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COOLED VEST

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WATER COOLING VEST

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EXECUTIVE SUMMARY

Neurosurgeons are among a select group of surgeons who are required to utilize real time imaging to assist them during surgery. The imaging techniques utilize x-rays so protective vests must be worn to shield the surgeon from excess radiation. Lead or beryllium vests are worn to achieve radiation protection, but the vest has side effects of its own. The vest is thick, heavy and restricts heat from leaving the body, despite comfortable ambient air conditions. The result of excessive heat generated causes neurosurgeons to lose focus and concentration on surgeries which can last as long as 8 hours. Our team has embarked on the task of designing and building a prototype cooling vest that a surgeon can wear between himself and the lead vest to keep his body at a comfortable temperature.

Numerous concepts were introduced and analyzed as potential methods of cooling a vest. The majority of these concepts sought to increase the amount of heat transfer by allowing for more natural convection and adding forced convection and conduction. Cooling technologies currently in existence were researched and analyzed. Gel cooling packs that stay cold for extended periods of time could increase conduction over time. Phase changing materials could absorb heat over time through their chemical phase changes. Air flowing throughout the upper torso (much like an air hockey table) could act like a fan over the torso. Tubes with a cooling fluid could be placed throughout a vest and circulated to keep the body cold. Thermoelectric cooling devices could be used in a system to cool the body or any type of cooling material.

After analyzing different combinations of cooling technologies, our team ultimately decided that our final design would consist of a vest combined with tubes to circulate water and a thermoelectric cooler in combination with a heat exchanger to cool water. The tubes would be made of polyethylene and connected in the shape of a manifold to minimize the change in temperature as the water goes across the body. The heat exchanger would be constructed by utilizing a water cooler which operates by conduction with the cold side of a thermoelectric cooler, and a heat sink and fan exhausting the heat on the hot side of thermoelectric device. A small PC water pump will circulate cooled water throughout the vest. The entire vest will be powered using Lithium Iron Phosphate batteries.

The prototype constructed by our team is different than the proposed manufactured prototype since it is not being mass produced yet. The polyethylene tubes were connected differently for the anterior manifold to increase mobility of the user. The heat sink was modified to accommodate the heat sink that was purchased from an online company. The batteries that power the vest were not all Lithium Iron Phosphate due to the high cost; we were forced to use Lithium Ion batteries as well.

Our team thoroughly tested the cooling vest to ensure that it would operate and prove that a cooling vest can be engineered without auxiliary systems. The prototype has proven that it is more than capable of delivering the client specifications as long as the batteries involved are replaced at two hour intervals. However, there are many improvements that can be added to our project such as a professional circuit board with feedback control and extruded tubes. The cooling vest is a solid product that can deliver mobile cooling for any surgeon that might need it.

INTRODUCTION

Problem Description

During surgery, neurosurgeons are required to wear a protective lead vest which is heavy, thick, and uncomfortable. The surgeries are image-guided using an x-ray source which causes the need of the lead vest to protect the doctor from radiation. The vest restricts heat transfer which results in the neurosurgeon feeling very warm, despite the ambient temperature being at a comfortable level. The result of excessive heat generated causes neurosurgeons to lose focus and concentration on surgeries which can last as long as 8 hours. Developing a cooling system for the neurosurgeons could benefit them by helping to prevent or limit fatigue during their surgery and in turn improve patient care.

Abstract

The need for a personal cooling system has existed for decades. The bulk of research and development for a personal cooling vest has been done by the military. Imagine a soldier on a mission in a desert area with temperatures rising to 125°F. In order to decrease fatigue while increasing performance the soldier wears a cooled vest which makes it feel like 75°F instead of 125°F. This is a definite need of the soldier. Now that same need of decreasing fatigue is spreading out to other areas such as athletics, high heat environments, and operating rooms.

Neurosurgeons have to perform image guided surgeries. In order to be able to do so they must wear lead vests to protect themselves from the radiation from the x-rays used to produce the images. These surgeries may last up to 8 hours long. The lead vest is heavy and does not allow for heat transfer. The lack of heat transfer causes the surgeon to experience warmer temperatures under the vest than that of the actual room temperature. This increase in temperature causes the surgeon to sweat and become fatigued over time. This is a problem because as the doctor becomes fatigue he begins to lose his ability to concentrate and perform at the level needed.

The project is to design a cooling system that can be worn under the lead vest. The cooling system will allow the surgeon to control his temperature and therefore he can reduce the level of fatigue he feels during and after a surgery. Being able to control his comfort level will help him to perform and concentrate at the level needed for the surgery. Since the surgeon already wears a heavy lead vest and needs a complete range of mobility as he is doing a very delicate spinal surgery, the cooling system will need to be light weight and self-contained. The goal of this project is produce a cooling vest that will allow the doctor to efficiently control his temperature under the lead vest.

BENCHMARKING

The need for a personal cooling system for personal, industrial, and military uses has existed for decades. Due to these needs and the numerous applications for a cooling vest a lot of research and product development has been done to create many cooling systems. The systems used in the current cooling vests can be broken down into five categories:

1. Gel cooling
2. Phase change cooling
3. Water cooling
4. Air cooling
5. Combo systems which involve hybrid vests where they use combination systems such as evaporative and phase-change systems together.

Gel Cooling Vests

Figure 1: Gel cooling vests [1]

Evaporative cooling uses material crystals that absorb water when soaked and then turn to a gel form. This gel form then can be cooled and it will slowly release the water in the form of condensation. This will reduce your body temperature. The average times needed to cool or freeze (charge) the gel is from 5 minutes to 2 hours. The time that the vest will cool your body for a gel that is charged for two hours ranges from 2 to 5 hours. The weight of the vest averages at about 2 lbs. An example is provided below.[1]

Arctic Heat, Body Cooling Vest

Figure 2: Arctic Heat gel cooling vest[2]

This Arctic Heat vest uses crystals that when soaked in water for 15 minutes become activated and form a gel. Then the gel can be cooled in either ice water or in a freezer. The effective cooling time when wearing the vest depends on external temperature and the time the gel was charged for. If the gel is placed for 5 to 10 minutes in ice water the effective cooling of the vest is 60 minutes. Placing the gel in the freezer for two hours allows for two hours of effective cooling. When used in direct skin contact the vest can reduce the skin temperature by 63^0F while if worn over other clothing the vest can reduce skin temperature by 54 ^{0}F. The entire vest with the gel packs weigh less than 2.2 lbs.[2]

Phase-Change Cooling Vests

Figure 3: Phase-change cooling vest[3]

Phase-changing vests make use of liquid packets that are either cooled or frozen to a solid form. From the solid form the packets cool the body by using the heat transfer property of a material when changing from a solid to a liquid. From the solid phase the packets need heat to fuel the phase change, thus the packets absorb the heat given off by the body which in turn cools the body. This absorption of heat returns the material inside the packet to a liquid. The packets can take on average up to 45 minutes to cool in ice water or slightly less in a freezer. Cooled packets can remain at 58 degrees Fahrenheit for an average of 2.5 hours. The average total weight of the vest is 5.5 lbs. An example product is provided below.

Climatech, CM2000

The CM2000 phase-change vest uses cooling inserts. The inserts are charged or cooled to a solid phase using a freezer or ice water. The vest is designed using a vented mesh to allow easy cleaning. Climatech uses the capability of layering these inserts to provide extended cooling. The CM2000 with only 1 layer of inserts in 120 degree Fahrenheit can provide cooling for 2 hours, while 2 layers can provide cooling for 4 hours, and three layers can provide up to 6 hours of cooling. With one layer of inserts the vest weighs only 5 lbs.[3]

Water Cooling Vests

These vests typically use a system where temperature controlled water is circulated around the body through tubes in the vest. The water is moved using a pump and as the water circulates it picks up heat from the body and leaves the vest at a warmer temperature than it came in as. The actual vests with water-filled tubes weigh from 10 ounces to 30 ounces. An additional cart is needed to hold the pump and cooled water.

Shafer Enterprises LLC, Cool Vest

Figure 4: Water cooled vest for surgeons[4]

The Cool Vest is specifically designed as a surgeon cooling system. This system implements using temperature controlled water that is circulated through the vest using a pump. The pump and temperature controlled water are stored in an additional cooler cart. The vest is connected to the cart using hoses. The hoses range from 8-12 ft long. This system allows for you to use it as long as needed. The Cool Vest can be worn under any garment, including lead vests.[4]

Air Cooling Vests

There is a couple of different air systems used. The first is a compressed air system[6]. This system is used in extremely high heat situations like welding, foundries, and sand blasting plants. It can cool by as much as 60 degrees Fahrenheit. The other system uses forced air flow by way of fans. This air cooling system is used in less heat intensive areas. Both of these systems work the same way by using forced air flow to speed the process of evaporation, thus keeping the body cool. An example of a fan powered system is below.

Entrak, VentilationVest

This system uses a lining made of air-permeable and compression-proof spacer fabric. Battery-powered fans are used to circulate ambient air around the body and they also remove moisture filled air that is warmed by the body heat given off. The ‘VentilationVest’ weighs 2.2 lbs and can be used up to eight hours on a single battery charge, using a lithium ion battery. The fans and battery can be removed so that garment can easily be washed [7].

PROJECT PLAN

A project plan is constructed to ensure that the engineering, manufacturing, testing and finalizing are carried out accordingly in a timely manner. The project plan is summarized in a Gantt chart [Appendix A] and could be boiled down to several important aspects during the whole duration of producing our prototype.

Customer requirements and engineering specifications

Our customer, Dr. Park gave us a list of what he wants for the cooled vest and we list them down as the customer requirements. With the customer requirements, we figure out how each customer requirement would relate to the engineering specifications. In order to transform the customer requirements into design quality and to deploy methods for achieving the design quality into component parts, we use a Quality Function Deployment (QFD) diagram.

Concept generation and selection

The way we come up with concept generation is through brainstorming. We put all the ideas that we have in mind into rough sketches. Next, we search for the cooling vest that are already in the market and benchmark it. Any design concept that is similar to the benchmark is eliminated and only five final design concepts are chosen. The five final design concepts will be weight against the engineering specifications and the design which has the highest weight would be the Alpha design.

Alpha design creation

When we have all the concept generations ready, we discussed our design concepts with our section instructor, Dr. Shih and Dan Johnson. They gave us good comments on how to improve our design concepts. From there, we went on to have further discussion with professors who have a deep knowledge on design layout of the tubes to increase the efficiency of heat transfer and who have a good insight on the new heat transfer technology. We approached Professor Borgnakke and Professor Kaviany who gave us advice on design layout and thermoelectric effect respectively. From there, we finalized our Alpha concept.

Prototype Manufacturing

After design review #3, we made a list of items that we need to build the prototype. Once, the list of items were approved by our section instructor, we proceed to buy them either using a purchase order or directly off from shelves. However, the only component that needs to be machined is the water cycler. It would be machined in the machine shop in GG Brown building. After building the prototype, we tested and validated it.

Design Finalization

After design review #4, the team will be ready to make any necessary modifications in order to meet the customer’s requirements. Testing and validation will continue with any new design changes. Nevertheless, all design changes and validation would be completed before the design expo which is held on December 4th, 2008.

SPECIFICATIONS

Our target client base is surgeons who are required to wear protective lead vest during long surgeries. Our sponsor, Dr. Paul Park, M.D is an Assistant Professor in the Department of Neurosurgery at the University of Michigan specializing in adult neurosurgery. Dr. Park informed us that the lead vest is heavy and it limits the heat transfer from the body to the ambient environment causing a higher skin temperature. The increase in body temperature leads to intense perspiration within the covered part of his body. Perspiration and heat lead to an uncomfortable environment and can potentially distract him on the surgery table. The creation of a cooling vest will help to avoid mistakes due to fatigue and will provide Dr. Park with much improved working conditions.

Customer Requirements

We arranged a meeting with Dr. Park to help us understand his requirements. The team had the opportunity to ask him several questions and get crucial feedback to produce a list of customer requirements. Among the questions asked were:

1. Do you walk around the surgery room a lot?
2. What can/cannot be brought in the Operation Room (OR)?
3. What kind of desirable temperature would you like to be at during operation?
4. What is the maximum operating time?
5. How much noise can be allowed in the OR?
6. What is your main concern about a cooled vest?
7. Would you like the cooled vest to be light?

Through these questions, we were able to extract the fundamental customer requirements as shown in table 1.

Table 1: List of Customer's Requirements.

No.	Customer Requirements	Weight
1.	Light weight	10
2.	Must cooled throughout surgery	10
3.	Reliable cooling ability	9
4.	Low bulk	8
5.	Does not inhibit motion or joints movement	8
6.	No protrusion in front (sterile area)	8
7.	Most weight supported below the torso	8
8.	Mobile (self-contained)	7
9.	Ergonomic	6
10.	Easy to put on	6
11.	Able to adjust desired temperature	5
12.	Moderately quiet	4

Based on the list of customer requirements generated, we ranked each customer requirement from the scale of 1 – 10 with 10 being the most important and 1 being the least. The ranking method was done based on our interview with Dr. Park. Through his intonation and facial gestures, we can make a good guess on some of the more important requirements and those that are just expectable needs.

From the Table 1, aspects such as low bulk, lightweight, reliable cooling ability and must cool throughout surgery are among the most important requirements. These requirements are specifically asks of us by Dr. Park and the building of the prototype must heavily rely on fulfilling these requirements. It is pivotal that we manufacture a prototype that has most of the weight supported below the torso and thin enough with a good cooling capability for him. This vest must be able to provide a cooled uniform temperature throughout the torso and must not limit the surgeon's ability to perform his objective.

There are other less important requirements such as adjustable temperature and moderate noise level in which Dr. Park did not specifically ask for, but would prefer if it we could fulfill those requirements.

Engineering Specifications

The translation of customer requirements to measurable engineering specifications is decided through a brainstorming session before we reached upon the final few feasible quantities of measurement that will correlate to our customer requirements (Table 2). We tried to have at least one engineering specification correlated to a certain customer requirement.

Table 2: Relating Customer Requirements to Engineering Specifications

No.	Customer Requirements	Corresponding Engineering Specifications	Target Value
1.	Light weight	Weight	Less than 1.25 lb above the waist
2.	Must cooled throughout surgery	Standalone operation time	10 hours
3.	Reliable cooling ability	Steady state temperature	69°F or 20.5°C
4.	Low bulk	Average vest thickness	1.5 cm
5.	Does not inhibit motion or joints movement	Total cooling area	800 cm^2
6.	No protrusion in front (sterile area)	Protrusion of mechanism	2 cm
7.	Most weight supported below the torso	Weight	Less than 1.25 lb above the waist
8.	Mobile (self-contained)	Protrusion of mechanism	2 cm
9.	Ergonomic	Young’s modulus of vest material	More than 2 GPa
10.	Easy to put on	Adjustable waist measurement	35-52 in
11.	Able to adjust desired temperature	Steady state temperature	69°F or 20.5°C
12.	Moderately quiet	Noise level	Below 20 dB

The correlation between low bulk with overall vest thickness and lightweight with the overall weight of the vest is the most obvious. Low bulk is something Dr. Park desires the cooling vest to be and we will be able to measure that by taking the average thickness of the vest we will manufacture. Since he also wants it light, we should take into account the weight distribution of the vest as we manufacture it. One of the less obvious correlations would be the ability to adjust the required temperature and reliable cooling ability. To measure the ability to adjust required temperature, we had to come up with the minimum temperature the cooling vest can produce. By having a range of temperature implies that we would have the temperature adjustable instead of rigidly installed to the vest. The reliability of the vest to cool on the other hand will be measured by the maximum heat power that can be extracted by the vest.

Some of the engineering specifications are not absolutely obvious. Protrusion of mechanism means how far away the vest actually protrudes from the body while adjustable waist measurement implies if the vest can cater to a range of wearer. Young's Modulus of the vest material is important to ensure that the vest is strong and flexible enough. Total cooling area is a representation of the contact area between the cooling medium and the body. Average vest thickness is a measurement of the vest's bulkiness.

With a high demand for a self contained cooling system compared to cooling systems on the market that require auxiliary power, our research lead us to a few significant products which will be used as our benchmarks. These products are divided into 4 categories which were explained in the Benchmark section. Since the purchasing of the product is not initiated due to financial constraints, many of the engineering specifications for the benchmark cannot be analyzed thoroughly. Nevertheless, some of them were provided by the manufacturers and we had to contact some of the manufacturers personally to obtain some engineering specifications as a mean of comparison. The most common information provided were the weight of the vest, its cooling capacity, the size of the vest and the length of the cooling period.

The application of QFD in the preliminary stages of design has definitely helped us to understand the importance of having a clear picture before diving into a final design. Through the QFD, we manage to see clear correlation between the customer requirements and engineering specifications. The engineering specifications are produced through brainstorming sessions finalized through popularity and rationality votes. The correlation matrix is decided the same way, through votes, and that is how we came up with the importance ranking for the engineering specifications. The benchmark rankings are based on each team member's opinion.

The QFD [Appendix B] comprised of two basic parts on a chart that intersect to allow our team to understand how important the customer requirements and engineering specifications relate to each other. By weighting the customer requirements in terms of importance and cross referencing this with the relationship with engineering specifications, we were able to obtain numerical values of importance for each engineering specification.

CONCEPT GENERATION

There are several stages of creating the ideas to build the cooling vest. Some of the stages involved are brainstorming (Deep Dive), benchmarking, and researching on the latest method of cooling technology. After brainstorming, five final designs were selected from our list that our team believed possessed distinct advantages of being a quality product. The five final designs were then compared within a concept selection matrix that weighed each product's ability to deliver the most important engineering specifications through voting. Each product was ranked on its ability to fulfill an engineering specification, and the results were summed in order to rate each design using a numerical score. The highest scoring design becomes the 'alpha design'.

Brainstorming

The first concept generation process was brainstorming for ideas. This allowed all team members to participate without any criticism in creating individual design ideas. The motive is to create as many ideas as possible to prevent our team from gravitating towards any particular idea and stunting creativity. Team members would generate rough sketches of their ideas regardless of the peculiarity of the ideas. At another point in the meeting, all the designs were explained thoroughly by each team member as the team listened carefully to all ideas. Criticism is put on hold and the feasibility of each idea will only be considered during the selection of the 5 main designs. In the process of brainstorming, we apply lateral thinking and thinking outside the box.

Benchmarking

The brainstorming session is followed by benchmarking current products in the market. The benchmarking is done by searching for any cooling devices out in the current market and the corresponding technology that allows these devices to run [refer to Benchmarking section]. The purpose of benchmarking is to eliminate design concepts that are similar to the products that already exist in the market and to narrow the design concept. From benchmarking, the team found out that there are a variety of cooling vests that exists in the market today. Our team was forced to discuss and analyze the design concepts thoroughly in order to differentiate and better our design concepts as compared to similar existing products.

Researching on Latest Cooling Technology

The team will take a step ahead by incorporating the latest methods of cooling technology into the cooling vest. Implementing new technology will differentiate our product from existing ones. The benchmarking of the current existing products in the market indicates that many cooling systems do not implement any of the latest cooling technologies. All the benchmarks use traditional ways of heat transfer. After researching the latest technology available, we decided to expand upon current cooling technology by applying thermoelectric coolers (also known as the Peltier device) that would work in conjunction with another older cooling technology. The Peltier effect is the technology behind the thermoelectric cooler that we have incorporated into several of our initial designs.

Final Five Designs

With more than ten designs from our brainstorming session, we had to narrow our design to the most feasible five before making a final decision to choose the Alpha design. To assist our judgment, we categorized all the preliminary designs into their primary cooling technologies through a functional decomposition diagram [Appendix C]. From our ideas, we decided that we could classify them into their working mechanisms, which are air cooling, fluid cooling, gel cooling and ice cooling (See Table 3). The sketches for these ideas are arranged in Appendix D

Table 3: Preliminary Design Categorization

Categories	Design name
Air Cooled	**Evaporative Cooling Vest** **Air Peltier Cooling Vest (Thermoelectric)** 1 Fan and Spacers on Both Side of Vest Fans Installed at Shoulder Pad Fans on Vest with Protruding External Fans Strategically Placed "Laptop Cooling" Fans Flow of Cool Air Through Double Layered Vest (Thermoelectric) Fins to Enhance Natural Convection Spacers Between Vest and Body
Fluid Cooled	**Water Cooling Vest (Thermoelectric)** Installation of Refrigeration System on Vest Water Capsule with Cold Water
Gel Cooled	**Gel Cooling Vest**
Ice Cooled	**Vest with Recharging Ice Packs(Thermoelectric)**

The final five concepts were chosen based on manufacturability and fulfillment of customer requirements. This decision making session was done with the intuitive feel and engineering judgment for each of the preliminary designs. During brainstorming, we did not limit ourselves to the required constraint, but in this session each team member gave their opinion and votes on how good they felt the vest will fulfill the customer requirements and the feasibility of manufacturing the design. This is a critical point of design selection because we have to discard ideas that are deemed ineffective.

CONCEPT SELECTION

After going through a series of discussion and brainstorming sessions, the final five concepts that we agreed upon are the best representations of each category. These designs are decided by our team as the most feasible, most advantageous in terms of manufacturability and most rational. The description for each design with accompanying Pros and Cons are described below with corresponding sketches on Appendix D.

Description of Final 5 Designs

Vest with Recharging Ice Packs

A vest lined with ice packs placed at "hot spots" along the torso to allow conductive cooling between the body and the ice packs, thereby cooling the body. Once the ice packs become warm a thermoelectric cooling device, placed next to the ice packs is activated removing heat from the icepacks until they return to a set temperature, allowing for extended cooling of the body

Pros:

Using only ice packs and a Peltier device, this vest will cool the body without any moving parts. Using ice also allows the user to achieve cooling temperatures much lower than air cooled vests.

Cons:

In order to maintain ice at its solid state, many Peltier devices will need to be used. The abundance of Peltier devices will generate a large amount of heat outside and needs to be vented. They will also use a large amount of power. This vest will be heavy and bulky and likely limit the user's mobility and range of motion.

Difference & Improvements compared to Competitor's Product:

Our design utilizes a Peltier cooler to "recharge" ice packs and allow for cooling of the vest.

Evaporative Cooling Vest

Evaporative cooling would be used to cool the body by blowing air over the thin film of sweat on the skin. Air at low humidity will pass through semi-permeable tubes and a transfer of heat and mass will occur between the skin and the air. The exiting air will be warmer than the ambient air and will be at a saturated level of humidity. Multiple shorter parallel tubes would be used to allow the air to be exhausted once it can no longer remove any more heat or humidity. These tubes will be located over "hot spots" of the body. An extra attachment can be added to cool the entering ambient air such as a Peltier cooler or an ice pack tube located on the belt in series with the blowers required to move the air through the vest.

Pros:

The evaporative vest utilizes the body's natural water source, sweat, to produce an the evaporative cooling effect on the skin. This will remove heat and keep the user from sweating.

Cons:

Evaporative cooling only works if the cooling vest is worn directly on the skin. This could be uncomfortable and make it difficult to clean the vest. The vest also requires multiple blowers which are powered by batteries. These batteries will likely need to be changed throughout the surgery since blowers require high electrical power output.

Difference & Improvements compared to Competitor's Product:
The evaporative cooling vest directs air through the vest instead of using the air hockey table effect. Additionally, our design exhausts air once it is no longer able to remove heat from the body.

Air Peltier Cooling Vest

This concept will pull air in two intake fans, one for the front side of the vest and one for the back side of the vest. The air will be cooled as it enters the vest using a Peltier cooler. The air will then travel through tubing made of a thermally conductive plastic. The plastic will absorb the heat given off by the body through conduction and heat will then be transferred to moving air. The tubing will be placed horizontally to enhance the flexibility of the vest and also to help prevent the tubing from being kinked. This will also result in the tubing that will be removing the heat from the body, to be a shorter length thus improving the efficiency of the vest. The warm air will then be removed using two exhaust fans, again one for the front of the vest and one for the back of the vest.

Pros:
The air Peltier cooling vest will be lightweight, allow for full body motion, and be completely mobile. Since the air Peltier device utilizes ambient air, its ability to cool increases with when the ambient air temperature decreases. Since, there is no fluids involve, there is no risk of leakage.

Cons:
The Peltier device utilizes large quantities of electrical energy which will require batteries to be changed often. It does not cool as well as water. The usage of a strong fan can produce a reasonable amount of noise.

Difference & Improvements compared to Competitor's Product:
Air cooling vests already on the market seek to create the "air hockey effect," which is simply air circulation underneath the vest that is random and uncontrolled. These vests also are attached to an external power or air source. By cooling the air and controlling its circulation, the air Peltier cooling vest will be more efficient and portable even though it is potentially noisier.

Water Cooling Vest

The water cooling vest will utilize thermally conductive plastic tubes that are placed throughout the vest and contain water. An aquarium pump will circulate the water through the tubes, which will remove the body heat via conduction and convection. The water will absorb heat as it flows through the vest and will exhaust heat at a heat exchanger. The heat exchanger will utilize a Peltier device to remove heat from the water. The hot side of the Peltier device will be attached to a heat sink with fins and a fan will blow over the heat sink to quickly remove heat from the Peltier device. A belt, to be worn on the waist, will be used to contain the battery pack, a pump, and a heat exchanger.

Pros:

The water cooling vest delivers exceptional cooling ability due to the water having a large thermal capacity. Using tubes to transport water also allows us to target the "hot spots" of the body by circulating the coldest water through these regions first. The water cooling vest will be mobile and will allow for full body movement of the user.

Cons:

Due to the density of water, the water cooling vest is heavier than conventional cooling vests that utilize air as a cooling fluid. The water is chilled using a Peltier device which is a high current electrical component: powering the heat exchanger could prove to be difficult.

Difference & Improvements compared to Competitor's Product:

The water cooling vests already on the market utilizes an external water cooler, water reservoir, and pump that must be connected to the vest and carried with the user. This design uses a method to compact the external device into a smaller device that can be worn on the belt thus making it self-contained.

Gel Cooling Vest

A thin layer of gel will be placed in between the inner and outer layers of the cooling vest. This gel has the ability to stay cool for approximately two hours; after two hours the gel will start to warm up quickly. There is an opening in the back of the vest that allows for gel to enter and exit the vest. Gel will be manually extracted and pumped into the vest for the duration of the surgery, every two hours. This process will be accomplished using a pump connected to a reservoir.

Pros:

The gel cooling vest utilizes a chemical gel that can stay cool for a long time. The vest is simply worn for the duration that the gel stays cool. Since the gel has no rigidity and is free flowing, the vest's shape is not altered. This means that the wearer retains full body movement and mobility.

Cons:

Although the gel cooling vest has no moving parts, there must be a valve in the back to allow gel to be extracted and pumped in. This could be difficult since the gel is a high viscosity fluid. The vest can only be worn for two hours and requires new gel every two hours. The vest might potentially get too heavy for comfort too.

Difference & Improvements compared to Competitor's Product:

The gel cooling vests already on the market don't utilize the gel as a fluid that can be moved around; we are creating a device that can move the gel around so that the cooling vest's usage time can be increased.

Concept Selection Process for the Alpha Design

The selection process for the alpha design is done through two processes. Initially, we took a numerical approach: a numerical rating (1 to 10 with 10 being best) of the top five engineering specifications will be multiplied by the percentage importance (Importance Rating) from the

QFD [Appendix B]. We assign the value of 0.1 to both manufacturability and safety arbitrarily to maintain a logical importance of the two criteria. The sum of these scores indicates how well the design can deliver engineering specifications and is listed at the bottom of the matrix. Next, we will analyze the numerical results to make sure they coincide with the research and logic of our design selection.

The Alpha design will have a good engineering specification score and be highly feasible in manufacturing terms. We have to ensure that although the Alpha design has a good ranking score and that it also has to have the capability to fully satisfy the customer requirements. The scoring matrix is shown in table 4.

Table 4: Scoring Matrix in deciding the Alpha design

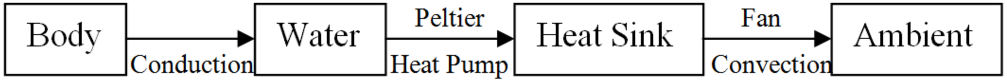
Design Concept Engineering Specifications	Importance Rating	Evaporative Cooling Vest	Vest with Recharging Ice Packs	Water Cooling Vest	Gel Cooling Vest	Air Peltier Cooling Vest
Weight	0.17	9	2	8	9	9
Average Vest Thickness	0.15	6	8	9	9	6
Portrusion of Mechanism	0.14	6	2	6	9	6
Standalone Operation Time	0.13	8	2	8	2	8
Steady State Temperature	0.12	8	7	10	7	9
Manufacturability	0.1	7	5	7	6	9
User friendly	0.1	8	4	8	6	8
TOTAL		6.77	3.82	7.29	6.44	7.09

After scoring our final five designs by voting, the matrix indicates that the Water Cooling vest has the best ability to deliver the engineering specifications, and thus the customer requirements to our client. The scoring matrix also indicates that the vest with rechargeable ice packs is not very feasible and that a Peltier device in conjunction with tubes that circulate fluid (both water and air) will produce the optimal performance for our client. The Water Cooling Vest is our Alpha Design since it delivers the highest amount of heat transfer, meets our engineering specifications the best, and was agreed upon the team as the superior engineering design. In terms of manufacturability, this design is relatively simple and can be easily put together as compared to the Vest with Recharging Ice Packs and Gel Cooling Vest. This idea is perceived to be user friendly as well because it is less bulky and easy to put on.

CONCEPT DESCRIPTION (ALPHA DESIGN)

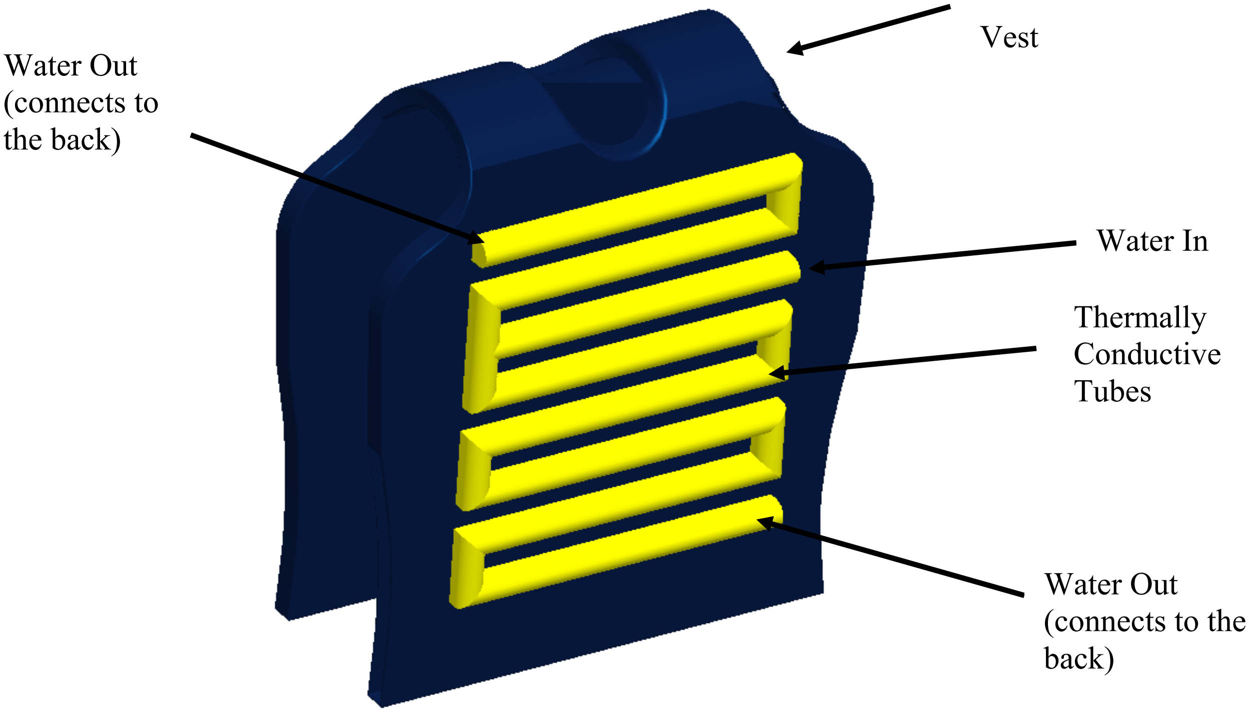
The alpha design that our team has chosen is the Water Cooling Vest. This vest will use tubes to circulate water throughout the vest and have a heat exchanger that re-cools recycled water using a Peltier device attached to it. Our vest is comprised of four main components: the vest itself, water tubes, the heat exchanger and a battery pack. Figure 5 shows how the heat is transferred from the body to the ambient.

Figure 5: Heat transfer method from body to ambient



The vest itself will be made by our team. A poncho style vest will best fit our design needs. The qualities we are looking for in such a vest are: durability, breathability of fabric, flexibility, lightweight, and easy to clean. The vest material should also allow for sturdy attachment of the water tubes. (See figure 6)

Figure 6: CAD model of the proposed Alpha design (vest and tubes)



The water tubes that we will purchase need to be flexible, lightweight, have a large thermal conductivity, and must be watertight. These tubes will be connected to the vest in such a pattern as to maximize the heat transfer from the body to the water inside the tubes. This will be achieved by circulating the water first through the "hot spots" of the body, such as the pectoral region on the front of the torso and the upper back. Also the layout of the tubes must not create rigidity in the vest that would limit mobility and lead to the possibility of the tubes being compressed. This will be achieved by having the tubes connected horizontally along the body. The water tubes will branch out as they circulate the body in a manner similar to the capillaries in our bodies. The tubes will then return into one exit flow and enter the heat exchanger. (See figure 7)

Figure 7: Incoming and exiting water flow at the belt with heat sink and pump

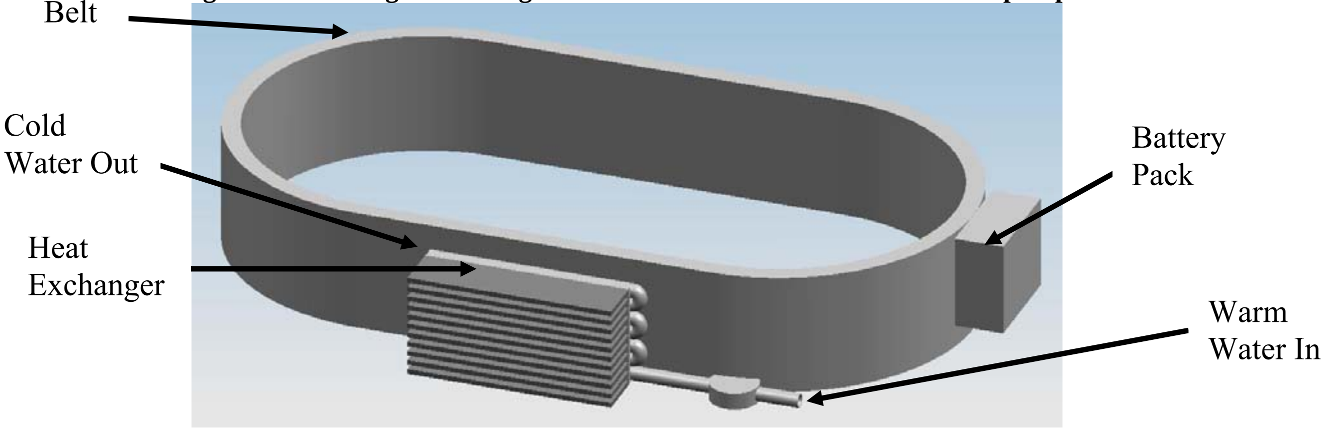
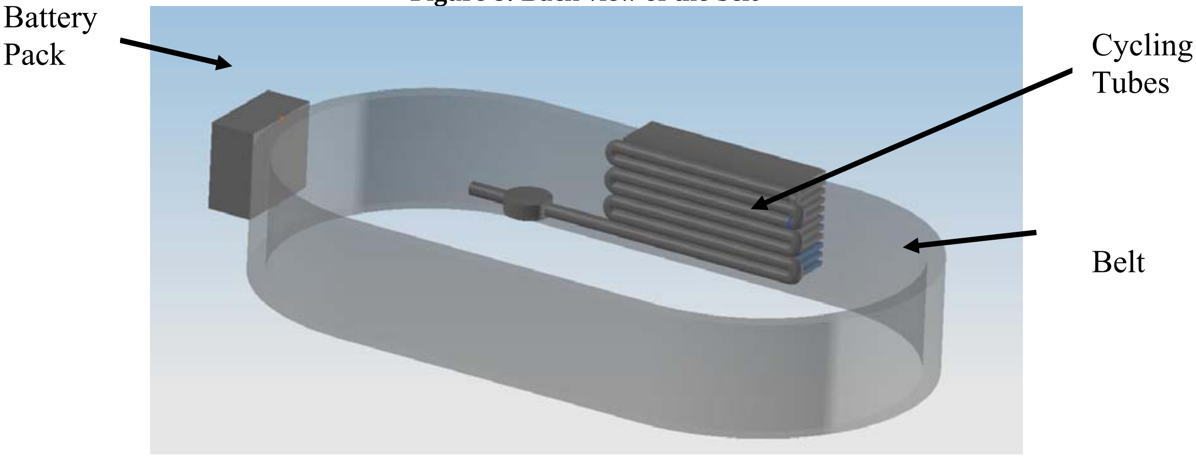
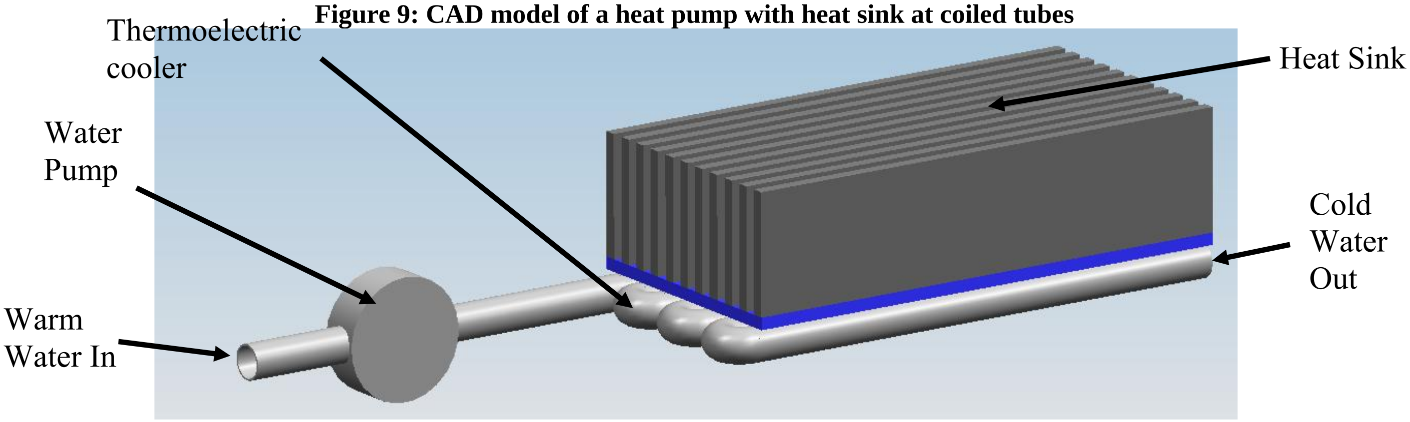


Figure 8: Back view of the belt



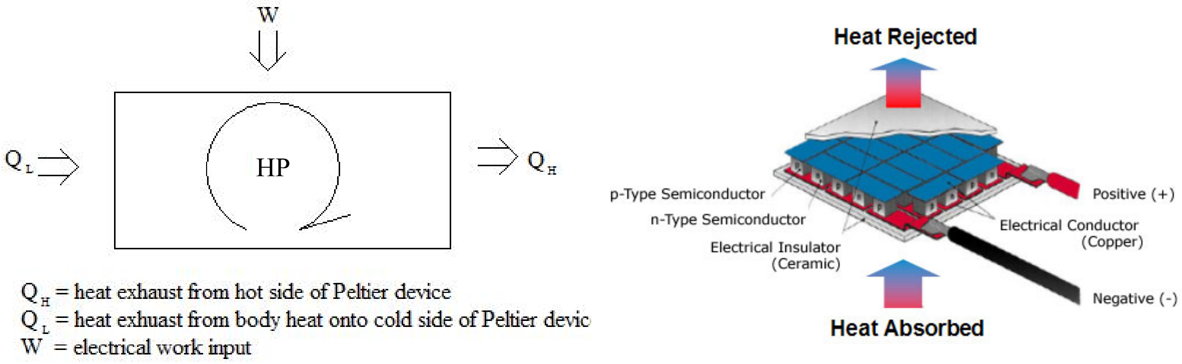
The heat exchanger is located on the backside of the wearer and will be attached to a belt (See Figure 9). The weight of the heat exchanger will be supported at the waist. The five main components of the heat exchanger are the copper baffolding, the Peltier device, a heat sink utilizing fins, an aquarium pump, and a temperature controller. The cold side of the Peltier device will touch against the baffolding to remove heat from the cycled water. The heat sink will straddle the hot side of the Peltier device and remove the heat ejected and then exhaust it to the ambient. This system is modeled thermodynamically as a heat pump as seen in Figure 10. The aquarium pump is located at the inlet of the heat exchanger and will cycle water throughout the whole vest.

Figure 9: CAD model of a heat pump with heat sink at coiled tubes



The battery pack will be attached to a belt and will generate the power requirements for the electrical components of the Water Cooling Vest. The battery will be attached in such a way that it is easy for a nurse to reach around and swap the battery pack, even in the middle of a surgery. The batteries that will power the electrical components will likely be Nickel Metal-Hydride, Lithium Ion, or Lithium Iron Phosphate, depending on which fulfills our energy requirements the best.

Figure 10: Thermodynamic Representation of Peltier Device modeled as a Heat Pump [1



PARAMETER ANALYSIS

In order to ensure that our prototype can be manufactured properly, we have broken our prototype into subcomponents for analysis. We will analyze different thermodynamic and electrical systems and design each one individually to meet engineering specifications. First, we determine the vest material, tube material and tube size. The materials and dimensions we choose must have an overall thermal resistance low enough to allow heat to exit the body and enter the moving water. Subsequently, we create a thermodynamic model for the cooling vest. This will determine the heat transfer that the vest can produce with different variables in design. Heat transfer will be different depending on the tube arrangement on the vest, so we must also consider different tube arrangements to find the best one.

Once the vest is designed, we must find a pump that can pump the water at a mass flow rate that maintains laminar flow and high convective heat transfer. Since the pump takes it from both ends, the pump will re-gain energy that would otherwise be lost to gravity: however, the pump still must overcome this initial pressure due to height. Next, we must design a heat exchanger that will straddle the cold side of the thermoelectric cooler to remove heat from the water. The heat exchanger must be able to remove heat from the water equal to the heat that is absorbed by the tubes in the vest. We will then attach a heat sink and fan to the hot side of the thermoelectric cooler to exhaust heat from the cooler. The heat sink and fan must be able to remove all heat exhausted from the thermoelectric cooler. The parts involved and its respective values can be summarized in a functional diagram of Figure 11 and Table 5.

Figure 11: Functional Diagram of Water Cooling Vest

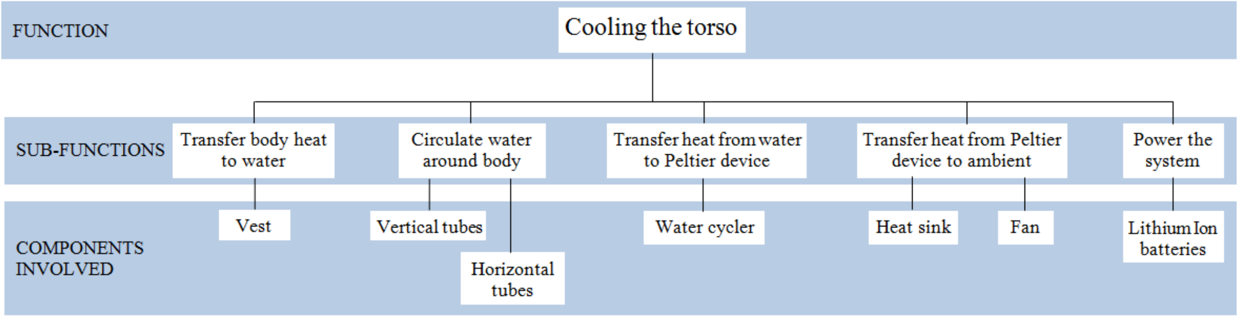


Table 5: Parameters Involved in Cooling Analysis

Parameters	Values
Removable Heat From Body	60 W
Vertical Tubes	2 symmetrical manifolds with 1/2" Outer Diamater and 3/8" Inner Diameter
Horizontal Tubes	10 tubes with 3/8" Outer diameter and 1/4" Inner Diameter
Maximal Heat Removed by Peltier device	120 W
Heat Sink's Resistance	0.15 °C/W
Water Pump's Pump Head	0.0649m

Vest

The vest that holds the tubes will made out of nylon material. To make our decision, we restricted the selection criteria to durablity and weight of the vest. The vest has to have high durablity which is represented by a high yield strength (elastic limit). This would allow the vest to be flexible and do not restrain the body movement. Another important criteria that we put into consideration is the Young's Modulus. The vest has to withstand the weight of the tubes and manifolds when they are sewn onto it. And therefore should have a moderately high Young's Modulus.[Refer to Appendix E]

Both diagram in Appendix E shows that polyamides (nylon) has high values for the two parameters which lead us to select nylon as the best materials to build the vest. Our choice is further supported by the low cost of nylon material. From Cambridge Engineering Selector (CES) Edupack 2008, nylon has the following properties as shown in Table 6.

Table 6: Properties of Nylon

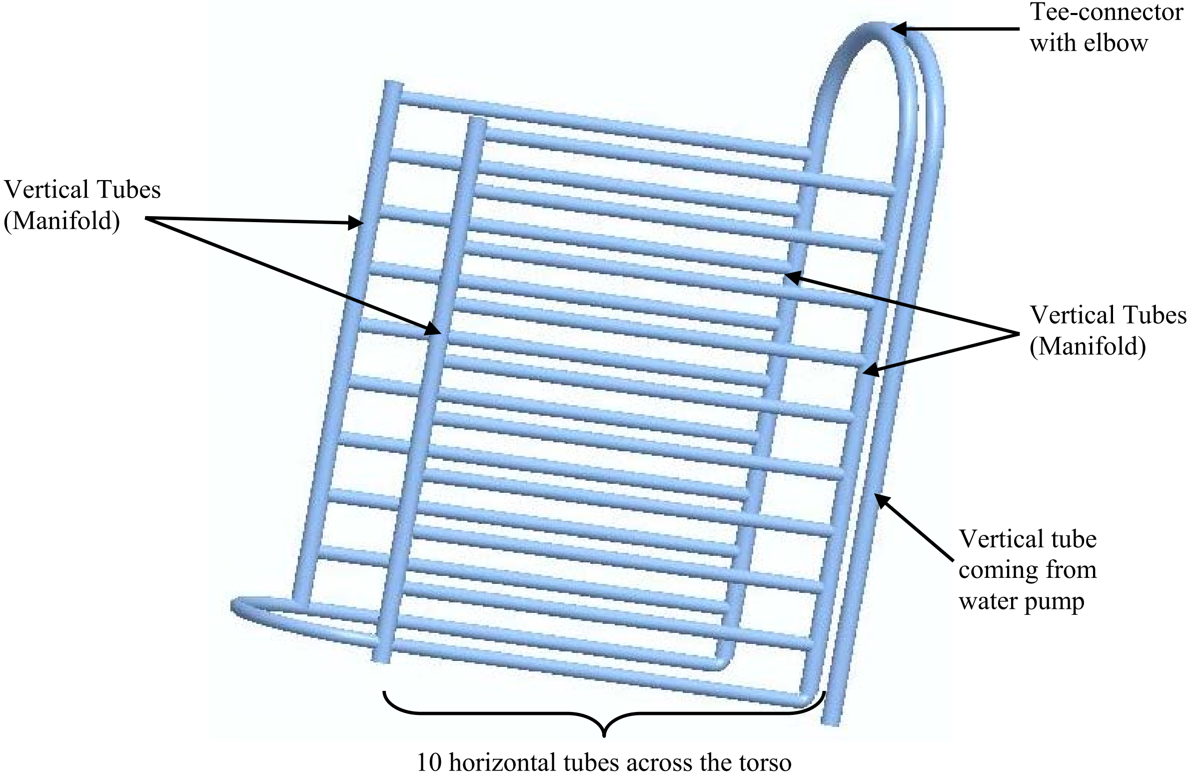
Properties	Value
Density	1.12 -1.14 x 10^3 kg/ m^3
Yield strength	50 - 94.8 MPa
Young's Modulus	2.62 – 3.2 GPa
Price	3.55 - 3.91 USD/kg
Thermal conductivity	0.23 - 0.25 W/mK

Tubes

In the alpha design, water flows in a single tube from the heat exchanger to the torso. The tube was arranged in loops to maximize the heat transfer between the body and the flowing water. This method would be inefficient according to Prof. Borgnakke who stressed that having a long tube has poor heat transfer because the cooling fluid will have reached the steady state temperature of the body before it completes the closed loop. The wearer of the tube will feel an obvious temperature gradient from one end to the other and that defeats the purpose of our design to have a uniform temperature distribution.

Therefore, for the prototype, we changed our tubes design to be in a manifold form (Figure 12). The front and the back will by symmetrical. On one side, the tubes layout consist of 2 vertical tubes (manifold), 12 inches apart with 10 tubes going across the 2 vertical tubes.

Figure 12: Tubes Layout



Vertical Tubes (Manifold)

All the vertical tubes will have an outer diameter of 1/2” and an inner diameter of 3/8”. This restriction is due to our customer requirements of having a vest with a low bulk, less than 1” in thickness. The first vertical tube (from pump to shoulder) will transfer water efficiently from the water pump up to the shoulder as it splits to the front and back manifold tubes. For the manifold, we are looking for good sturdiness and the transfer capability. A larger fluid flow through the manifold is necessary as the manifold will continue to branch out to the smaller tubes that run across the torso. Therefore, the manifold’s inner diameter should be larger than the horizontal tubes’ inner diameter. Tubes larger than 1/2” outer diameter are discarded because it will add volume to the flowing water and weight to the vest. Based on Eq. 11, Table 7 summarizes the weight of the water on the wearer with different inner diameter tubes. Smaller than 3/8” outer diameter are discarded because the manifold would have to withstand the water pressure from the pump and distribute the water through the horizontal tubes.

Horizontal Tubes

The horizontal tubes are designed to have good thermal conductivity and low density. These two parameters drive the tube selection because we require a good heat transfer between the body and the flowing water but at the same time maintaining a low overall weight of our cooling vest. The availability, cost and the hardness of the tubes material will contribute to our final decision. We will be using off the shelf tubes because thermally conductive polymer tubes require a high cost to order and are to be ordered in bulk.

The horizontal tubes have a smaller diameter as compared to the vertical tubes to encourage water flow and maintain a small fluid weight. We decided to use a 1/4” inner diameter tube with 3/8” outer diameter. This tube dimension is decided because it is easily obtainable from off the shelf. The 1/16” thickness of the tubes is the minimum thickness of tubes that can be obtained for a 1/4” inner diameter. Any horizontal tubes smaller than the one decided is going to cause a higher resistance to water flow and force water to flow across too fast to allow for a good heat transfer time. The weight of the water would increase tremendously too if the tubes diameter is increased. Table 7 shows the weight of the water on the vest with different diameter tubes. The horizontal tubes will always have a smaller diameter than the manifold tubes because the mass flow will have to be split to a tenth.

Table 7: Weight of Water with Different Tubes' Inner Diameter

Inner diameter of Manifold (in)	Inner diameter of Horizontal Tubes (in)	Weight of water
3/4	1/2	1.97 kg
1/2	3/8	1.06 kg
3/8	1/4	0.49 kg

Based on table 7, we tried to maximize the tubes’ diameter because bigger volume would encourage better heat transfer while trying to keep the weight of the water near our target value of 0.567kg (1.25 lb). The table showed that the inner diameter that we choose for both the manifold and the horizontal tubes will suffice.

The material selection is done based on thermal conductivity, density, price and availability. The most common tube materials that can be found off the shelf are polyethylene, vinyl, latex, nylon, copper and steel. Based on the formula on Appendix F, the resistance per length, $R_{t,cond}'$ (m·K/W) should be minimized. The resistance of the transfer depends on the thickness, t (m), inner radius, r_i(m) and thermal conductivity, k (W/m·K) of the tubes. Our objective is to minimize $R_{t,cond}'$ by using thin tubes with a moderately high thermal conductivity. Metals are discarded as our tube material because they are heavy and rigid. The other material that we researched upon is a cooling polymer that has a higher than usual thermal conductivity as compared to other polymers (COPE, TPE) [9] but is discarded because the manufacturer do not produce in small quantities and the price is beyond our desirable budget.

Table 8: Materials and Deciding Parameters

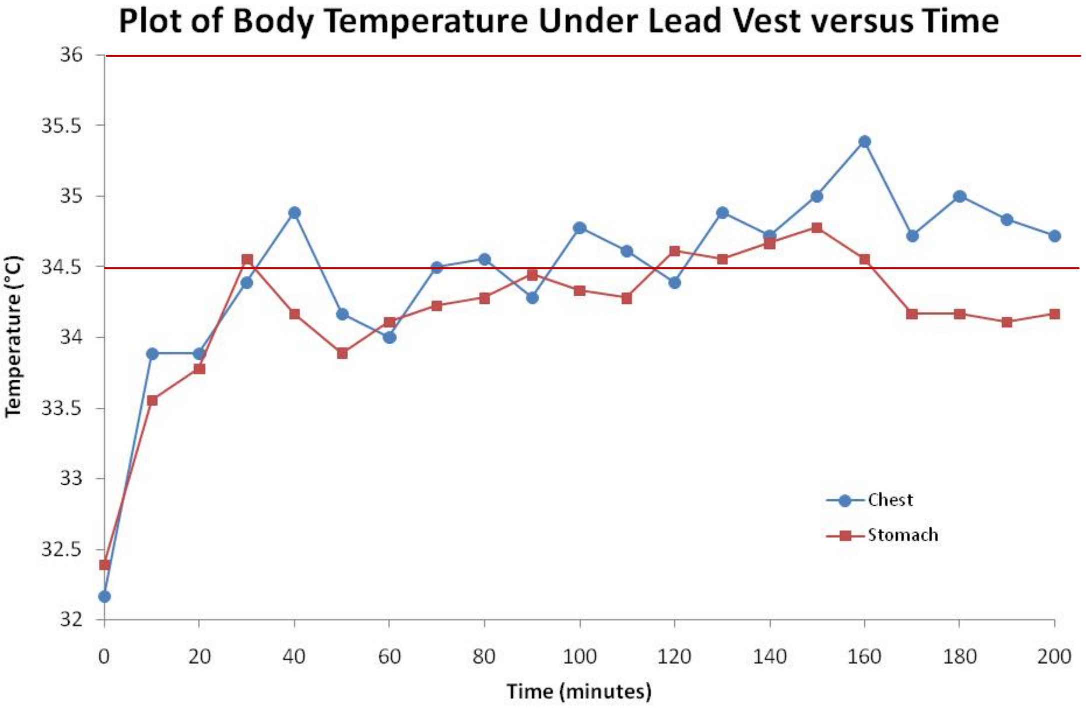
Material	Average Conductivity, k (W/m·K)	Average Density, ρ (kg/m)	Average Price, $ (US dollars)	Resistance per length, $R_{t,cond}'$ (m·K/W)
Polyethylene	0.419	950	1.95	0.085
Vinyl	0.22	1440	1.60	0.162
Latex	0.12	925	2.51	0.296
Nylon	0.243	1130	3.73	0.146
Copper	275	8935	7.07	0.0001
Stainless Steel	18	7850	8.09	0.002
COPE	2.3	1470	88.18	0.015
TPE	3	1250	110.23	0.012

Our final decision is polyethylene because it has the lowest resistance compared to the other polymer materials. The CES EduPack 2008 is also used to support our final decision [refer to Design For Manufacturability Section]. Table 8 shows the specifications of the materials based on the CES EduPack 2008.

Body Temperature Analysis

To obtain the skin temperature change of a wearer of the lead vest, an experiment was conducted by taking temperature measurements on the chest and abdominal area of a typical wearer. Using a type 'K' thermocouple manufactured by Digi-Sense®, we obtain temperature readings accurate to 0.1°C. The experiment is carried out for 200 minutes to obtain a stable steady state temperature under the lead vest. The graph of body temperature, T (°C) versus time (minutes) is plotted. Based on the result obtained in Figure 13, it can be deduced that the body temperature will reach a steady state temperature after more than 50 minutes on the lead vest. The steady state temperature fluctuates in the range of 34°C – 35.5°C. The body temperature should ideally be kept below that range and therefore, the comfortable skin temperature is set to be 33°C for the construction of our thermodynamic model.

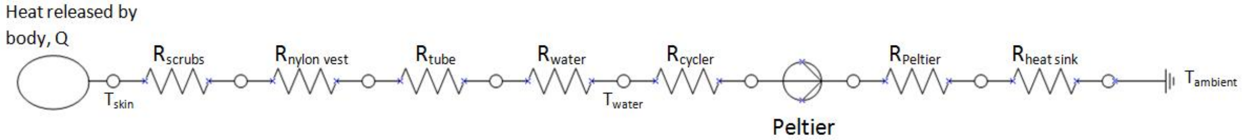
Figure 13: Body Temperature (°C) versus Time (minutes)



Determination of Removable Heat based on Thermodynamic Model

A major problem area for our design is to determine the amount of cooling provided by the vest while keeping the weight to a minimum. To determine this, a thermodynamic model is made. The purpose of this thermodynamic model is to determine the heat transfer rate from the surgeon's body to the water used as the cooling fluid. This value will allow us to determine if enough heat is removed from the body to maintain a comfortable skin temperature. This heat transfer rate will then determine the performance requirements of the thermoelectric cooler, since the amount of heat removed by the water from the body is the same amount of heat that must later be removed from the water by the thermoelectric cooler. This model will also determine the difference in water inlet and outlet temperature. This value must be relatively small, approximately one Kelvin difference in temperature so the wearer does not notice the temperature gradient. This value is affected by the heat transfer and the water mass flow rate determined by the pump. The model also determines the total mass of the vest including tubing and water mass. See Figure 14 for electrical equivalent of the thermal model.

Figure 14: Thermal Resistance Model



Prior to the construction of this model, the assumptions we make are:

1. Steady state conditions
2. Tube temperature is constant
3. Non-insulated tubes in thermo equilibrium with skin temperature
4. Heat transfer only through horizontal tubes
5. Manifold tubes (vertical) heat transfer is negligible compared to the horizontal tubes so it is neglected

Resistance to heat transfer

The total resistance to heat flow, $\boldsymbol{R_{eq}}$ (K/W), can be determined by adding the individual resistances since they are in series in our model [Eq. 1 and Fig 14], so each individual resistance must be calculated. The resistances to conductive heat transfer through a flat surface; such as through the scrubs, nylon, and the aluminum water cooler, is determined using Eq. 2 by inputting the material thickness, $\boldsymbol{t}$ (m), the surface area, $\boldsymbol{A}$(m^2), and conductivity, K (W/m·K), but each using their respective material properties shown in Table 9. The resistance to conductive heat transfer through a rounded tube is determined using Eq. 3 by inputting the tube thickness, $\boldsymbol{t}$ (m), conductivity, K (W/m·K), the outer diameter of the individual horizontal tube D_{oh} (m), and the inner diameter of the individual horizontal tube D_{ih} (m), with the required material properties in Table 9 and 10. This requires the material properties to determine the value of resistance. For heat transfer through convection, which occurs between the water in the tube and the tube wall, the flow properties and material properties determine the resistance to heat transfer. The Reynolds number, $\boldsymbol{Re_D}$ shown in Eq. 4, is calculated using the individual horizontal tube mass flow rate, $\dot{m}_i$ (kg/s), the inner diameter of the individual horizontal tube, D_{ih} (m) and viscosity, μ

($N \cdot s/m^2$) to determine the type of flow experienced throughout the tubes. This allows us to choose the proper equation for the Nusselt number, $\boldsymbol{Nu_D}$. The water flow will always remain laminar since the Reynold's number remains below 2300, the water in the tubes has a Reynold number of 656, so in this case the Nusselt number is a constant value shown in Eq.5, for a tube at constant temperature as in this case. The convection coefficient, *h* ($W/m^2 \cdot K$) can then be determined using Eq. 6. The resistance in turn is determined using Eq. 7 with the value of h, D_{oh}, D_{ih} and the individual horizontal tube length, L_h. The values for the resistance to heat transfer for the Peltier and the heat sink were quoted from the part manufacturer.

$$\boldsymbol{R_{eq} = \Sigma R_{ind}\ (in\ series)} \qquad Eq.1\ [10]$$

$$\boldsymbol{R_{conduction} = \frac{t}{KA}} \qquad Eq.2\ [10]$$

$$\boldsymbol{R_{tube\ conduction} = \frac{\ln\left(D_{oh}/D_{ih}\right)}{2\pi t K}} \qquad Eq.3\ [10]$$

$$\boldsymbol{Re_D = \frac{4\dot{m}_i}{\pi D_{ih}\mu}} \qquad \text{Eq. 4 [10]}$$

$$\boldsymbol{Nu_D = 3.66} \qquad \text{Eq. 5 [10]}$$

$$\boldsymbol{Nu_D = \frac{hD_{ih}}{K}} \qquad \text{Eq. 6 [10]}$$

$$\boldsymbol{R_{convection} = \frac{1}{h*\left({}^{1}/{}_{2}\pi D_{oh}L_h\right)}} \qquad \text{Eq .7 [10]}$$

For a prescribed horizontal tube length, inlet water temperature, T_i (K), outlet water temperature, T_o (K), and mass flow rate, $\boldsymbol{\dot{m}}$ (kg/s) can be determined using Eq. 8 to 10 and knowing the ambient temperature, T_∞ (K). Then by solving for T_o, the total heat transfer from body to vest can then be determined, and is equal to the amount of heat transfer from the body to the individual tube multiplied by the number of horizontal tubes.

$$\boldsymbol{\dot{Q} = \dot{m}C(T_o - T_i) = \frac{\Delta T_{lm}}{R_{eq}}} \qquad \text{Eq. 8[10]}$$

$$\boldsymbol{\Delta T_{lm} = \frac{T_o - T_i}{\ln\left(\frac{T_\infty - T_o}{T_\infty - T_i}\right)}} \qquad \text{Eq. 9[10]}$$

$$\boldsymbol{\frac{T_\infty + T_o}{T_\infty + T_i} = e^{-\frac{1}{m\dot{C}R_{eq}}}} \qquad \text{Eq .10[10]}$$

Weight Equations for Vest, Water and Tubes

The weight of the vest is determined by the volume of water and volume of tube material multiplied by its respected density.

$$Volume_{water} = N\pi L_h\left(\frac{D_{ih}}{2}\right)^2 + 4\pi L_m\left(\frac{D_{im}}{2}\right)^2 + \pi L_{extra}\left(\frac{D_{im}}{2}\right)^2 \qquad \text{Eq. 11}$$

$$Volume_{tubes} = N\pi L_h\left(\frac{D_{oh} - D_{ih}}{2}\right)^2 + 4\pi L_m\left(\frac{D_{om} - D_{im}}{2}\right)^2 + \pi L_{extra}\left(\frac{D_{om} - D_{im}}{2}\right)^2 \quad \text{Eq. 12}$$

$$mass\ of\ vest = \rho_{water}\, Volume_{water} + \rho_{tubes}\, Volume_{tubes} \quad \text{Eq. 13}$$

The inputs and analysis equations will be organized into a Microsoft Excel file [Appendix G] allowing for rapid adjustment of the input variable parameters, depending on available products, until we are satisfied that the heat transfer and vest weight requirements are met. Once we are satisfied we will know all product requirements relating to the cooling vest, either by direct input, such as tube sizes, or indirectly, such as battery capability which is determined by the thermoelectric cooler requirements.

Non-varying parameters for the Thermodynamic Model

Some of the properties of the thermodynamic model are predetermined by the medium of cooling, vest material and the tubes dimension. These are represented by table 9.

Table 9: Non-Varying Parameters in the Thermodynamic Model

Parameters	Values
Water properties: [10]	
Viscosity, μ	855×10^{-6} N·s/m^2
Specific heat, C	4180 J/kg
Conductivity, K_w	.613 W/m·K
Density, ρ_w	998 kg/m^3
Vest properties: Nylon [10]	
Conductivity, K_n	.25 W/m·K
Thickness, t_v	1 mm
Scrub uniform properties: 50% Cotton 50% Polyester [10]	
Conductivity, K_s	.09 W/m·K
Thickness, t_s	1 mm
Skin (refer to figure 13)	
Comfortable skin temperature, T_s	33°C (93.13 ^{o}F)

Varying parameters for the Thermodynamic Model with chosen values

These parameters are adjusted accordingly to obtain the optimal heat and temperature output.

Table 10: Varying Parameters in the Thermodynamic Model

Parameter	Value
Total number of horizontal tubes, N	20
Total mass flow rate, $\dot{\boldsymbol{m}}_{tot}$	.056 Kg/s
Individual mass flow rate, $\dot{\boldsymbol{m}}_i$	.0028 Kg/s
Horizontal tube length, L_h	12 in
Horizontal tube inner diameter, D_{ih}	.25 in
Horizontal tube outer diameter, D_{oh}	.375 in
Manifold tube length, L_m	15 in
Extra manifold tubing, L_{extra}	13 in
Manifold tube inner diameter, D_{im}	.375 in
Manifold tube outer diameter, D_{om}	.50 in
Density of tube material, ρ_t	910 Kg/m^3
Conductivity of tube material, K_t	.41 W/m·K

Properties determined from models

All the products required to achieve these cooling results are available to purchase. The thermoelectric cooler utilized has a higher cooling capability then required to provide extra cooling during excessively hot situations, but requires extra power. The difference in properties is shown in table 11.

Table 11: Properties Calculated from Thermodynamic Model

Parameter	Value at 18V 5A into Thermal Electric Cooler
Total heat transfer rate from body, $\dot{\boldsymbol{Q}}$	59.27 W
Water inlet temperature, T_i	20 ^{o}C (68 ^{o}F)
Water outlet temperature, T_o	20.24 ^{o}C (68.425 ^{o}F)
Change in water temperature, ΔT	.24 ^{o}C (.425 ^{o}F)
Total mass of vest, M_{vest}	1.82 lbs
Total thermal resistance of cooling vest, $R_{Vest,tot}$	4.45 K/W

Selection of Thermoelectric Cooler

The main constraints for choosing a thermoelectric cooler for the cooling system are the maximum heat to be removed from the body and the power requirements. For this system, to be able to achieve different temperatures to be used for cooling, the thermoelectric cooler must be able to remove a minimum of 60W (refer to table 11 for total heat transfer rate) of heat as determined by the thermodynamic model of our system.

There are two more conditions that must be taken into consideration. The cold side of the thermoelectric cooler must not be at or below the dew point of the ambient air. If the temperature reaches this dew point temperature, water in the air will begin to condensate and can cause serious damage to the system. The operating room temperature can range between 65°F and 80 °F (18.3°C and 26.6°C) as taken by our team. The dew point can be found using the following equation.

$$Tf_d = Tf - \frac{(100-RH)}{2.778} \qquad \text{Eq. 14}$$

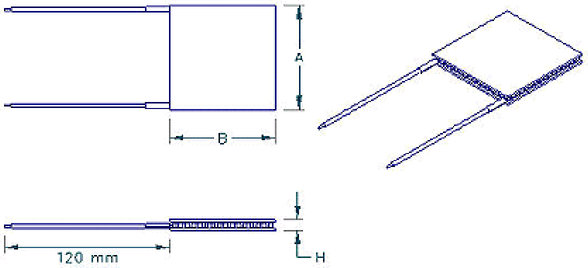
$Tf_d$and Tf are the dew point temperature and the ambient temperature of the air in degrees Fahrenheit respectively. RH is the relative humidity of the ambient air. The calculated dew point temperatures for relative humidity between 50 and 70 percent are as shown in Table 11.

Table 12: Dew Points at different ambient temperature

Ambient Air Temperature(°F)	Dew Point at 50% RH(°F)	Dew point at 70% RH(°F)
65	47	54.2
80	62	69.2

The other constraint is that the thermoelectric cooler cannot be overpowered. According to TE Technology, Inc if overpowering occurs, the temperature ratings can be exceeded and this can cause permanent damage as well. [11]

Figure 15: HP-199-1.4-1.15 with dimensions 40 X 40 X 3.6 mm (A X B X H)



For our cooling vest the thermoelectric cooler that is going to be used is the HP-199-1.4-1.15 from TE Technology, Inc. This thermoelectric cooler provides a maximum heat removal of 120 watts at a maximum voltage and current of 24.6V and 7.9A respectively [Appendix H]. According to TE Technology, Inc when maximum efficiency is wanted the thermoelectric cooler should be run at 1/3-2/3 of the maximum voltage and current. Within this operating range the cooler can remove between 48 watts and 95 watts of heat. Our operating voltage within this range is between 8.2V and 16.4V. The operating current will be between 2.63A and 5.27A. To protect against condensation the operating temperature difference (T_{Hot}-T_{cold}) across the thermoelectric cooler will be kept at below a 10 degree difference.

Water Pump

We need to determine the pump head we need for our cooling system to find the appropriate pump which could overcome the resistance in the tube and height elevation. Every pump has its own pump head value which is a measurement of how strong a pump is. The unit of pump is in unit of meter [m].

In the process of selecting the suitable pump for the cooled vest, we started with the first step of selecting a pump which has a reasonably volume flow rate. With the volume flow rate, it is converted to mass flow rate and the fluid velocity flowing through the tubes can be calculated. The fluid velocity is important to determine the Reynold's number which is going to decide the friction factor. The sum of friction factor gives the fluid head loss which can be converted to pump head. If the given pump head value from the pump specification is higher than the calculated pump head, we can verify that the selected pump has the capability of pumping the water throughout the tubes.

Resistance to Fluid Flow

Fluid flow in a tube is subjected to various resistances which are a result of the frictions within the tube. There are two kinds of friction occurring in the tube; friction between fluid and tube, and between fluid and the adjacent layers of fluid. The former is influenced largely by the inner roughness of the tube which affects the type of flow in the tube. A high inner roughness of a tube creates eddy currents which potentially build up turbulent flow in a tube when the eddy currents become large.

On the other hand, friction between the fluid and the adjacent layers of fluid is resulted from the sliding of layers of fluid sliding against each other. This friction is known as the fluid's viscosity which describes the fluid's internal resistance to flow. There are two kinds of viscosity; dynamic and kinematic viscosity.

Dynamic viscosity

Dynamic viscosity is ratio of the shear stress acting along any plane between adjacent plane in a fluid elements and the rate of deformation of the velocity gradient perpendicular to this plane. The dynamic viscosity could not be used as the viscosity to calculate the Reynold's number. The dynamic viscosity must be converted into its kinematic viscosity equivalent before the viscosity value could be used to determine Reynold's number.

Temperature Effect on the Dynamic Viscosity

Dynamic viscosity is dependant of the temperature of the fluid flow. Therefore, to get the correct value, the dynamic viscosity has to be obtained at the operating temperature of the water flowing in the vest. There are three locations in the cooling system which has different temperature; inlet of the manifold, in the tube across the trunk, and outlet of the manifold. The temperature in the tube over the trunk is the average temperature of the inlet and outlet of the manifold. This is shown below.

Table 13: Temperature at Three Locations in the Cooling System

Location	Temperature (^{0}C)
Inlet of the manifold	20.00
In the tube over the trunk	20.26
Outlet of the manifold	20.52

Since the change of temperature is very small, the change of dynamic viscosity is insignificant. Therefore, the dynamic viscosity is constant throughout the cooling system. The dynamic viscosity of water at 20 ^{0}C is 1.003 x 10^{-3} kg/ms.[12]

Kinematic Viscosity

Kinematic viscosity is the ratio of dynamic viscosity to density. The density of water at 20 ^{0}C is 998.0 kg/m^3. [12] The calculation of kinematic viscosity is shown below.

$$\text{Kinematic Viscosity, } \nu = \frac{Dynamic\ Viscosity,\mu}{Density,\rho} \qquad \text{Eq.15}$$

$$= \frac{1.003 \text{ x } 10^{-3} \text{ kg/ms}}{998.21\ kg/m^3}$$

$$= 1.005 \text{ x } 10^{-6}\ m^2/s$$

Conservation of mass

Conservation of mass states that the total mass of a closed system is the constant. In other words, the mass flow rate across any cross sectional area in tube of a closed system is the constant everywhere in the tube. However, if the tube is split into two, the mass flow rate of each of the tube is half of the original mass flow rate.

The selected pump has volume flow rate, $\dot{V}$of 3.8 liter/minute.

Converting volume flow rate to mass flow rate:

$$\text{Mass flow rate, } \dot{m} = \frac{\dot{V}}{\rho} \times \frac{1000}{60} \qquad \text{Eq.16}$$

$$= \frac{3.8}{998.0} \times \frac{1000}{60}$$

$$= 0.0635\ kg/s$$

where $\dot{V}$ is the volume flow rate (liter/minute), ρ is the density (kg/m^3)

1. Mass flow rate at the manifold

   The cold water flow coming out of the pump is connected to two manifolds which bring the cold water across the trunk and back of the body. Therefore, the mass flow rate into each of the manifold is half of the mass flow rate out of the Pump.

$$\text{Mass flow rate into each manifold, } \dot{m}_{manifold} = 0.5 \times \dot{m}_{pump} \qquad \text{Eq. 17}$$

$$= 0.5 \times 0.0635\ kg/s$$

$$= 3.175 \times 10^{-2}\ kg/s$$

2. Mass flow at the tubes

   There are nine tubes branching out from the manifold. Thus, the mass flow rate branching out to each tube is one ninth of the mass flow rate of the manifold.

$$\text{Mass flow rate into each tube, } \dot{m}_{tube} = \frac{1}{10}\dot{m}_{manifold} \qquad \text{Eq. 18}$$

$$= \frac{1}{10} \times 0.03175\ kg/s$$

$$= 3.175 \times 10^{-3} kg/s$$

   Calculating the fluid velocity:

$$\text{Fluid velocity, } v = \frac{\dot{m}}{\pi r^2 \rho} \qquad \text{Eq. 19}$$

   where $\dot{m}$ is the mass flow rate (kg/s), r is the radius of the tube (m), ρ is the density (kg/m^3)

Because the manifold and the tube across the trunk have different radii, the fluid velocities are shown in table 14.

Table 14: Different Flud Velocities across Different Segments of Tubes

Types of tube	Radius, (m)	Mass Flow Rate, (kg/s)	Fluid Velocity, (m/s)
Manifold	4.7625 x 10^{-3}	3.175 x 10^{-2}	1.51 x 10^{-3}
Tube across the trunk	3.175 x 10^{-3}	3.175 x 10^{-3}	0.100
Tube from pump to manifold	4.7625 x 10^{-3}	6.35 x 10^{-2}	0.893

Reynold's Numbers

Reynold's number is a dimensionless number that measures the ratio of inertial forces to viscous forces. It is used to characterize the type of fluid flow such as laminar of turbulent flow. Laminar flow happens at low Reynold's numbers where the fluid flow is constant and smooth. Whereas, turbulent flow occurs at high Reynold's numbers where there are many random vortices, eddies and other random fluid flow.

The formula for Reynold's number is shown below.

$$\text{Reynold's Number, } Re = \frac{Fluid\ Velocity \times\ Internal\ Tube\ Diameter}{Kinematic\ Viscosity} \qquad \text{Eq. 20}$$

The Reynold's numbers at those three locations (same as the dynamic & kinematic viscosity) are shown in Table 15.

Table 15: Reynold's Number at Three Locations of the Cooling Vest System

Location	Fluid Velocity, (m/s)	Inner Tube Diameter, (m)	Kinematic Viscosity, (m^2/s)	Reynold's Number, Re (dimensionless)
Manifold	1.51×10^{-3}	9.525×10^{-3}	1.005×10^{-6}	14.31 (laminar)
In the tube over the trunk	0.100	6.35×10^{-3}	1.005×10^{-6}	631.84 (laminar)
Tube from pump to manifold	0.893	9.525×10^{-3}	1.005×10^{-6}	8463.5 (turbulent)

Effect of the Inner Roughness of the Tube

Eddy currents in a tube are created by the inner roughness of the tube which increases the friction between the pipe wall and the fluid. Strong eddy currents can create turbulent flow in a tube. In the case of turbulent flow, the inner roughness of a tube can significantly affects the friction factor.

The type of polymer for the tube is polyethylene. Hence, the inner roughness of polythene, k is 0.001 mm. [13]

Friction Factor

Friction factor is determined by the type of fluid flow. A flow is laminar if Re ≤ 2300 whereas a flow is turbulent if Re ≥ 2300. The equation for getting the friction factor is shown below.

$$\text{Laminar (Re} \leq 2300\text{): friction factor, } f = \frac{64}{RE} \qquad \text{Eq.21[13]}$$

$$\text{Turbulent (Re} \geq 2300\text{): friction factor, } \frac{1}{\sqrt{f}} = -1.8log\left[\left(\frac{6.9}{Re} + \left(\frac{k}{3.7}\right)^{1.11}\right)\right] \qquad \text{Eq. 22[13]}$$

$$\text{where } k = \frac{inner\ tube\ roughness,(mm)}{inner\ tube\ diameter,(mm)} = \frac{0.001}{9.525} = 1.05 \times 10^{-4} \text{ [dimensionless]} \qquad \text{Eq. 23[13]}$$

Table 16: Reynold's Number at Three Locations of the Cooling Vest System

Location	Reynold's Number, Re (dimensionless)	Friction Factor [dimensionless]
Manifold	14.31 (laminar)	4.472
In the tube across the trunk	631.84 (laminar)	0.101
Tube from pump to manifold	8463.5 (turbulent)	0.0325

Fluid Head Loss

Friction factor obtained above is used to determine the fluid head loss. Fluid head is the measurement of the energy lost of moving fluid in a tube due to resistances in the tube. Fluid head loss can be determined from Eq. 24. Table 17 summarizes the fluid head loss of different locations on the tubes.

$$\text{Fluid head loss, } h = \left(\frac{fL}{D}\right) \times \left(\frac{v^2}{2g}\right) \qquad \text{Eq. 24[13]}$$

where f = friction factor (dimensionless), L = length of pipe work (m),
d = inner diameter of pipe work (m), v = velocity of fluid (m/s)
g = acceleration due to gravity (m/s^2)

Table 17: Fluid Head Loss

Location	Length, (m)	Inner Tube Diameter, (m)	Fluid Velocity, (m/s)	Friction Factor (dimensionless)	Fluid Head Loss, (m)
Manifold	0.594	9.525×10^{-3}	1.51×10^{-3}	4.472	2.146×10^{-2}
In the tube across the trunk	0.2794	6.35×10^{-3}	0.100	0.101	2.265×10^{-3}
Tube from pump to manifold	0.3302	9.525×10^{-3}	0.893	0.0325	4.579×10^{-2}
				Total Fluid Head Loss	6.952×10^{-2}

Pressure drop

In order to select the appropriate pump that could push the water throughout the cooling vest system, the pressure drop across the cooling vest system must be smaller than the pressure drop that can be achieved by the pump.

The equation to calculate the pressure drop is shown below.

$$\begin{aligned} \text{Pressure drop, } Pd &= h\rho g \qquad \text{Eq. 25} \\ &= 6.952 \times 10^{-2} m \times 998 kg/m^3 \times 9.81 m^2/s \\ &= 680.58\ Pa \end{aligned}$$

where Pd = pressure drop (Pa), h = total head loss (m), ρ = fluid density (kg/m3) and g = acceleration due to gravity (m/s^2)

Converting Pascal to pump head:

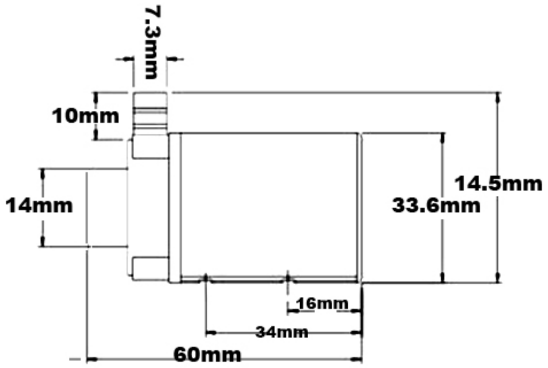
$$\text{Pump Head} = 680.58 Pa \times 10.197 \times 10^{-5} = 0.0694\ m \qquad \text{Eq. 26}$$

The pump head needed to push the water throughout the cooling vest system is 0.0694 m.

The smallest head pump that could be found is the DC 12V mini water pump, weighing 103 grams. The pump head of this pump is 2m which is a strong pump for our cooling system. The figure and dimensions of the pump are shown in Figure 16 and 17 respectively.

Figure 16: DC 12V mini pump [20]

Figure 17: Dimension of the DC 12V mini pump [14]



The description of the pump is shown in table 18. The pump takes only 5.4 watts of power.

Table 18: DC 12V Pump Description

Description	**Value**
Rated Voltage	12 Voltage
Rated Current	0.45 Ampere
Capacity	3.8 Liter/ minute
Pump Head	2.5 meter
Motor	DC brushless motor
Pump	Centrifugal pump
Working Life	20,000 hours

Change in Heat Removed and Temperature Difference with Mass Flow Rate

The change in mass flow rate could potentially affect our temperature difference across the tube and the heat removed. At a constant thermoelectric cooler power, if the pump can produce a high mass flow rate with good efficiency, we would be able to get more heat removed with a minimal temperature distribution, implying a more efficiency cooling system with a small temperature gradient. The pump can potentially pump 0.06 kg/s but due to an increase in gravitational potential, the maximum flow around the loop is calculated to be 0.054 kg/s. What we must take into account is extra losses due to the use of a non-ideal pump, but figure 18 and 19 shows that our heat removal rate from the body will be sufficient with the horizontal tubes with a small temperature gradient.

Figure 18: Change in Heat Removed versus Mass Flow

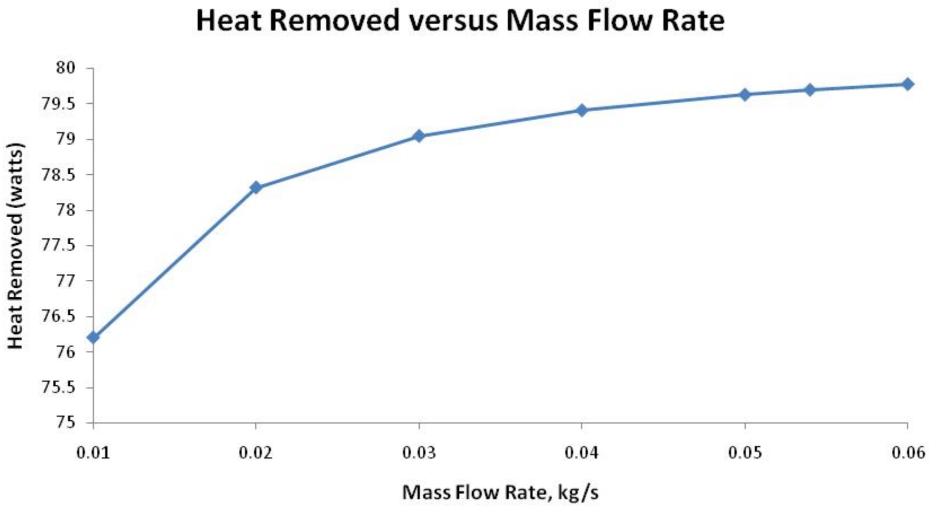
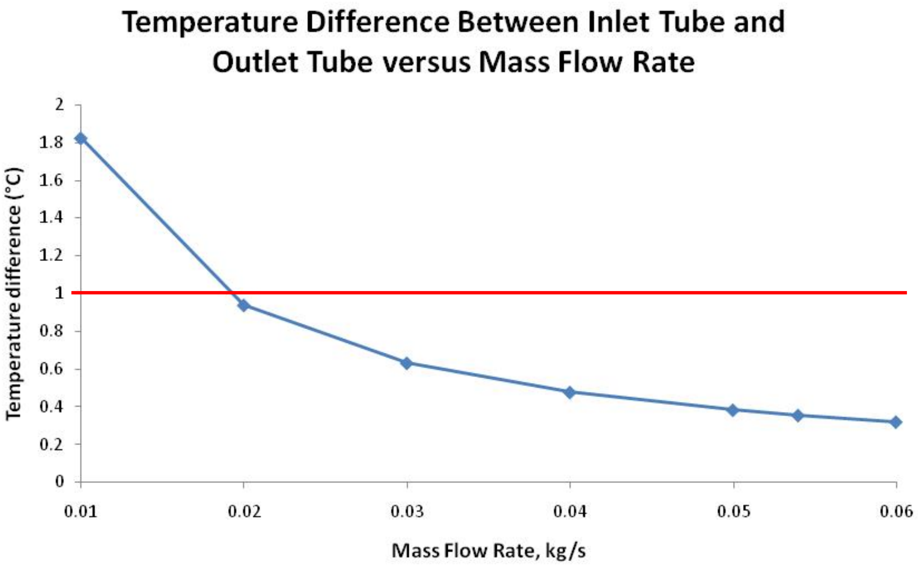


Figure 19: Change in temperature difference across the tubes versus mass flow



Heat Sink and Fan

The hot side of the thermoelectric cooler will stay at T_{Hot} between 42^oC and 48^oC based on the graph at Appendix H to operate efficiently. The ambient air temperature is at $T_\infty = 22.8^oC$ or 73°F in the operating room as recorded by our team members. The thermoelectric cooler is modeled as a heat pump as shown in figure 10 and should therefore follow Eq. 27, and we can determine the required amount of heat that must be removed through the heat sink. A heat sink was chosen based on its heat transfer resistance, quoted by the manufacturer [15]. The resistance is calculated to be $R_{h.sink} = 0.128$ °C/W ~ 0.168 °C/W. From Appendix I, we determine the FS10040 model to be a sufficiently good heat sink because it releases all heat from the hot site of the thermoelectric device.

$$Q_H = Q_L + \dot{W} \qquad \text{Eq. } 27$$

The FS10040 heat sink model has a thermal resistance of 0.15°C/W and weighs 402 g having the dimension of 122mm × 98mm × 40mm with flanges on the side. The heat sink will be equipped with a fan to enhance heat transfer through forced convection. The M92P fan manufactured by Oriental Motor has a speed of 3400 RPM and draws 0.24A, 12V. It will sit on top of the heat sink and will be sufficient to release the heat produced by the thermoelectric cooler to the ambient.

Battery Supplies and Electrical Components

Our cooling vest requires a vast amount of electrical energy to operate. Since our client has requested that the vest be self sufficient, we are not able to use electrical outlet power. Our team has chosen to power the vest using batteries that are lightweight, cost effective, reusable, and provide enough energy to allow the vest to operate throughout the duration of the client's surgeries. The batteries will likely utilize multiple batteries in the form of a battery pack. Our team has researched many different rechargeable battery options and selected a battery pack option that we believe will deliver our client's requirements.

Our team decided that in order for the battery pack to provide us enough electrical power, the battery pack would weigh no more than two pounds, provide 2-8 hours operation time, have a maximum voltage, V_{max} (volts) of 18 volts and a maximum current, I_{max} (ampere) of 6 amperes. We researched five different rechargeable battery technologies and compared each of these battery's characteristics to determine which would meet our engineering specifications the best. The five battery technologies are lead acid, nickel-cadmium, nickel-metal hydride, lithium-ion and lithium iron phosphate. For each battery, we determined the nominal voltage of an individual battery, the specific energy density, the volumetric energy density, the specific power density, and its average cost. The table 19 summarizes each battery's characteristics.

Table 19: Battery with its engineering specifications

	Voltage individual cell (Volts)	Specific Energy Density (Wh/kg)*	Volumetric Energy Density (Wh/L)*	Specific Power Density (W/kg)	Recharge Cycles (#)	Cost/Wh (US$/Wh)
Lead Acid	10.5 – 14.8	40	75	180	800	$0.17
Nickel-Cadmium	1.2 – 1.5	40	150	150	2000	$1.50
Nickel-Metal Hydride	1.2 – 1.5	90	300	1000	1000	$0.99
Lithium Ion	2.4 – 4.2	160	270	1800	1200	$4.27
Lithium Iron Phosphate	2.5 – 4.2	200	657	2000	2000	$9.30

*Wh represents Watthours

Besides these specifications, we also analyzed each battery by examining the applications in which it is used. The lead acid battery is utilized in automobiles and is heavy and large compared to the rest, but is resilient to heat and cold and can provide high surge currents. The Nickel-Cadmium battery is hazardous to the environment and wears easily, losing charge capacitance between charges. Nickel-Metal Hydride batteries improve on Nickel-Cadmium technology, but are susceptible to “memory” which causes the battery to prematurely lose energy capacity. Lithium Ion batteries must be carefully monitored so that its chemistry isn’t compromised which renders the battery useless. Lithium Iron Phosphate technology improves on the current Lithium Ion battery technology by increasing volumetric energy density, but comes at an increased cost.

Picking the battery to use

After examining our options, our group immediately eliminated lead acid and nickel-cadmium batteries. The lead acid battery is too heavy and cannot provide sufficient power. Nickel-cadmium batteries also cannot provide enough power. Nickel-Metal Hydride batteries provide sufficient power but do not come in high voltage battery packs. We eventually decided to use lithium ion and lithium polymer batteries because they provide enough power over a sufficient period of time without costing too much. We will also use individual battery sources for each electrical device: thermoelectric cooler, heat sink fans and water pump. Each battery pack will be tailored towards the individual specifications of the electrical device, and will utilize a battery pack configuration that increases the operation time of each electrical device. Operation time, t (seconds) for each battery pack electrical device combination is calculated using operating voltage, V_{device} (volts), operating current, I (ampere), energy capacity, Ah (ampere hours), and supply voltage, $V_{battery}$ (volts). (Eq. 28)

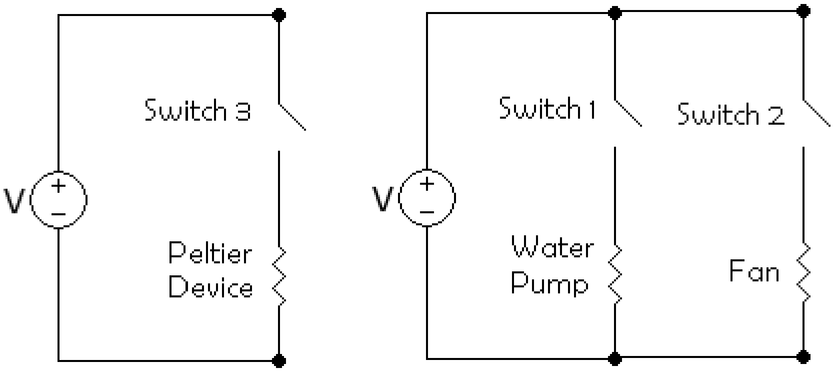
$$t = \frac{V_{battery}\,Ah}{V_{device}\,I} \qquad \text{Eq. 28}$$

The thermoelectric cooler will use five 3.7V 10Ah high capacity Li-Ion Polymer battery packs in parallel, which effectively creates an 18.5V 10Ah battery pack. The Peltier device requires 18V 5A to operate. Using Eq. 28, we determined that using this battery pack, the Peltier device can run for two hours on a single charge of this battery pack.

Since the water pump and heat sink fun are both 12V electrical devices, they will both be attached to the same battery pack. Our team has chosen a 12V 2.7 mAh Lithium Iron Phosphate battery, which will be wired to the water pump and heat sink fan in parallel. The water pump requires 12V .45A and the heat sink fan requires 12V .24A for a Thevenin equivalent 12V .69A electrical power consumption. Using equation 28, we determined that using this battery pack, the water pump and heat sink fan can operate for four hours on a single charge of this battery pack.

Each electrical device must be hooked up in a closed loop circuit to operate. Each component will have a switch to close the circuit, and the Peltier device will have a potentiometer in a parallel circuit to vary the voltage and current (Figure 20). This will allow the Peltier device to operate at a lower power output so that the temperature of the flowing water can be regulated.

Figure 20: Electrical circuit for each electrical device



Design for Manufacturability – Cambridge Engineering Selector (CES) EduPack 2008

We used CES Edupack 2008 to assist in deciding the final material for several components of our prototype. The vest, tubes and heat exchanger material are weighed upon several parameters on the CES software before the final decision is made. The CES analysis for the vest is summarized on the 'vest section' in Parameter Analysis and Appendix E. The CES software helps us to rank the potential candidate by cost, density, strength and other important engineering characteristics.

Material Selection for Heat Exchanger

In CES edupack 2008, we select all the possible materials under the Tree Selection Stage. Next, in the Limit Selection Stage, good conductor is checked to show us the good conductors from all the materials that CES has. When we plot the graph of thermal conductivity versus density, we limit our selection to materials which has a high thermal conductivity and a low density. This is to minimize the weight of the belt. The result of thermal conductivity plotted against density is shown in Figure 21 and Figure 22 is a zoomed in version.

Figure 21: Thermal Conductivity versus Density

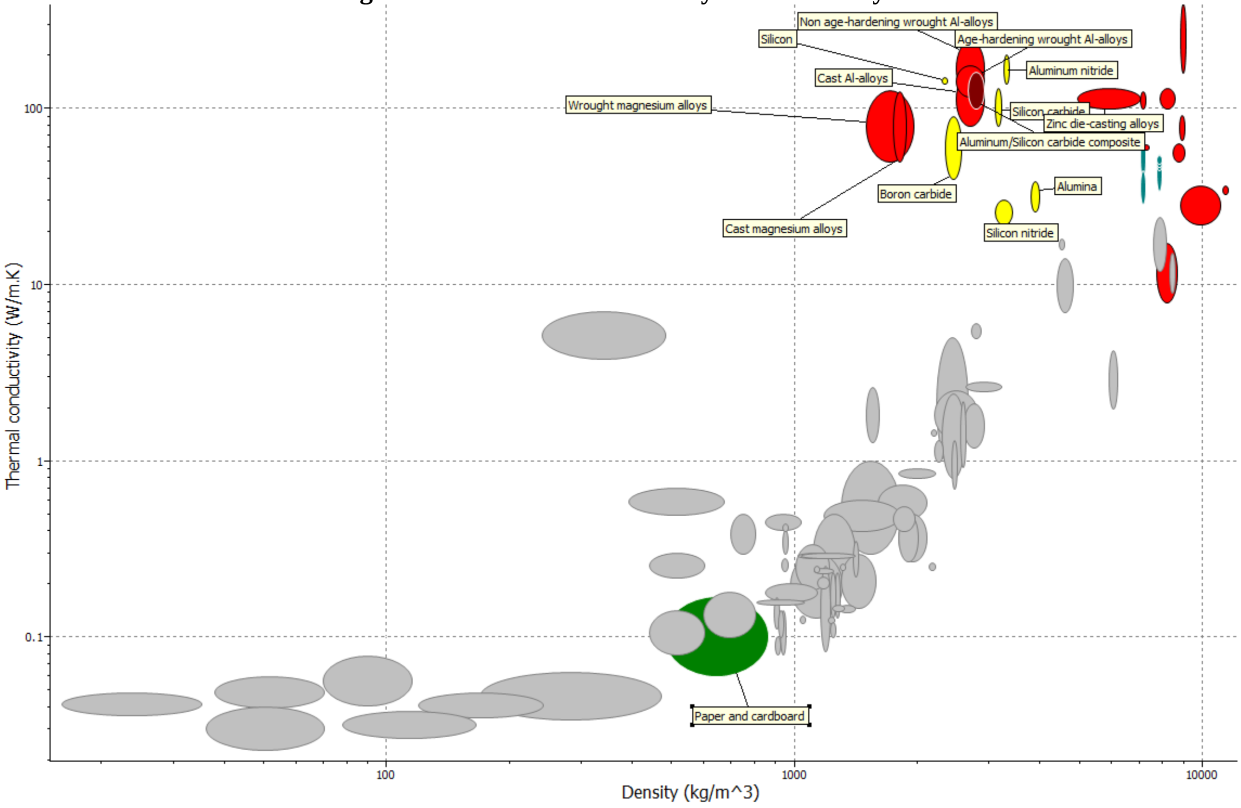
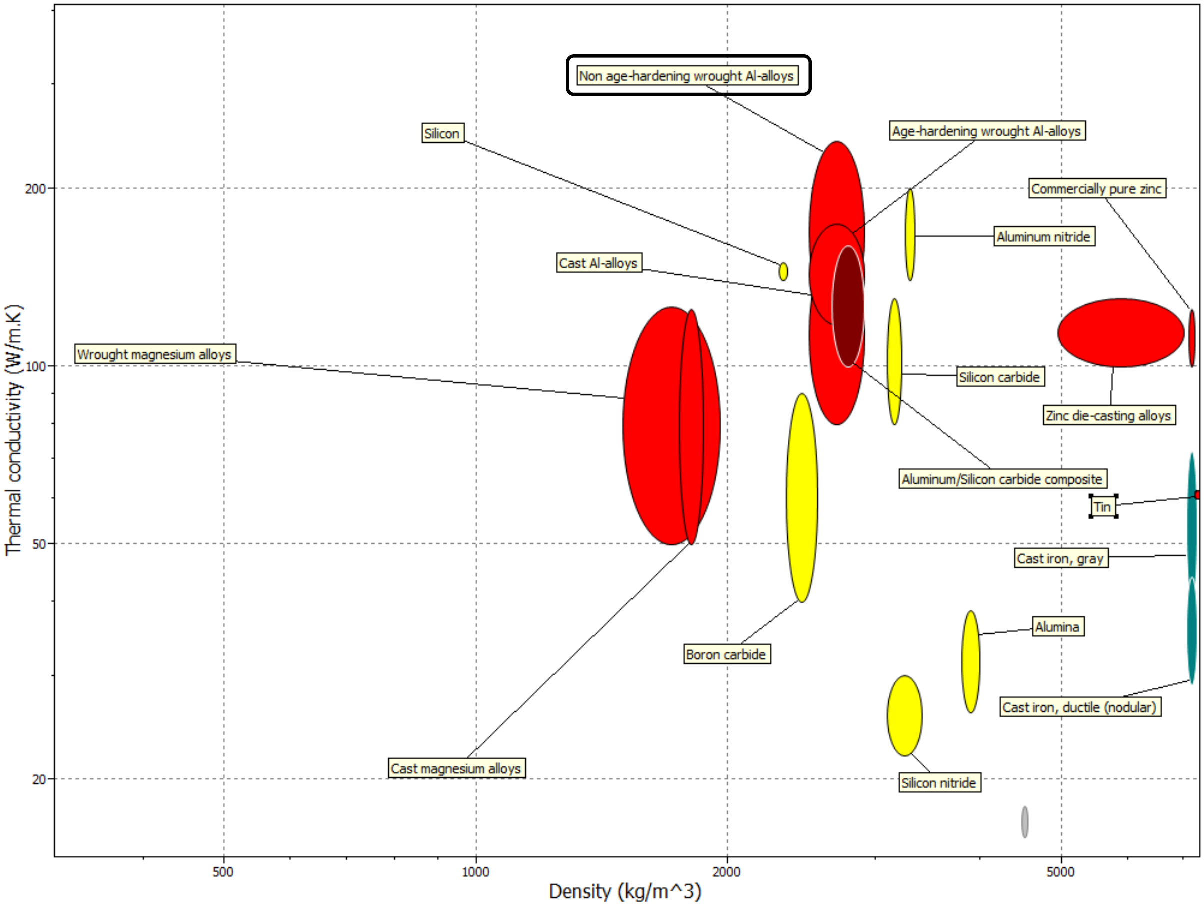


Figure 22: The Potential Heat Exchanger Materials



The two possible materials that can be used as the material for heat exchanger are the aluminum alloy and magnesium alloy. Aluminum alloy has higher thermal conductivity than magnesium alloy. However, magnesium has low density which is good to reduce the amount of weight on the belt. Since putting a slightly heavy material on the belt does not really put much burden on the person who is wearing it, aluminum (non age-hardening wrought alloy) is chosen over magnesium. With higher thermal conductivity, the former would be a very great advantage when taking away heat from the thermoelectric cooler. This increase the power efficiency of the thermoelectric cooler. The properties of non age-hardening wrought aluminum alloys are shown in Table 20.

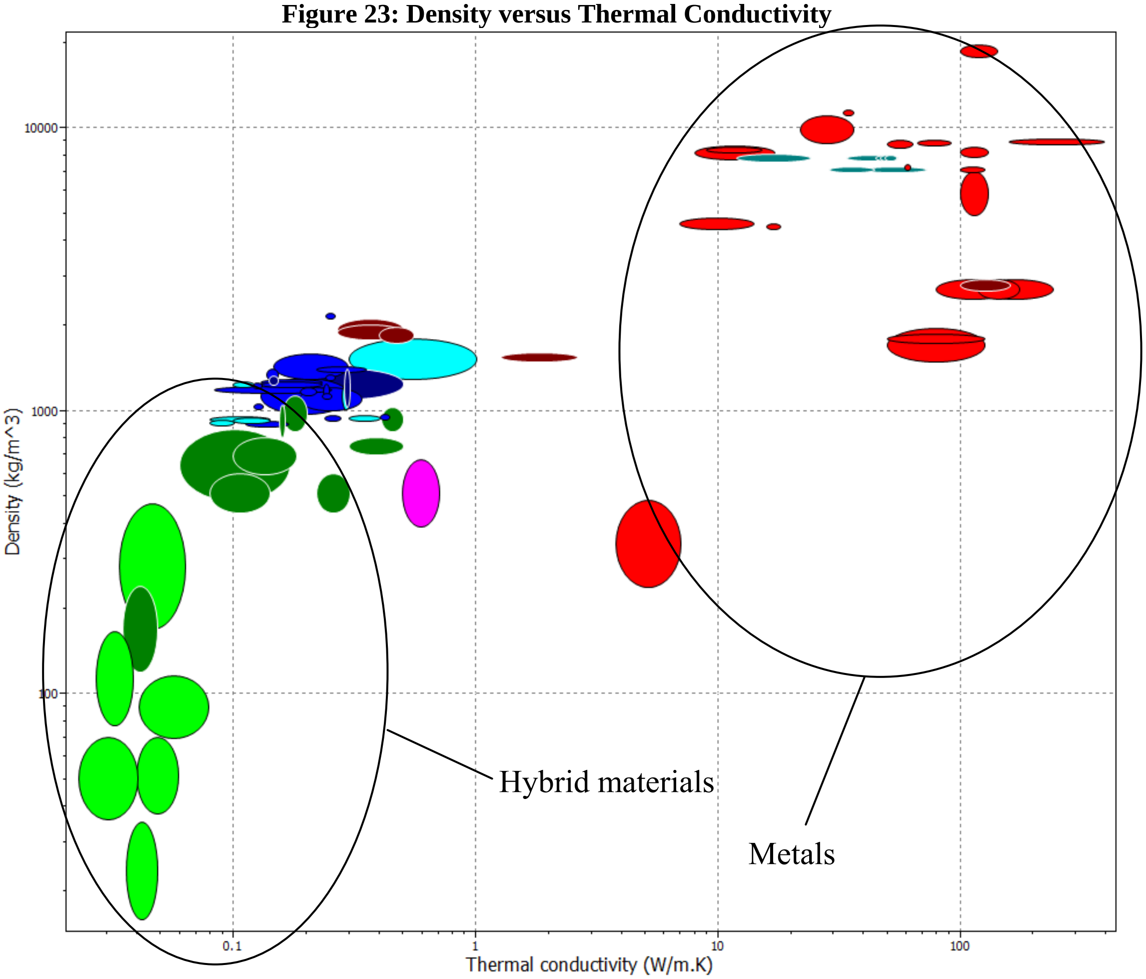
Table 20: Properties of Non Age-Hardening Wrought Aluminum Alloy

Properties	Value
Density	2.5 – 2.9 x 10^3 kg/ m^3
Thermal conductivity	119- 240 W/mK
Young's Modulus	68 – 72 GPa
Price	2.51 – 2.76 USD/kg

Material Selection for Tubes

Under the Tree Selection Stage, we limit our tubes material to polymers, metals and hybrids. Ceramics and glasses are ruled out because it is brittle and not suitable for our design. The graph of density versus thermal conductivity shows that metals are good thermal conductors but they are relatively heavy, which is against our customer requirements. The hybrid materials on the other hand have very poor thermal conductivity even though the density is low. This would basically allow us to rule out metals and hybrid materials as our range of choice, leaving us with only polymers.

Figure 23: Density versus Thermal Conductivity



Zooming into the range of polymers (figure 24), we selected a few potential materials. The tube's material should have a high thermal conductivity and low density. This leads us to finalize our candidates to silicone elastomers, epoxies, hardwood, polyethylene and ionomer.

Figure 24: The Potential Tube's Materials

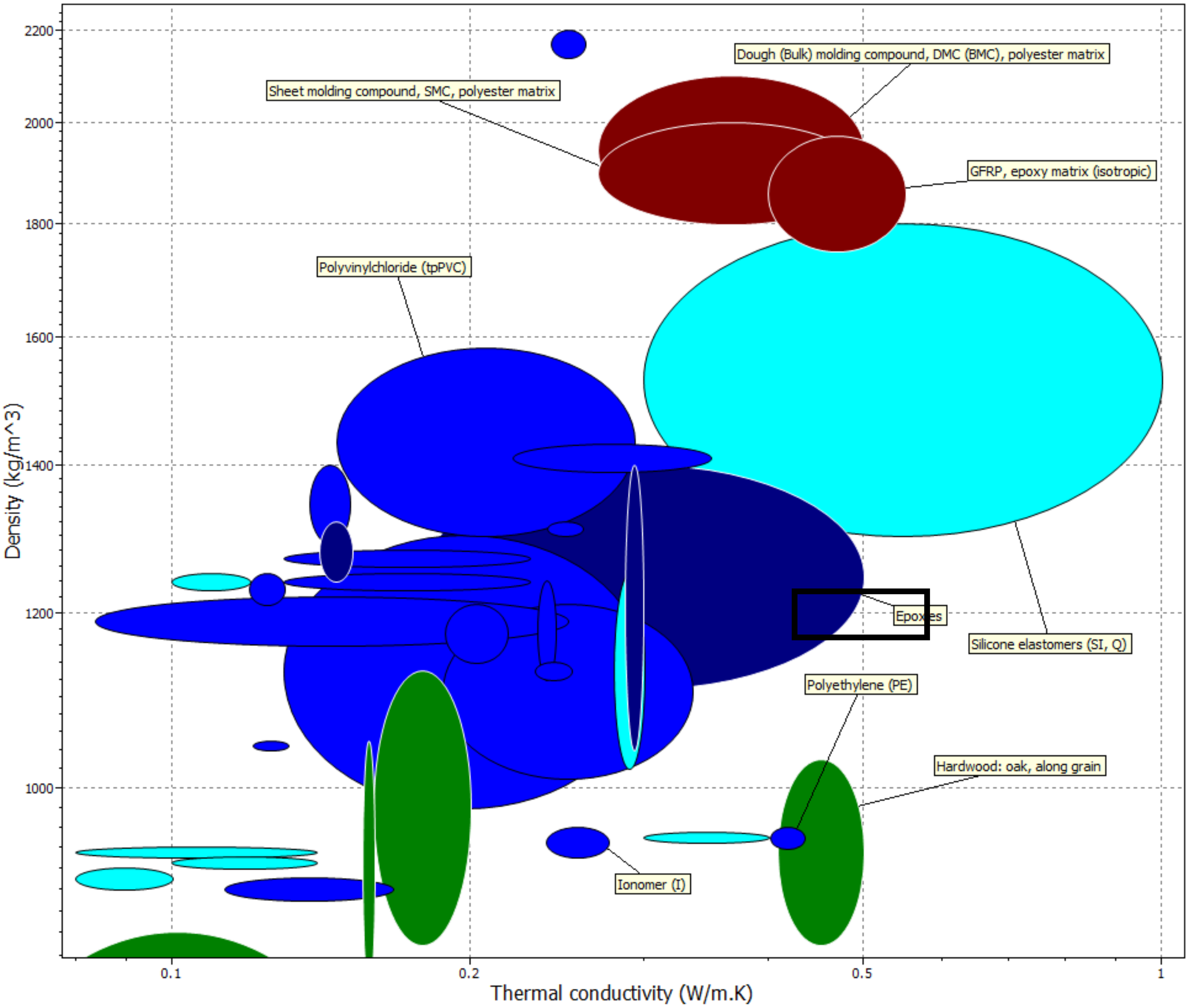
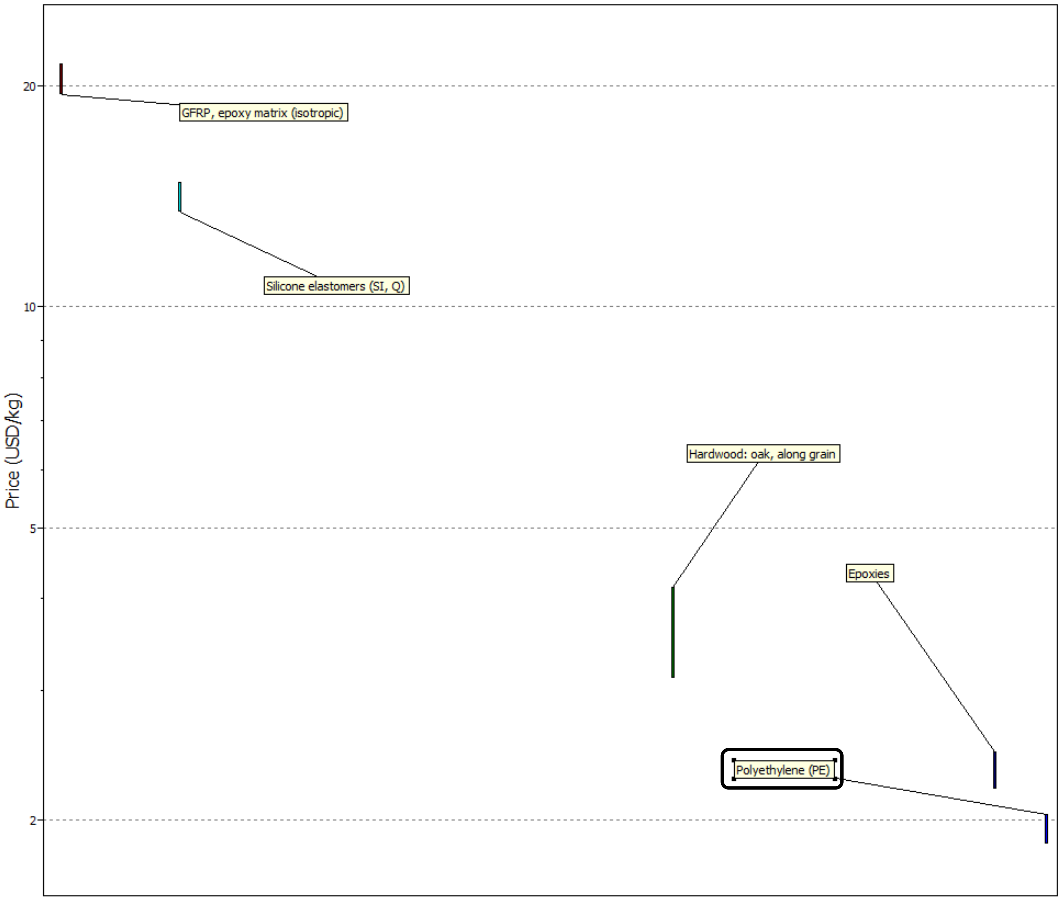


Figure 25 : Price charts of materials



Our final decision is made based on the price the availability of the materials. Figure 25 shows that even though silicone elastomer might have a better thermal conductivity, it is extremely pricey and on top of that, it is not a very common tubes material. Polyethylene will be our finalized decision because it is cheap and is commonly used. The properties of polyethylene are shown in Table 21.

Table 21: Properties of Polyethylene

Properties	Value
Density	939 kg/ m^3
Thermal conductivity	0.403 W/mK
Young’s Modulus	62.1 GPa
Price	1.85 USD/kg

Failure Modes and Effects Analysis (FMEA)

Our sponsor, Dr. Paul Park requested that the cooled vest to be water tight to prevent water from leaking in the operation room. He is very concerned about this safety issue because the operation room has to be sterilized and water leaking from the vest is going to contaminate the sterilized room. Also, water leaking while operation is going on will interrupt any crucial surgery operation and has the chance of the leaking water getting to the patient. Any of these incidents is strictly undesired.

By putting this concern in our mind, we know that all the tube connections have to be tightly secured in order to prevent any leakage. We secured every tube connections with sealants, clamps and sealing tape. The area that supports the weight of the vest, which is at the shoulder, is clamped and sealed with sealing tape because that area is very prone for the tubes to get disconnected easily. The other reason for clamping and sealing it is because the PVC tube does not fit tightly into the nylon tee-connector.

Besides that, we are using two kinds of tubes (PVC and polyethylene). The polyethylene tube fits in tightly into the nylon T-connector and so, we apply sealant only there. However, the tube connections between the PVC tubes with nylon T-connectors are not very tight and thus, we decided to clamp and seal the tube connection of this type which could be found near the shoulder area of vest. All the connections with the water cooler are sealed with vinyl tape and the tube connections with the pump is clamped and sealed with sealing tape to give extra sealing.

The lithium ion batteries leak if they are dropped on the ground and this can be very dangerous. As a safety measurement, whenever the batteries are taken out from the belt, placing the batteries on flat surfaces has to be done gently and carefully. This is to make sure that the chemical in the batteries stays stable at the time.

Also, all the wiring connections are sealed with electrical tape so that the copper wires do not touch each other. This is to prevent the electrical circuit from being short circuited.

Design for Environment

We used Simapro to make the environmental assessment on the whole vest. The components that we analyzed in Simapro were the tubes, water cooler, vest, pump and belt. The battery could not be analyzed due to the lack of current data in Simapro because the technology of lithium ion battery is very new. Due to the hazard materials in the battery, the end of life disposal will have a great environment impact.

We inputted the original materials used to manufacture each component and the corresponding weights. The Simapro calculated the environmental impact using Eco-Indicator 99 as shown in Figure 26, Figure 27, Figure 28 and Figure 29.

Figure 26: The total mass used to manufacture each components

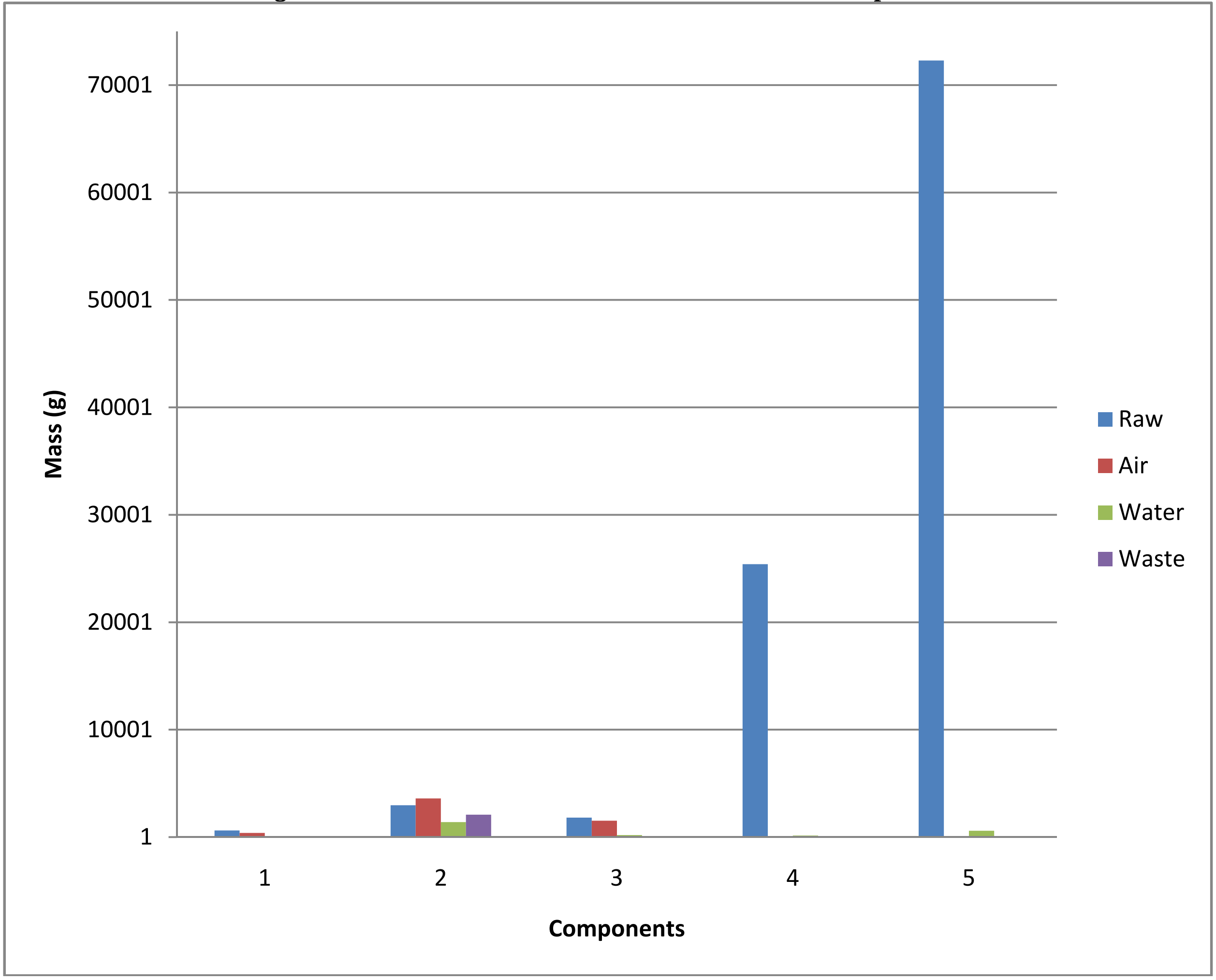


Figure 27: The characterizations of environmental impact on each component

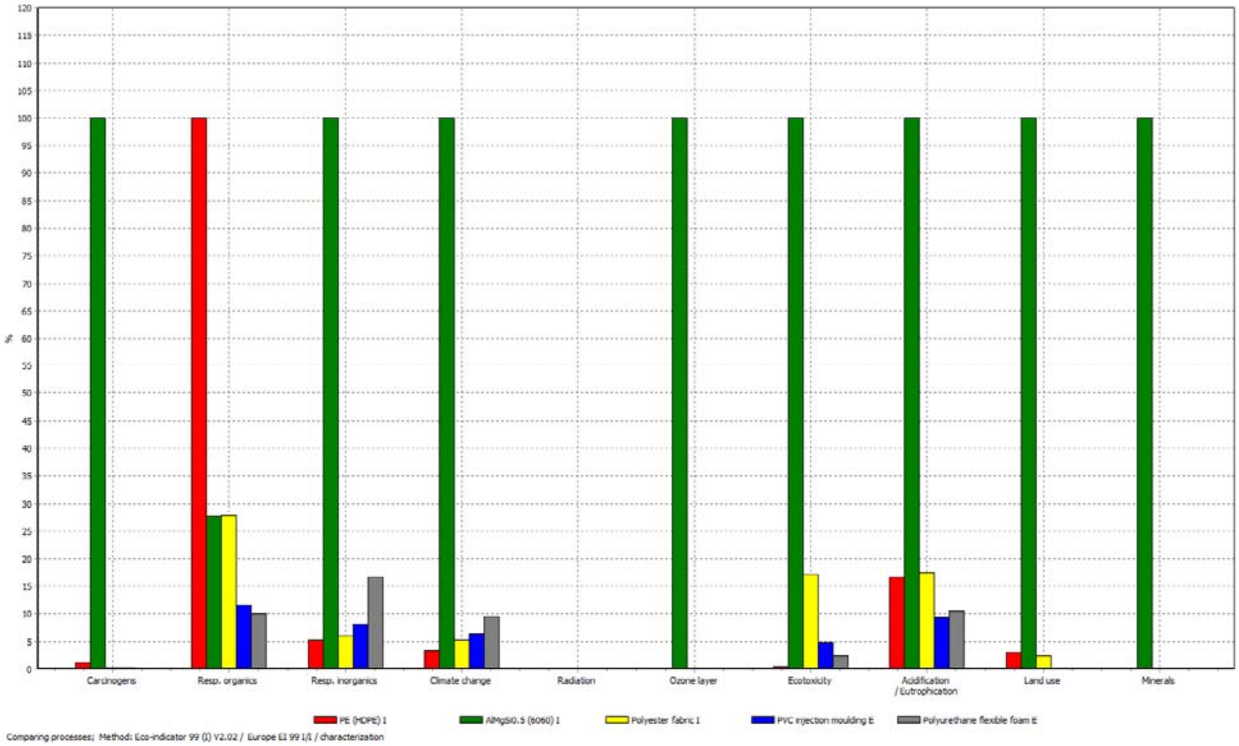


Figure 28: The normalization of the environmental impact

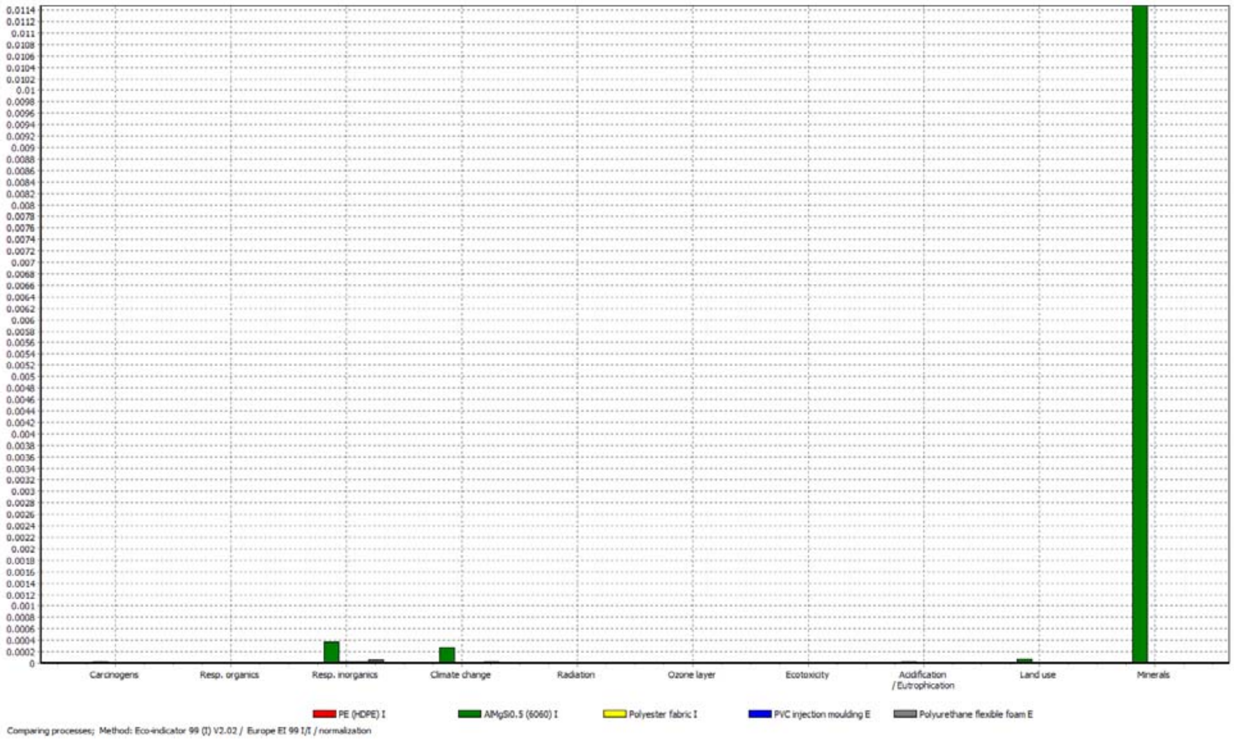
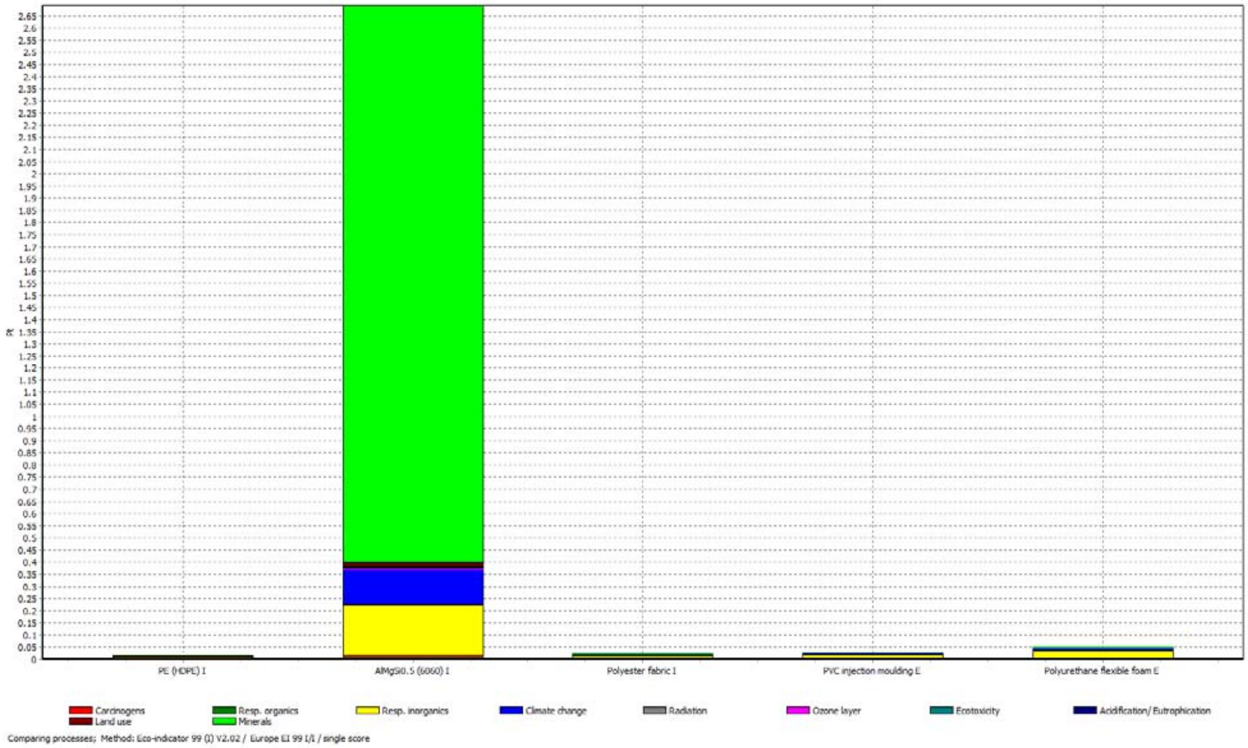
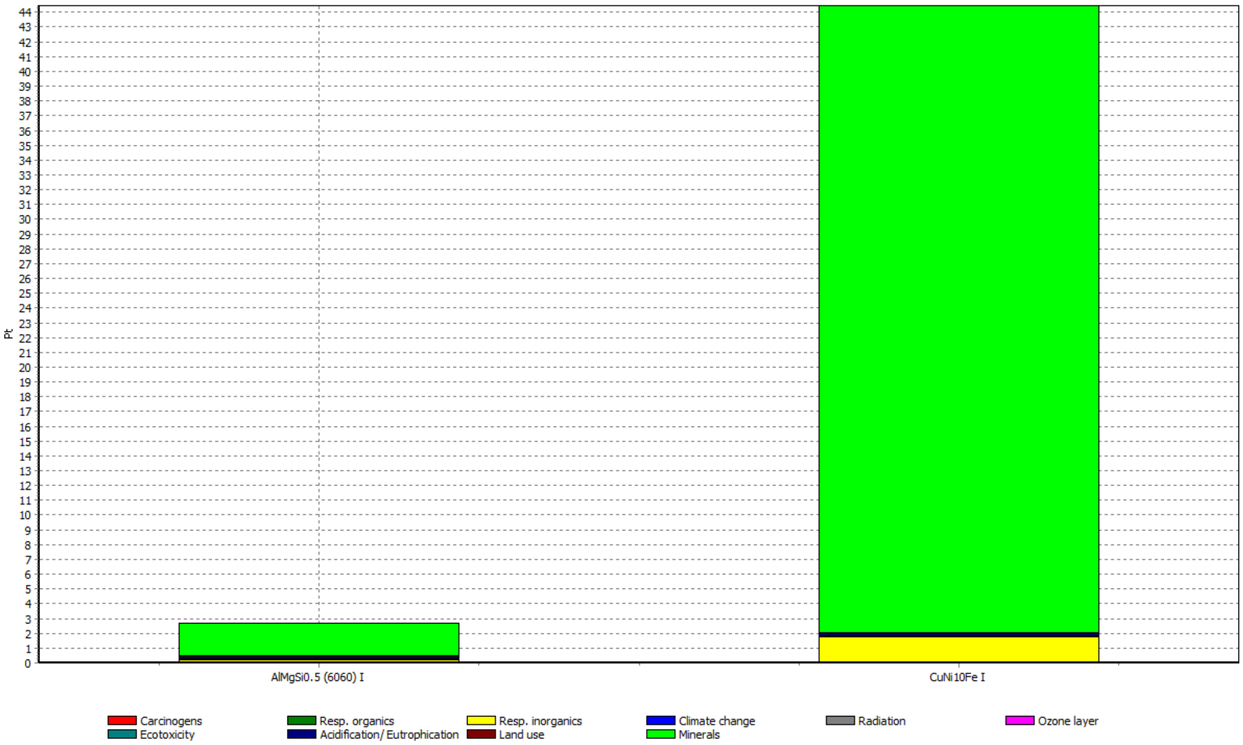


Figure 29: The single score point of each component



From Figure 29, it shows that the water cooler scored the highest point in the assessment. This means that the water cooler gives the most environmental impact. Since it has the highest environmental impact, we performed another Simapro on water cooler but with different material. We compare copper to aluminum and the result is shown in Figure 30.

Figure 30: Comparison of single score point on the environmental accessment between aluminum and copper



Comparing 0.9 kg 'AlMgSi0.5 (6060) I' with 0.9 kg 'CuNi10Fe I'; Method: Eco-indicator 99 (I) V2.02 / Europe EI 99 I/I / single score

Figure 30 shows that copper has higher single score point on the environmental accessment which means that copper is not very environmental friendly as compared to aluminum. Therefore, we would stick to using aluminum to build the water cooler in the future because it is more environmental friendly compared to its competitor, copper.

FINAL DESIGN

Our team has selected the Water Cooling Vest as our final cooling vest design for neurosurgeons and has proceeded to design and engineer this vest. The design consists of a vest and belt combination that houses a complex thermodynamic and thermoelectric system. A water pump and thermoelectric cooler functions to pump cooled water throughout tubes placed strategically throughout the vest. Figure 31 shows a computer generated model of our water cooling vest with water flow while figure 32 shows the detailed belt assembly.

Figure 31: CAD model of Final Design

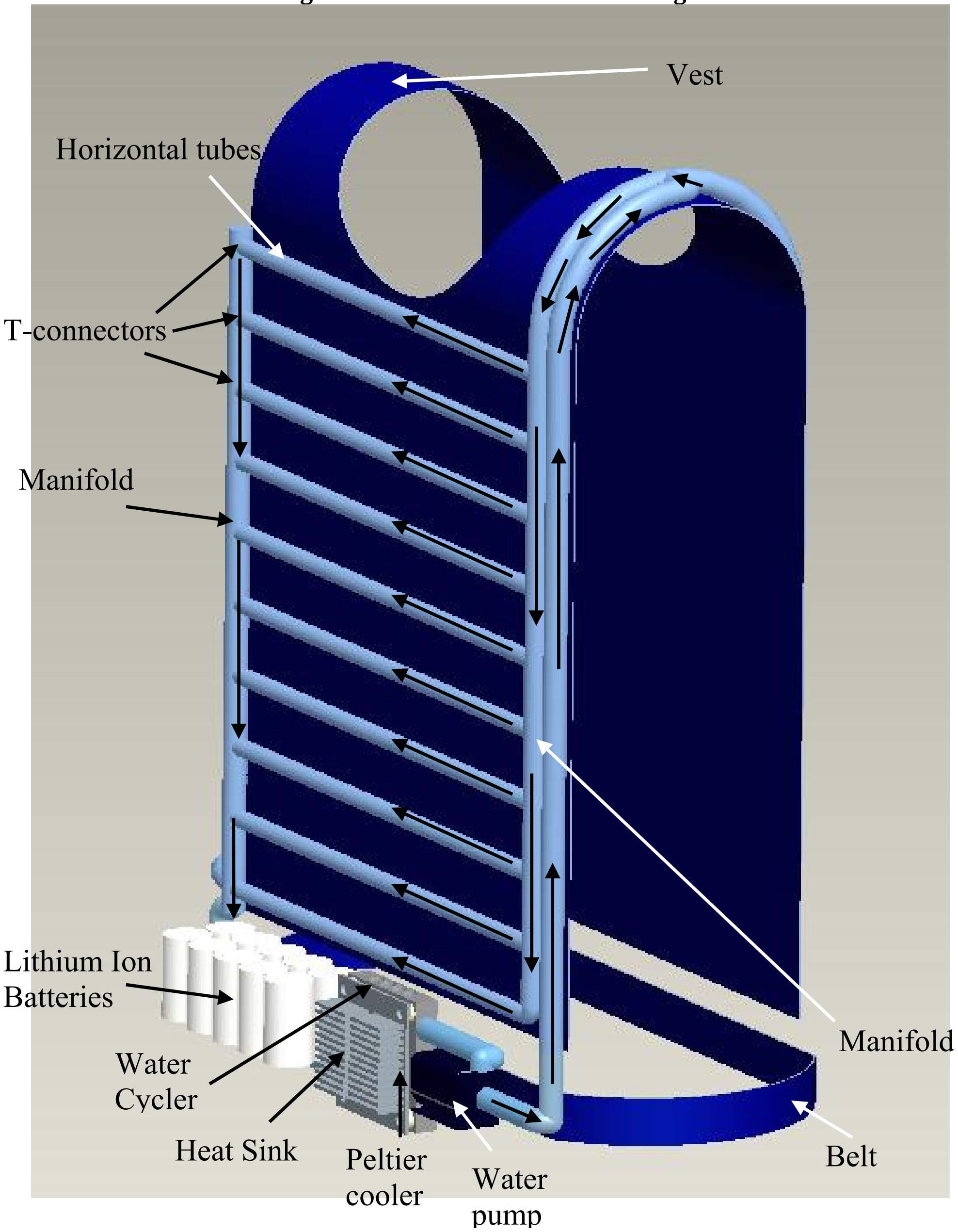
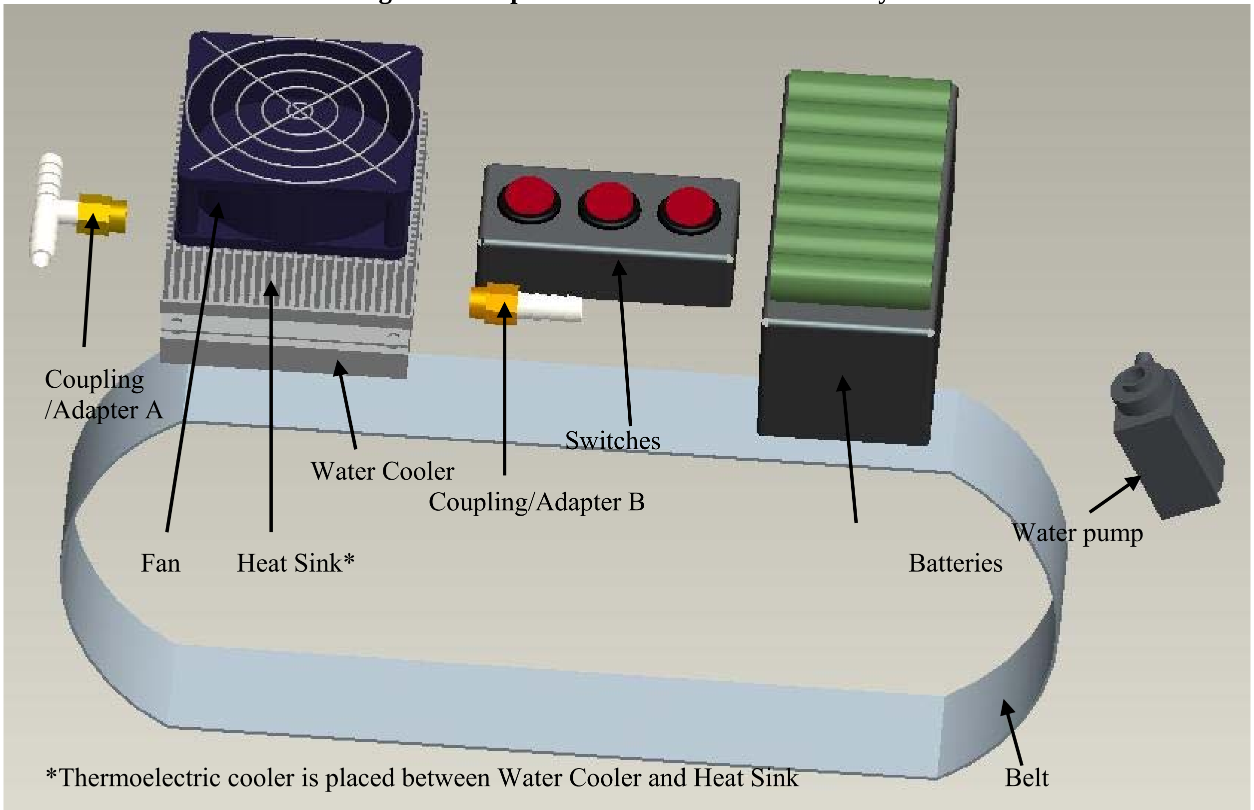


Figure 32: Exploded View of the Belt Assembly



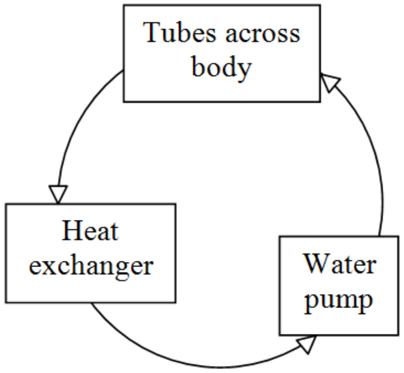
*Thermoelectric cooler is placed between Water Cooler and Heat Sink

The final design has been changed from the alpha design to improve water flow, flexibility and cooling capability. While the alpha design has a single tube flow, the final design will utilize a manifold tube design. A vertical tube will transfer water from the water pump, separating at the right shoulder to 2 manifolds which will distribute water across the torso through 10 evenly arrange horizontal tubes. The water travels a smaller distance; therefore change in temperature across the tubes is small. This will increase the efficiency of the cooling vest because the temperature would be evenly spread on the body.

The second change that was made to the final design is the water cooler. While the older design uses a copper baffolding to encourage heat transfer between the water and the thermoelectric cooler, the final design will use an aluminum block with tap holes that form a manifold within the block [Appendix K shows the water flow in the water cooler]. The reason behind this design change is because the newer design is easier to manufacture and will provide a better contact surface between the thermoelectric cooler and the flowing water.

Figure 33 shows the water cycle in the water cooling vest. As the water flow meets at Coupling/Adapter A (refer to Figure 32), it will flow into the heat exchanger and be cooled before being circulated again by the water pump. Coupling/Adapter B will be connected to the heat pump.

Figure 33: Water Cycle on the Water Cooling Vest



The total vest will weigh no more than two pound and the belt with the electrical components will weigh no more than ten pounds.

Our team has researched different materials for tubes and vest material and has decided to create a nylon vest that houses tubes that are made out of polyethylene. The thermal conductivity of these two materials in conjunction with water as a cooling fluid will allow us to remove a specific heat rate equal to the specific heat produced by the human body. This will ensure that the surgeon that wears the vest will be sufficiently cooled.

To cool and circulate the water, we will be using a Peltier device, a water pump and a heat sink. The Peltier device is a thermoelectric cooler that uses electric work to divide the thermal energy of a metallic plate which creates a hot side and a cold side. A water cooler will be attached to the cold side of the Peltier and cool water as it passes through. The hot side of the Peltier must have a heat sink to exhaust the excess heat: otherwise the hot side of the Peltier will become too hot and cause inefficient at cooling. Fans will be attached to the heat sink to aid in forced convection. These devices will all be powered by batteries which along with the Peltier device, water pump, heat sink and fan will all be held on the posterior of the belt. As cooled water exits the water cooler, it will be pumped through the body by a water pump.

The components' descriptions for our final prototype are summarized in table 22. Appendix J includes the cost of individual components which are purchased directly from specialized manufacturers and hardware stores.

Table 22: Water Cooling Vest Components Summary

Components		Description
Vest		Made of nylon
Tubes	Cooling tubes	Polyethylene tubes are used for good thermal conductivity
	Transfer tubes	Polyvinyl tubes are used for flexibility
Tube fittings	T- Connectors	3/8” × 3/8” × 1/4” connects manifold to horizontal tubes
	Elbows	Reducing elbows 3/8” × 1/4” are used at corners of the manifold
	Couplings	Various reducing couplings are used to accommodate different tube size
	Male Pipe Branch Tee	Used for incoming water from the front and back manifold to the water cooler
Water Cooler		Made of aluminum block with same width and length as the heat sink and of 1/2” thickness
Water cooler fittings	Plugs	Made of brass and is used to close holes in heat exchanger
	Couplings	Made of brass and is used to allow water to flow out of the water cooler and to the tube fittings.
	Adapter	
Thermoelectric cooler		Maximum heat removal of 120 watts
Heat Sink with Fan		Thermal resistance of 0.15 °C/W
Water Pump		Pump head of 2.5 meters
Belt		Thick and strong weightlifting VALEO belt is used
Velcro attachment		Allows for quick removal of batteries, heat exchanger, pump and switches
Batteries	Lithium-Ion Polymer	Used to power thermoelectric cooler
	Lithium-Ion Phosphate	Used to power heat sink’s fan and water pump
Project Box		Platform for switches
Switches		Turn power on and off
Wires		Connects batteries, switches and components.
Hose clamp		Tighten joints between polyvinyl tubes and T-connectors
Marine Adhesive Sealant Fast Cure 4000 UV		Avoid water leakage at manifold and horizontal tubes joints.
Water Proof Tape (Magic Tape)		Avoid water leakage at couplings and adapters
TP-1 Thermal Paste		Enhance heat conduction at the contact area of the thermoelectric cooler.

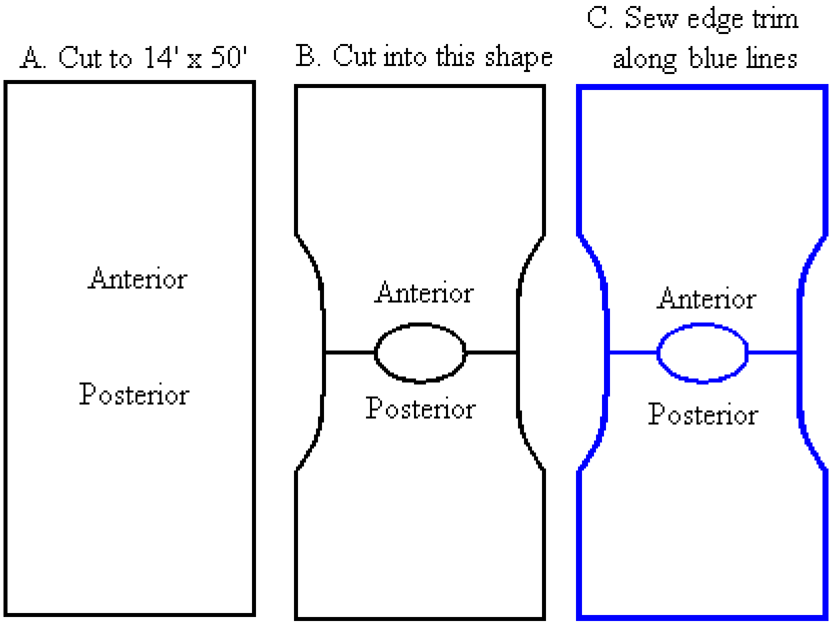
PROTOTYPE MANUFACTURING PLAN

The following describes the manufacturing processes used to create the prototype cooling vest that was presented at the Design Expo on December 5, 2008. Our prototype was constructed using materials immediately at our disposal or easily attainable through ordering online. The cooling vest is made out of nylon, and the thermodynamic and electrical systems implemented are completely independent of additional systems. We started by fabricating a vest and creating a manifold tube layout to circulate water throughout the vest. Next we designed the heat exchanger and an electrical circuit to power it via battery packs. Our next step involved placing the heat exchanger and all electrical components on a belt to offset the weight. Finally we put the tubes, the vest, and the belt assembly together to create our cooling vest prototype. The prototype will meet all of our engineering specifications and will have the same dimensions as the final product designed for manufacturing.

Step 1: Fabricating the Vest

The vest will be created using sport nylon that is cut into the shape of a poncho-style vest as shown in Figure 34. Two identical pieces will be created so that the tubes can fit in between two layers of nylon. Each piece will be created by starting with a 14' x 50' rectangle. At the center of the rectangle an oval will be cutout and this will serve as the opening for the head. The two sides adjacent to the oval opening will be indented to allow room for the user's arms. Once the nylon has been cut to the appropriate dimensions, we utilized a sewing machine with edge trim to close the edges to prevent the vest from fraying at the edges.

Figure 34: Making the Initial Vest Halves.



The long side of the vest will have Velcro sewn to it so that the two vest halves can be attached to each other. The rest of the vest is divided in terms of the inside half (side that is closest to the body when worn) and outside half (side that is furthest from the body when worn). Four D shaped hooks equidistant from each other and along the sides of the inside vest are attached to the posterior side of one half of the vest. At the same positioning on the anterior of the other half of the vest, strips of Velcro will be placed by attaching the end of each Velcro strip (see figure 35). The finished vest is shown in figure 36.

Figure 35: Attaching the Velcro and Hooks to the Vest

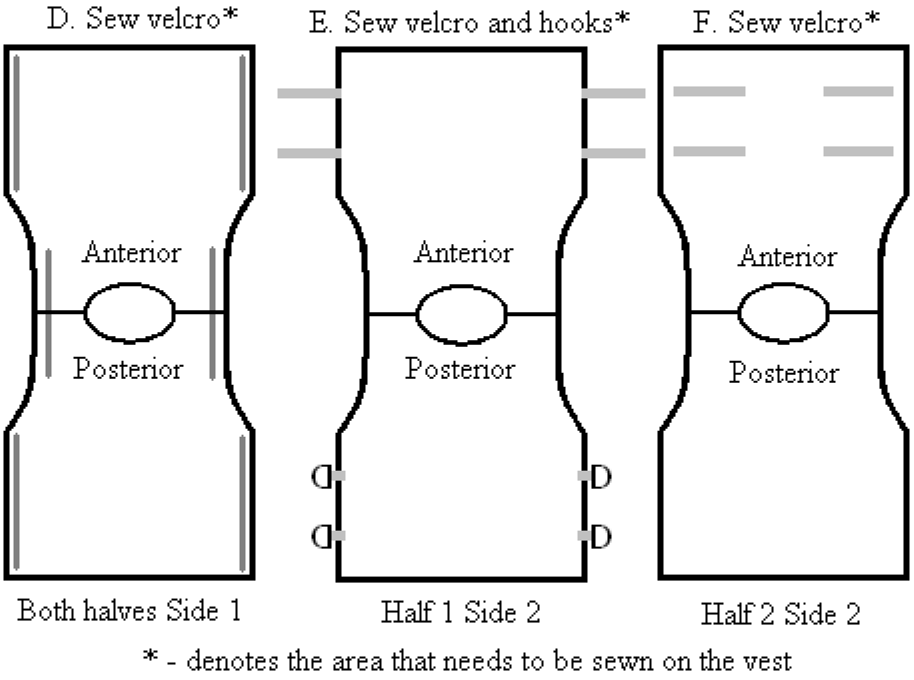


Figure 36: Final Vest to House our Water Cooling Tubes

Step 2: Creating the Tube Layout

The tubes that circulate the water throughout the vest are comprised of polyethylene and polyvinyl tubes that are laid out in a manifold design. The connections between the tubes are made using barbed T-connecters (3/8”×3/8”×1/4”). To prevent the manifold tubing layout from being overly rigid, we modified the T-connectors to make them shorter, thus allowing greater flexibility. We sawed off two barbs from each side of the connector using a hacksaw, which effectively reduced the total length of the T-connecter from 2.23 inches to 1.29 inches. This must be performed to all barbed T-connectors but the overall result is more tolerance in the horizontal tubes. This is shown in Figure 37 and 38.

Figure 37: Barbs to be Removed

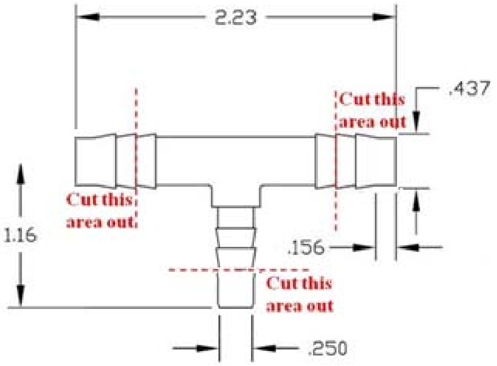
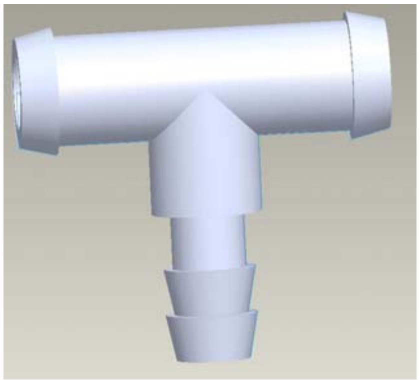


Figure 38: CAD Model of Finished T-connectors



To create the tubes, we had to cut out the different lengths of the tubes to conform to the shape of our manifold design. We used a utility knife to cut the tubes as recommended by the employees at the hardware stores where we purchased the tubes. The 1/4” inner diameter polyethylene tubing will be cut into twenty 12” length tubes which will form the horizontal tubes. The 3/8” inner diameter polyethylene tubes need to be cut into thirty-six 1.3” short tubes. The 3/8” polyvinyl tubes will be cut into each of the following lengths 2”, 4”, 5”, 8”, 10” and 20”, which will connect the anterior and posterior manifold tubes, the water pump and the water cooler. Each of the connectors will be attached to each adjacent component in figure 37 by using 3M’s Marine Adhesive Fast Cure 400 UV. This adhesive will prevent air or water from leaking from our tubes to ensure that the water circulation is closed. To reinforce the connections further, we used Glasgow Manufacturing’s Magic tape and hose clamps to wrap around and clamp each connection between the polyvinyl tubes and the connectors. After constructing the manifold tube design, the layout was left out to dry for 24 hours so that the sealant could properly cure and provide us with waterproof connections. The following is a step-by-step explanation for assembling the manifold tube layout (see Figure 39)

1. Manifold Assembly A (build upwards)
    a. Start with an elbow
    b. Connect 1.3” polyethylene tube to elbow
    c. Connect tube to T-connector
    d. Connect tee-connector to 1.3” polyethylene tube
    e. Repeat until 9 T-connectors and 9 1.3” tubes are connected

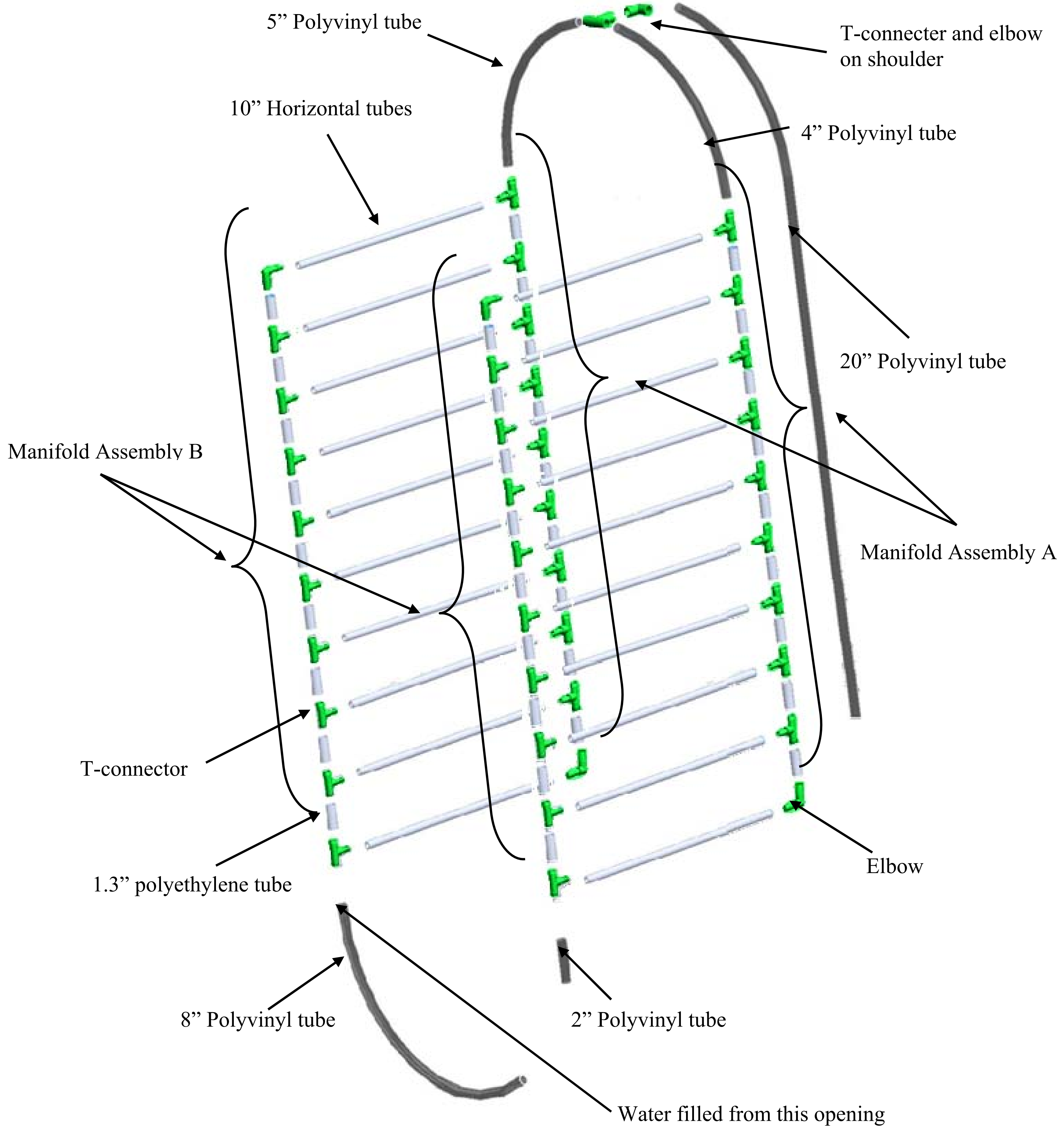
2. Manifold Assembly B (build upwards)
    a. Start with a T-connector
    b. Connect 1.3” polyethylene tube to junction
    c. Connect tube to T-connector
    d. Connect T-connector to 1.3” polyethylene tube
    e. Repeat till 8 T-connector and 9 1.3” tubes are connected
    f. Connect elbow to final tube

3. Connect manifold A to B using the 10 12” tubes at the T-connectors to get tube layout. Repeat again for a mirror image manifold tubing layout for the back

4. Connect 4” and 5” polyvinyl tube to the top T-connector of the two manifolds A (front to back).

5. Connect the two manifold A’s with a T-connector. Connect an elbow fitting on the other open end of the T-connected. Then connect a 20” polyvinyl tube to the other end of the elbow. This long tubing will go straight to the water pump and act as a vertical tube that will bring water up to the shoulder before it is split at the T-connector.

Figure 39: Manifold Tube Assemblies as they would lie Within the Vest



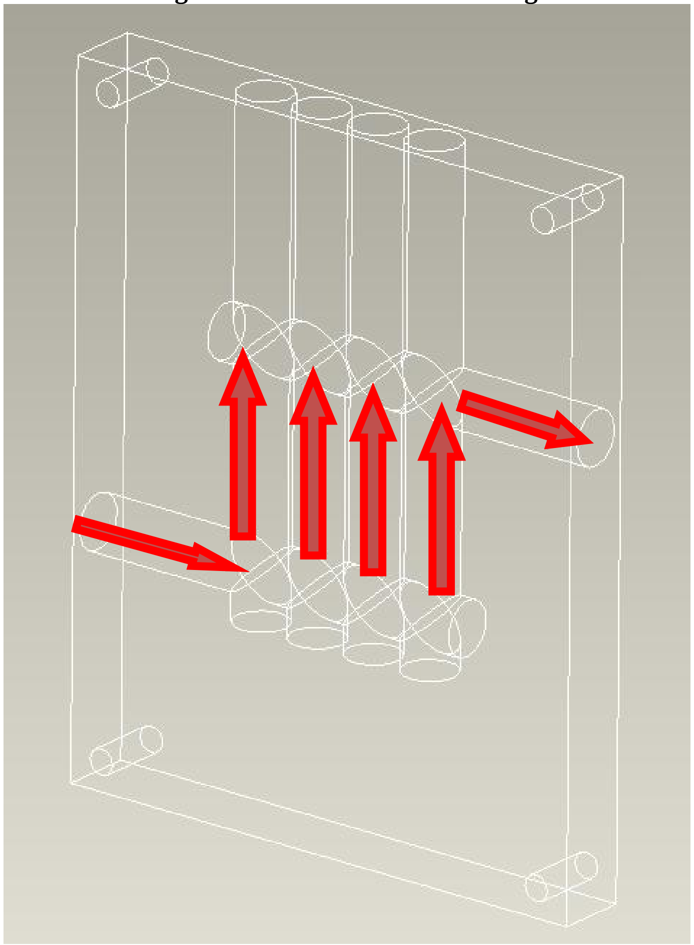
Step 3: Creating the Heat Exchanger

The heat exchanger will be created by combining three major thermodynamic devices together. The center of the heat exchanger is a thermoelectric Peltier cooler. The cold side of the thermoelectric cooler will contact the aluminum water cooler that allows water that flows through it to get cooler. The hot side of the thermoelectric cooler will be attached to a heat sink which will exhaust the heat produced by the thermoelectric cooler and the vest's wearer. The thermoelectric cooler and the heat sink were purchased online and require no manufacturing processes.

Water Cooler

The water cooler that allows for heat transfer between the cold side of the thermoelectric cooler and the water will have to be machined from a 2 3/4" × 2 3/4" × 1/2" block of 6061 aluminum. Two 3/8" bores will be drilled into one of the 2 3/4"×1/2" edge of the aluminum all the way through .63" from the perpendicular edges. Four 3/8" bores will be drilled into the perpendicular face separated by .06" initially offset by .03" from the center. All the holes, except for the water inlet and outlet, will be plugged to keep the water cycler sealed. These holes must be tapped to allow for the plugs and inlet/outlet fittings to be screwed in. See figure 40 below.

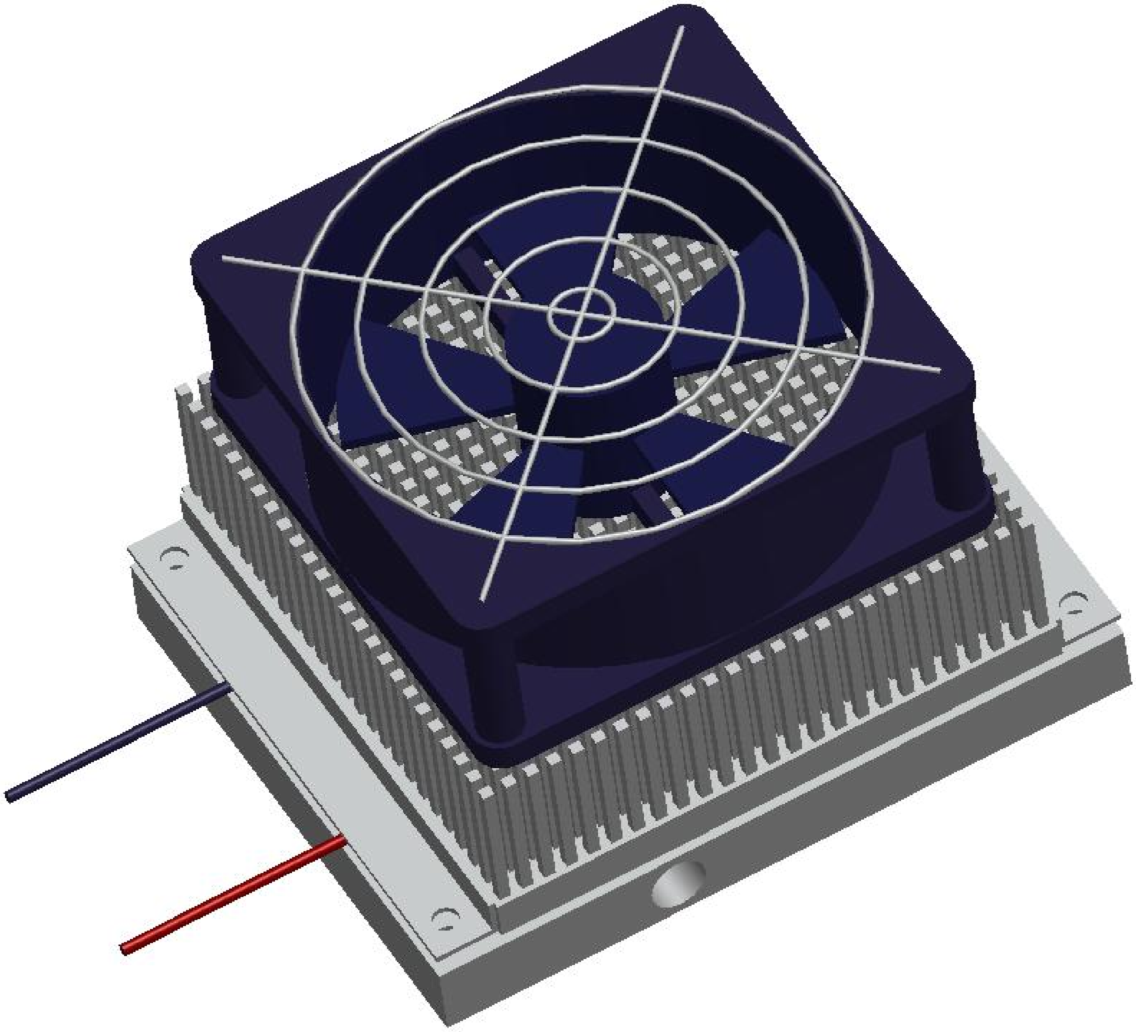
Figure 40: Water Cooler Drawing



Assembling the Heat Exchanger

Once the water cooler was properly manufactured and plugged to create the flow channels, we combined the parts to create the heat exchanger. First, each component was cleaned with rubbing alcohol to reduce the negative effects of debris on heat transfer. The water cooler is lay placed down flat with the side that contains the holes for the heat exchanger screws pointing upwards. A small pea-sized drop of thermal paste (TE Technology TP-1) was applied to the center of the water cooler and the cold side of the thermoelectric cooler was placed on top. Next, spacers were placed at each of the corners of the water cooler to prevent over compression of the thermoelectric cooler. Another pea-sized drop was added to the hot side of the thermoelectric cooler whereupon the heat sink was placed. The heat sink fan screws were then used to hold each component together and were tightened until the thermoelectric cooler was firmly held in place. (See reference [15] for more detailed information on how to mount the thermoelectric cooler)

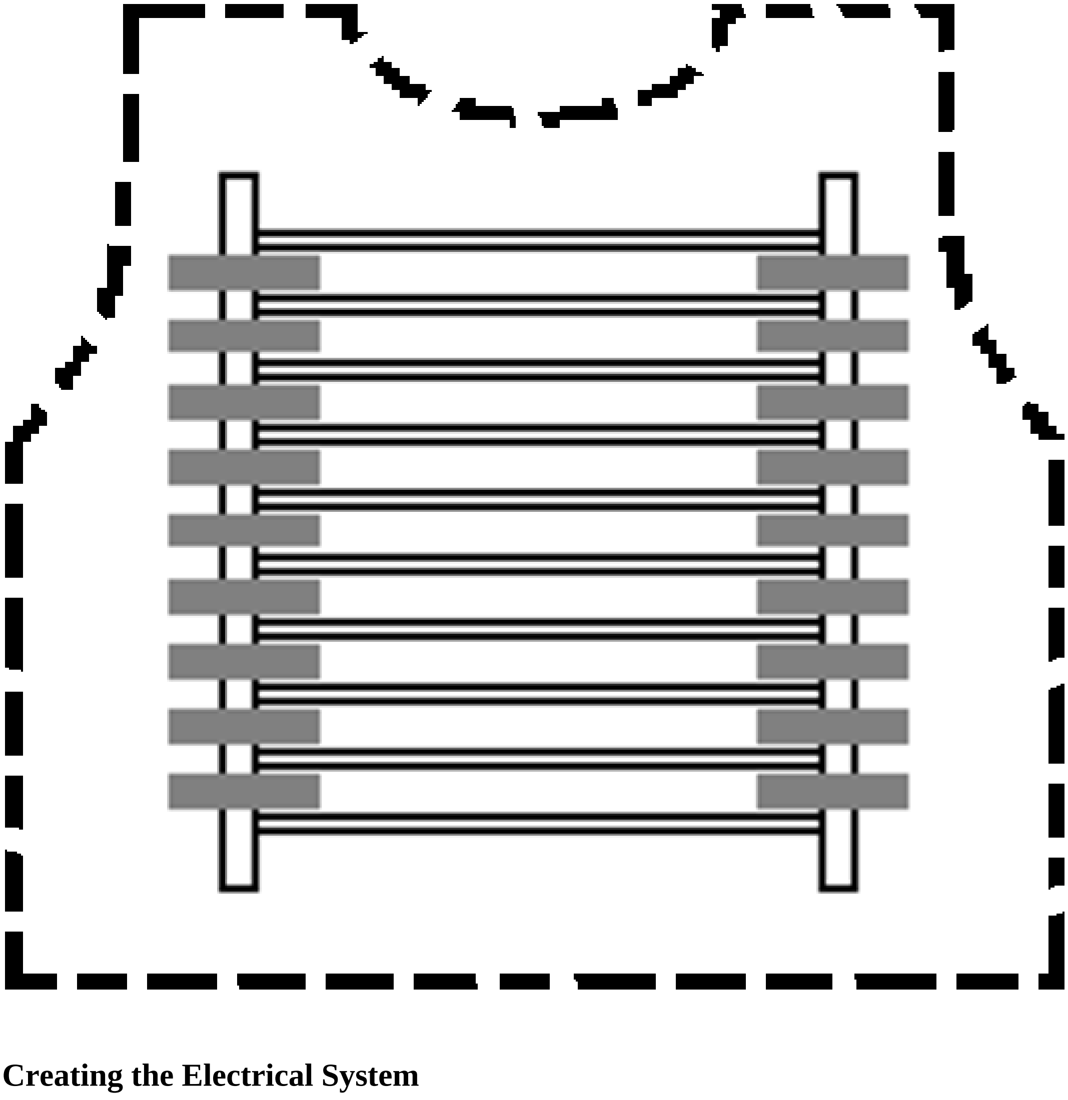
Figure 41: Heat Exchanger with all of its Components Properly Combined.



Step 4: Merging the tube assembly with the vest

In order for the tubes to be held properly by the cooling vest, we must make sure that the vest and the tube assembly is held together tightly. This was accomplished creating 1/2" x 3” nylon strips and sewing edge trim at the edges so that these strips wouldn’t fray after the vest is used. The strips were then positioned along the manifold tubes towards the center of the inside half of the vest and were sewn onto the vest using a sewing machine. Next, the tube assembly was placed onto the vest, and the strips were moved around the manifold tubing, and another pass of the sewing machine completed the mechanism to hold the tubes in place. This process was repeated for both sides of the vest. Once the vest and tube layout were merged, the outside and inside layers of the vest were also combined. Figure 42 shows the placement of the nylon strips over the manifold tubes (denoted in gray).

Figure 42: Nylon Strips (grey) over Manifold Tubes



Step 5: Creating the Electrical System

To create the electrical connections for our electrical components, our team used 18 gauge electrical wires and flux core solder to make the connections. Our team utilized three RadioShack SPST R013 135B rocker-style switches to control each electrical component (thermoelectric peltier cooler, heat sink fan, water pump) and a RadioShack Model 270-1807 electric project box to hold the wires and switches.

The first step was to modify the project box to hold our switches and conceal as much of the wiring as possible. Three 3/4” holes were drilled into the top of the project box that were equidistant and centered. The switches when pushed into these holes will snap into place; note the orientation of the switches and make sure they are uniform. Next, five 1/8” holes are drilled into the long side of the project box and four 1/8” holes on the opposite side. Red (denotes positive voltage connections) and black (denotes negative voltage connections) wires (all generously cut to allow room for adjustment) were inserted into the project box that would eventually lead to the various electrical components. These wires are hooked up in the format shown in figure 44 and soldered using a 40 Watt soldering iron and flux core solder.

Figure 43: 3/4" Holes that are drilled into the circuit board. Switches are labeled here as they appear.

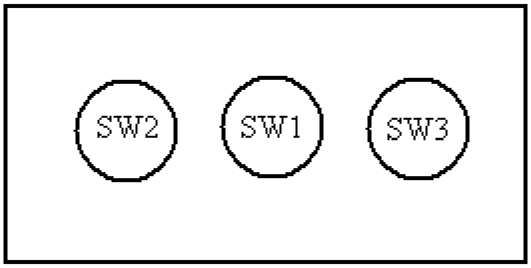
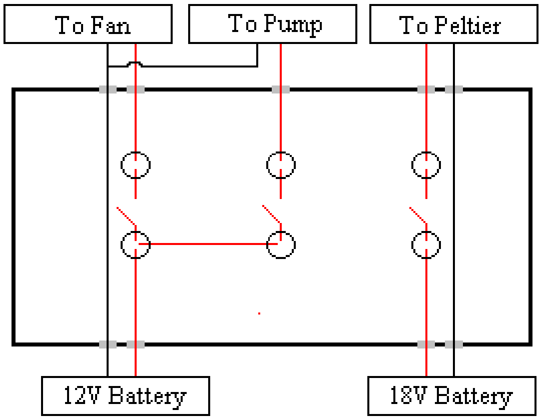


Figure 44: Circuit box internal wiring. Gray denotes 1/8” holes and circles denote areas to solder.



The batteries that we used to power the cooling vest are 1x 12V 2.7 Ah Lithium Iron Phosphate battery and 5x 3.7V 10Ah Lithium Ion batteries. First the 3.7V 10Ah batteries must be combined to create an 18.5V 10Ah battery pack that will provide power to the thermoelectric cooler. This battery pack was created by wrapping all 5 cells using shrink wrap and heating the battery pack until the shrink wrap bound it tightly. A layer of electric tape was applied to the outside to add extra protection. Next the positive and negative leads of each adjacent cell were soldered together except the positive lead on the 1st cell and the negative lead on the 5th cell. The connections were taped in a manner that allowed the each cell of the battery pack to be charged (as shown in figure 45). Next, molex adapters were soldered onto each of the battery packs as well as the project box to allow for easy attaching and detaching of the battery packs. Black electric tape was used to cover the soldered joints. The final step was to solder each of the electrical components to a positive and negative lead on the project box. Once again, black electric tape was utilized to cover up and electrically insulate the soldered joints. The final electrical system is shown in figure 46.

Figure 45: battery pack with multiple leads, each lead represents the addition of another cell in the series

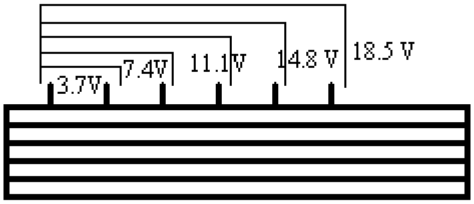
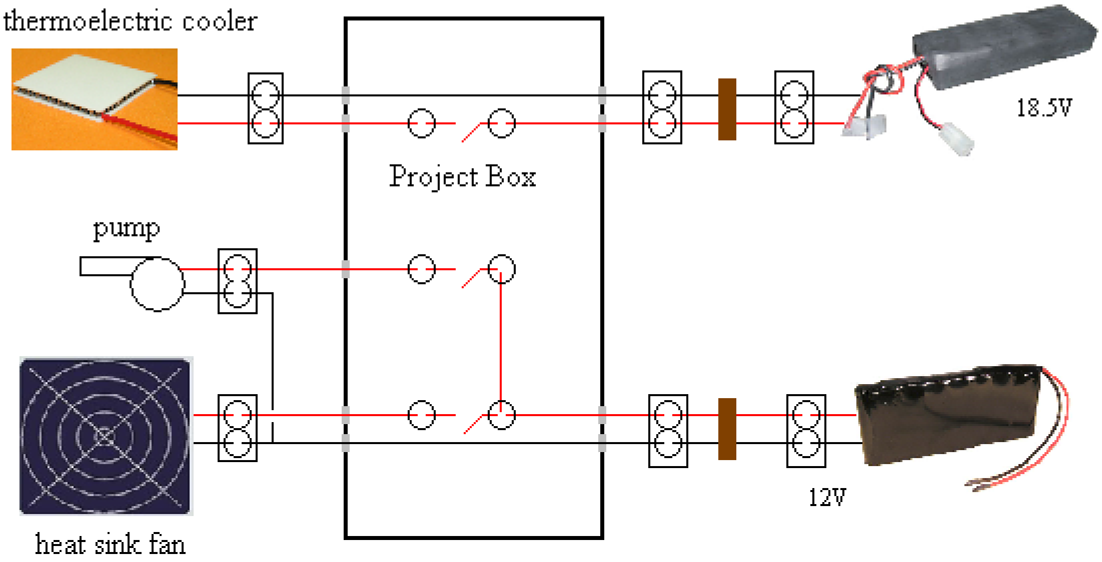


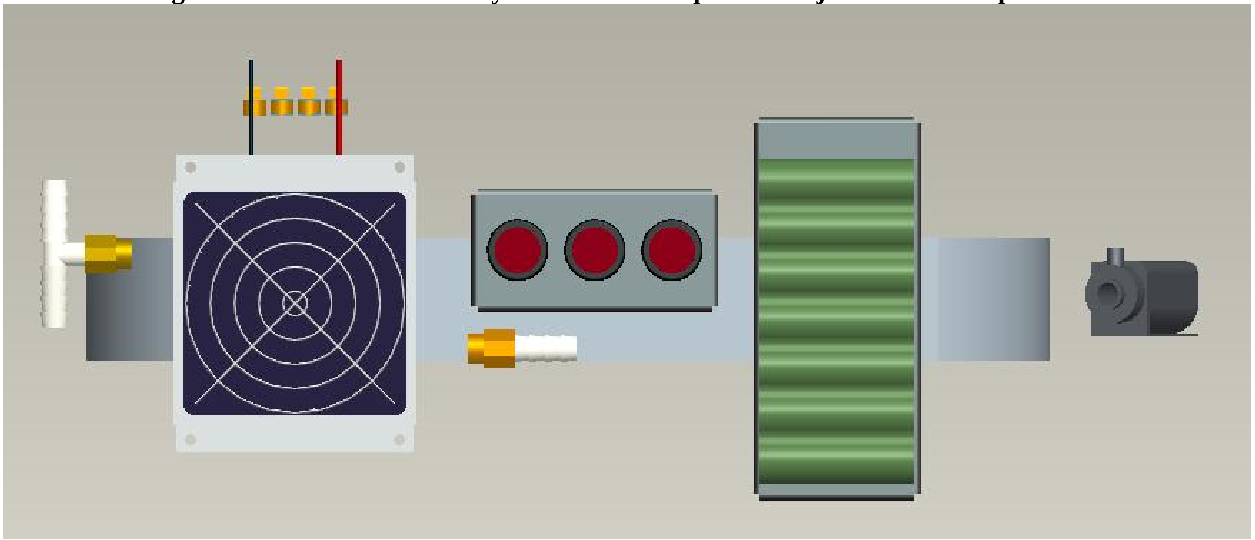
Figure 46: Complete electric system diagram. Circles denote soldered joints; squares denote electric tape to insulate joints



Step 6: Belt Assembly

All the components will be attached to the belt by Velcro straps. The pump, batteries, switches and water cooler will have straps attached to them by gluing or screwing the straps on the components. The water cooler and pump will be connected to the clear polyvinyl tubes to ensure a closed loop. When the belt was completed, it was sewn onto the outside half at the bottom of the vest to allow our client to easily wear and remove the cooling vest.

Figure 47: Entire belt assembly with all the components adjacent to actual positions



Step 7: Fill the tubes with water

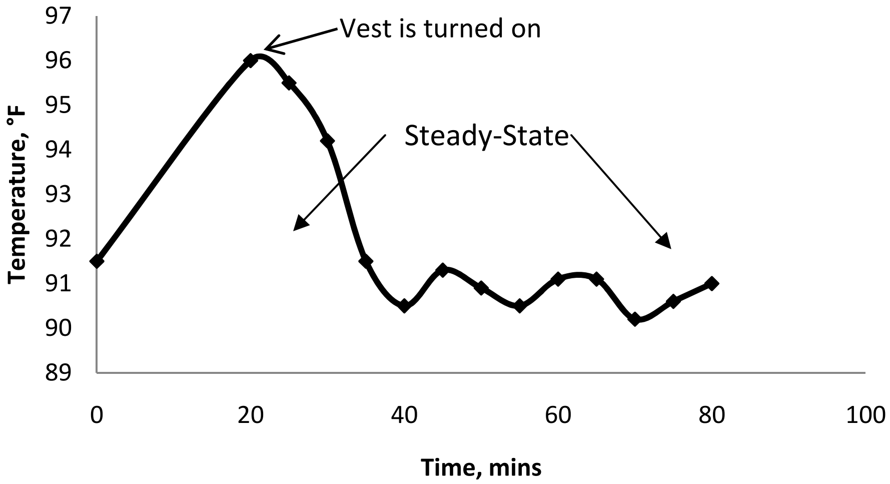
The tubes are filled by connecting water source to opening at the front right corner layout (see figure 39). Turn on water source and run water through the tubing layout until all air within the tubes is removed. Leave the water source on for at least 15 minutes. We then check for any possible leaks.

VALIDATION AND TEST RESULTS

First Testing Procedure

To validate the cooling vest a set of temperature testing procedures were run. In order to do the testing a thermocouple was used to acquire the temperature readings. The thermocouple was placed at the area between the chest and the abdomen. The first measurement taken was the steady-state skin temperature without any of the vests on. This temperature was recorded as 91.5°F. Next a member of the team wore both the cooling vest and the lead vest for a period of 20 minutes. At this point a temperature reading was taken and the result was 96°F. The cooling vest was then turned on and temperature readings were recorded every 5 minutes for a complete hour. The temperature recordings indicate that within the first 15 minutes the cooling vest brought the skin temperature back down to the steady state temperature of 91.5°F. Upon reaching this steady-state temperature the cooling vest kept the skin temperature within a standard deviation of .4°F of 91.5°F. This result proves that the cooling vest is removing the 59.24 watts that is estimated in our thermo-model that the body is producing and since this heat is being removed the body remains at a steady-state skin temperature. These results prove that the cooling vest actually performs as it was designed to.

Figure 48: Cooling Vest Performance, Temperature versus Time



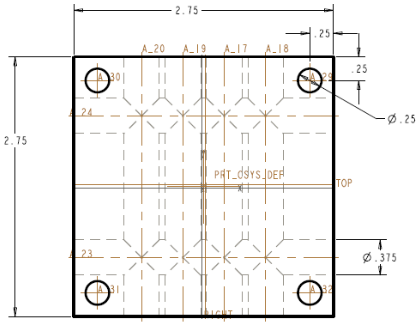
Second Testing Procedure

A second test was performed to determine the life of the battery powering the thermoelectric cooler. This battery drains faster than that the battery powering the fan and the pump and thus it determines the maximum operation time of the cooling vest. This validation was done concurrently with the first testing procedure described above. The first step was to hook an ammeter in series with the thermoelectric cooler's battery and the thermoelectric cooler itself. This allowed us to monitor the current being drawn by the thermoelectric cooler and also to see when the batteries were no longer powering the thermoelectric cooler. From a full charge the battery powering the thermoelectric cooler was able to supply power for a total of 1 hour and 58 minutes, which nearly reaches the predicted time of 2 hours, before the required current was no longer able to be met. The actual operating time should be expected to be less than that of the estimated time due to losses of energy that are that are unpredictable. These results validate that the actual operating time is what we estimated it to be.

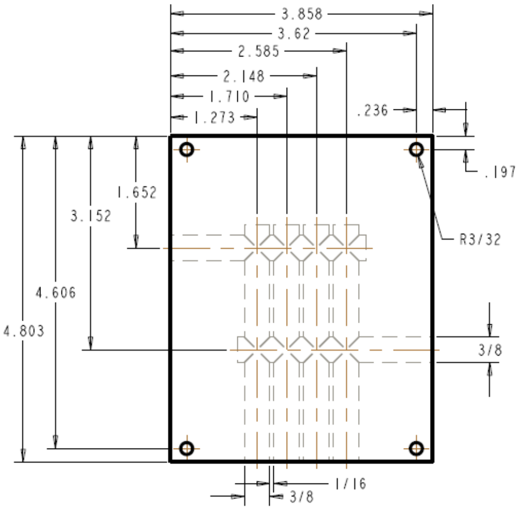
ENGINEERING CHANGES NOTICE (ECN)

Water cooler

WAS:



IS:



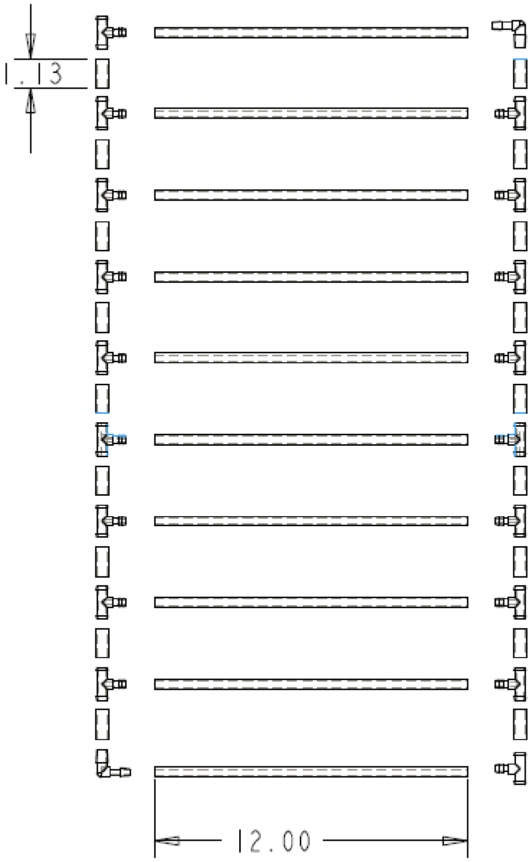
Changes Made: The width and length of the water cooler is changed to accommodate the heat sink used. The width, length and the screw hole has the same dimension as the heat sink's. The flow holes are also now not drill all the way in, but only to an extent where it can form a manifold pattern.

Reason for change: The dimensions are made the same as the heat sink's to ease our task of assembling the heat exchanger. Screws will be bolted through the water cooler and heat sink's flange and bolted at the end. The flow holes are not drilled all the way through to have better water flow and avoid trapped bubbles or water.

Changes authorized by Daniel Johnson and the UM Cooled Vest Team.

Horizontal tubes for front layout

WAS:



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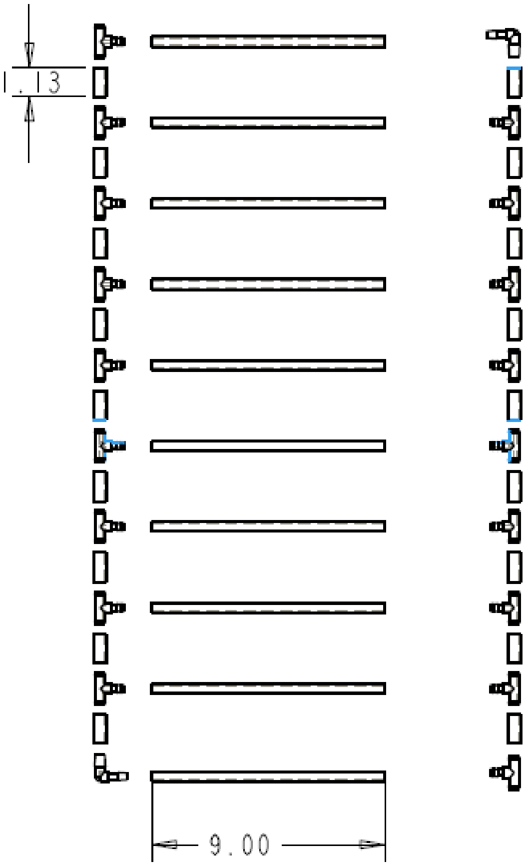


Change made: The horizontal tubes of the front layout is shorten to 9” from the previous 12”

Reason for change: The 12” horizontal tubes were deemed too long and can potentially inhibit the motion of the wearer. We measured our teammate’s chest length and found 9” to be a better length. Despite the shortening of the tubes, the layout still has a consistent cooling capability.

Changes authorized by Daniel Johnson and the UM Cooled Vest Team.

DISCUSSION

Our team has managed to produce a working prototype that has achieved its preset goals. This prototype has met every client specification that was requested of our team at the beginning of the design process; however, our prototype isn't without weaknesses, and it certainly could use some improvement.

Strengths

The greatest aspect of the cooling vest that our team has designed is its ability to provide mobile sustained cooling to a user. There are numerous cooling vests on the market today, but none of them has endeavored to produce a cooling vest that does not need to be plugged in to an external power supply or water cooling system. This is a large bonus to our target client base which includes surgeons who would like to wear a cooling vest that allows them to move around the surgery room safely.

Our vest is also light weight, works well in rooms as warm as 80° F and allows full mobility to the surgeon that will be wearing it. The vest is also quite durable and the nylon material is easy to clean. The vest is easy to maintain, since the water used is in a closed system, and the batteries are attached using molex connectors and are easy to plug into the vest and unplug. In the unlikely event of a leak, the cooling fluid is water and should pose no threat to the surgeon or the patient.

Weaknesses

Even though the cooling vest works quite well, there are many things that prevent this product from being even better. The first is that the polyethylene tubes are quite rigid, and it is difficult for different people's body's to conform to the tube layout that has already been made. The tubes are also thicker than we had hoped, which results in lower heat transfer. Due to the layout of the tubes, it is difficult to fill or refill the water in the tubes if necessary. This process usually took our team at least 15 minutes to achieve, and was done numerous times throughout testing.

The electrical system of the cooling vest is simple and not as refined as our team had hoped for. The project box that contains the switches and the wiring for our electrical components was made by just soldering and has no fail safes that a circuit board would. The lack of an overall system performance monitor is detrimental to the maintenance and operation of the vest. This also prevents the surgeon from being able to adjust the cooling vest to meet his desired temperature.

Due to the lack of electrical engineering knowledge in our team, we were not able to correctly create our own Lithium Ion Battery pack with PCBs and were therefore forced to charge our batteries individually. This results in a long charge time for the batteries before they can be used, and could cause confusion to the user. If the battery packs are not handled properly, leaking of the battery could occur, which could harm the surgeon and anybody nearby.

The belt that is used to hold our components is just a weight belt. Our team was force to attach strips of Velcro and glue to each of the components to attach them to the belt. These connections are not as sturdy as a belt that is made with slots and compartments for each of the components. This leads to difficulty putting on the belt and limits the vest from being more user friendly. The belt also lacks a method to conceal the electrical wires that are required to connect each electrical device to the switches and the batteries. Having the electrical wires concealed and insulated would be much safer.

CONCLUSION

Surgeons have long been affected by excess heat surrounding their bodies due to stress and other environmental factors. When using imaging technology, a protective lead vest shields the surgeon from harmful x-rays, but the addition of a lead vest exacerbates the heat problem that already exists. Neurosurgeons that are constantly required to wear these protective lead vests will become fatigued and perspire profusely during long surgeries which can decrease their attention and focus, impeding their ability to perform their tasks at their best ability. Surgeons have already tried some of the cooling vests on the market today, but these vests require external systems to aid the cooling vest. They're looking for a cooling vest that they can wear to stay cool, but won't compromise their ability to move around the operating room freely. Doctor Paul Park of the Department of Neurology here at the University of Michigan has requested that our team design a cooling vest that utilizes a cooling system that is mobile.

Our team researched several cooling technologies that exist today to see if it was possible to utilize these technologies to our advantage. Gel cooling packs that stay cold for extended periods of time could increase conduction over time. Phase changing materials could absorb heat over time through their chemical phase changes. Air flowing throughout the upper torso (much like an air hockey table) could act like a fan over the torso. Tubes with a cooling fluid could be placed throughout a vest and circulated to keep the body cold. Thermoelectric cooling devices could be used in a system to cool the body or any type of cooling material.

The final design for our cooling vest includes a tube layout to circulate water throughout a vest, and a thermoelectric peltier cooler to cool the water inside the vest. Polyethylene tubes would be constructed into a manifold tube layout to distribute the water evenly to the torso. A heat exchanger will use a thermoelectric cooler to cool the water that circulates. The thermoelectric cooler works as a heat pump, absorbing heat through a water cooler on its cold side and heat sink and fan on its hot side. A PC water cooling pump will circulate water throughout the vest. This design would be powered using Lithium Ion and three switches will control the power to the pump, the heat sink fan and the thermoelectric cooler. The pump, the heat exchanger, the batteries and all the electrical components will be attached to a belt that will be worn at the waist.

We manufactured a prototype cooling vest to test the concepts that we had engineered and to see that our vest was truly mobile. The tube manifold layout was changed to allow for more movement in the front by reducing the lengths of the cross flowing tubes. The water cooler's dimensions were modified to accommodate the size of the heat sink that would be attached to it. Different batteries were utilized because Lithium Iron Phosphate batteries are more expensive than Lithium Ion Batteries, and Lithium Iron Phosphate batteries are not as readily available as their Lithium Ion counterparts. These changes did not change our vests ability to cool the user that was wearing it.

The vest was tested to ensure that it could provide the cooling ability that we had designed it to do. The vest was tested by one of our team members by wearing the cooling vest, the lead vest and an extra sweater to simulate a surgical gown and stress caused by the surgery. With the cooling vest turned off, our team member's skin temperature rose from 91° F to about 95° F in about 15 minutes. When the cooling vest was turned on, his skin temperature returned to the normal 91° F and stayed constant for the duration that the cooling vest operated. Our team member was also still able to move around and was not restricted in the motions a surgeon is required to go through when he performs a surgery.

Given the time and resources, the next step for our team would be to introduce a feedback control system that can monitor the cooling vest's performance. This improvement to the prototype would significantly increase battery life and would reduce a surgeon's assistance need to constantly turn on and off the thermoelectric cooler to keep the surgeon at a comfortable skin temperature.

RECOMMENDATIONS

The main objective in creating this prototype was to implement a new thermodynamic cooling system that does not already exist on the market today. Since our main objective was to prove that the concept that we had engineered would work, we did not have the time or the resources to engineer the vest to run at optimal efficiency. Improvements our team would like to see include: professionally extruded tubes for the manifold, feedback control system to monitor electrical energy consumption and a better insulative layer between the water cooler and the heat sink.

Our team would like to see a manifold tube design that is completely extruded so that it requires no connections or sealant and would be completely waterproof. The fluid flow through extruded tubes would be significantly better, which could reduce the power requirement for the water pump and cause the water flow to be more uniform. Extruded tubes will also be more flexible and will deliver a more even distribution of cooled water to the front and back sections of the vest. Extruded tubes would also be thinner, resulting in higher conductive heat transfer and a lighter vest that could conform to a wider demographic range that includes men and women.

Implementation of a feedback control system would dramatically improve the overall performance of our cooling vest. This is true for a number of reasons: Feedback control would limit the power consumption by the thermoelectric cooler which at its maximum uses 90 Watts of energy. Sensors relaying real time skin temperature readings of the user would result in energy savings and would prevent the user from becoming too hot or too cold. Feedback control would monitor the batteries to ensure that the batteries are properly charged and could display the percentage of power left (or estimated time of operation). Monitoring the battery packs could also warn the user if the battery pack begins to operate outside of normal parameters.

Insulation between the hot side and cold side of the heat exchanger could dramatically improve the efficiency of the heat exchanger. The thermoelectric cooler moves heat energy from one side of its plates to the other side, but if there is not a good insulation, some of the heat energy that the thermoelectric cooler works to move gets transferred via convection or conduction back onto the cold side, creating electrical energy loss. By limiting the amount of thermal heat energy that is able to transfer back onto the cold side of the thermoelectric cooler, the efficiency of the thermoelectric heater would increase, thus increasing the efficiency of the heat exchanger and the vest.

ACKNOWLEDGEMENTS

We would like to thank everyone who has contributed to this project. Our section instructors, Dr. Shih and Dan Johnson helped us in giving us guidance and great suggestions through the course period. We discussed with Professor Borgnakke about the design for the tube layout and Professor Kaviany about the efficiency of thermoelectric effect. At the machine shop, Bob Coury and Marv helped us to machine the water cycler. Last but not the least, Amanda Gaytan helped us to make the purchase order. We also would like to acknowledge people who have helped us indirectly or directly but their name are not mentioned here.

INFORMATION SOURCES AND REFERENCES LIST

Besides using manufacturer's websites as our information sources, we also approached Prof. Borgnakke and Prof. Kaviany to learn more about the capability of our prototype before it is built. They assisted us in understanding how we can improve our design and how the thermoelectric cooler works. The other sources that we used are listed below.

[1] KOOL N' SAFE (2007) *Standard Evaporative Cooling Vest.* Retrieved on September 30th,2008 from <http://www.koolnsafe.com/product.sc?categoryId=6&productId=3>

[2] Artic Heat (2008) *Cooling Vests*. Retrieved on September 30th,2008 from <http://www.arcticheatusa.com/main.html>

[3] ClimaTech (2008) *CM2000*. Retrieved on September 30th,2008 from <http://www.climatechsafety.com/CM2000.aspx>

[4] Shafer Enterprises LLC (2007) *Cool Vest*. Retrieved on September 30th,2008 from <http://www.coolshirt.net/Surgeons%20Cool%20Vest%20Brochure%202007.pdf>

[5] Polar Products Inc.(2008) *Polar Soft Ice Active Cooling Vest.* Retrieved on September 30th,2008 from <http://www.polarsoftice.com/softiceactivevest.html>

[6] Vortec (2008) *Personal Cooling Vest.* Retrieved on September 30th,2008 from <http://www.vortec.com/personal_air.php>

[7] Entrak (2008) *VentilationVest.* Retrieved on September 30th,2008 from <http://www.entrak.de/index.php?id=1344>

[8] MS Cooling (2008) *Evaporative & Phase Change Cooling Military Vest.* Retrieved on September 30th,2008 from <http://www.mscooling.com/store/1818679/product/7026>

[9] Cool Polymers (2008) *CoolPoly® Thermally Conductive Plastics FOR Tubing Applications* Retrieved on October 5th,2008 from <http://www.coolpolymers.com/tubing.asp>

[10] Incropera, F. Dewitt, D. Bergman, T. Lavine, A. (2007) *Fundamentals of Heat and Mass Transfer, 6th Edition.*New Jersey:Jason Wiley and Sons

[11] TE. Technology (2008). *HP-199-1.4-1.15.* Retrieved on October 15th,2008 from < http://www.tetech.com/Peltier-Thermoelectric-Cooler-Modules/High-Performance/HP-199-1.4-1.15.html>

[12] White, F. M. (2006) Appendix A, *Fluid Mechanics, 6th Edition.* McGraw-Hill

[13] Pipe Flow (2008) *Pipe Flow 3D – Pressure Drop Theory*. Retrieved on October 20th,2008 from <http://www.pipeflow.co.uk/public/control.php?_path=/497/503/510>

[14] Ebay (2008) *DC 12V mini water pump best for PC CPU cooling system.* Retrieved on October 20th,2008 from <http://cgi.ebay.com/ws/eBayISAPI.dll?ViewItem&item=300182869093&ssPageName=MERC_VI_RCRX_Pr4_PcY_BIN_Stores_IT&refitem=300269604392&itemcount=4&refwidgetloc=active_view_item&usedrule1=CrossSell_LogicX&refwidgettype=cross_promot_widget&_trksid=p284.m184&_trkparms=algo%3DCRX%26its%3DS%252BI%252BSS%26itu%3DISS%252BUCI%252BSI%26otn%3D4>

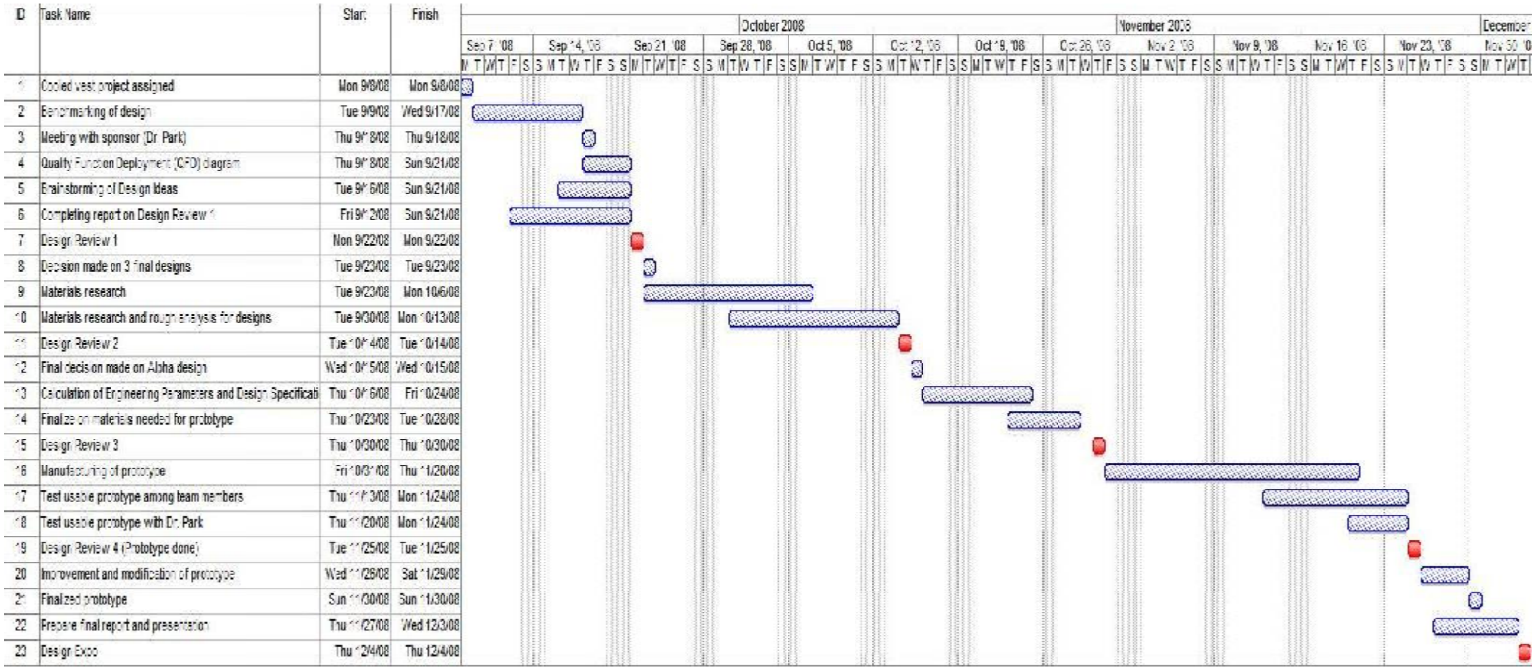
[15] Alpha Novatech (2008) *FS60 , FS80 , FS90 , FS100 SPECIFICATION & THERMAL DATA* Retrieved on October 23th,2008 from <http://www.alphanovatech.com/c_fse.html>

[16] TE Technology (2007) *Thermoelectric Module (TEM) Peltier Element Mounting Procedure* Retrieved on October 24th,2008 from <http://www.tetech.com/docs/tem_(thermoelectric_module)_mounting_procedure.pdf>

[17] WAtronix, Inc (2007) *INB Thermoelectric Products.* Retrieved on October 14th,2008 from < http://www.inbthermoelectric.com/>

Appendix A: Gantt Chart

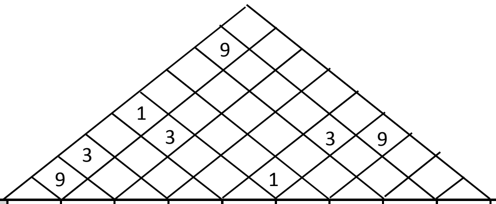
Figure 49: Gantt Chart for Project Plan



ID	Task Name	Start	Finish
1	Cooled vest project assigned	Mon 9/8/08	Mon 9/8/08
2	Benchmarking of design	Tue 9/9/08	Wed 9/17/08
3	Meeting with sponsor (Dr. Park)	Thu 9/18/08	Thu 9/18/08
4	Quality Function Deployment (QFD) diagram	Thu 9/18/08	Sun 9/21/08
5	Brainstorming of Design Ideas	Tue 9/16/08	Sun 9/21/08
6	Completing report on Design Review 1	Fri 9/12/08	Sun 9/21/08
7	Design Review 1	Mon 9/22/08	Mon 9/22/08
8	Decision made on 3 final designs	Tue 9/23/08	Tue 9/23/08
9	Materials research	Tue 9/23/08	Mon 10/6/08
10	Materials research and rough analysis for designs	Tue 9/30/08	Mon 10/13/08
11	Design Review 2	Tue 10/14/08	Tue 10/14/08
12	Final decision made on Alpha design	Wed 10/15/08	Wed 10/15/08
13	Calculation of Engineering Parameters and Design Specificati	Thu 10/16/08	Fri 10/24/08
14	Finalize on materials needed for prototype	Thu 10/23/08	Tue 10/28/08
15	Design Review 3	Thu 10/30/08	Thu 10/30/08
16	Manufacturing of prototype	Fri 10/31/08	Thu 11/20/08
17	Test usable prototype among team members	Thu 11/13/08	Mon 11/24/08
18	Test usable prototype with Dr. Park	Thu 11/20/08	Mon 11/24/08
19	Design Review 4 (Prototype done)	Tue 11/25/08	Tue 11/25/08
20	Improvement and modification of prototype	Wed 11/26/08	Sat 11/29/08
21	Finalized prototype	Sun 11/30/08	Sun 11/30/08
22	Prepare final report and presentation	Thu 11/27/08	Wed 12/3/08
23	Design Expo	Thu 12/4/08	Thu 12/4/08

Appendix B : Quality Function Deployment

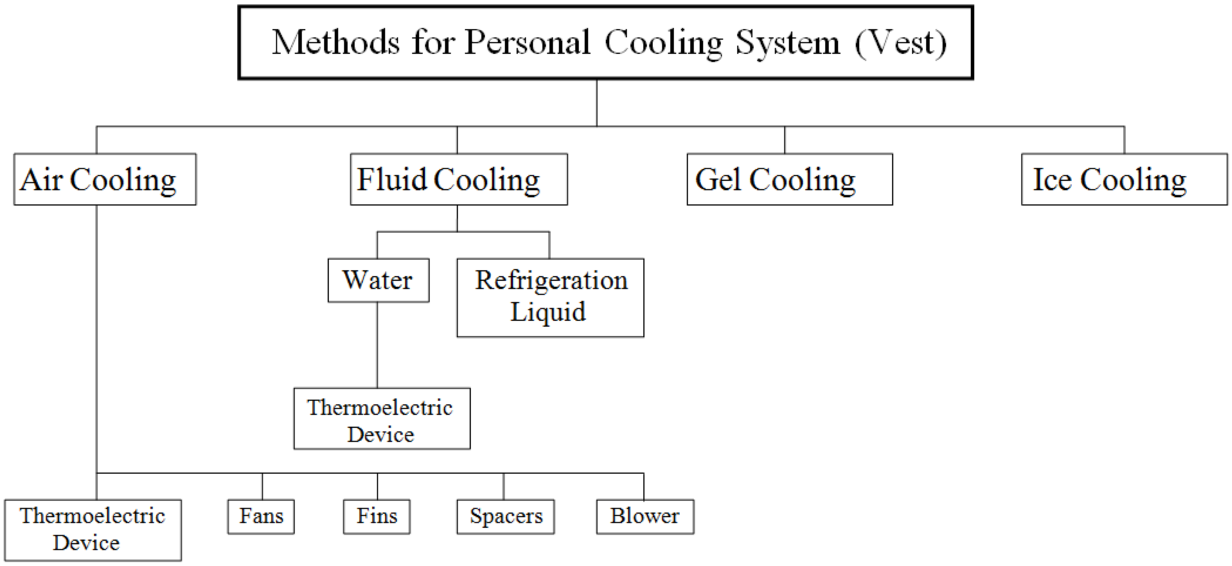
Figure 50: Quality Function Deployment



Customer Requirements / Engineering Characteristics	Weight	Average vest thickness	Weight	Adjustable waist measurement	Young's modulus for vest material	Total cooling area	Steady state temperature	Noise level	Protrusion of mechanism	Standalone operation time	TOTAL	Gel Cooling, Artic Heat	Phase Change Cooling, Climatech CM 2000	Water Cooling, Shafer Enterprises LLC	Air Cooling, Entrak Ventilation Vest
Low bulk	8	9	3		9	1			9			7	6	9	9
Lightweight	10	9	9		1	1			3			8	5	9	7
Ergonomic	6	3	3	9	9	1		1	1			9	6	8	7
Doesn't inhibit motion/joints movement	8	3	3	3	3	3			3			9	7	9	8
Reliable cooling ability	9		1			3	9			9		8	7	6	8
Able to adjust desired temperature	5						9			9		3	4	6	8
Moderately quiet	4						1	9		1		10	10	5	6
No protrusion in front(sterile area)	8	1		1		9			9			7	6	9	8
Mobile (Self-contained)	7	1	3	1		1			3			10	10	5	10
Most weight supported below the torso	8		9	3					3	3		9	9	8	6
Easy to put on	6	9	9	3	3				1			7	9	9	9
Must cool throughout surgery	10						9	1		9		4	6	9	8
Total Score		273	312	135	178	154	220	52	255	244	1823				
Percentage		14.98	17.11	7.405	9.764	8.448	12.07	2.852	13.99	13.38	100				
Ranking															
Measurement Units		cm	lbs	in.	Gpa	cm^2	°F	dB	cm	hours					
Gel Cooling, Artic Heat		2.2	1.5	35-52	5.8	900	63	0	N/A	2					
Phase Change Cooling, Climatech CM 2000		3	5	40-52	N/A	1400	68	0	N/A	6					
Water Cooling, Shafer Enterprises LLC		1	1.25	38-66	N/A	450	71	0	N/A	10					
Air Cooling, Entrak Ventilation Vest		1	2.9	39-57	3.5	1200	70	40	3	6					
Target values		1.5	1.25	35-52	3	800	69	20	2	10					

Appendix C: Functional Decomposition

Figure 51: Functional Decomposition on Type of Cooling



Appendix D: Preliminary Design Ideas

Figure 52: Conceptual sketch of vest with recharging ice packs.

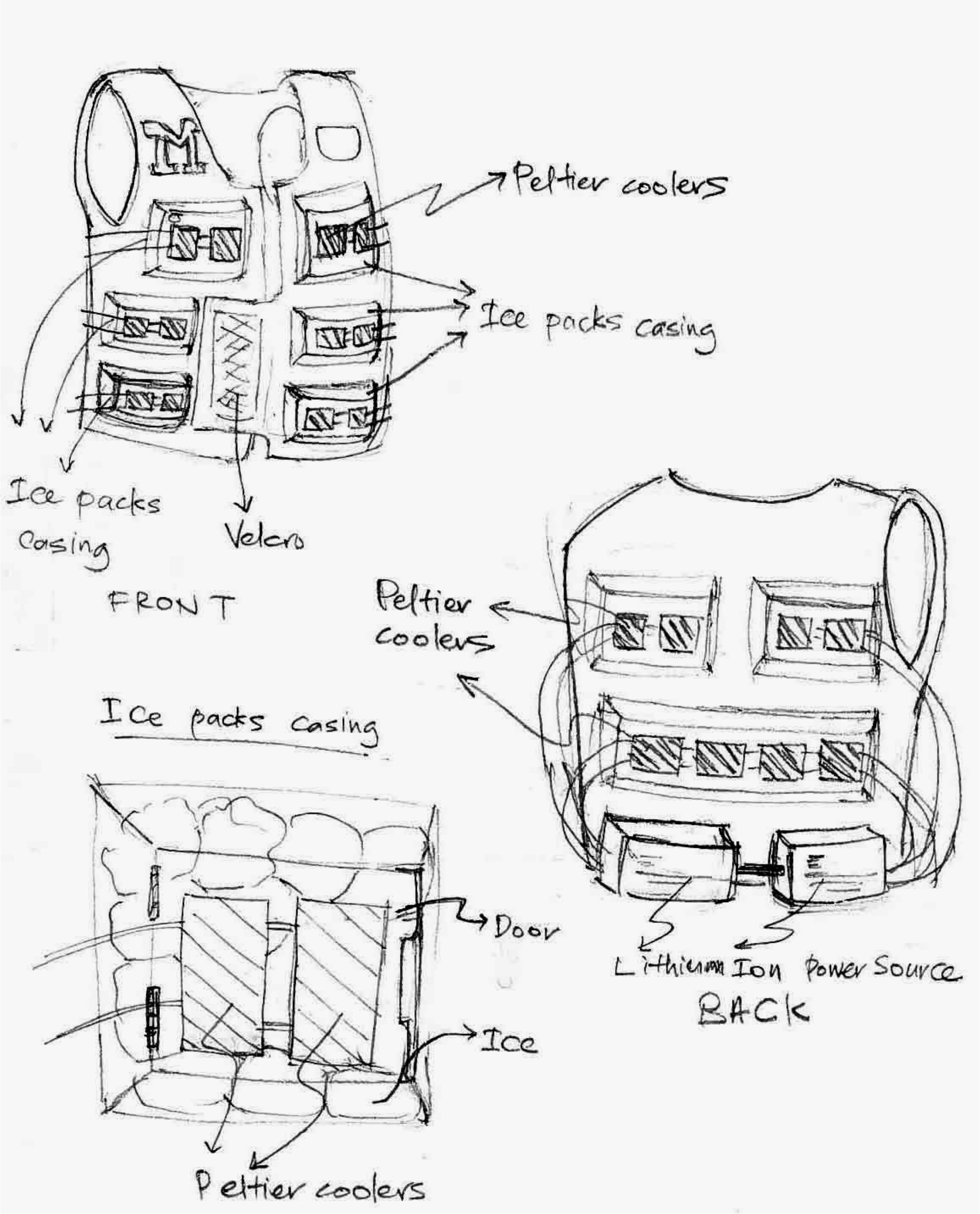


Figure 53: Conceptual sketch of an evaporative cooling vest.

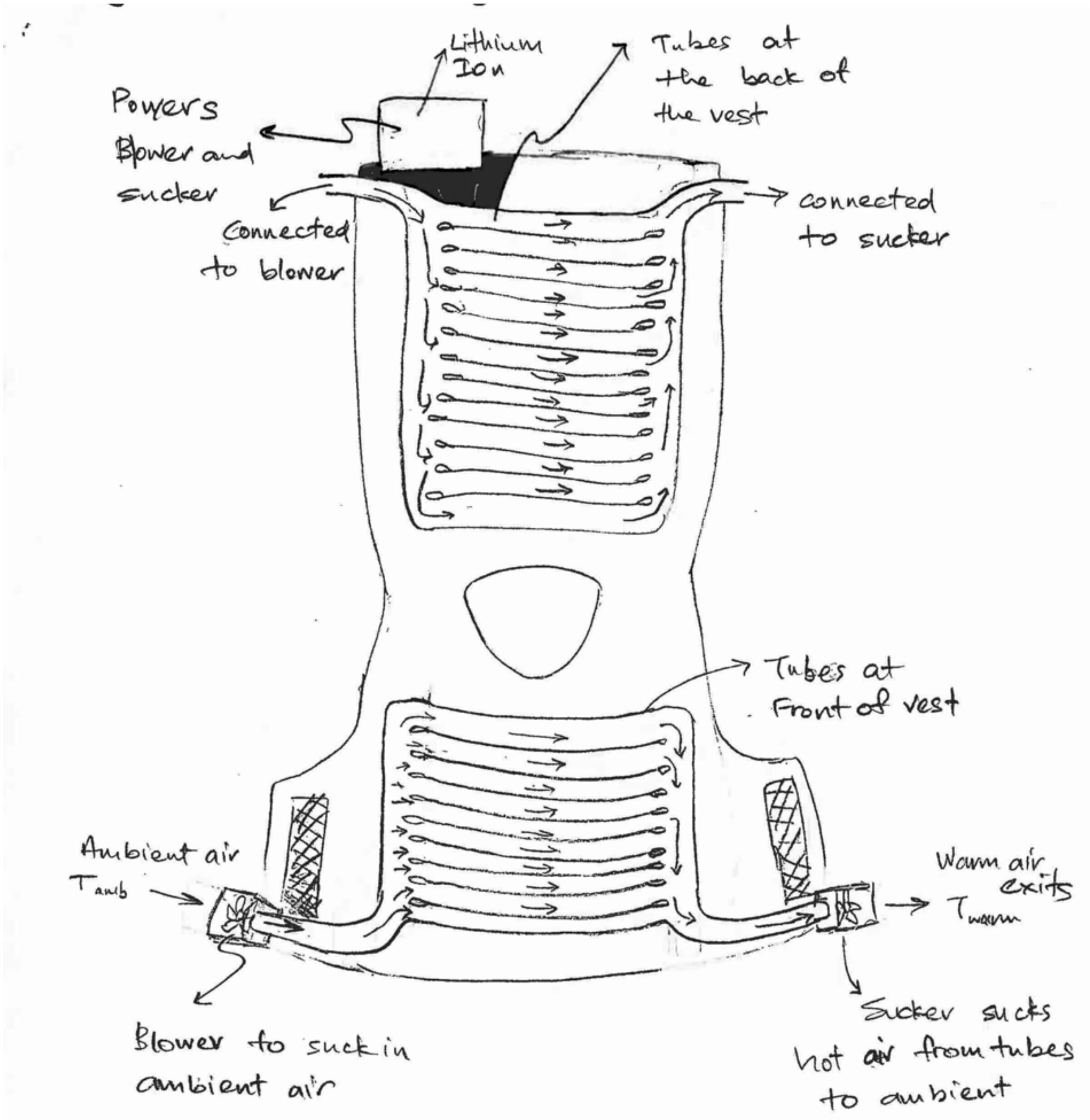


Figure 54: Conceptual sketch of an air cooling vest using thermoelectric coolers.

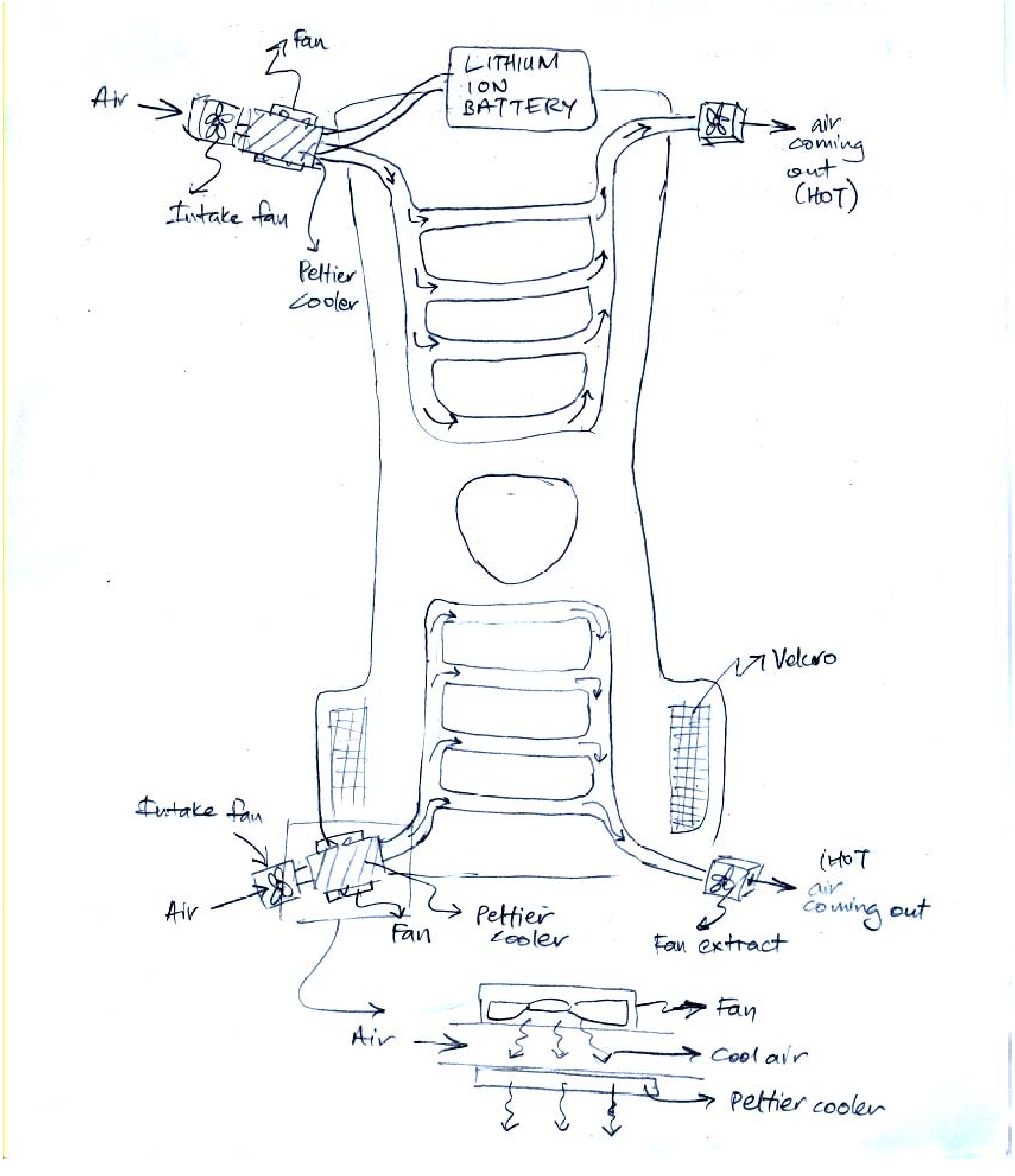


Figure 55: Conceptual sketch of a water cooled vest with the utilization of a thermoelectric cooler.

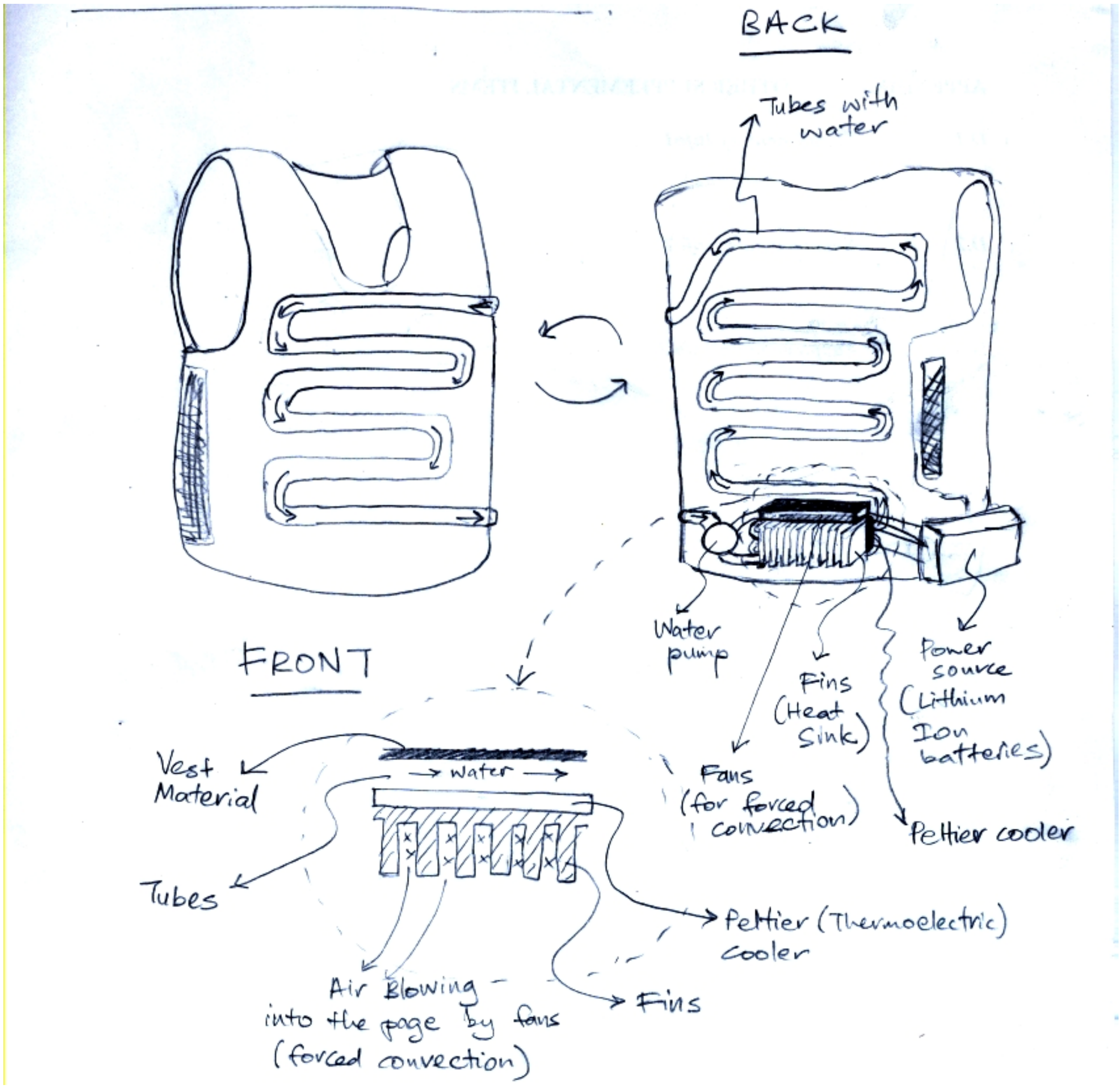


Figure 56: Conceptual sketch of a gel cooling vest.

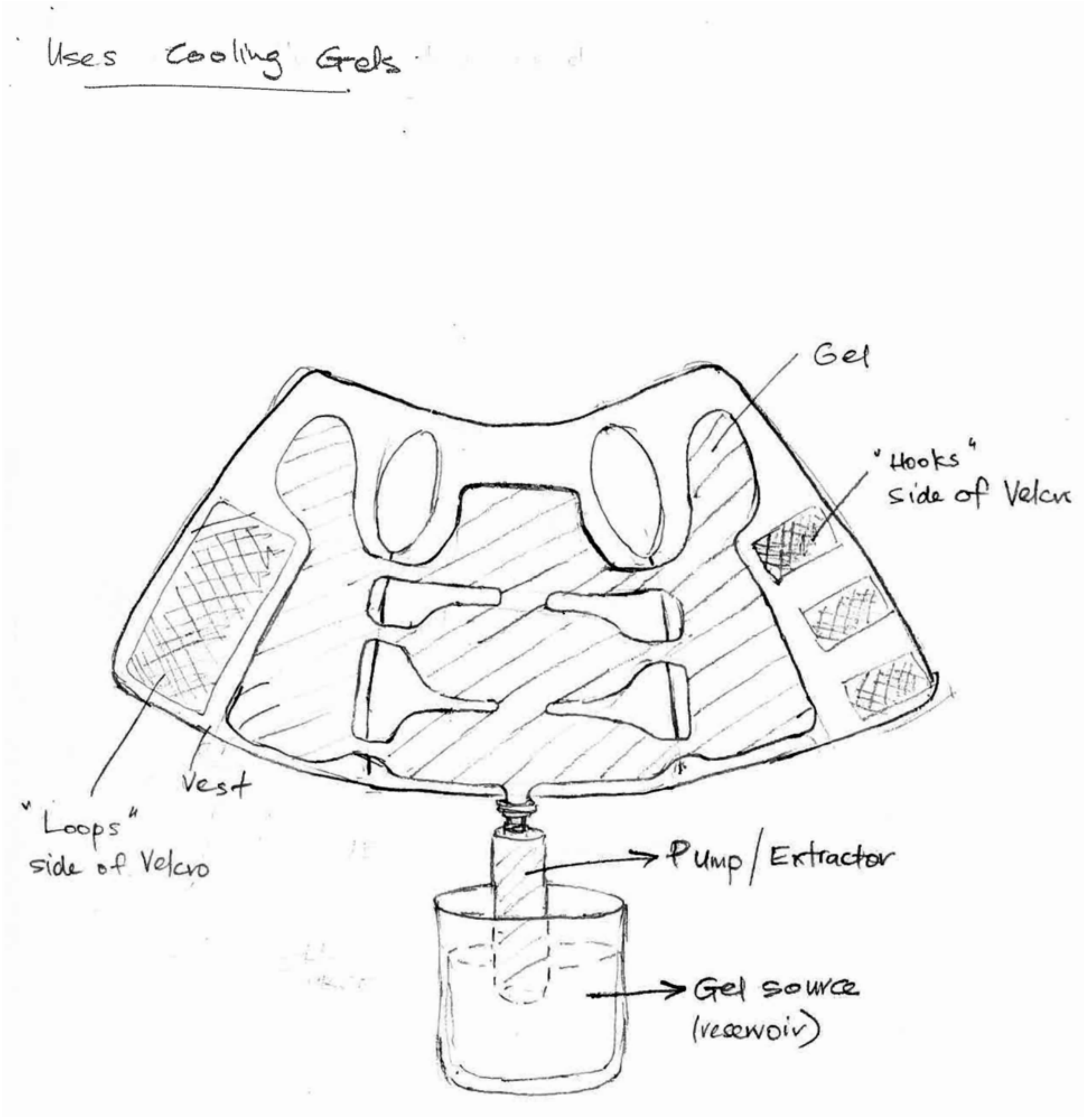


Figure 57: Fans on vest with external fans

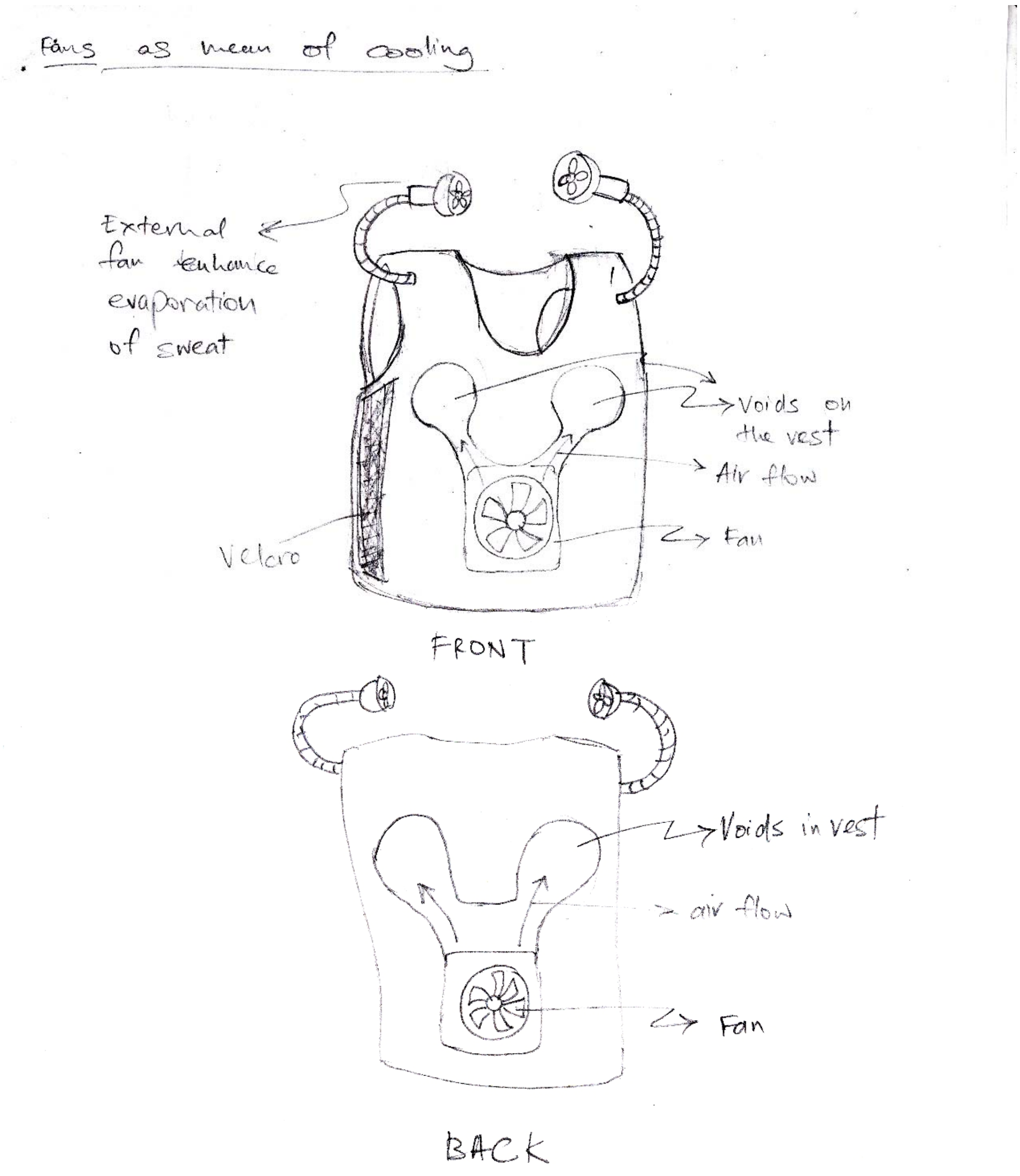


Figure 58: 1 fan and spacers on both side of the vest

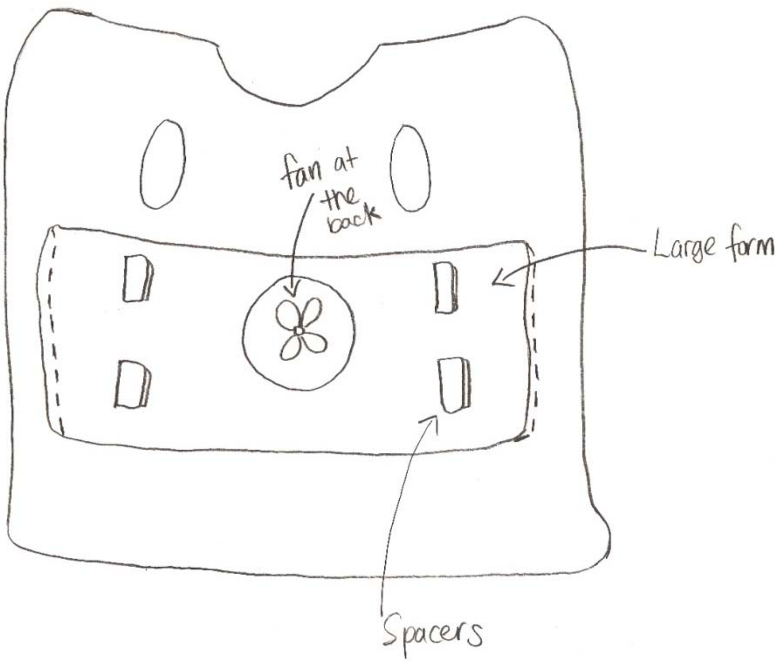
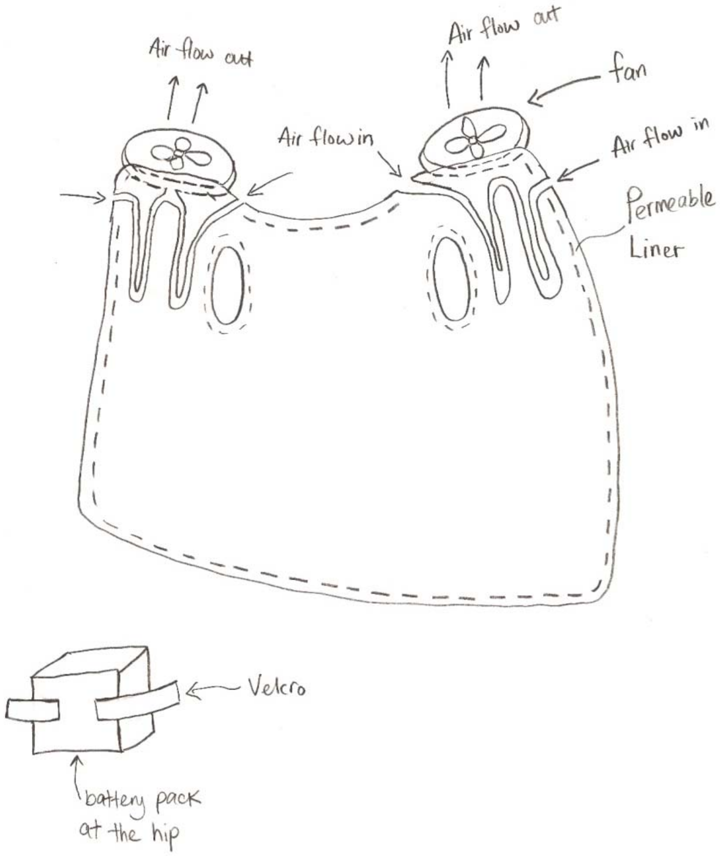


Figure 59: Fans installed at shoulder pad



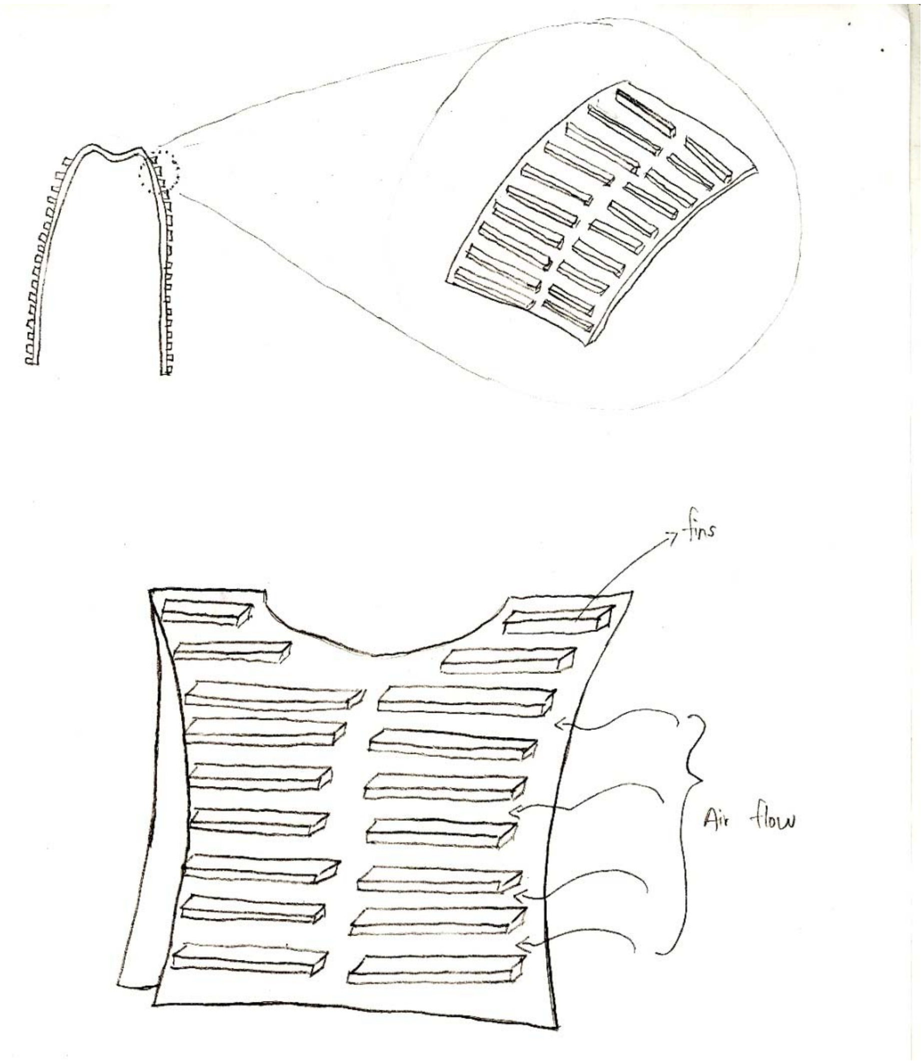


Figure 60: Fins to enhance natural convection

This conceptual sketch shows a simple vest, made of 2 layers of latex, inbetween is sandwiched a layer of spacers made of a flexible polymer. The spacers allow for increased heat transfer and allow for the possibility of more free convection.

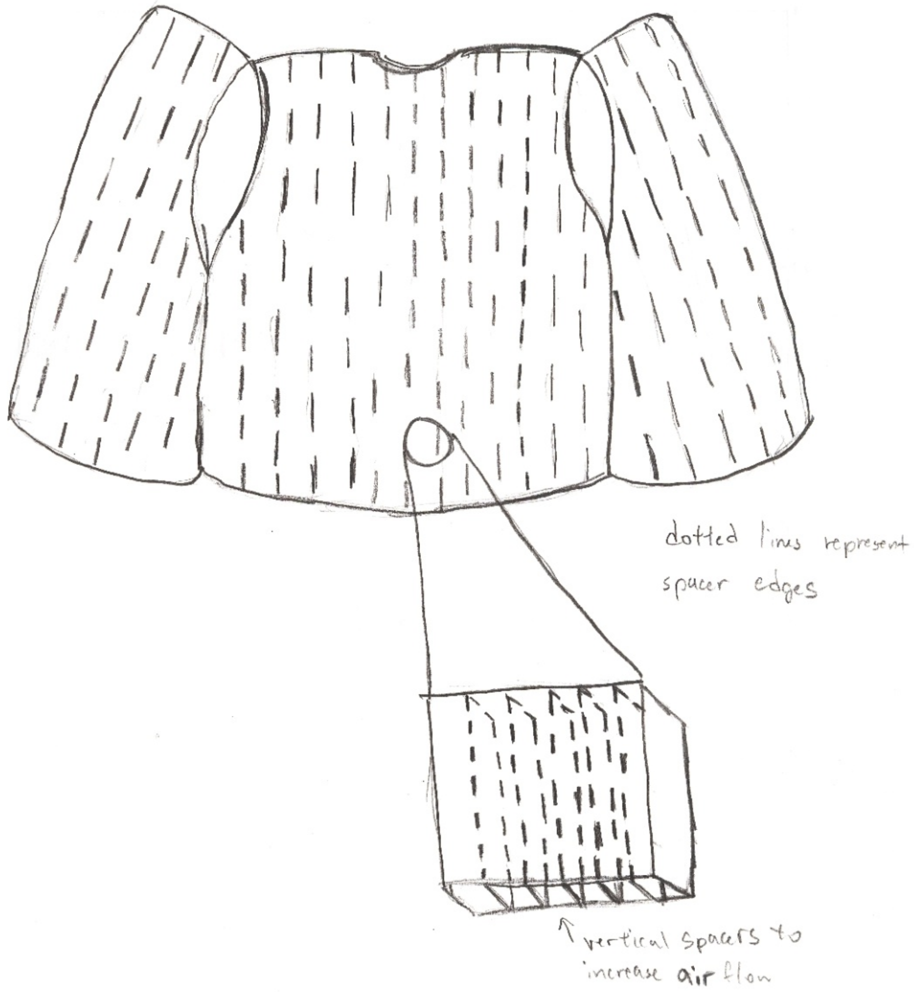


Figure 61: Spacers between vest and body

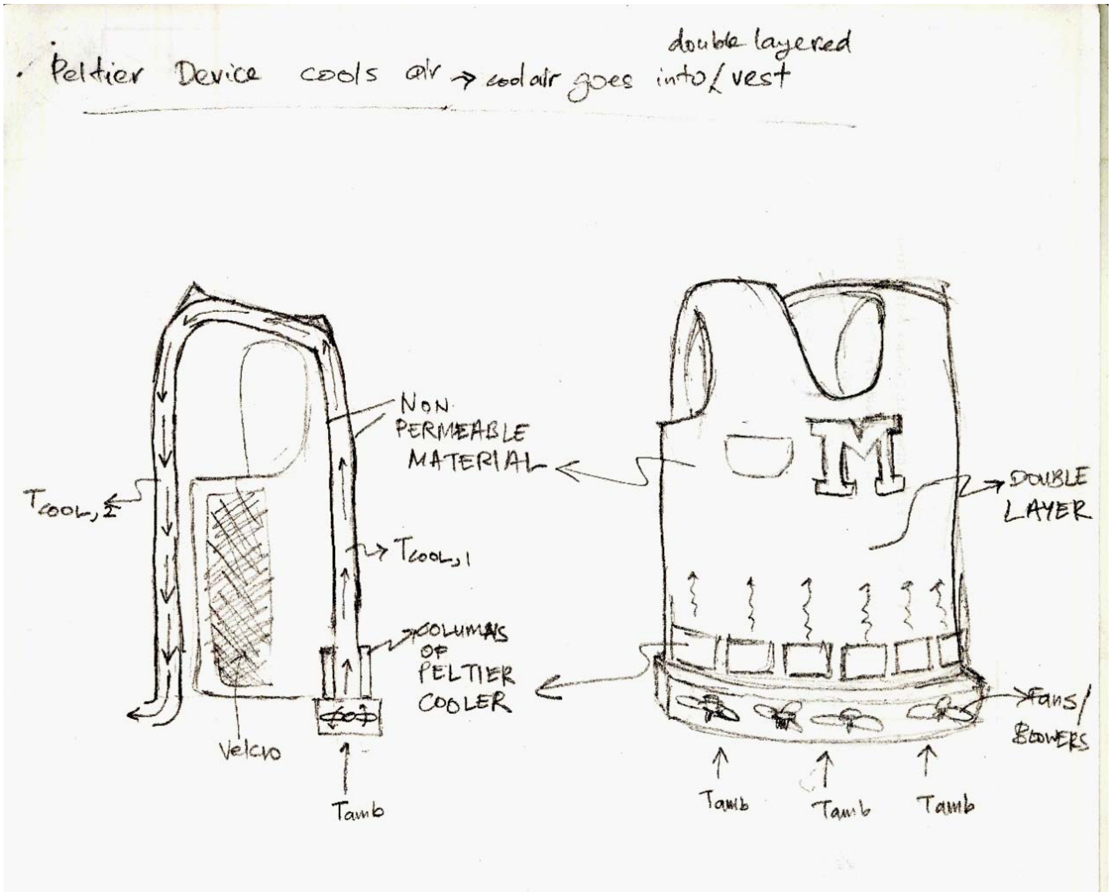


Figure 62: Flow of cool air through double layered vest

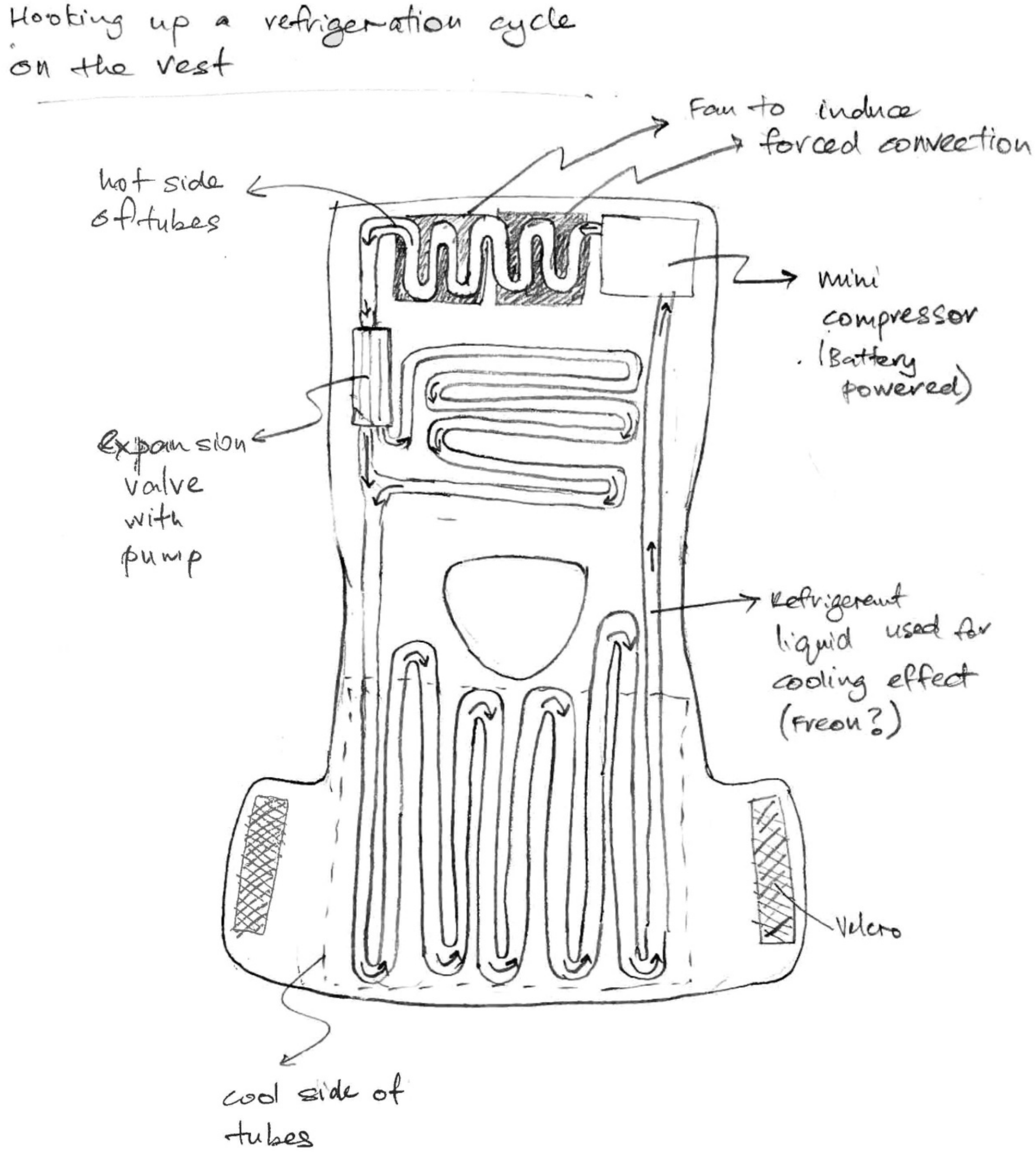


Figure 63: Refrigeration cycle on vest

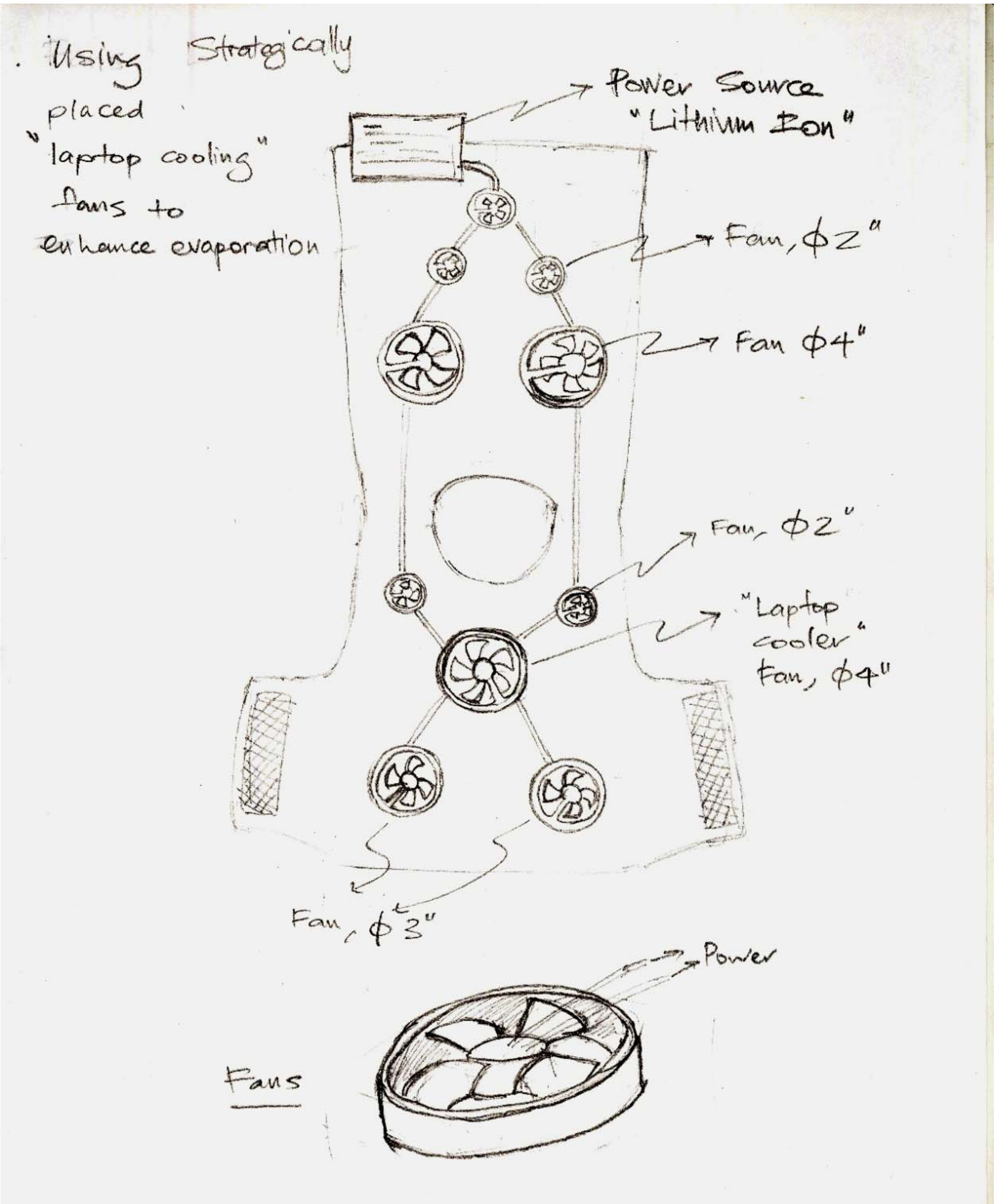


Figure 64: Strategically placed laptop fans on vest

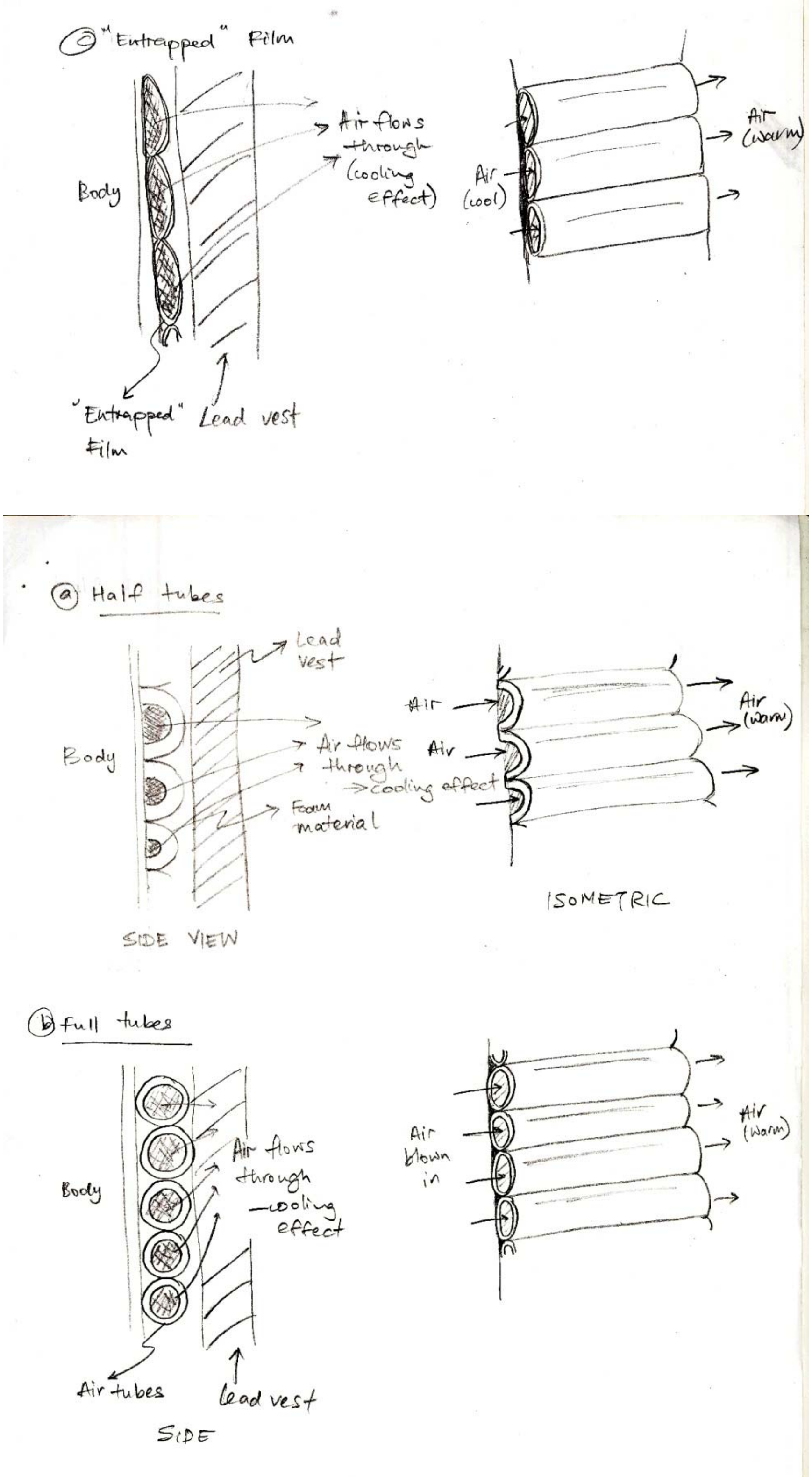
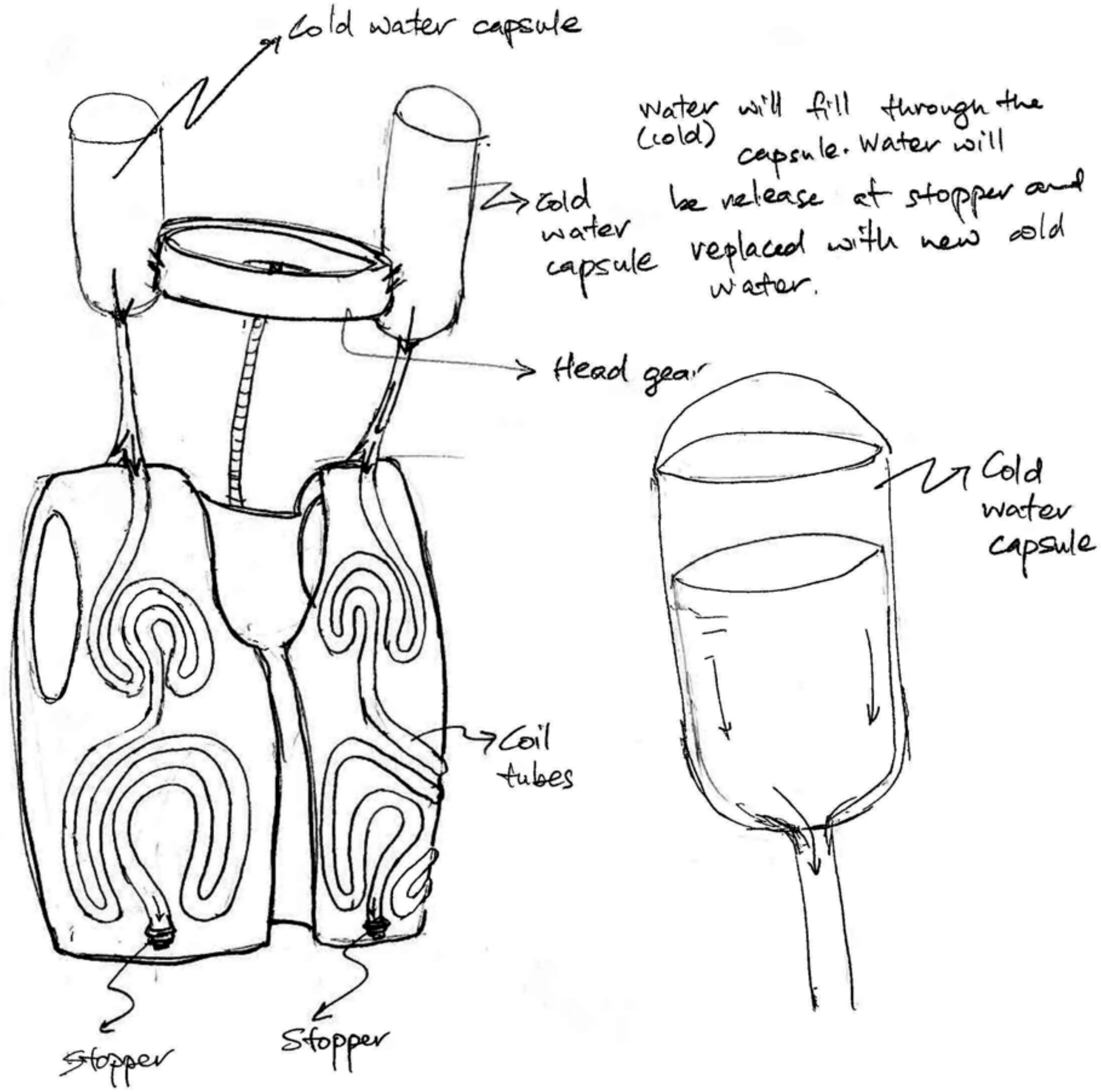


Figure 65: Tubing types for attachment to vest



Water will fill through the (cold) capsule. Water will be release at stopper and replaced with new cold water.

Figure 66: Water capsule with cold water

Appendix E: Vest Material Selection

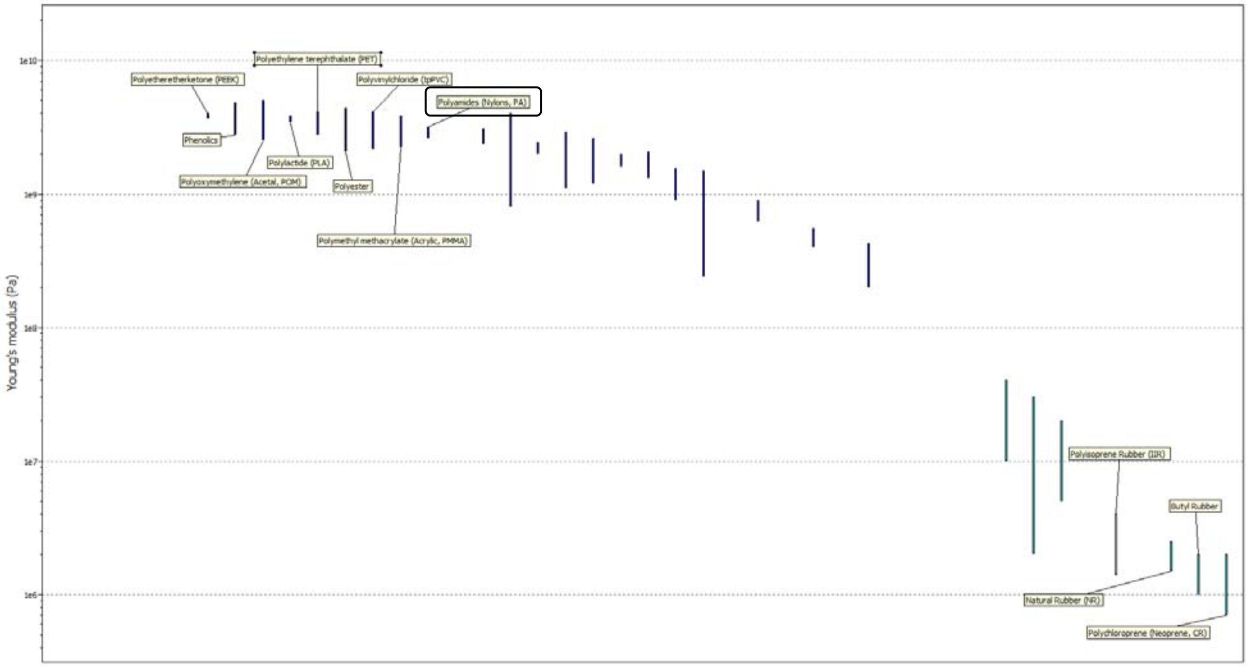


Figure 67: The Young's Modulus of all the polymers

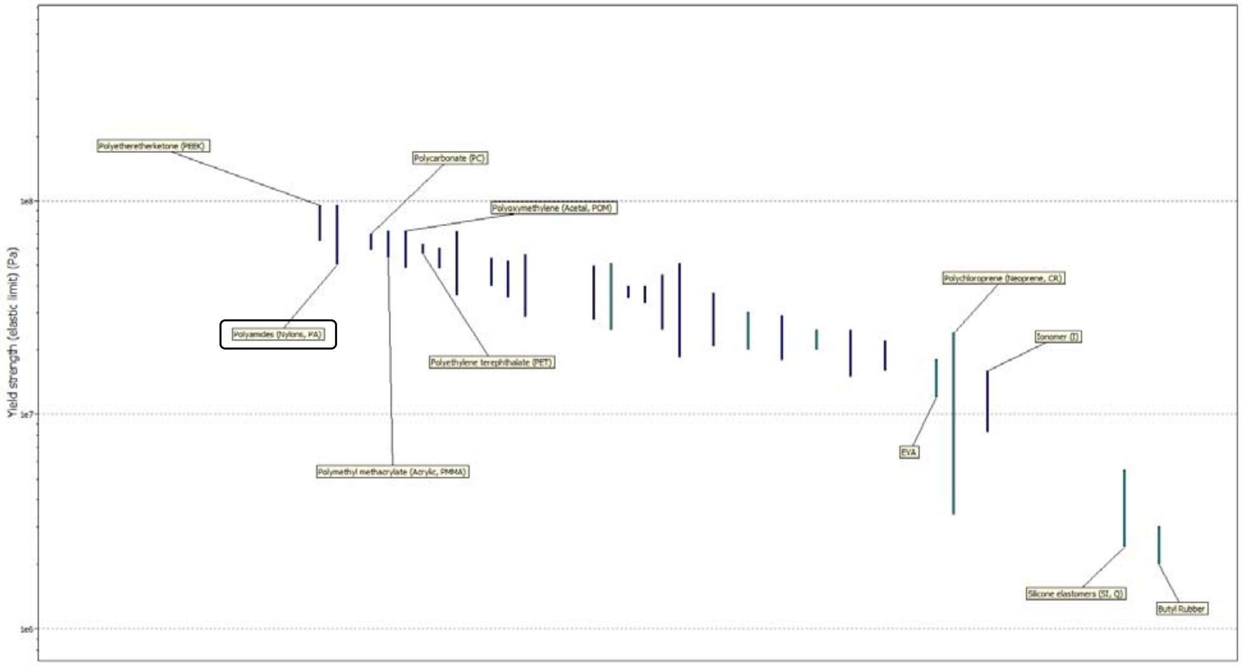


Figure 68: Yield strength of all the polymers

Appendix F: Tubes calculation

For the radial system, the conduction heat flux (per length) across the tube could be represented by the equation:

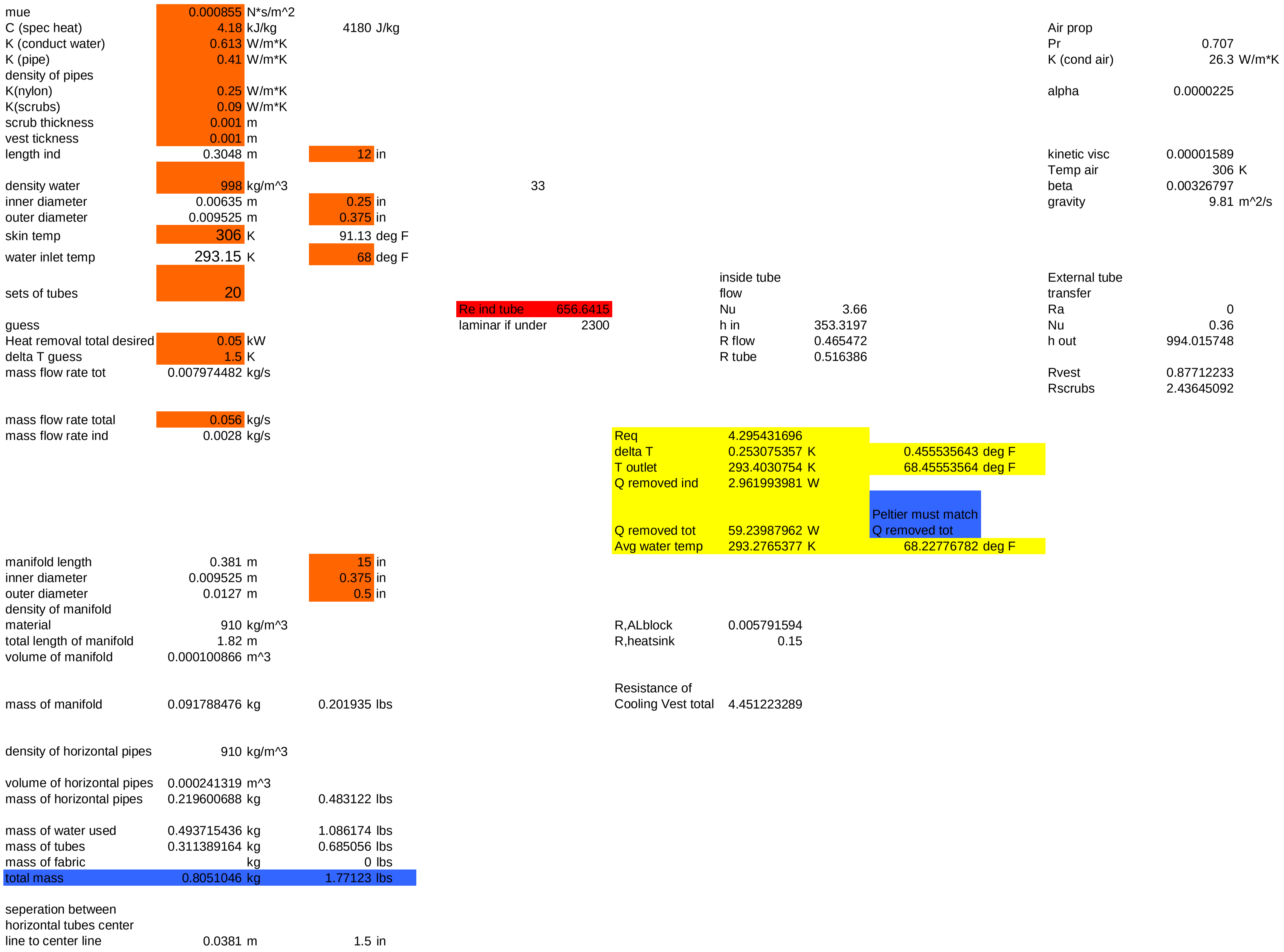
$$\boldsymbol{q_r}' = \frac{\mathbf{2}\boldsymbol{\pi k}(\boldsymbol{T_{s,1}} - \boldsymbol{T_{s,2}})}{\ln{(\boldsymbol{r_2}/\boldsymbol{r_1})}} \qquad \text{Eq. 30}$$

In which case, the resistance (per length) of the heat transfer through conduction could be represented as

$$\boldsymbol{R_{t,cond}}' = \frac{\ln{(\mathbf{1}+\boldsymbol{t}/\boldsymbol{r_i})}}{\mathbf{2}\boldsymbol{\pi k}} \qquad \text{Eq. 31}$$

Appendix G: Thermodynamic Model

Figure 69: Excel Sheet of Thermodynamics Model



mue	0.000855	N*s/m^2		
C (spec heat)	4.18	kJ/kg	4180	J/kg
K (conduct water)	0.613	W/m*K		
K (pipe)	0.41	W/m*K		
density of pipes				
K(nylon)	0.25	W/m*K		
K(scrubs)	0.09	W/m*K		
scrub thickness	0.001	m		
vest tickness	0.001	m		
length ind	0.3048	m	12	in
density water	998	kg/m^3		
inner diameter	0.00635	m	0.25	in
outer diameter	0.009525	m	0.375	in
skin temp	306	K	91.13	deg F
water inlet temp	293.15	K	68	deg F
sets of tubes	20			
guess				
Heat removal total desired	0.05	kW		
delta T guess	1.5	K		
mass flow rate tot	0.007974482	kg/s		
mass flow rate total	0.056	kg/s		
mass flow rate ind	0.0028	kg/s		
manifold length	0.381	m	15	in
inner diameter	0.009525	m	0.375	in
outer diameter	0.0127	m	0.5	in
density of manifold material	910	kg/m^3		
total length of manifold	1.82	m		
volume of manifold	0.000100866	m^3		
mass of manifold	0.091788476	kg	0.201935	lbs
density of horizontal pipes	910	kg/m^3		
volume of horizontal pipes	0.000241319	m^3		
mass of horizontal pipes	0.219600688	kg	0.483122	lbs
mass of water used	0.493715436	kg	1.086174	lbs
mass of tubes	0.311389164	kg	0.685056	lbs
mass of fabric		kg	0	lbs
total mass	0.8051046	kg	1.77123	lbs
seperation between horizontal tubes center line to center line	0.0381	m	1.5	in

	33
Re ind tube	656.6415
laminar if under	2300

inside tube flow	
Nu	3.66
h in	353.3197
R flow	0.465472
R tube	0.516386

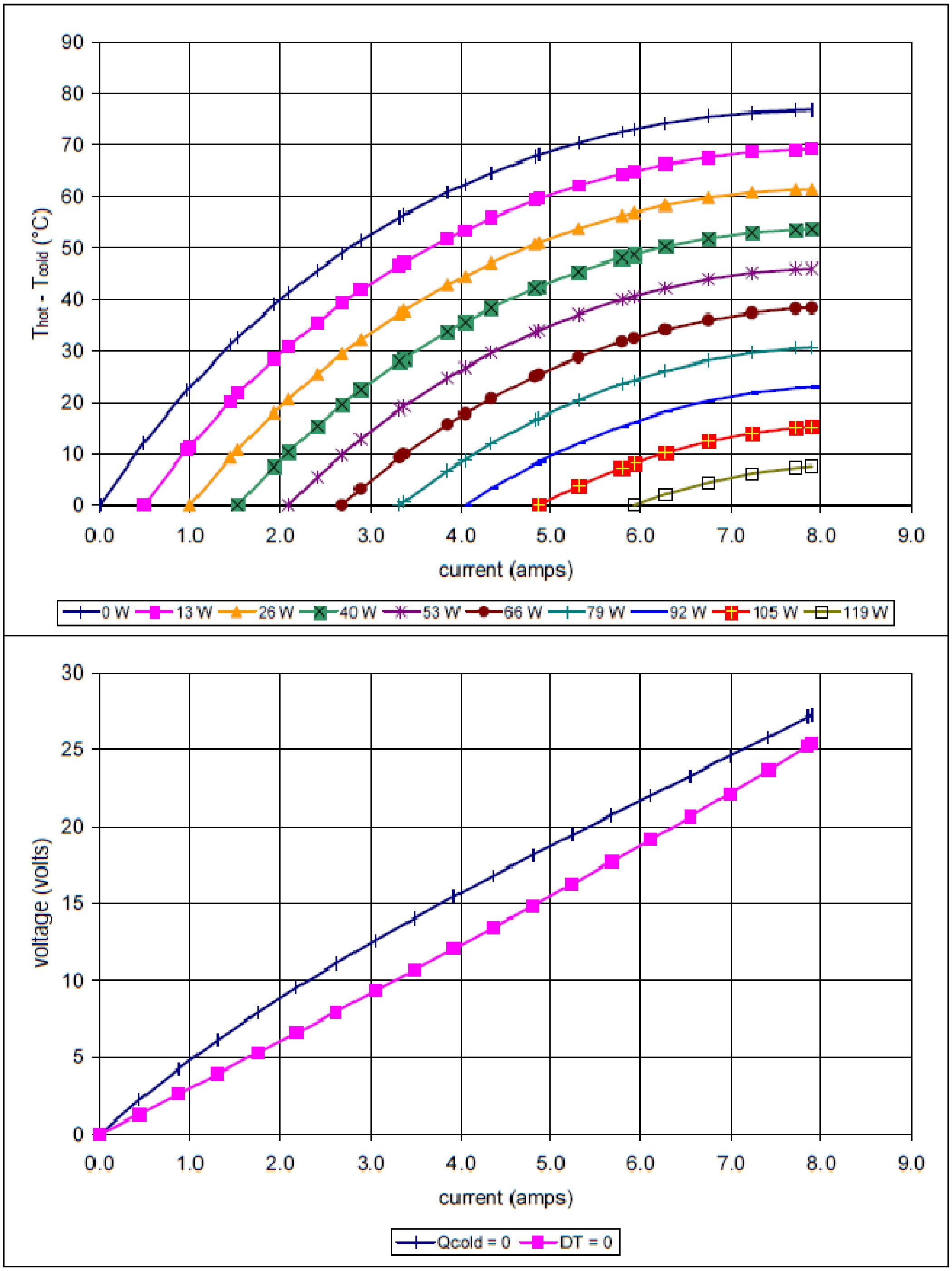
Req	4.295431696			
delta T	0.253075357	K	0.455535643	deg F
T outlet	293.4030754	K	68.45553564	deg F
Q removed ind	2.961993981	W		
			Peltier must match Q removed tot	
Q removed tot	59.23987962	W		
Avg water temp	293.2765377	K	68.22776782	deg F

R,ALblock	0.005791594
R,heatsink	0.15
Resistance of Cooling Vest total	4.451223289

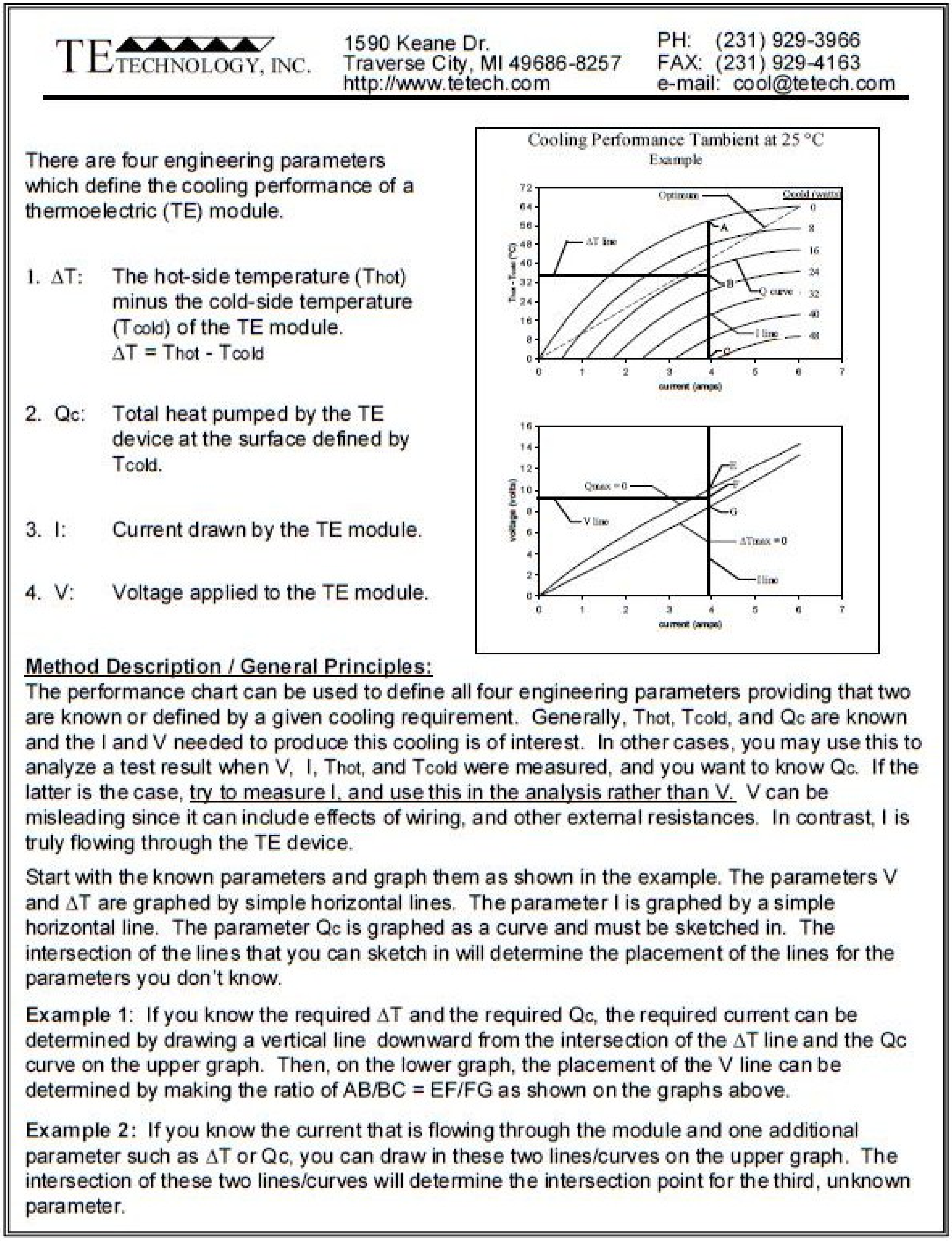
Air prop		
Pr	0.707	
K (cond air)	26.3	W/m*K
alpha	0.0000225	
kinetic visc	0.00001589	
Temp air	306	K
beta	0.00326797	
gravity	9.81	m^2/s
External tube transfer		
Ra	0	
Nu	0.36	
h out	994.015748	
Rvest	0.87712233	
Rscrubs	2.43645092	

Appendix H: Thermoelectric cooler graphs and manual

TE TECHNOLOGY, INC.
1590 Keane Drive, Traverse City, MI, 49686-8257 USA
PH: 231-929-3966 FAX: 231-929-4163 email: cool@tetech.com



Potted HP-199-1.4-1.15 at a hot-side temperature of 50 °C



TE TECHNOLOGY, INC.
1590 Keane Dr.
Traverse City, MI 49686-8257
http://www.tetech.com
PH: (231) 929-3966
FAX: (231) 929-4163
e-mail: cool@tetech.com

There are four engineering parameters which define the cooling performance of a thermoelectric (TE) module.

1. ΔT: The hot-side temperature (Thot) minus the cold-side temperature (Tcold) of the TE module.
   $\Delta T = T_{hot} - T_{cold}$
2. Qc: Total heat pumped by the TE device at the surface defined by Tcold.
3. I: Current drawn by the TE module.
4. V: Voltage applied to the TE module.

Cooling Performance Tambient at 25 °C
Example

Method Description / General Principles:
The performance chart can be used to define all four engineering parameters providing that two are known or defined by a given cooling requirement. Generally, Thot, Tcold, and Qc are known and the I and V needed to produce this cooling is of interest. In other cases, you may use this to analyze a test result when V, I, Thot, and Tcold were measured, and you want to know Qc. If the latter is the case, try to measure I, and use this in the analysis rather than V. V can be misleading since it can include effects of wiring, and other external resistances. In contrast, I is truly flowing through the TE device.

Start with the known parameters and graph them as shown in the example. The parameters V and ΔT are graphed by simple horizontal lines. The parameter I is graphed by a simple horizontal line. The parameter Qc is graphed as a curve and must be sketched in. The intersection of the lines that you can sketch in will determine the placement of the lines for the parameters you don't know.

Example 1: If you know the required ΔT and the required Qc, the required current can be determined by drawing a vertical line downward from the intersection of the ΔT line and the Qc curve on the upper graph. Then, on the lower graph, the placement of the V line can be determined by making the ratio of AB/BC = EF/FG as shown on the graphs above.

Example 2: If you know the current that is flowing through the module and one additional parameter such as ΔT or Qc, you can draw in these two lines/curves on the upper graph. The intersection of these two lines/curves will determine the intersection point for the third, unknown parameter.

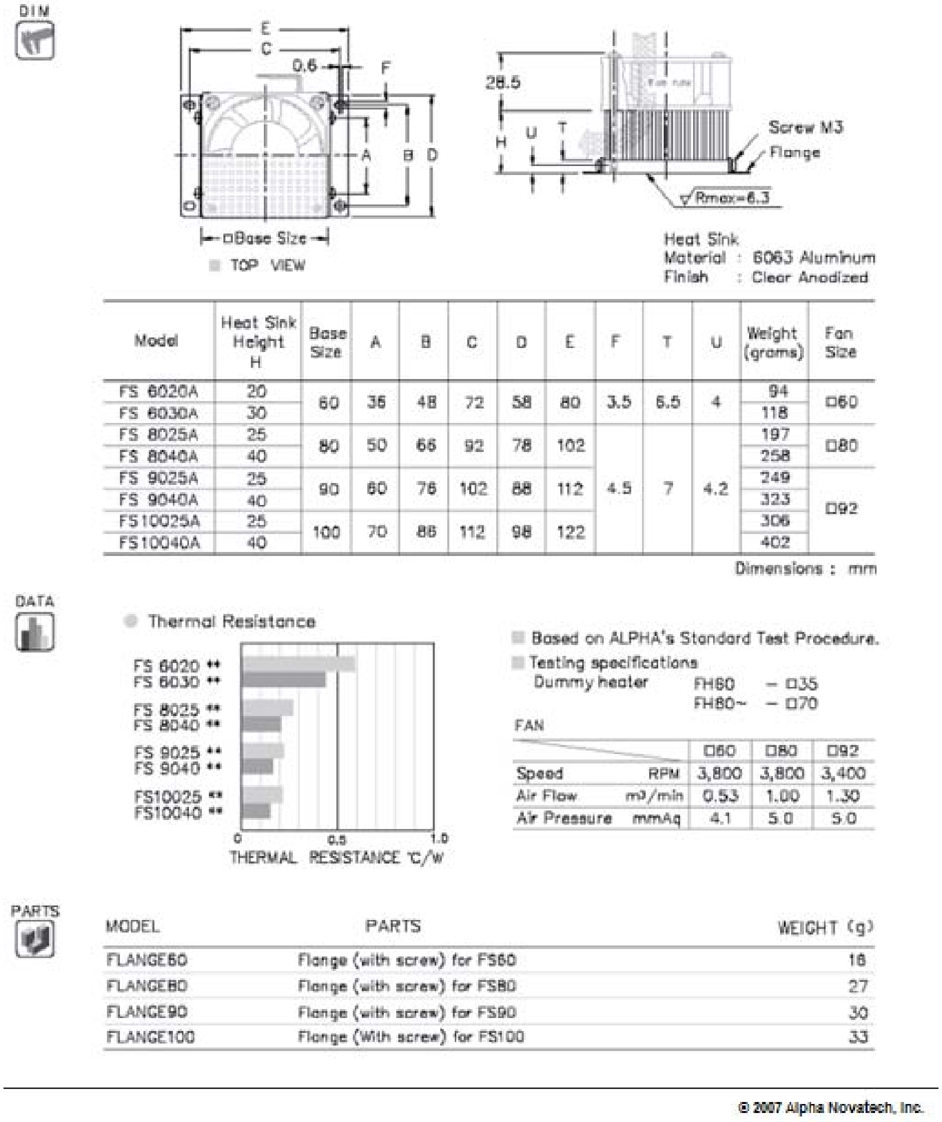
Appendix I: Heat Sink and Fan Calculation

Since the cooling system will absorb $\dot{Q}_L$= 59.27 W (from table 10) and the thermoelectric cooler will ideally put in electrical power, $\dot{W}_{electrical}$= 90 W from the given charts on Appendix H, from Eq. X, we calculate the heat rate produced to be $\dot{Q}_H$≈150W.

With $T_{Hot} = 42^oC \sim 48^oC$ and T_∞ = 22.8°C, we obtain the change in temperature, ΔT (°C) to be between the range of 19.2°C and 25.2°C.

Based on the heat equation, $\dot{Q}_H = \frac{\Delta T}{R_{h.sink}}$, we then calculate the heat sink's resistance, $R_{h.sink}$ (°C/W).

$R_{h.sink}$ = 0.128 °C/W ~ 0.168 °C/W



□Base Size

TOP VIEW

Heat Sink
Material : 6063 Aluminum
Finish : Clear Anodized

Model	Heat Sink Height H	Base Size	A	B	C	D	E	F	T	U	Weight (grams)	Fan Size
FS 6020A	20	60	36	48	72	58	80	3.5	6.5	4	94	□60
FS 6030A	30										118	
FS 8025A	25	80	50	66	92	78	102	4.5	7	4.2	197	□80
FS 8040A	40										258	
FS 9025A	25	90	60	76	102	88	112				249	□92
FS 9040A	40										323	
FS10025A	25	100	70	86	112	98	122				306	
FS10040A	40										402	

Dimensions : mm

Based on ALPHA's Standard Test Procedure.

Testing specifications
Dummy heater FH60 – □35
FH80~ – □70

FAN

		□60	□80	□92
Speed	RPM	3,800	3,800	3,400
Air Flow	m³/min	0.53	1.00	1.30
Air Pressure	mmAq	4.1	5.0	5.0

PARTS

MODEL	PARTS	WEIGHT (g)
FLANGE60	Flange (with screw) for FS60	18
FLANGE80	Flange (with screw) for FS80	27
FLANGE90	Flange (with screw) for FS90	30
FLANGE100	Flange (With screw) for FS100	33

Appendix J: Bills of Materials

Table 23: Bills of Materials

Components		**Part Number**	**Quantity**	**Cost($)**	**Purchased From**
Vest		N/A	4ft^2	$ 7.50	Jo-Ann Fabrics
Tubes	Cooling tubes	N/A	20ft^2	8.00	Carpenter’s Bros.
	Manifold tubes Polyethylene	N/A	2ft^2	1.00	Carpenter’s Bros.
	Transfter tubes Polyvinyl	N/A	5ft^2	3.50	Carpenter’s Bros.
Tube fittings	T- Connectors	64053	36	21.28	www.usplastics.com
	Elbows	2974K691	4	2.20	www.mcmaster.com
	Couplings	N/A	2	1.40	Carpenter’s Bros.
	Male Pipe Branch Tee	N/A	1	0.70	Carpenter’s Bros.
Water Cooler		N/A	1	0.00	Donated by Machine Shop
Water cooler fittings	Plugs	N/A	4	8.50	The Home Depot
	Couplings	N/A	2	5.00	The Home Depot
	Adapter	N/A	2	5.00	The Home Depot
Thermoelectric cooler		HP-199-1.4-1.15	1	38.10	www.tetech.com
Heat Sink with Fan		FS10040PU	1	43.20	www.alphanovatech.com
Water Pump		300182869093	1	26.50	www.ebay.com
Belt		N/A	1	14.99	
Velcro attachment		N/A	6	8.00	Carpenter’s Bros.
Batteries	Lithium-Ion Polymer	PL-9059156-5S-TM	1	213.35	www.batteryspace.com
	Lithium-Ion Phosphate	LF-H1P2S4R1WR	1	48.45	www.batteryspace.com
	18V Charger	CH-LI21V3A	1	48.45	www.batteryspace.com
	12V Charger	LFP-Cable-15.2V1.5A	1	29.95	www.batteryspace.com
Project Box		N/A	1	2.69	Radioshack Store
Switches		N/A	3	6.00	Radioshack Store
Wires		N/A	5ft	4.00	Radioshack Store
Hose clamp		N/A	10	7.00	Carpenter’s Bros.
Marine Adhesive Sealant Fast Cure 4000 UV		1RWH9	1	15.27	www.grainger.com
Water Proof Tape (Magic Tape)		N/A	1	4.00	Meijer
TP-1 Thermal Paste		8010	1	13.00	www.tetech.com
TOTAL COST				**$ 587.03**	

Appendix K: Water Cooler Design

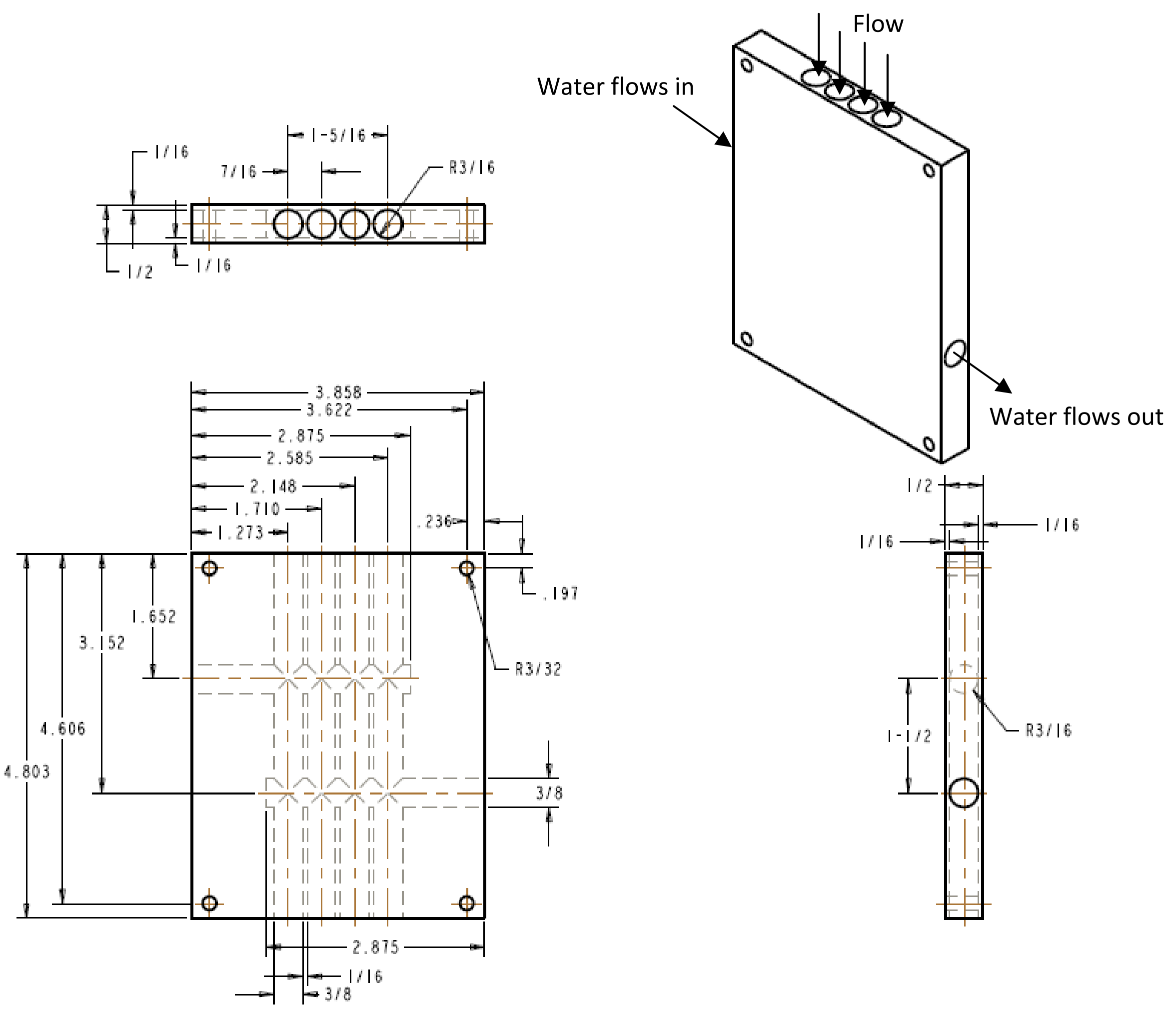
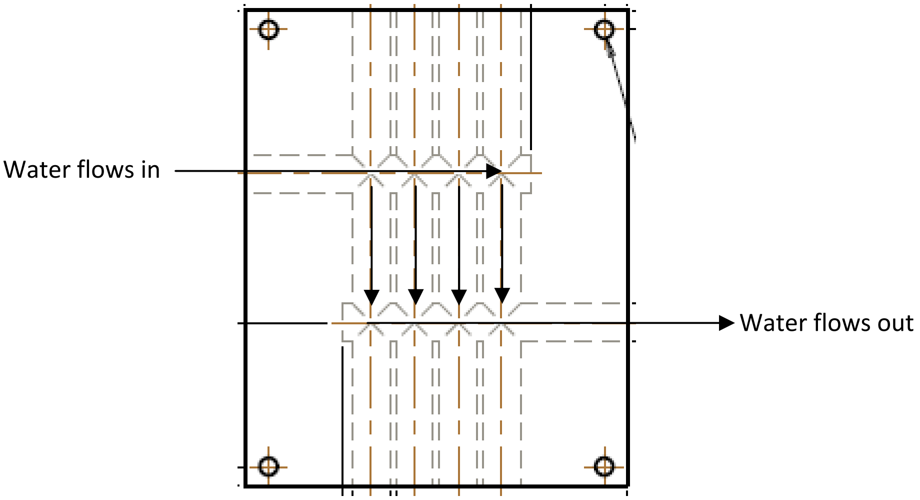
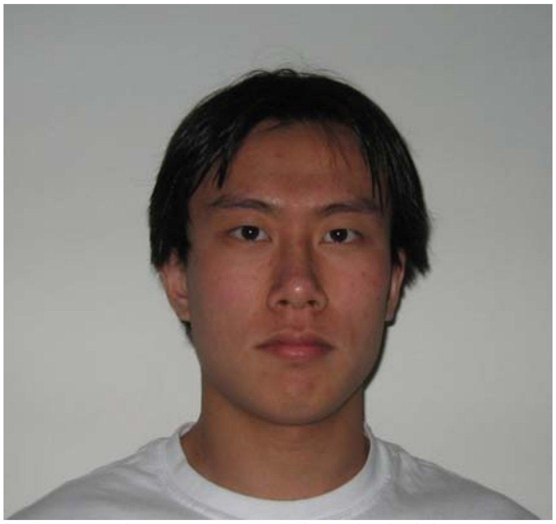


Figure 70: Water Cooler Drawing

Water Flow in the Water Cooler



TEAM BIOGRAPHY



Yeu-Cherng Chi

My name is Yeu-Cherng "Multy" Chi. I was born in Taichung, Taiwan and was raised prim arily in Columbus, Indiana. I came to the University of Michigan with aspirations of becoming a mechanical engineer. I knew fairly well in high school that I wanted to become an engineer, but I didn't realize I wanted to be a mechanical engineer until later. Mechanical engineering was especially appealing to me because it encompassed a broad scope of engineering applications: everything from airplane design to high performance sports vehicles and even military applications such as ballistics. At the present, I am interested in the automotive industry and would like to work on powertrains, hybrids or 8 piston transmissions. In my spare time I enjoy playing basketball and football, workout and playing video games.

Yee Chon Chin

I was born in Malaysia and attended University of Michigan in 2005. After graduating from high school, I was offered a scholarship from the government of Malaysia to study mechanical engineering in the Unites States of America. I was offered the scholarship because of the excellent result that I received in O level examination. My scholarship includes a full tuition fee and cost of living.

I set my interest in Mechanical Engineering because I has a deep interest in the studying the mechanisms of objects that interact with humans. I find it very fascinating to understand the law of nature and the fundamental of mechanics that could be applied to design or built a prototype. By understanding several laws and theorems, I could be able to analyze a structure so that I could design a structure that could service its purposes safely. For example, learning about the fracture toughness helps me to understand the criteria needed to design a structure that operates under fluctuating stress so that a structure does not fail. The crack length, the thickness and stress applied could potentially affect the fracture toughness and a detail analysis would help to prevent failure from happening.

Pursuing doctorate is my plan for the future. I believe there's more that I can learn and understand through research. Through research, I can explore more areas to improve the areas where technology could not help us today especially in helping lives of people.

Daniel Dimoski

I am a 4th year senior Mechanical Engineering student at the University of Michigan. I am from Royal Oak, Michigan. I am interested in mechanical engineering because the subjects that are taught fascinate me. The experiences I have gained, and the problem solving techniques I have developed can be applied to many diverse fields. My work experiences include two summer internships at General Motors and one summer working at the Spin Physics Lab at U of M. My future plans include finishing my masters degree (MSE) in Mechanical Engineering and then pursuing a career in the industry. Interesting facts: Captain of high school cross country and track teams, member of Engineering Global Leadership honors program and accepted into Tauber Institute for Global Operations.

Ronald Kroll

My name is Ronald Kroll. I was born in Rogers City, MI and raised in Posen, MI. My family consists of thirteen children, with me being the tenth child. I have seven brothers and five sisters. I grew up on a farm in which potatoes were the main crop. I played track, basketball, and football in high school. I enjoy many outdoor sports including hunting and fishing. My brother Bill, who is the second oldest in the family, is the reason I became interested in engineering. He is an electrical engineer and very successful. I chose to do mechanical engineering because I am a hands-on person and mechanical engineering allows you to be able to see an issue, design a solution, and see the result. I am currently on plan to graduate in April 09'. My plan after graduation is to get a job in either design or in the business side of engineering. The reason for the latter is that one day I would like to own an engineering firm or my own business.

Andrew Chin Hock Low

My name is Andrew Chin Hock Low and I am born in Malaysia. I am currently in my senior year in Mechanical Engineering with a concentration in manufacturing systems. I have always liked Mechanical Engineering because of the flexibility, creativity and skills involved. One needs to have a high observational acumen to be able to perceive a mechanism or even imagined one. The field of Mechanical Engineering is so broad, it allows for an endless learning of new knowledge every day. I am also very interested in manufacturing processes improvement and enthusiastic to learn more about design processes. I hope to be able to be a Design Engineer someday to be able to innovate and create products that will cater to the needs of society.