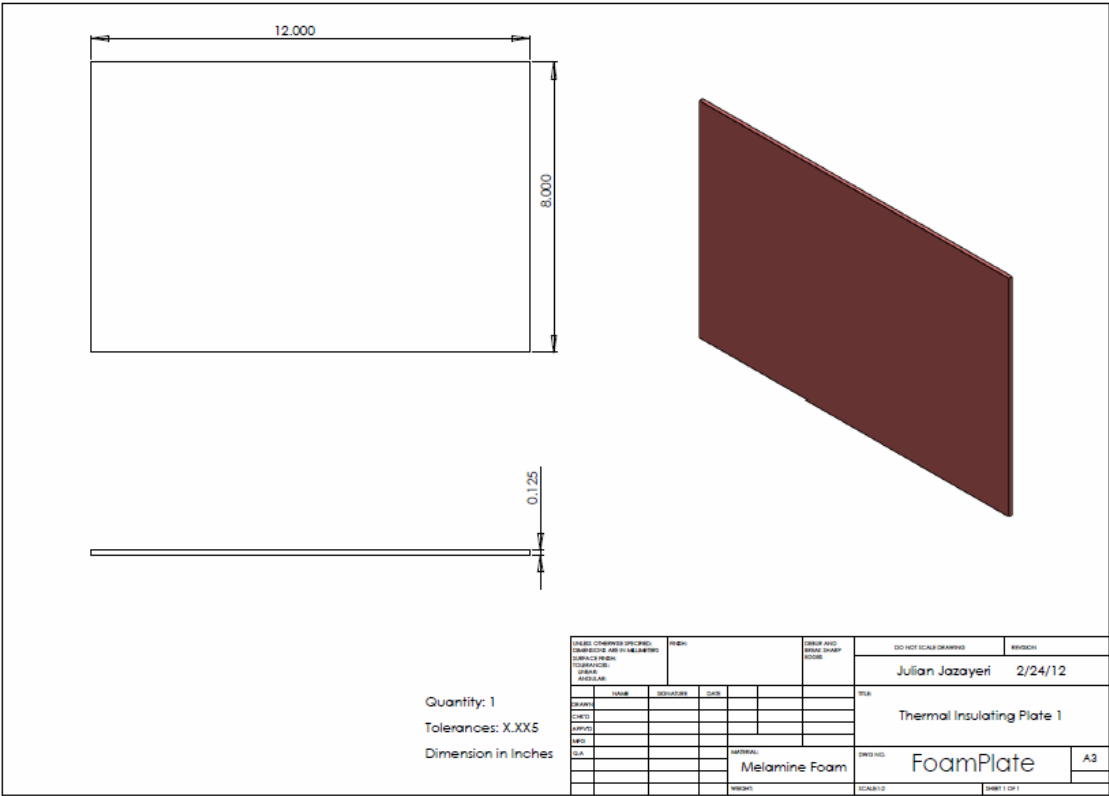
Internal Layer



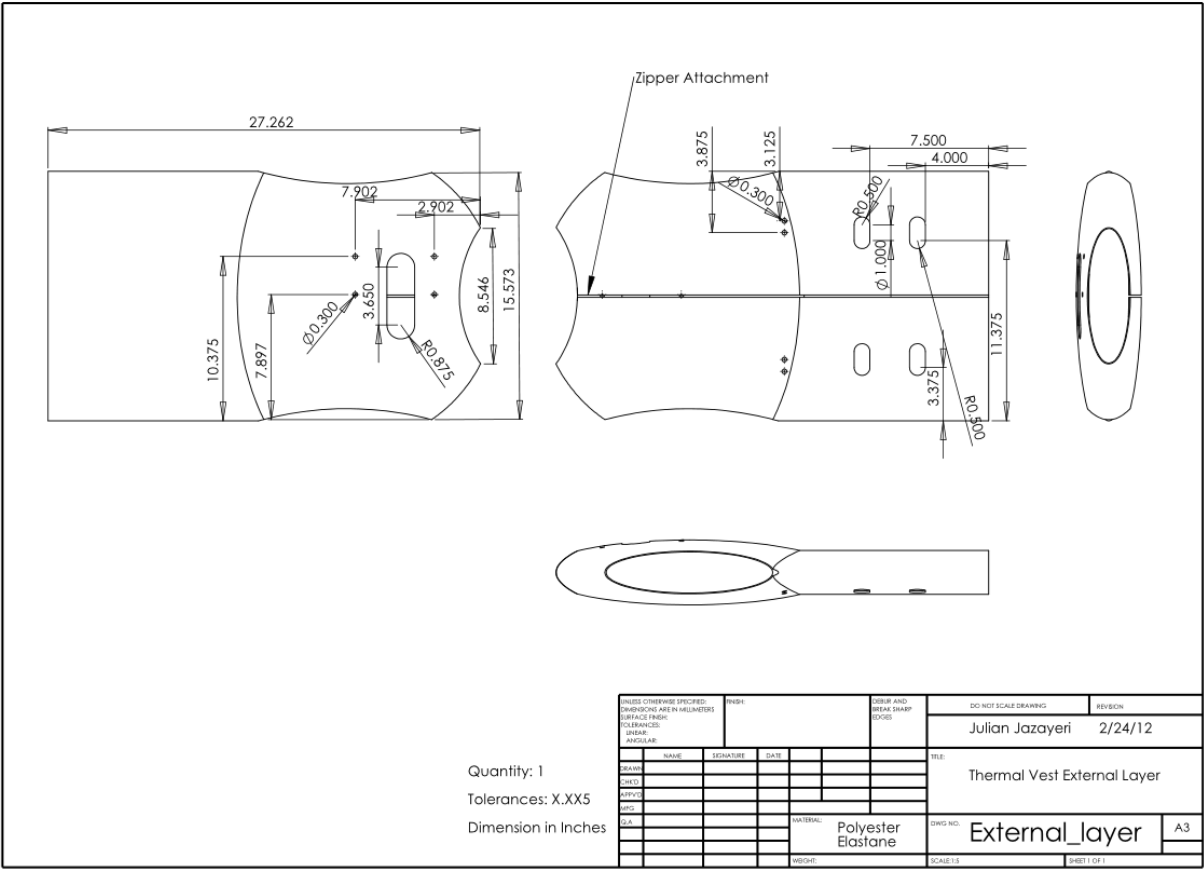
Quantity: 1
Tolerances: X.XX5
Dimension in Inches

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONS DECIMALS				FINISH		DRESS AND MARK SHARP EDGES		DO NOT SCALE DRAWING		REVISION	
								Julian Jazayeri		2/24/12	
								TBA		Thermal Vest External Layer	
								DWG NO.		External_layer	
								MATERIAL		Polyester Bastane	
								WEIGHT		SCALE: 1/8" = 1"	
										SHEET 1 OF 1	

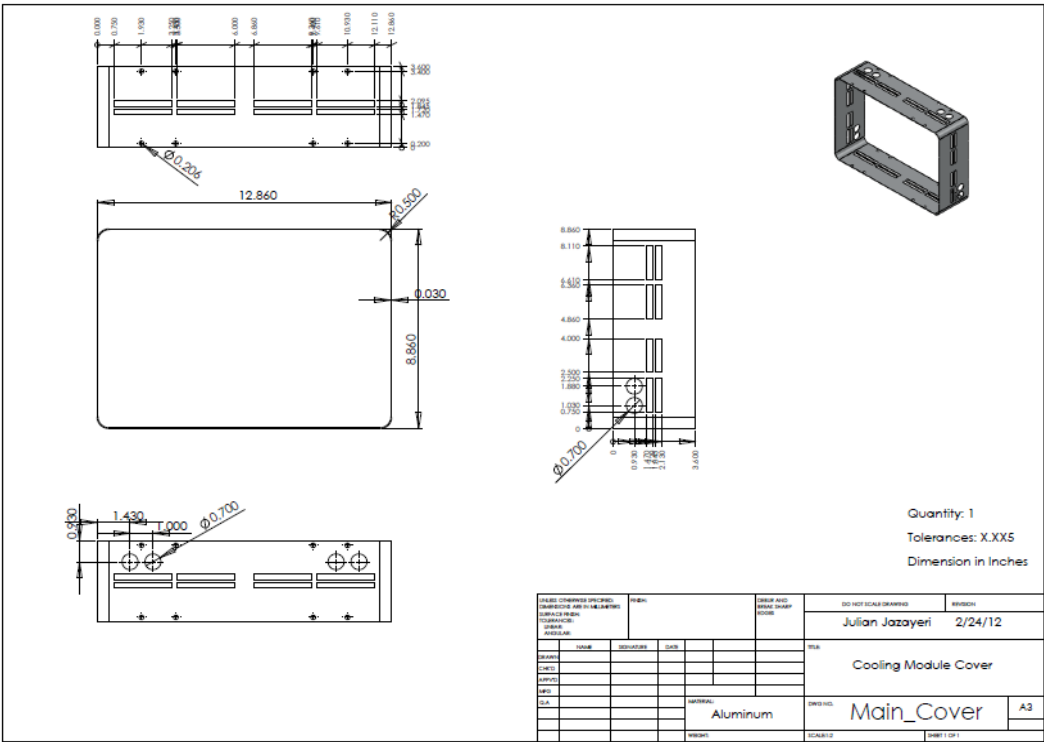
Foam Plate



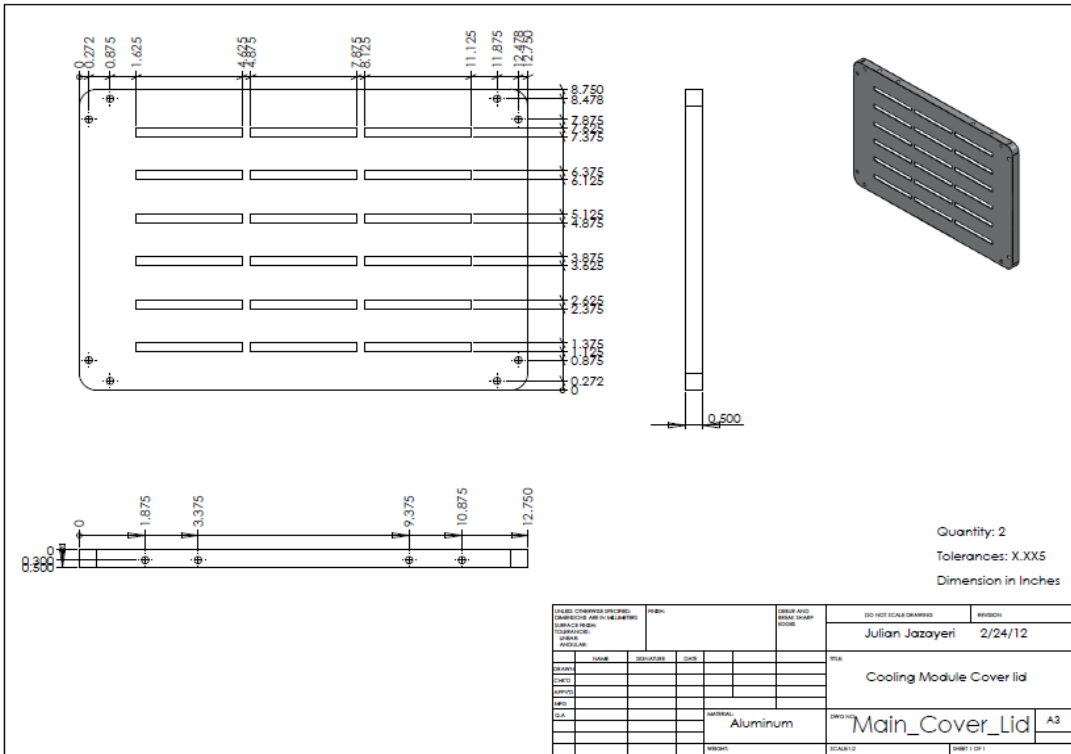
External Layer



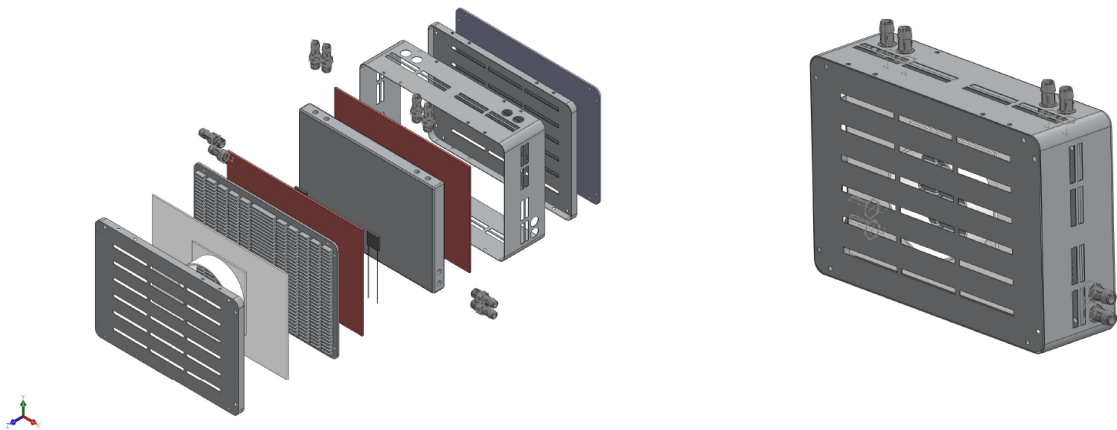
Main Covering Detailed Drawing



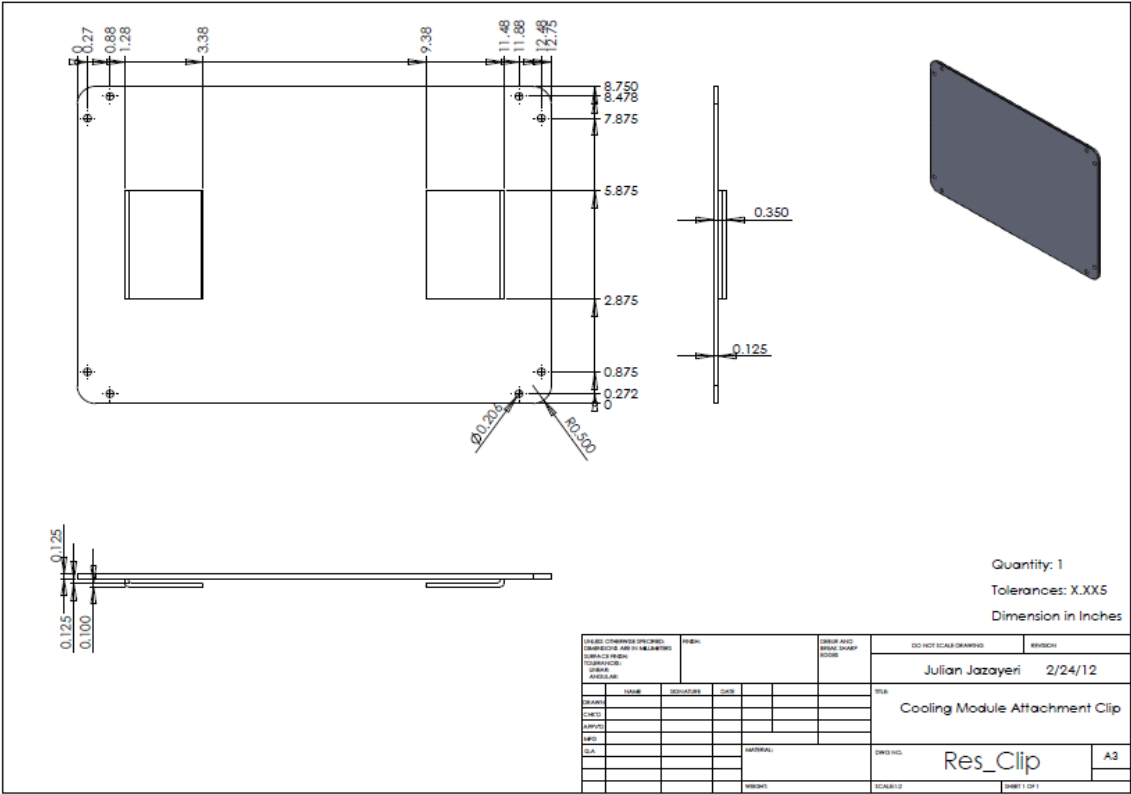
Main Covering Lid Detailed Drawing



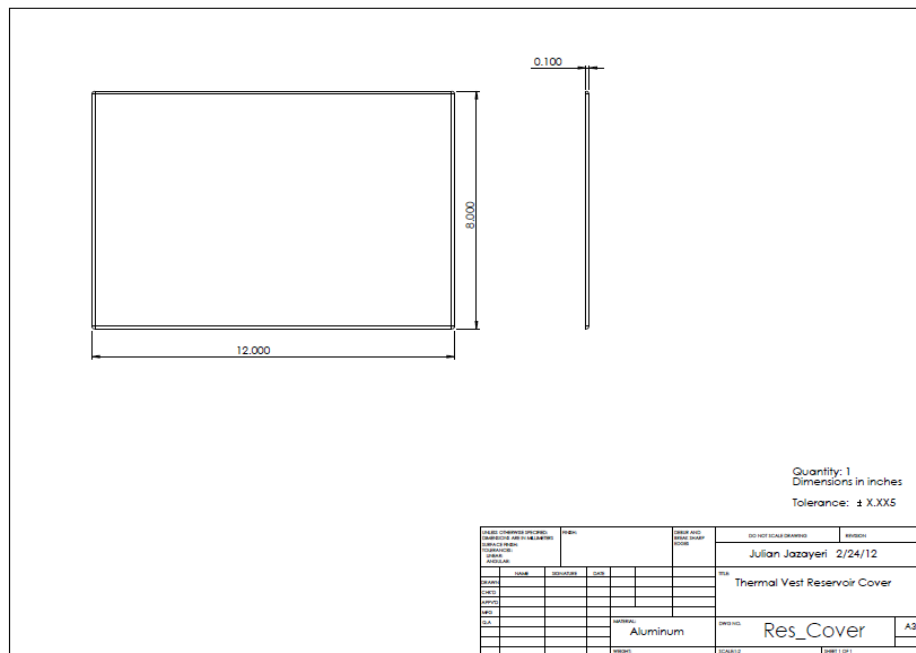
Reservoir Assembly



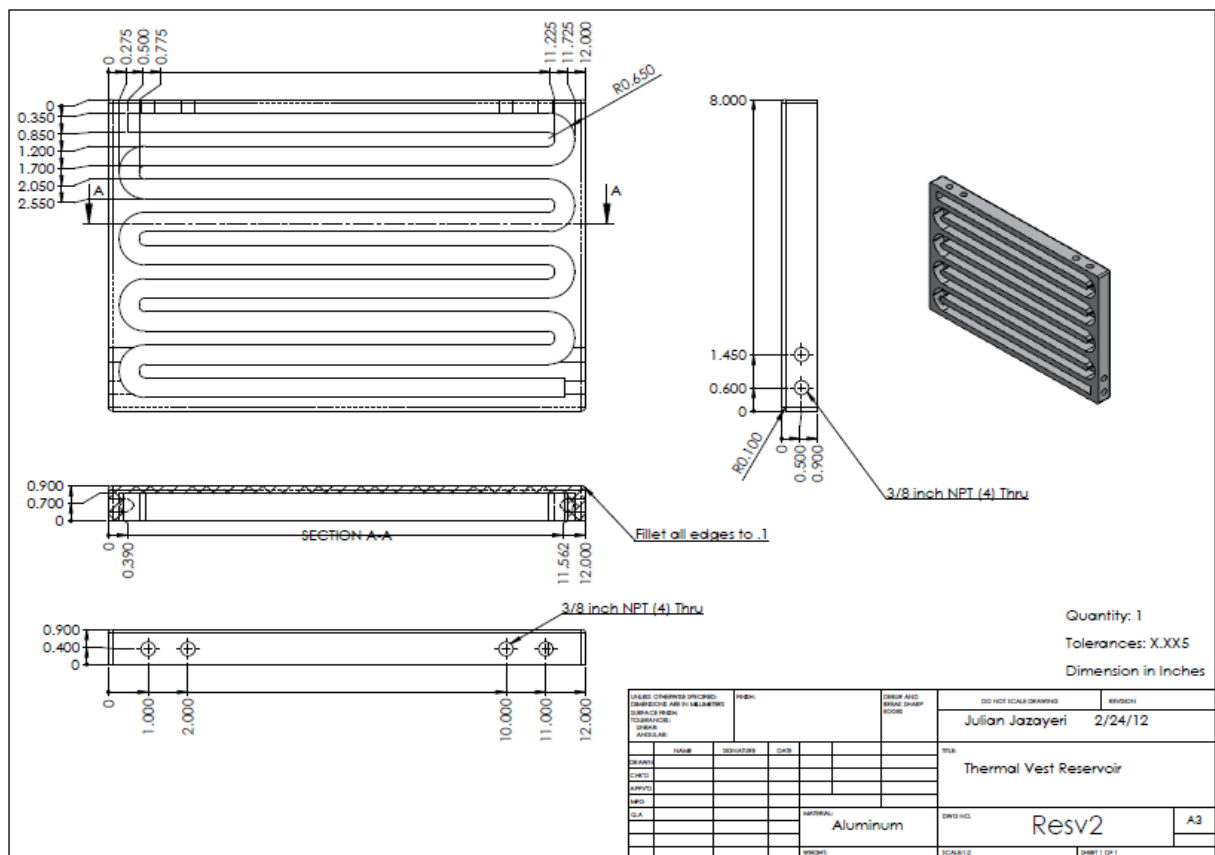
Reservoir Clip Detailed Drawing



Reservoir Cover Detailed Drawing



Aluminum Reservoir

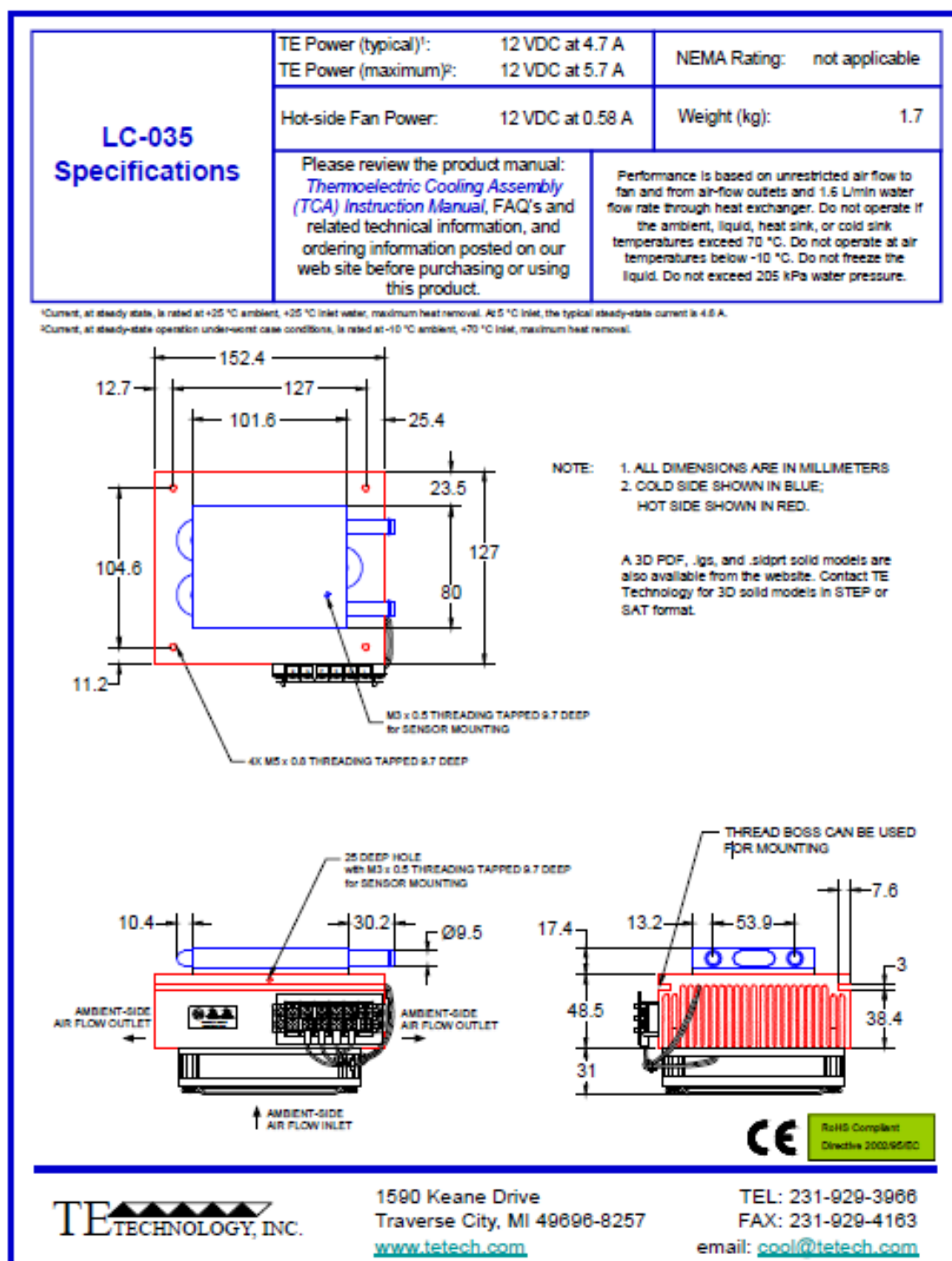


Appendix E

Tests #1&2 Bill of Materials				
Component	Material/Type	Vendor	Volume/Quantity	Price
Thermocouples	Supplied	-	6	\$0.00
Data Acquisistion software	Supplied	-	1	-
Vest	Sports cooling Vest	Veskimo	1	\$363.34
Ice	Supplied	-	4	\$0.00
Trash Bags	-	-	2	\$1.00
			Total Cost	\$364.34
Test #3 Bill of Materials				
Component	Material/Type	Vendor	Volume/Quantity	Price
Thermocouples	Supplied	-	4	\$0.00
Data Acquisistion software	Supplied	-	1	-
Ice	Supplied	-	4	\$0.00
Heater	Submersible 150 W	Visi-Therm	1	\$20.00
Tubing	Standard Tubing	Home Depot	5	\$30.00
Water Pump	728310 Sub	EcoPlus	2	\$45.00
Alumium Cylinder	6060 T6	-	-	\$40.00
Water Tight Connectons	Neoprene	Home Depot	4	\$10.00
Thermal Compound	Radio Shack	3 Containers	10	30
Buckets	Standard Paint Buck	Home Depot	2	\$5.00
			Total Cost	\$180.00
Test #4 Bill of Materials				
Component	Material/Type	Vendor	Volume/Quantity	Price
Thermocouples	Supplied	-	6	\$0.00
Data Acquisistion software	Supplied	-	1	-
Aluminum Block	6060 T6	-	-	\$60.00
Thernoelectic Module	Standard Single	Custom Thermoe	1	\$30.00
			Total Cost	\$90.00
Test #5 Bill of Materials				
Component	Material/Type	Vendor	Volume/Quantity	Price
Alumium Cylinder	6060 T6	-	-	\$40.00
Water Pump	Standard 25 W	EcoPlus	1	\$26.00
Water Tight Connectons	Neoprene	Home Depot	2	\$5.00
Tubing	TPE Elastomer	Cool Polymers	300	\$0.00
Buckets	Standard Paint Buck	Home Depot	1	\$2.50
Heater	Submersible 150 W	Visi-Therm	1	\$20.00
Thermocouples	Supplied	-	6	\$0.00
Data Acquisistion software	Supplied	-	1	-
Under Armor	Cool Armor	Sports Store	6 ft ^2	\$80.00
Under Armor	Warm Armor	Sports Store	6 ft ^2	\$80.00
Ice	-	-	4	\$8.00
			Total Cost	\$261.50

Prototype BOM					
Component	Material/Type	Vendor	Volume/Quantity	Price(\$)	Total Price
Cooling Fan	DFB122512M NanJing Song Zi	NanJing	1 Fan	55	\$55.00
Attachement Clip	ABS Plastic	Cal Poly	1 Clip	30	\$30.00
System Housing	Al6061	McMaster Carr	1 Sheet	9.7	\$9.70
Insulative Layer	Melanine Foam	Grainger	1 Sheet	30	\$30.00
Reservoir	Al 1100	McMaster Carr	1 Sheet (12inx12inx.375in)	98.2	\$98.20
Sealent	Pelseal® 2078	McMaster Carr	2.5 oz.	33.33	\$33.33
Thermoelectric Module	Multi Stage	Custom Thermoelectric	2 TEM's	65	\$130.00
Heat Sink	Al 1100	McMaster Carr	1 Sheet (12inx12inx.375in)	98.2	\$98.20
Thermal Paste	Thermal Compound	Radio Shack	2 Containers	10	\$20.00
Connections/valves	Quick Connect Male	McMaster Carr	2 Connects	9.58	\$19.16
					\$523.59

Appendix F

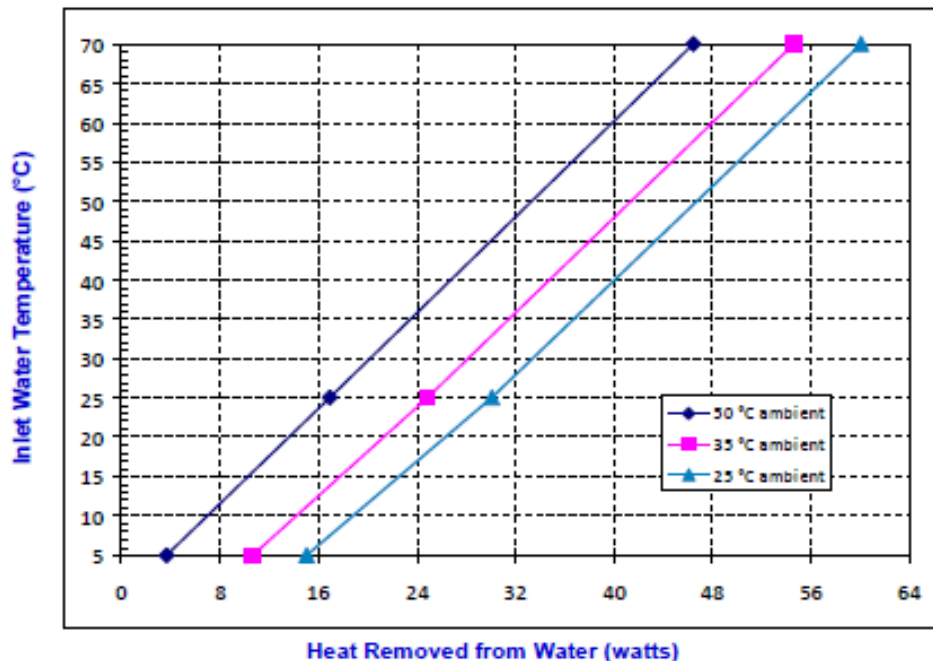


NOTE: All specifications are subject to change without notice.

LC-035 26-FEB-2012 Page 2 of 3

LC-035 Cooling Performance Graph

(removing heat from water, flowing at 1.6 L/min)



How to use the Performance Graph:

1. Select Performance Line.

The diagonal lines shown represent cooling performance at the indicated ambient air temperature (inlet to ambient-side fan). If the cooler is to operate at a different ambient, then you must sketch in a new performance line. This can be drawn parallel to one of the existing lines, using the distance between the existing lines as a scale to properly locate the new line.

2. Select Enclosure Temperature.

Draw a horizontal line on the graph corresponding to the desired inlet water temperature until it intersects with the performance line corresponding to the ambient temperature at which the cooler is to operate.

NOTE: heating performance is not shown. Contact TE Technology, Inc. if you require this information.

3. Determine Cooling Capacity.

The maximum amount of heat that the cooler can remove from the water is determined by the intersection point (determined in the previous step). If the heat load exceeds the cooling capacity, then the cooler will not be able to maintain the desired water temperature. If the heat load is less, then the cooler can operate with less input power.

Example: You need to maintain the water at 15 °C while in a 25 °C ambient. The cooler can remove a maximum of approximately 22 W of heat from the water. If the heat load (internally generated heat plus the heat gain through insulation, solar, vapor condensation, etc.) in the water exceeds this, you would need more coolers and/or a larger cooler.

TE TECHNOLOGY, INC.

1590 Keane Drive
Traverse City, MI 49696-8257
www.tetech.com

TEL: 231-929-3986
FAX: 231-929-4163
email: cool@tetech.com

NOTE: All specifications are subject to change without notice.

LC-035 20-REV-2012 Page 3 of 3

Appendix G

Detailed Supporting Analysis

MATLAB Program Output

Operating Temperatures with the system expelling 500 BTUs/hr

Temperature of the Skin (F)

91

Temperature of the Inner Fabric (F)

90.1101

Temperature of the Tubing (F)

86.9064

Temperature of the Fluid (F)

86.7324

Temperature of the Reservoir (F)

72.2832

Temperature of the Thermoelectric Module Supply Plate (F)

72.2689

Temperature of the Thermoelectric Module Waste Plate (F)

117.7311

Thermoelectric Module Plate Temperature Difference (C)

25.2567

Temperature of the Waste Heat sink (F)

117.6460

Temperature of the Atmospheric Air (F)

95

Temperature of the Waste Air (F)

97.6974

Reynolds number in the tubing

9.1157e+003

Reynolds number in the Reservoir

3.2556e+003

Reynolds number in the Heat Sink

1.4592e+004

Convection Coefficient in the Tubing (BTU/Hr)/(ft²*F)

1.9521e+003

Convection Coefficient in the Reservoir (BTU/Hr)/(ft²*F)

305.9194

Convection Coefficient in the Heat Sink (BTU/Hr)/(ft²*F)

52.5403

Input Power Required to Operate System (Watts)

28.7273

Number of Currently Selected Thermoelectric Modules

2

Hours of Operation

8

Number of Selected Batteries Required for continuous Operation

3

Total Estimated Weight of Thermal Vest (lbs)

16.1937

Operating Temperatures with the system expelling 1000 BTUs/hr

Temperature of the Skin (F)

91

Temperature of the Inner Fabric (F)

89.2202

Temperature of the Tubing (F)

82.8128

Temperature of the Fluid (F)

82.4647

Temperature of the Reservoir (F)

53.5664

Temperature of the Thermoelectric Module Supply Plate (F)

53.5379

Temperature of the Thermoelectric Module Waste Plate (F)

136.4621

Thermoelectric Module Plate Temperature Difference (C)

46.0690

Temperature of the Waste Heat sink (F)

136.2920

Temperature of the Atmospheric Air (F)

95

Temperature of the Waste Air (F)

100.3947

Reynolds number in the tubing

9.1157e+003

Reynolds number in the Reservoir

3.2556e+003

Reynolds number in the Heat Sink

1.4592e+004

Convection Coefficient in the Tubing (BTU/Hr)/(ft²*F)

1.9521e+003

Convection Coefficient in the Reservoir (BTU/Hr)/(ft²*F)

305.9194

Convection Coefficient in the Heat Sink (BTU/Hr)/(ft²*F)

52.5403

Input Power Required to Operate System (Watts)

46.0708

Number of Currently Selected Thermoelectric Modules

2

Hours of Operation

8

Number of Selected Batteries Required for continuous Operation

Total Estimated Weight of Thermal Vest (lbs)**17.9200****MATLAB code used:**

```

%% This Program Models the Thermal System of the Liquid Filled Active
Regulating Thermal Vest
%% By Julian Jazayeri
%% Inputs: Heat Direction, Energy Requirement, Skin Temperature, Fabric
inputs, Tube inputs, TEM inputs, Fluid Properties, Pump Inputs, Rerervoir
Inputs, Fluid Flow Properties
%% Outputs: Operating Temperatures and paramerters of the componenets of the
system in order to transfer the heat required
%% Assumptions:
% System is at steady state at all heat transfer locations
% Human Body needs to expel 1000 BTU/hr to maintain the core body temp
% Atmospheric temperature is defined
% Surface Area of torso is approximatetly 5.4 ft^2
%% Clear Work Space
clc;
clear;
%% Inputs
%% Cooling or Heating
i=1; %
i=1 for cooling, i=anything for heating
if i==1 %
    n1=.3; %
Nud Coeficient
else
    n1=.4;
end
%% Constant Inputs
grav=32.2; %
Gravitational Constant (ft/s^2)
Egen=1000; %
Body heat generation (Btu/hr)
Tskin=91; %
Temperature of the skin (F)
Tatm=95; %
Atmospheric Temperature (F)
Acds=10.8*.5; %
Surface area of Torso (ft^2)
t=8; %
Hours of Operation (Hours)
%% Conductive Fabric Inputs (86% Cat Ionic Polyester, 14% Elastane)
Kc1=.3*(1/1.73); %
Thermal Conductive Fabric Conduction Ceoficient (W/m*k)=>(btu/hr)/ft*F
FabThi=(.02/12); %
Thermal Conductive Fabric Thickness (ft)

```

```

Wfab=1; %
Weight of Conductive internal Fabric (lbs)
%% Tube Inputs (TPE D8102)
ID=(2/16)/12; %
Tube Inner Diameter (ft)
OD=(3/16)/12; %
Tube Outer Diameter (ft)
ktb=3*(1/1.73); %
Tubing Thermal Conductivity (W/m*k)=>(Btu/hr)/ft*F
LenTube=45; %
Lenght of Tubing in Vest (ft)
Ain=(ID/2)^2*3.14; %
Internal Area of Tubing
Ao=(OD/2)^2*3.14;
Atbi=ID*3.14*LenTube; %
Contact Surface Area inside of tube (ft^2)
Atbo=ID/2*LenTube; %
Contact Surface Area outside of tube (ft^2)
tubeden=78.1056; %
Density of tubeing material (lb/ft^3)
Wtube=(Ao-Ain)*LenTube*tubeden; %
Weight of Tubing Components (lbs)
%% TEM Inputs (Multi Stage Custom Thermoelectric 19012-5L31-06CQQ)
nt=2; %
Number of Thermoelectric Modules
dTmax=84; %
Max TEM Temperature side difference
Vmax=15.5; %
DC Voltage Input
Imax=6; %
Input Current (Amps)
Emax=35; %
Input Energy (Watt)
Len=nt/12; %
Lenght of TEM (ft)
Wid=nt/12; %
Width of TEM (ft)
Area=Len*Wid; %
TEM Conductive Surface Area (ft^2)
S=Area; %
Shape Factor 2d Conduction
qss=.932; %
Steady State Conduction 2d factor
Wtem=.125*nt; %
Thermoelectric module component weight (lbs)
%% Fluid Properties (water)
vis=1.052*10^-5; %
Kinematic Fluid viscosity (ft^2/s)
uvis=2.034*10^-5; %
Dynamic Fluid Viscosity (lb s/ft^2)
den=1000*.06242; %
Fluid Density (kg/m^3)=>(lb/ft^3)
%% Pump Inputs (Series GB magnetic Drive Pump From micro pump)
np=1; %
Number of pumps
HeadHeight=2; %
Pump expected maximum head loss (ft)

```

```

Ppump=(den*HeadHeight)*(0.479); %
Pump Pressure from Head Height (mbar)
Vdot=((4000)-(Ppump/1000)*100)*0.000000589*np)/3; %
Volumetric flowrate (ml/min)=>(ft^3/s) Pump gear P35 at 3450 RPM
mdotpu=Vdot*den; %
Pump Mass flow rate (lb/s)
Vpu=26; %
Pump Input Voltage
Ipu=.18; %
Pump Input Amps
Epuin=Vpu*Ipu*np; %
Pump Input max power (watt)
Wpump=.8*np; %
Weight of Pump components (lbs)
%% Reservoir Inputs (Aluminum Material 1050A H9)
ResLen=8/12; %
Reservoir Length (ft)
ResWid=12/12; %
Reservoir Width (ft)
Resthi=.15/12; %
Reservoir Thickness (ft)
ResWalthi=.15/12; %
Reservoir wall thickness (ft)
Dres=.35/12; %
internal path diameter (ft)
AinRes=3.14/4*Dres^2; %
internal res path area (ft^2)
reslen=((ResWid-2*(ResWalthi))*Dres*9+(11.75/12)); %
Internal res fluid contact length (ft)
Ares=3.14*Dres*reslen; %
internal reservoir contact surface area (ft^2)
Wres=19.21/3; %
Internal Res Weight (lbs)
Khs=230*(1/1.731); %
Thermal Conductivity of Copper Heat Sink Material (W/(m*K)=>(btu/hr)/(ft*F)
%% Fluid Flow Properties (res/vest)
vel=mdotpu/(den*Ain); %
Fluid Velocity (ft/s)
Re=vel*(ID)/vis; %
Reynolds Number inside tubeing
Pr=7; %
Prandtl Number
k=.58/1.731; %
Fluid Thermal Conductivity (BTU/(hr*ft*F)
velres=mdotpu/(den*AinRes); %
Velocity of Fluid inside reservoir (ft/s)
Reres=velres*Dres/vis; %
Reservoir Reynolds Number
Vflu=Ain*LenTube+AinRes*reslen; %
Volume of fluid in Vest (ft^3)
Wflu=Vflu*den; %
Weight of fluid in vest (lbs)
%% Waste Heat Sink (Aluminum Material 1050A H9)
denal=167; %
Aluminum Density (lb/ft^3)
hsLength=12.75/12; %
Heat sink Length (ft)

```

```

hsWidth=8.75/12; %
Heat sink Width (ft)
hsthick=.15/12; %
Heat sink Thickness (ft)
finlen=.35/12; %
Heat sink fin lenght (ft)
finwid=.75/12; %
Heat sink fin width (ft)
finthi=.35/12; %
Heat sink fin thickness (ft)
finrow=32; %
Heat sink number of fin rows
fincol=12; %
Heat sink number of fin columns
nf=finrow*fincol; %
Heat sink number of fins
hsbotarea=hsLenght*hsWidth; %
Heat sink bottom area (ft^2)
hstoparea=finlen*finwid*nf; %
Heat sink top area (ft^2)
Val=30/(12^3); %
Heat sink Volume (ft^3)
Whs=Val*denal; %
Weight of Aluminum (lbs)
Khs2=230*(1/1.731); %
Thermal Conductivity of aluminum Heat Sink Material (W/(m*K)=>(btu/hr)/ft*F)
fla=((hsLenght-(fincol*finwid))*finthi)+(hsWidth-
(finrow*finlen)*finthi))*2;% Heat sink internal flow area (ft^2)
da=((fla)/3.14)^(1/2)*4; %
Effective Heat Sink flow diameter
Acair=(hsLenght*hsWidth)+nf*finlen*finwid*2+(finthi*finwid*nf)+(finthi*finlen
*nf*2); % Heat sink to air contact area (ft^2)
%% Fan inputs (DFB122512M NanJing Song Zi Commercial Trade Co. Ltd)
Wfan=.266*2.2; %
Weight of the Fan (lbs)
Efan=3; %
Electrical energy input to fan (W)
Vdotfan=79.66/60; %
Flow rate of fan (ft^3/min)=>(ft^3/s)
%% Fluid Flow Properties (Atmospheric Air)
avisc=16*10^-6*10.764; %
Kinematic Viscosity of air
aden=1*.06242; %
Air Density (kg/m^3)=>(lb/ft^3)
mdota=Vdotfan*aden; %
Mass Flow Rate of the air through the fan (lbs/s)
avel=Vdotfan/(fla); %
Air velocity in Cooling unit (ft/s)
Reair=avel*da/avisc; %
Reynolds number of the flowing air
ka=.03*(1/1.731); %
Thermal Conductivity of air (W/(m*K)=>(btu/hr)/ft*F)
%% Heat Transfer Models
%% 1-D Conduction Heat Transfer Stage 1 (Heat Transfer from the Skin to the
Internal Vest Surface)
if i==1

```

```

        Tfab=Tskin-(Egen*FabThi)/(Acds*Kc1); %
Conductive Fabric Operating temperature (F)
else
    Tfab=Tskin+(Egen*FabThi)/(Acds*Kc1);
end
%% 1-D Conduction Heat Transfer Stage 2 (Heat Transfer from The Internal Vest
Surface to the Tubing Material)
if i==1
    Ttb=Tfab-(Egen*(OD-ID)/2)/(Atbo*ktb); %
Tubing Operating Temperature (F)
else
    Ttb=Tfab+(Egen*(OD-ID)/2)/(Atbo*ktb);
end
%% Internal Flow Forced Convecrion Stage 3 (Heat Transfer from the Tubing
material to the Flowing fluid)
if (Re>=2500) %
    Dev=10*ID; %
Lenght of Fully Developed Flow (ft)
    if Dev>LenTube
        display('Flow in Tubing is not Fully Developed');
    end
    if (Re>20000) %
        f=.316*Re^(-1/4); %
Turbulent friction Factor
    else %
        f=.184*Re^(-1/5); %
Turbulent friction Factor
    end
    Nud=.023*Re^(4/5)*Pr^nl; %
Fully Developed Turbulent Flow Nusselt
else %
    Dev=.05*Re*Pr*ID; %
Lenght of Fully Developed Flow (ft)
    if Dev>LenTube
        display('Flow in Tubing is not Fully Developed');
    end
    f=64/Re; %
Laminor Fully Developed Flow Friction Factor
    lenratio=LenTube/(ID);
    Nud=3.66+(.0668*(1/lenratio))*Re*Pr/(1+.04*((1/lenratio)*Re*Pr)^(2/3));%
Laminor Fully Developed Flow Nusselt Number (3.66-4.36) Typically
end
H1=Nud*k/(ID); %
Convection Coeficient (BTU/(hr*F*ft^2))
if i==1 %
    Tf=Ttb-Egen/(H1*Atbi); %
Temperature of flowing fluid at operating temperature (F)
else
    Tf=Ttb+Egen/(H1*Atbi);
end
%% Internal Flow Forced Convection Stage 4 (Heat Transfer from the flowing
fluid to the Res/Heat Exchanger)
if (Reres>=2500)
    if (Reres>20000) %
        fres=.316*Reres^(-1/4); %
Turbulent friction Factor

```

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        else
            fres=.184*Reres^(-1/5);
Turbulent friction Factor
        end
        Nudres=.023*Reres^(4/5)*Pr^n1;
Fully Developed Turbulent Flow Nusselt
    else
        Devres=.05*Reres*Pr*Dres;
Lenght of Fully Developed Flow (ft)
        fres=64/Re;
Laminor Fully Developed Flow Friction Factor
        lenratio2=reslen/Dres;

Nudres=3.66+(.0668*(1/lenratio2))*Reres*Pr/(1+.04*((1/lenratio2)*Reres*Pr)^(2/3));

Laminor Fully Developed Flow Nusselt Number (3.66-4.36) Typicly
    end
    H2=Nudres*k/(Dres);
    if i==1
        Tres=Tf-Egen/(H2*Ares);
Temperature of the Flowing Fluid
    else
        Tres=Tf+Egen/(H2*Ares);
    end
    %% 2-D Conduction Heat Transfer Stage 5 (Heat Transfer from the Res/Heat Exchanger to the Thermoelecric Module)
    if i==1
        Tsp=Tres-Egen*Resthi/(Khs*qss*S)*(S/(4*3.14)^(1/2));
Temperature of the Thermoelectric module Supply Plates for 1000(btu/hr) (F)
        Twp=(Tatm-Tsp)+Tatm;
Temperature of the Thermoelectric Module Waste Plates for 1000(btu/hr) (F)
    else
        Tsp=Tres+Egen*Resthi/(Khs*S*qss)*(S/(4*3.14)^(1/2));
        Twp=(Tatm-Tsp)+Tatm;
    end
    dT=abs(Tsp-Twp)*(5/9);
Thermoelectric module plate tmeperature difference (C)
    %% 2-D Conduction Heat Transfer Stage 6 (Heat Transfer From the Thermoelectric Module to the Waste Heat Exchanger)
    if i==1
        Thsb=Twp-Egen*hsthick/(Khs2*qss*S)*(S/(4*3.14)^(1/2));
Temperature of the heat sink bottom (F)
        Thst=Thsb-Egen*finthi/(Khs2*hsLenght*hsWidth);
Temperature of the heat sink top (F)
    else
        Thsb=Twp+Egen*hsthick/(Khs2*qss*S)*(S/(4*3.14)^(1/2));
        Thst=Thsb+Egen*finthi/(Khs2*hsLenght*hsWidth);
    end
    Thsave=(Thsb+Thst)/2;
Average Heat sink temperature (F)
    %% Internal Flow Convection Heat Transfer Stage 7 (Heat Transfer from the Heat Exchanger to Atmosphere)
    if (Reair>=2500)
        if (Reair>20000)
            fair=.316*Reair^(-1/4);
Turbulent friction Factor

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        else
            fair=.184*Reair^(-1/5);
Turbulent friction Factor
        end
        Nudair=.023*Reair^(4/5)*Pr^n1;
Fully Developed Turbulent Flow Nusselt
    else
        Devair=.05*Reair*Pr*da;
Lenght of Fully Developed Flow (ft)
        fair=64/Reair;
Laminor Fully Developed Flow Friction Factor

        Nudair=3.66;
Laminor Fully Developed Flow Nusselt Number (3.66-4.36) Typically
    end
    H3=Nudair*ka/(Dres);
    if i==1
        Tair=Tatm+Egen/(H3*Acair);
Temperature of the Flowing Fluid
    else
        Tair=Tatm-Egen/(H3*Acair);
    end
    %% Power Requirements
    Et=Emax*(dT/dTmax)*nt;
Energy for the TEM (Watts)
    Ep=Epuin;
Energy for the Pumps (Watts)
    E=Et+Ep+Efan;
Total Energy for the system (Watts)
    Vdc=14.4;
Current Chosen Power Source Potential Supply (volts)
    Adc=4.8;
Current Chosen Power Source Amperage (a-h)
    Pdc=Vdc*Adc;
Current Chosen Power Source Supplied Power (watt-h)
    Pdcl=Pdc/t;
Current Chosen Power Source Supplied Power for chosen operation time (watts)
    nb=E/Pdcl;
Number of Chosen Batteries to Power Vest for continuous operation
    Wbatt=nb*.86;
Weight of Battery Components (lbs)
    %% Total Weight
    Wcoolingunit=11.16;
Weight of temperature regualting module imported from Soliworks file (lbs)
    Wt=Wbatt+Wpump+Wfab+Wtube+Wcoolingunit;
Total Weight of Vest
    %% Display Results
    if i==1
        disp('Operating Temperatures with the system expelling 1000 BTUs/hr');
    else
        disp('Operating Temperatures with the system providing 1000 BTUs/hr');
    end
    disp('-----');
    disp('Temperature of the Skin (F)');disp(Tskin);
    disp('Temperature of the Inner Fabric (F)');disp(Tfab);
    disp('Temperature of the Tubing (F)');disp(Ttb);
    disp('Temperature of the Fluid (F)');disp(Tf);

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disp('Temperature of the Reservoir (F)');disp(Tres);
disp('Temperature of the Thermoelectric Module Supply Plate (F)');disp(Tsp);
disp('Temperature of the Thermoelectric Module Waste Plate (F)');disp(Twp);
disp('Thermoelectric Module Plate Temperature Difference (C)');disp(dT);
disp('Temperature of the Waste Heat sink (F)');disp(Thsave);
disp('Temperature of the Atmospheric Air (F)');disp(Tatm);
disp('Temperature of the Waste Air (F)');disp(Tair);
disp('Reynolds number in the tubing');disp(Re);
disp('Reynolds number in the Reservoir');disp(Reres);
disp('Reynolds number in the Heat Sink');disp(Reair);
disp('Convection Coefficient in the Tubing (BTU/Hr)/(ft*F)');disp(H1);
disp('Convection Coefficient in the Reservoir (BTU/Hr)/(ft*F)');disp(H2);
disp('Convection Coefficient in the Heat Sink (BTU/Hr)/(ft*F)');disp(H3);
disp('Input Power Required to Operate System (Watts)');disp(E);
disp('Number of Currently Selected Thermoelectric Modules');disp(nt);
disp('Hours of Operation');disp(t);
disp('Number of Selected Batteries Required for continuous
Operation');disp(round(nb));
disp('Total Estimated Weight of Thermal Vest (lbs)');disp(Wt);

```

Appendix H

Gantt Chart

