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# The Cooling Vest- Evaporative Cooling

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# **The Cooling Vest- Evaporative Cooling**

**A Major Qualifying Project Report**

**Submitted to the Faculty**

**of the**

**WORCESTER POLYTECHNIC INSTITUTE**

**In partial fulfillment of the requirements**

**for a Bachelor of Science Degree**

**in the fields of Chemical Engineering and Mechanical Engineering**

By:

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Date: April 30, 2009

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# Abstract

The objective of this project was to investigate the cooling capability of an evaporative cooling vest; specifically, cooling of the torso region was studied. Modifying Natick Soldier Systems microclimate design, a microenvironment was created between the skin of the torso region and the outer layer of the cooling vest. This system allowed for environmental controls and modifications. To lower the temperature of the torso, sweat, absorbed from the human torso into the wicking material of the cooling vest, was evaporated.

The average individual sweats approximately 1L/hr during normal activity. It was determined that less than 1L/hr was necessary to lower the temperature of the torso within the microenvironment. Evaporation was achieved through an airflow blown through the vest and around the torso. The air flow was 10cfm. As the torso sweats, the sweat was absorbed by the wicking material of the vest and evaporated into the surrounding air. This was simulated by saturation of a wicking material that was wrapped around the replica torso. The air present in the vest's environment was low humidity ( the relative humidity was ~24-26 %) but higher than the humidity of the pre determined modeled calculations. These conditions were still capable of significant evaporation. To assist evaporation, a thermoelectric cooler system was mounted in between two 1060 alloy aluminum heat sinks. A blower system and vest channels completed the total apparatus and was mounted inside a vest created for soldier specifications.

Using this model, a vest was designed, developed and tested using a mannequin with sweating capabilities. Through modeling and design test experimentation it was determined that this evaporative cooling system is indeed feasible, lowering the body temperature an average of 10°F degrees from its starting point. Other applications of the vest were hypothesized and specifications for alterations were given.

# Acknowledgments

We would like to thank those who helped further our education, research, and development techniques. Great thanks to our sponsor Tiburon Associates, Inc (especially the Director of Engineering) who allowed us to work on such an innovative idea and provided us with the tools necessary for success.

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# Material List/Descriptions

## **Thermoelectric cooler:**

The Thermoelectric Cooler is designed by Marlow Industries. The hot side temperature is 27°C, 50°C. The maximum watts range between 20 and 22 depending on the temperature.

(Appendix B, Figure 32)

## **Infrared thermometer:**

OS425-LS Non-contact Infrared Thermometer with White Led Flashing. Measurement range -60° C to 1000°C. Accuracy is  $\pm 1$  °C. Response time is 1 second, and the distant spotting is 50:1. Life time is 140 hours of continuous use.

## **Heat sinks:**

Hot Side: MASSCOOL 5C12B3 CPU heat sink. Thermal Resistance: 0.621°C/W

Cold Side: Brand unknown, donated by WPI Chemical Engineering Department.

## **Blower:**

The air blower is a 97mm DC San Ace . Its frame and impeller are made from plastics, and the dielectric strength is 50/60 Hz 500 VAC1 minute between lead conductor and frame. The operating temperature of -20°C to 60°C, and the life expectancy is 40,000 hours. (Appendix B, Figure 31)

## **Thermocouples:**

The thermocouples are letter K. K denotes that the material is ( Chromel-Alumel).

## **Power Supply:**

ATX 300 Watt power supply.

## **Mesh lined Vest:**

The mesh lined vest was an alteration of a jacket with mesh lining inside. Excess material was removed to allow large open areas for air to be removed from the location of the armpits. The neck lining was also removed and re established lower on the neckline.

**Wicking material:**

The wicking material was a sheet of Shamwow® that covered the entire torso around the skin. . The wicking material is designed to remove liquid from the surface on which it is present through its porous material construction.

**Replica Torso:**

The replica torso design was intended to simulate the human body's skin temperature. The torso was designed to the average human male measurements, and replicated by an alumina cylinder. The skin was replicated by silicon sheets, most commonly used in current design applications of mannequins.

# Paper References

(Mannequin Store 2008)

(NIOSH 1986)

(Casey 2007)

(LLC 2009)

(Teal 2006)

(Universal Industrial Gases 2009)

(Tiburon Associates 2006)

(Marlow Industries 2007)

(Mather 2004)

(Craig Freudenrich 2009)

# Introduction

This MQP investigates torso body cooling as a method of assisting the regulation of a person's core body temperature in harsh environments. A stable core body temperature is essential for proper and optimal function. In extreme hot and stressful environments this can often be difficult for individuals without proper cooling mechanisms.

The human body contains its own mechanism to regulate body temperature, sweating. The process of evaporation of the sweat from the surface of the skin into the surrounding environment cools the body. This cooling is due to the latent heat of evaporation of water. In hot environmental conditions it is important for the human body to remain at a stable core temperature. When an individual becomes incapable of keeping his/her body temperature regulated, several detrimental effects occur, such as dehydration, heat stress/stroke, and elevated heart rate. This elevated body temperature affects an individual's ability to function at peak performance. Adding to the detrimental effects of heat stroke, an individual begins to experience a breakdown of the central nervous system once the body reaches a body temperature of approximately 107.6°F (42°C).

The objective of this research is to demonstrate the feasibility of a cooling system for individuals in order to assist in maintaining stable core body temperatures even in extreme hot environments. This will be accomplished by maintaining a steady state skin temperature air flow of 95°F, and taking advantage of evaporative cooling. The air source supply will be the surrounding air in the environment of 120°F. A mechanism for pre-cooling air, a thermoelectric cooler (TEC) cooling system, will cool the air from 120° F to 110°F before it enters the cooling vest. The details of the TEC, results and evaluation of cooling vest testing and overall efficiency of the cooling vest can be found in the following report.

# Background

The human body has a specific core temperature range necessary for an individual to maintain peak performance capabilities. This core temperature optimization and control are vital for strenuous situations in which optimal human performance is necessary. Current situations in Iraq bring forth a need to address the strenuous missions and the environmental impact upon the soldiers. There are presently no universally accepted means that effectively dissipate body heat from the soldier, thus creating unstable and dangerous conditions for the human body. The goal of the proposed thermoelectric cooling vest is to reduce the incidence of heat related injuries and increase the rate of successful mission completion.

Illnesses due to heat induced situations occur when the total heat load surpasses the capacity of the human body to cool the core temperature and maintain normal functions without excessive strain. The total heat loads of a situation pertaining to Iraq are the environment and the long duration of the missions. In Iraq, where cooling supplies and shade are limited, soldiers face harsh conditions. Many are without means to cool themselves. These harsh environments result in situations where soldiers encounter heat related fatigue failure and heat stroke. Iraq's conditions and mission requirements can be a dangerous combination for the human body to endure. The central nervous system begins to break down around 107 ° F. The average temperature in Iraq reaches 70°F - 120°F; the upper temperature can be dangerous and fatal to bodily functions especially during critical missions which require optimal performance.

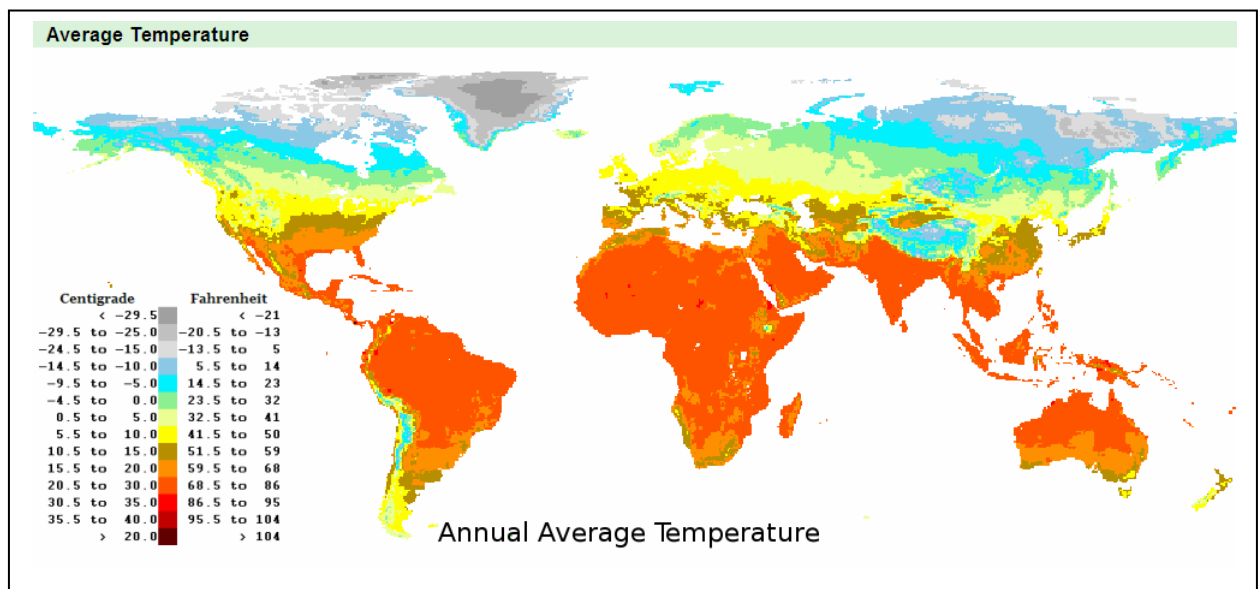


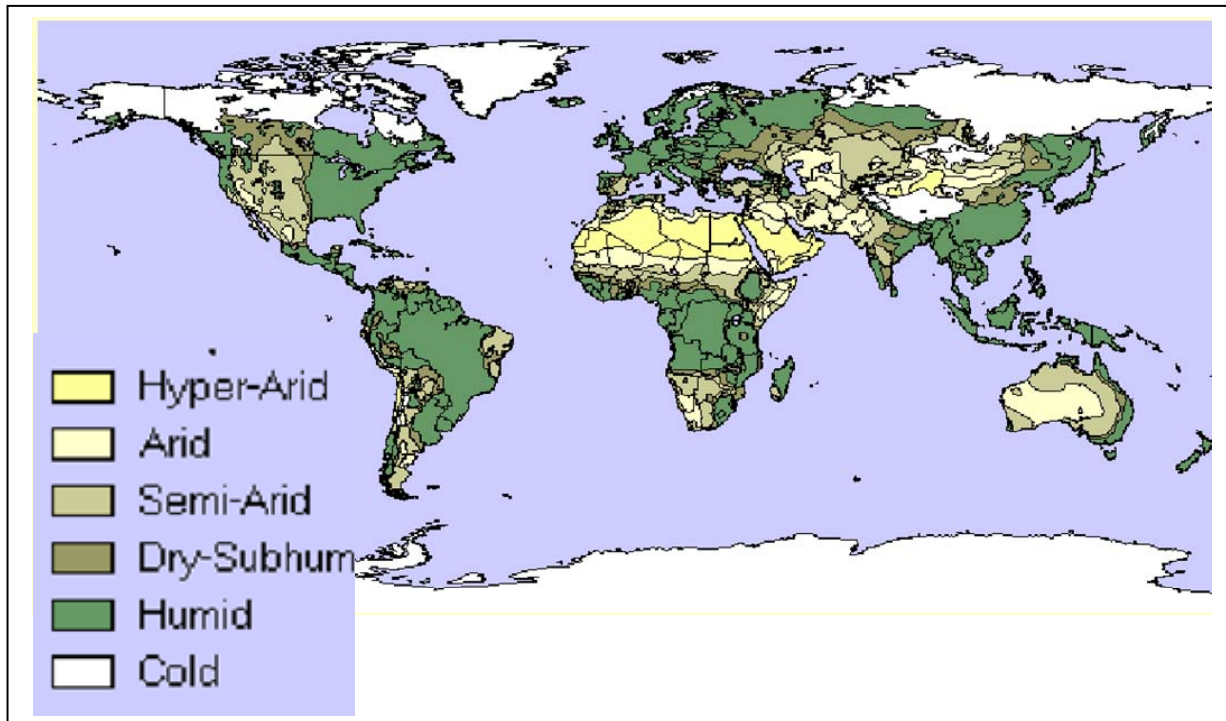
Figure 1: Average temperature chart for the world

The critical body temperature for peak performance is between 101°F and 102.2 °F (NIOSH 1986). This temperature represents heat stress for situations that are not encountered for prolonged time periods. The benefit of a cooling system would be to prevent the soldiers from reaching this point, by maintaining the core body temperature at a lower safe temperature; one that is maintained by the body. This vest will be designed to reduce or eliminate the detrimental effects of heat stress and strain. Typical heat strain factors that can be measured include the body and skin temperature, sweat production and evaporation, and amount of insulation an individual is wearing. (NIOSH 1986)

Heat strain reaches a very dangerous level at a body temperature of 104°F. This temperature is accepted as the onset temperature where a human is in impending danger of irreversible heat stroke (NIOSH 1986). The atmospheric temperature alone is dangerous to the human body, but, coupled with long periods of exercise, a fatal situation can result. The human body itself generates heat due to its metabolic procedures; heat is gained as well from the environment, and since the soldiers are equipped in many layers of clothing (insulation), the heat loss from the body to the surrounding environment is considered minimal. The response from the body to the heat stress is described as the heat strain. At a certain core body temperature, the human's compensatory mechanisms begin to shut down and lose overall control regulating body temperature (NIOSH 1986). Once the peak is reached there is often significant damage that requires immediate attention. Although repeated exposure to heat stress can result in adaptations to capabilities to regulate core temperatures, referred to as acclimatization, the duration in which the soldiers are exposed to heat stress often is too great for even those bodies that are acclimated to extreme environments. Therefore, due to the current conditions, heat stress must be carefully addressed and alleviated. Acclimation of the soldier needs to occur before strenuous activity is undertaken. The individual must spend time allowing his/her body to adjust to the environment. The build up to an environment needs to be a slow and steady one for it is very easy for individuals to become deacclimated to their surrounding and cause harm to their bodies and compensatory functions. Once the change has become implemented and it is obvious from medical examination that acclimation has occurred, the individual may begin taking part in moderate levels of activity. This helps to ensure that the effects of heat stress will be reduced. The individual must also continuously remain acclimated in order to not become deacclimated which occurs quickly when the individual is no longer in an extreme environment.

Another factor that affects body cooling is humidity. The vest will be specifically designed for soldiers in a low humidity environment. This is advantageous for an evaporative cooling system because with less moisture, the air passing over a body with perspiration can absorb more water and provide more cooling. The relative humidity is

between 9 and 11% for the area of interest. The climate in Iraq shown in figures 1 and 2 supports our proposed values and calculations for the application environment.



**Figure 2: Humidity Levels for the world**

Due to present conditions, there have been new developments to regulate the core body temperature. This involves keeping soldiers at optimal levels of performance without putting them at risk for heat stroke or other health related problems. Many applications have been developed in order to carry out this task. The current method of design to control core body temperature is a vest. The vest can be worn by the soldiers under their protective garments to regulate their temperature and attempt to present a cool and safe level of core temperature. There have been many experiments to find the most suitable design that is applicable and particular to the situation. Natick Soldier Systems, Natick, MA, (current project mentor) has investigated several techniques for cooling Department of Defense personnel and presented an overview for each type of system in briefing form. Some of the current applications are listed below:

Figure 3 illustrates the mass of a system in correlation with the overall mission duration. It is important to see how each cooling system lines up with the others. In this MQP scenario, a light weight and long lasting mechanism is desired. It is important for the individuals to maintain a healthy core temperature as long as possible.



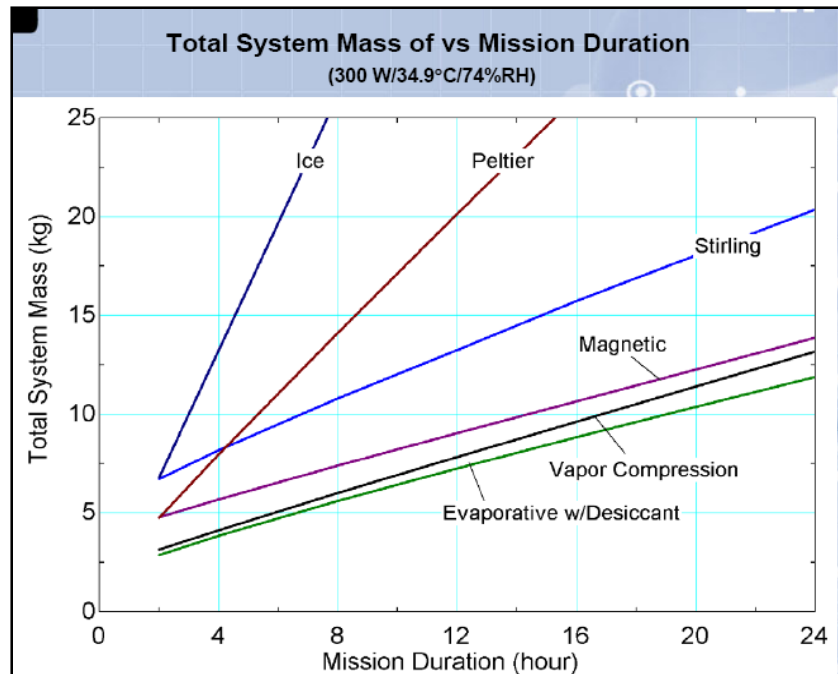


Figure 3: The System Mass versus the Overall Duration Time for Current Applications of Cooling (Teal 2006)

#### Evaporative Cooling:

Evaporative cooling uses the absorbed heat of evaporation of water to cool the individuals. In the case of soldiers, the outer garments must be removed to allow for placement of the vest (and then replaced), and an extensive supply of water must be at hand. The evaporative vest has fairly long mission duration, but the mass of the vest increases with the length of the duration. The mass (water), which is in the transferring state, is serving multiple functions by helping hydrate (drinking), then helping to cool the soldier (evaporation). Water has to be carried for drinking so by reusing the water (sweat) to cool, no additional water is required for the evaporative cooling vest. Compared to phase change options it allows for a much lighter vest. The vest can be designed with wicking material to keep the sweat away from the body. The vest can be formed of simple parts, needing only a fan and clear airway across the wet surface. One disadvantage is the vest must be near or preferably in direct contact with the skin. This is to maximize the rate of sweat evaporation. The fan is battery powered, so a battery or power source must be available. The air flow through the vest helps the efficiency of the body's natural form of cooling. (See slide 27 in Appendix B)

#### Phase Change (Solid-Liquid):

A current application used frequently in commercial operations is the phase changing vest. This vest relies on cold packs that change from a solid to a liquid when they

melt. This system's weight to duration ratio is the highest. The packs must have a cold location to refreeze when melted and this often requires a significant amount of time. When the pack is warmed, the weight must still be carried with no cooling effects. The vest is simple in design; a vest with pockets full of ice packs. (Slide 28, Appendix B)

#### Personal Cooling System:

This system circulates cold water through a tube-lined shirt, but is at an elevated temperature when exiting the shirt. The water is brought back to a cool temperature when it passes over ice contained in a bottle. The ice bottle needs replacement every 30-60 minutes. This creates a disadvantage to an individual who is on a long duration mission. The "portable" system requires electricity, ice storage, and is connected by a tube. All three are very limiting factors. (See slide 29 in Appendix B)

#### Compressed Air System:

This system is advantageous for personnel contained in mobile military vehicles, but for those on the ground it is not relevant since they cannot be attached to a compressed air system. (See slide 30 in Appendix B)

#### Cooling System:

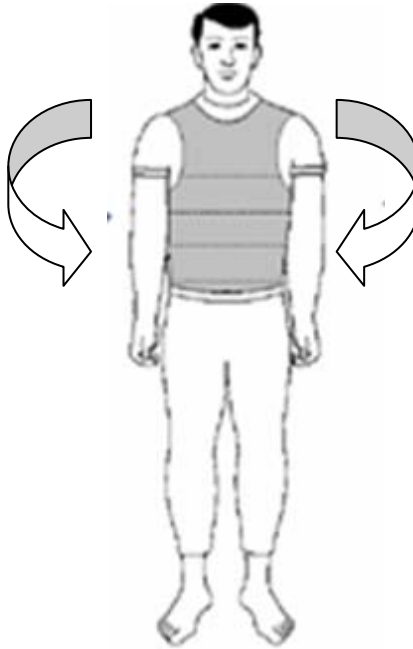
The cooling vest requirements for this approach dictate that the vest must be lightweight, long lasting, durable and must withstand the pressure of garments worn on top of the vest. The leader for this cooling system requirement is the Department of Defense since they need soldiers to perform for extended periods of time and they cannot schedule breaks to recover. This MQP looks at the task of designing a cooling vest that will be light weight, portable, and cool the skin to maintain the core temperature at a safe level.

This cooling vest is designed to not only aid soldiers in Iraq, but to be a universal cooling vest that can be incorporated into commercial industries and the needs of the community. The sports industry spends a great deal of time and money to maintain athletic performance in sports such as football and race car driving; therefore there is a solid market for flexible, light weight cooling vests. The medical industry designs systems that are not necessarily efficient or portable, but meet the medical needs of the patient; therefore a portable and efficient system would be well accepted within the medical community. Current manufacturing environments present extreme environments to workers. It is very difficult to cool large factories and therefore workers can only work for certain periods of time before their efficiency begins to diminish and they need to seek a cool environment. Cooling vests would be very beneficial in this environment and not only help to increase comfort of workers but also help to increase productivity. The application

of a forced air thermoelectric aided evaporative cooling vest is very flexible and adaptable to present needs.

# Methodology

This MQP focuses on the development of a model to simulate an individual in a hot, dry environment through the creation of a microclimate environment. The microclimate will be located around the torso and for a soldier includes the area covered by body armor and a cooling vest. (Figure 4) The model created will be used to show that evaporative cooling is a feasible method to maintain core body temperature.



**Figure 4: Location of the micro-climate**

## Objectives:

**The global objective for this MQP is to establish a stable core body temperature and enhance performance of individuals in long term environments of extreme heat.** Specifically pertaining to the model environment, the work of this MQP involves:

- Determine, through calculation and experiment the temperature and air flow rate required in the vest in order to keep the human body at a functional temperature
- Optimize flow rate based on air flow and evaporation efficiency
- Design a cooling system based on calculated required flow rate and temperature
- Develop an experiment to test a sweating mannequin with the designed cooling vest
- Design and run experiments on the mannequin with and without the cooling vest

- Compare theoretical calculations with experimental data.

This research allowed the researchers to determine the cooling capability of an evaporative cooling vest.

### Overview:

The following pages will show calculations for the cooling (in watts) and the amount of water evaporated for the model system developed by the engineers. The variables will be the air flow, air temperature into the vest, air distribution (modified after design and assembly), ambient air temperature and body temperature. The values of these variables will be determined and controlled by experimental procedures and mechanisms created and designed by the engineering group. The laboratory experiments will measure the wet and dry bulb temperatures of the surroundings. The group will design and test the air flow system and the thermoelectric cooling system and measure the operating parameters: air flow volume, TEC voltage and current, delta temperatures. From this data and appropriate equations the amount of cooling from the thermoelectric cooler system, a relative efficiency of the TEC, and the amount of water evaporated will be calculated. Analyzing the results of this calculation will allow for a calculation of the efficiency of the designed thermoelectric cooling device, and whether or not it is beneficial in the given circumstances. The engineers will also critique the design and final product in order to provide suggestions to improve the system, and form recommendations on how to modify the application for other uses.

### Model System in Detail:

A person is confined in a hot environment of 120 °F, with relatively low humidity (9-11% RH). The individual is participating in moderate activity, which further increases his/her body temperature, and sweat rate. An individual without any protective measures would not be able to last very long in this environment since the exposure to high temperature and stress raise core body temperature quickly. As heat stress begins to set in, the body is no longer able to effectively operate its compensatory mechanisms to maintain a stable core temperature.

In a steady state, the temperature of the skin ( $T_{sk}$ ) is the sum of the temperatures due to the core body temperature ( $T_{core}$ ), the heat generated during the activity ( $T_{activity}$ ), and the contributions from temperature of the surrounding ( $T_{surrounding}$ ), as shown in equation (1).

$$T_{sk} = T_{core} + T_{activity} + T_{surrounding}(R+C+CD)$$

Equation 1 (NIOSH 1986)

For this project,  $T_{sk}$  is equal to the temperature of the micro-climate. The objective is to decrease the temperature of  $T_{sk}$  to 95° F, in order to keep the core temperature as constant as possible - ideally at 98.6° F. The goal is to also keep the skin temperature as constant as possible to prevent detrimental effects of fluctuating body temperature. In order to maintain a constant core temperature, the contributions from the work activity and the surroundings need to be minimized, or one needs to cool the micro-environment.

The first factor to take into consideration is the environmental contributions. Since the individual is wearing protective clothing, the effect of heat by radiation is minimal (discussed in the radiation section ), except for the exposed skin areas. These areas are the hands, head, and back of the neck. Conduction was also very minimal because of the layer of protective clothing. Convection due to the environment was negligible because the clothing is tightly fitted on the individual, and air flow from the environment is negligible, for a still standing area. The temperature increase from the environment will slowly heat the layer of clothing, and then the individual, but to a minimal effect that the cooling vest will be able to account for the change.

The skin temperature can be lowered by modifying the microclimate. Using a cooling garment, which will enclose the volume of the microenvironment around the torso, a lower temperature can be achieved. Cooling the environment adds a new temperature term to the skin temperature equation (1). This temperature term is the temperature due to evaporation,  $T_{EVP}$ , and aids in reducing the overall temperature. The skin temperature equation is now modified to reflect this element.

$$T_{sk} = T_{core} + T_{activity} + T_{surrounding} + T_{Evp}$$

Equation 2 (NIOSH 1986)

The new variable contribution to the equation is the temperature of evaporation. The contribution of the evaporative cooling to the skin temperature lowers the temperature, thus resulting in a cooling effect within the micro-environment. The focus of this effort is  $T_{EVP}$  and the cooling effect of the individual in order to maintain a safe and cognitive level of performance.

The latent heat of evaporation of water has a value around 2257 kJ/kg for the temperature range of interest. In the experimental design of the micro-climate environment the objective was to reduce the body temperature equal which includes a 100 watt heat load generated by the individual. This is a proposed solution to cool the individual to the desired temperature, and maintain  $T_{sk}$  within the normal functional range.

There were a few challenges that had to be addressed in conducting experiments to test our hypothesis that evaporative cooling with TEC precooled air would indeed cool a person's core level to a functional and desired temperature.

The first challenge began with preliminary equations to demonstrate the feasibility of our design plan. Starting with an idea for a model and the situation, the model system below was created. Figure 5 is a cross section of the simulated person, cooling vest, microclimate, and environment.

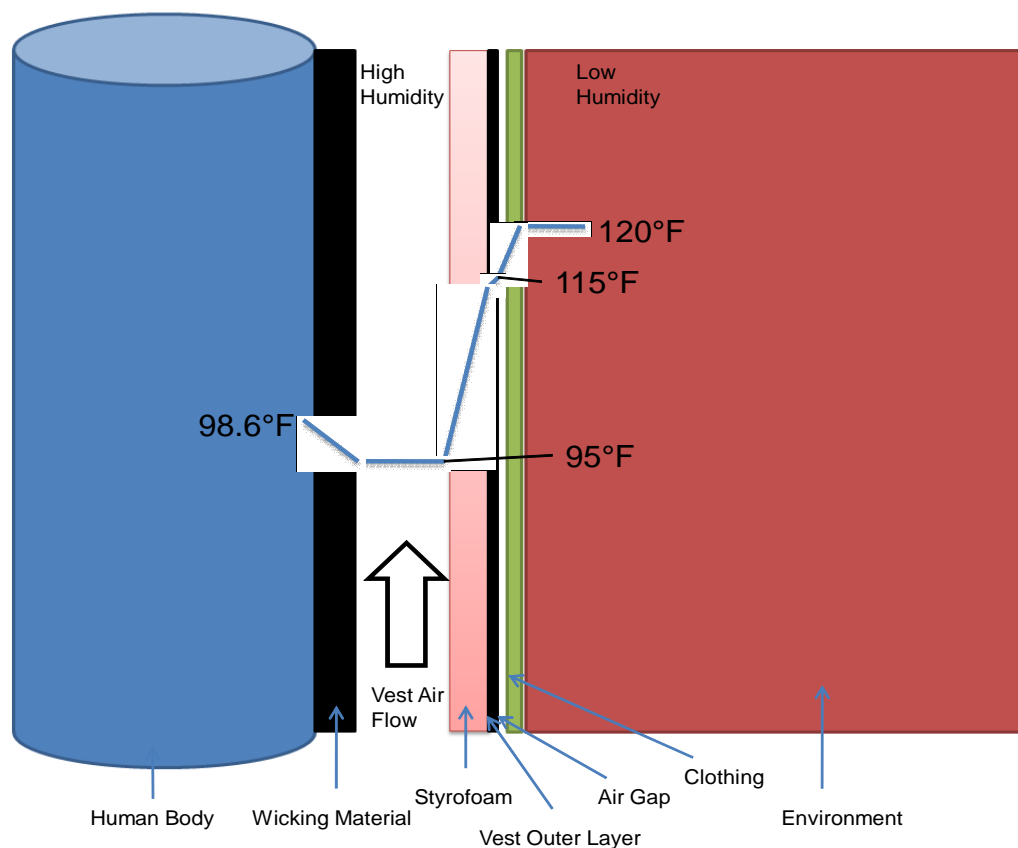


Figure 5: Design of the Model System

Using this physical model, a group of questions were created that needed to be answered to test the legitimacy of the process. Using the model scenario, knowledge of heat transfer, thermodynamics, fluids, chemistry and basic engineering knowledge, equations and desired parameters were constructed.

### Sweat Mechanism:

The human body contains its own mechanism to regulate body temperature, sweating. Located near the surface of the skin of the human body are many sweat glands. The location of these sweat glands near the skin creates an optimal situation for evaporative cooling. The sweat glands, when stimulated by the control system in the body (the cholinergic sympathetic nerves), allow the body to secrete the solution known as sweat. Sweat's primary component is water. It is important to focus on the sweat rate of the type of individual that will benefit the most from evaporative cooling. One subject of study is soldiers who are stationed in hot environments of low humidity. These individuals have an average sweat rate of 2L/h due to their highly active life style. This sweat rate is extremely high because it is after the soldiers have undergone acclimatization. Acclimatization is the processes in which the body becomes accustomed to the surroundings, and therefore results in a decrease in salt loss from sweat and urination. The average time for acclimatization to heat exposure is 3 days, after which the body will begin to retain the needed fluids to maintain hydration and compensatory skills.

An over exposure to a hot environment can have adverse effects on the human body.

*Total Heat stress*

$$\begin{aligned} &= [(Heat\ generated\ in\ the\ body\ (metabolic\ heat)) \\ &+ (heat\ gained\ from\ the\ environment\ (environmental\ heat)) ] \\ &- heat\ loss\ from\ the\ body \end{aligned}$$

*Equation 3*

Metabolic heat rate is determined by calculating the kilo calories/min that an average male would use multiplied by the duration of use. The individual described below is for a single layer of clothing using the equations found in NOISH: For a 154 pound male walking and using both arms the metabolic rate can be calculated as: 3 kcal/min( for walking ) + 1



kcal/min ( using both arms) or **> 4 kcal/min** - 3 kcal/min for strenuous walking, 1 kcal/min for using arms to carry machinery, and perform military tasks.

This is an example for a specific case of an individual wearing one layer of clothing. There is a net heat generated between the convection, radiation, conduction, and evaporation terms. However, the material balance does not sum to zero, rather it differs by 256.6kJ/hr. This difference can be explained by the fact that some method is needed to supplement the body's natural ability to dissipate heat. Radiation and convection in the soldier's case will be lower than calculated for an individual wearing only one item of clothing. A soldier is equipped with layers of protective clothing, as well as tightly fitting under garments, that reduce the effect of convection and radiation. For the 154 pound male it can be assumed that the radiation is taken for the whole body when the microclimate is just the torso area, which means for the soldier the overall radiation term of 384 kJ/hr can be divided by the area of the torso, giving a values of 128 kJ/hr. The convection also pertains to just the torso region and can be reduced to 39 kJ/hr. These two changes bring the difference between the heat generated and dissipated by evaporation to 121 kJ/hr or 33.611 Watts. A smaller difference between the total heat generation and the evaporation term would be calculated, allowing the heat balance to be satisfied. The excess heat must somehow be removed from the system, and most likely the calculation from the blocking of radiation and convection are less due to our soldier's equipment and protective wear. An increase of the evaporative cooling would be the method for the extra heat removed. Based on this approximation a cooling system would have to remove the 33.611 watts for the human torso area. The soldier situation must consider these factors in the design of a micro-environment for experimentation. In the soldiers situation the sweat rate for our soldier is altered because he will sweat at a higher sweat rate. As well in the current situation with the 154 pound male, evaporation is taken into account alone without the aid from the TEC cooling vest. This proves that the cooling vest needs to remove the excess heat in order to stabilize the individual and dissipate the excess heat produced.

When the body begins to encounter an adverse effect from the heat stress, the result is denoted as heat strain. Heat stress can result in malfunction in the compensatory mechanism of the human body. The compensatory mechanism provides the body the capability to maintain the body temperature at levels that allows for normal body functions.

"An essential requirement for continued normal body function is that the deep core temperature be maintained within the accepted range of 37°C (98.6°F) +/- 1°C (1.8°F). To achieve this, the body equilibrium requires a constant exchange of heat between the body and the environment"

There are three major modes of heat exchange between an individual man and the environment. These modes of exchange are known as convection, radiation, and evaporation. Conduction is another mode of heat exchange that is also present. The overall heat exchange is defined as the heat balance equation, and it is made up of the previously mentioned modes of heat exchange.

#### Convection:

The rate of convection is defined as the heat exchange between the skin of the individual and the ambient air. The ambient air is located within close proximity to the skin. The following equation describes the calculation for conduction.

$$C = 7.0Va^{0.6}(t_a - t_{sk})$$

For a surrounding air temperature of 43.33°C and a skin temperature of 35°C, the heat exchange for convection is:

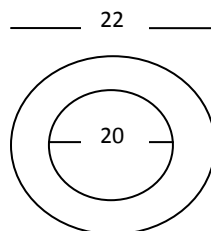
$$C = 7.0 (.3^{0.6})(43.33 - 35) = 28.3 \left( \frac{kcal}{h} \right) = 24.36 Watts$$

Equation 4

$C$  = Convection heat exchange (kcal/h)

$Va$  = air velocity in m/s (assuming a uniform air flow over the body for the model system-laminar flow)

For the space between the body and the cooling jacket, the cross sectional surface area is illustrated in design below and calculated to be the velocity of air flow between the skin and the cooling jacket or:



$$\left(\frac{22}{12}\right)^2 - \left(\frac{20}{12}\right)^2 = 1.8326 \text{ ft}^2$$

$$\text{velocity} = \frac{V}{A} = \frac{10 \frac{\text{ft}^3}{\text{min}}}{1.8326 \text{ ft}^2} = 5.56 \frac{\text{ft}}{\text{min}}$$

$$5.56 \frac{\text{ft}}{\text{min}} * \frac{1 \text{ min}}{60 \text{ s}} * \frac{\text{m}}{.3048 \text{ ft}} = .300 \frac{\text{m}}{\text{s}}$$

Equation 5

$t_a$  = air temperature in C (43.33°C)

$t_{sk}$  = mean weighted skin temperature (35°C)

$T_a > 35^\circ\text{C}$  heat gain to the body from the ambient air by convection

The convection contribution to the model system is very small. Therefore one can make the assumption that is viable to neglect this number in the final equation. With respect to conduction, since the human torso is clothed, the amount of conduction affecting the body skin temperature is also negligible. Therefore these two terms will be omitted during experimental procedures, and in the final calculations.

### Radiation:

Radiation is the second mode of heat exchange. The radiation is described as the temperature gradient between the mean radiant temperature of the surroundings and the mean weighted skin temperature (NIOSH). Radiation can be calculated for the layer of clothing worn by the individual. The current equation will be calculated for an individual with one layer of clothing. This will represent just the vest, although the soldiers or individuals in extreme environments will most likely be wearing more than just one layer.

$$R = 6.6(T_w - T_{sk})$$

$$R = 6.6(48.9 - 35) = 91.79 \left( \frac{\text{kcal}}{\text{hour}} \right) = 79.08 \text{ watts}$$

Equation 6

R= radiant heat exchange (kcal/h)

T<sub>w</sub>= mean radiant temperature of solid surrounding surface (48.9°C)

T<sub>sk</sub>= mean weighted skin temperature (35°C)

The radiation will first affect the outside of the clothes and eventually heat the human torso. Although if the soldier or individual in the hot environment is wearing more heavily protective clothing than the radiation level will be less. For now the assumption is that the individual only has one piece of protective clothing on.

If the radiation on the skin was calculated for a naked body, one can calculate area that would actually be exposed to the radiation. If the human body area is 2m<sup>2</sup> then the human head can account for about 1/8 of this area. Calculations below show the total radiation for the naked person exposed to radiation.

$$\frac{Q}{t} = \epsilon \sigma A (T_{hot}^4 - T_{cold}^4)$$

$$\frac{Q}{t} = 0.97 * 5.67 * 10^{-8} \left( \frac{\text{W}}{\text{m}^2 \text{K}^4} \right) * 2\text{m}^2 * (321.9\text{K}^4 - 308\text{K}^4) = 191.2 \text{ Watts}$$

$$191.2 \text{ Watts} * \left( \frac{1}{8} \right) = 23.9 \text{ watts}$$

Equation 7

A= 2m<sup>2</sup> area for the human body

$$\epsilon = 0.97$$

$$\sigma = 5.67 * 10^{-8} \left( \frac{\text{W}}{\text{m}^2 \text{K}^4} \right)$$

T<sub>hot</sub>= 48.9 °C

T<sub>cold</sub> = 35 °C

The actual amount of radiation that will affect the individual will be from the exposed body parts, the head, the face, and the hands. An individual can reduce these adverse affects by simply covering the exposed surfaces, and therefore eliminate a significant proportion of radiation.

### Evaporation:

Evaporation is where the sweat (comprised primarily of water) is removed from the body skin surface and creates a heat loss within in the body (as the skin cools heat from the core is dissipated toward the skin). The maximum evaporative capacity is a function of the air movement and the water vapor pressure difference between the ambient air and the wetted skin at skin temperature (NIOSH 1986)

$$E = 14V_a^{0.6}(P_{sk} - P_a)$$

$$E = 14[(.3)^{0.6}(42 - 5.19)] = 250.246 \left( \frac{\text{kcal}}{\text{hr}} \right) = 215.73 \text{watts}$$

Equation 8

E= Evaporative Heat loss Kcal/hr

V<sub>a</sub>= air speed m/s (.3m/s calculated from above equation)

P<sub>a</sub>= water vapor pressure of ambient air in mm Hg for 43°C ( 5.19mmHg)

Assume relative humidity of 8% at ATM

P<sub>sk</sub> = vapor pressure of water on skin assumed to be 42mmHg at 35 °C skin temperature

From the calculated results above, it is demonstrated that evaporation can create an ample amount of cooling for the individual in a hot low humidity environment. Therefore it is plausible to control the microclimate and alter it to a beneficial state for the well being of the human.

### Calculating Evaporation

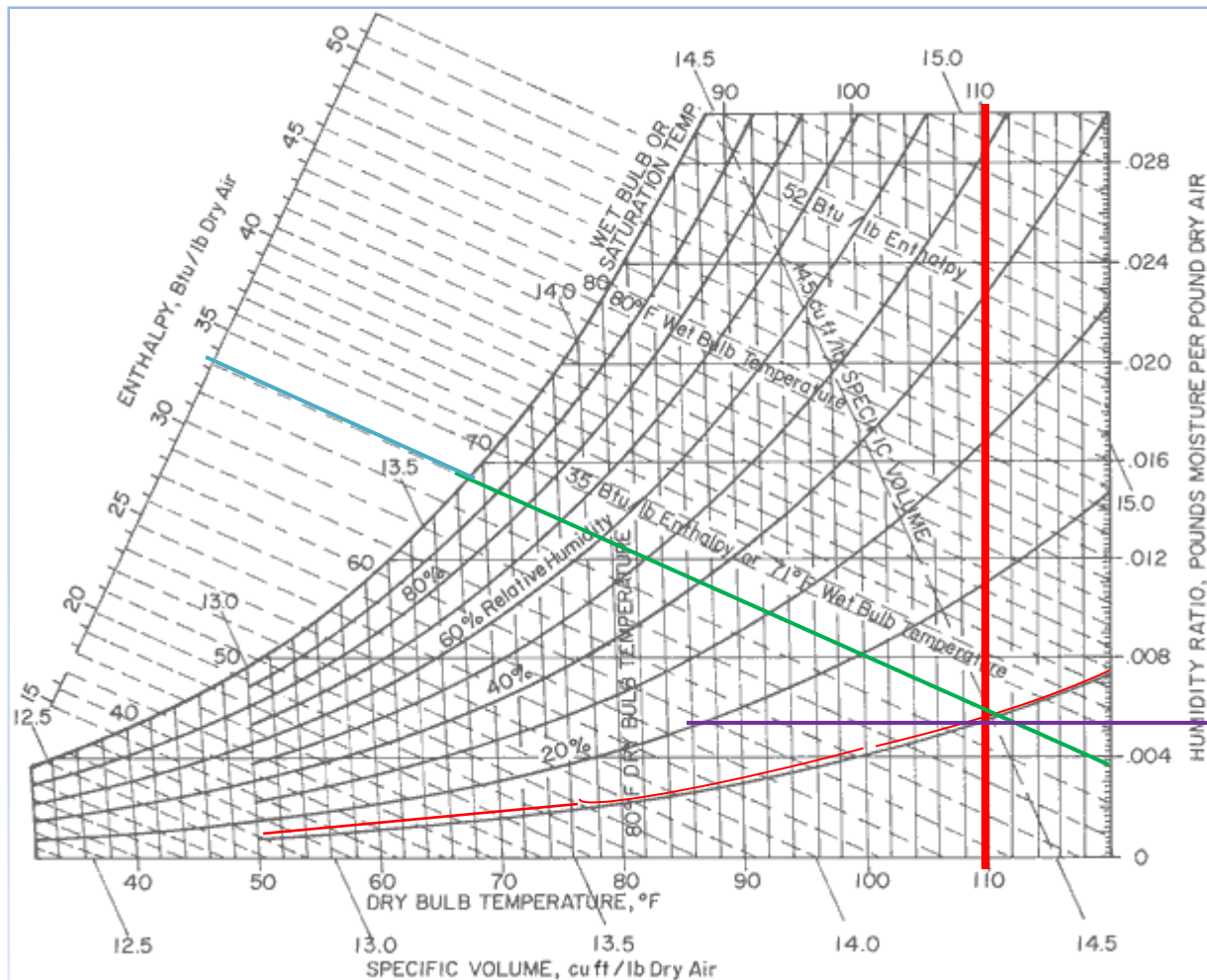
Evaporation is a very advantageous mechanism in cooling the human body. The evaporation of water (sweat) from the surface of the human body will create heat loss from the human body's core. This in turn will allow the individual to feel a decrease in his/her body temperature, and allow compensatory function to remain at an operational level. Evaporation is made up of three main parts. It is the difference between the water vapor

pressure on the skin wetted surface (water from the human body sweat), the air layer contained next to the skin, and the velocity of air movement over the skin. By increasing air velocity, one is able to increase the amount of evaporation occurring. In the test condition the humidity is low, assumed to be (8-10%) relative humidity. The reason this low humidity is beneficial is because humid environments limit the overall amount of sweat that can evaporated. Sweat that drips off the body, or finds another way to exit the skin layer beside evaporation will not result in heat loss from the body.

The preliminary equations and all experimental data takes into account the assumption that water in the individual is continuously being replaced (hydrated), and therefore the sweat rate of 2L/h is always constant. One objective of the experiment is to calculate the number of watts to reduce skin to 95°F. A second data collection objective is to find the grams of H<sub>2</sub>O evaporated to reduce skin temperature to 95°F, and thus determine resulting enthalpy. All of these values can be predetermined by preliminary equations utilizing the Psychometric Charts. This allows the experimental data to be compared to the pre-experiment calculated values and to analyze the plausibility and functionality of the experiment.

An example of the Psychometric chart can be found in Figure 6 The charts contain information pertaining to dry bulb temperature, humidity ratio (moisture content), saturated air or 100 % moisture holding capacity, wet bulb temperature, enthalpy, dew point or saturation temperature, relative humidity and specific volume.

The lines on Figure 6 demonstrate how to read the information from the graph. The situation is an environment of 110 °F and a known relative humidity of 10%. The intersection of the two lines drawn and followed to the right gives the value for the humidity of pound moisture per pound dry air. If a line is drawn perpendicular to the dotted lines and flowed to the left (green line) the edge of the bold curve will denoted the wet bulb temperature. A straight (blue line) line from the left handed curve up to the enthalpy line will give the enthalpy for the system.



**Figure 6: Psychrometric Chart**

Known: Dry bulb temperature (110°F)

Relative humidity (10%)

**Key**

<span style="color: green;">—</span>	Wet Bulb Temperature in °F	68.5
<span style="color: purple;">—</span>	Humidity ratio lbs moist air/ lbs dry	.005
<span style="color: blue;">—</span>	Enthalpy (Btu/ lb Dry Air)	32.48

A table of values for the model system was determined by an automatic calculator (Universal Industrial Gases 2009). Using the values from the table, Watts to reduce skin to 95°F and Grams H<sub>2</sub>O evaporated, can be calculated. Values for certain temperature ranges can be found below in table (1&2)

**Table 1: Data read from Psychrometric Charts for defined temperatures and humidity's**

Dry Bulb		Relative Humidity	Wet Bulb		Dew Point		H <sub>2</sub> O/Dry Air
°C	°F	Percent %	°C	°F	°C	°F	g/kg
37.8	100.0	10.0	17.3	63.3	1.0	33.8	4.1
40.0	105.0	10.0	18.5	65.3	2.6	36.7	4.6
43.3	110.0	10.0	20.3	68.5	5.1	41.3	5.5
43.9	111.0	10.0	20.6	69.0	5.6	42.0	5.6
47.2	117.0	10.0	22.3	72.1	8.1	46.6	6.7
47.8	118.0	10.0	22.6	42.0	8.5	47.2	6.9
48.9	120.0	10.0	23.2	73.7	9.3	48.7	7.3
37.8	100.0	9.0	17.0	62.7	-0.4	31.3	3.66
40.0	105.0	9.0	18.2	64.7	1.2	34.1	4.12
43.3	110.0	9.0	19.8	67.7	3.6	38.5	4.91
43.9	111.0	9.0	20.2	68.3	4.1	39.3	5.07
47.2	117.0	9.0	21.8	71.3	6.5	43.7	6.01
47.8	118.0	9.0	22.1	71.8	6.9	44.5	6.2
48.9	120.0	9.0	22.7	72.8	6.6	43.8	6.56
37.8	100.0	11.0	17.7	63.9	2.3	36.2	4.48
40.0	105.0	11.0	18.9	66.0	4.0	39.2	5.05



**Table 2: Calculated data values from Psychometric Charts**

Enthalpy	Specific volume	Density	Delta T (95 °F / 35°C)	cp	Watts to reduce skin to 95 OF	Grams H <sub>2</sub> O evaporated reduce skin to 95 °F
				kJ/Kg C0	10 CFM	
kJ/kg	M <sup>3</sup> /Kg	Kg/M <sup>3</sup>				10CFM
48.4	0.9	1.1	2.8	1010.7	14.92289722	0.372451678
51.9	0.9	1.1	5.0	1010.9	26.84461905	0.669998812
57.6	0.9	1.1	8.3	1011.2	44.73610041	1.116541608
58.6	0.9	1.1	8.9	1011.2	47.74564485	1.19165503
64.6	0.9	1.1	12.2	1011.5	65.54085175	1.635794969
65.8	0.9	1.1	12.8	1008.8	68.57900545	1.711622432
68.0	0.9	1.1	13.9	1011.7	74.6841702	1.863997592
47.32	0.9	1.1	2.8	1010.7	14.92207458	0.372431146
50.74	0.9	1.1	5.0	1010.9	26.84314909	0.669962124
56.12	0.9	1.1	8.3	1011.1	44.73278712	1.116458913
57.13	0.9	1.1	8.9	1011.2	47.74241629	1.19157445
62.29	0.9	1.1	12.2	1011.4	65.53589365	1.635671222
64.02	0.9	1.1	12.8	1011.5	68.76229077	1.716196941
66.06	0.9	1.1	13.9	1011.6	74.67828083	1.863850603
49.43	0.9	1.1	2.8	1010.8	14.92373321	0.372472543
53.12	0.9	1.1	5.0	1011.0	26.84639166	0.670043053
58.96	0.9	1.1	8.3	1011.3	44.73876546	1.116608123
60.07	0.9	1.1	8.9	1011.3	47.74887341	1.191735609
66.42	0.9	1.1	12.2	1011.6	65.54570435	1.635916082
67.63	0.9	1.1	12.8	1011.7	68.77280533	1.716459368
69.89	0.9	1.1	13.9	1011.7	74.69005956	1.864144581

The watts to reduce skin to 95°F and grams H<sub>2</sub>O evaporated reduce skin to 95°F were calculated using the following formulas.

*Watts to reduce skin to 95°F:*

$$\text{Flow} \left( \frac{\text{m}^3}{\text{s}} \right) * \text{density final} \left( \frac{\text{kg}}{\text{m}^3} \right) * \text{specific heat} \left( \frac{\text{J}}{\text{kg}^\circ\text{C}} \right) * \Delta T$$

$$.0047 * 1.13 * cp * \Delta T$$

Equation 9

Where the Specific heat cp = 1.005 kJ/kgK for 20-40 °C, 1.009 for 60 -80°C :

*H<sub>2</sub>O evaporated reduce skin to 95°F:*

At  $\Delta H$  latent heat of water 240 J/kg

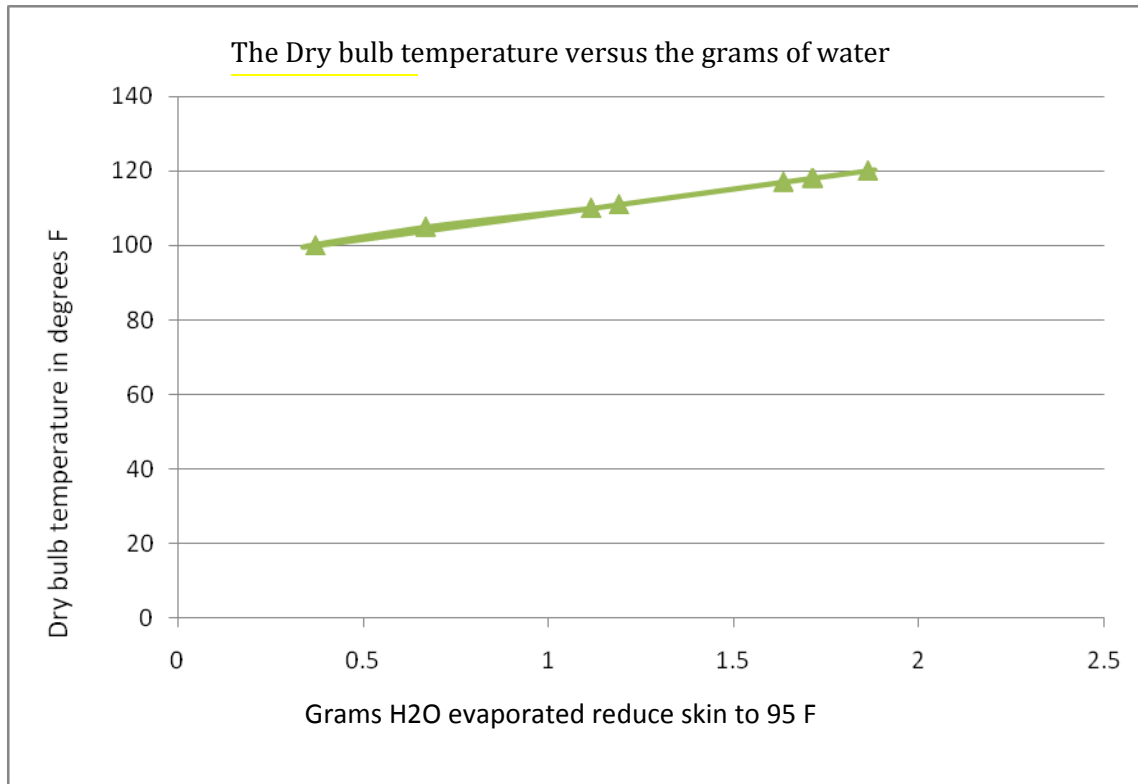
$$\left( \frac{\text{watt}}{2404} \right) * 60$$

Equation 10

The next step is to determine if there is enough water from the sweat rate to use the evaporative cooling system. This requires the simple multiplication of the last column by

60. This shows that there is plenty of water present for evaporation. For our assumption, the amount of water evaporated will not saturate the air and to verify this the relative humidity was gathered for the necessary parameters from the psychrometric graph. The amount of water available is greater than the amount of water absorbed. If all the water is absorbed the result can be an excess of cooling which will be addressed in recommendations on how to rectify the problem. Below is a graph of the Dry bulb temperature versus the grams of water to be absorbed.

**Table 3: Dry Bulb Temperature versus the grams of water to be absorbed**



As can be seen in the graph above, as the temperature rises the grams of water needed to be reduced rise as well. It still holds certain from the data calculated in the psychrometric charts that a sweat rate of 2L/hr is more than enough water to reduce the skin temperature.

These were calculated results based on our assumptions of the environment, the model and the vest. The environment was assumed to have a constant non fluctuating temperature of 120 F ( 48.9 C). The relative humidity was assumed to be low 8-11%. These values were the constants that were used in the preliminary equations. The environment was assumed to have no air movement, and be maintained at a steady state.

# SolidWorks Design

Solidworks was used to create a structural representation of the TEC assembly. The parts were measured and created separately in Solidworks. They were then assembled to have analysis run on the parts.

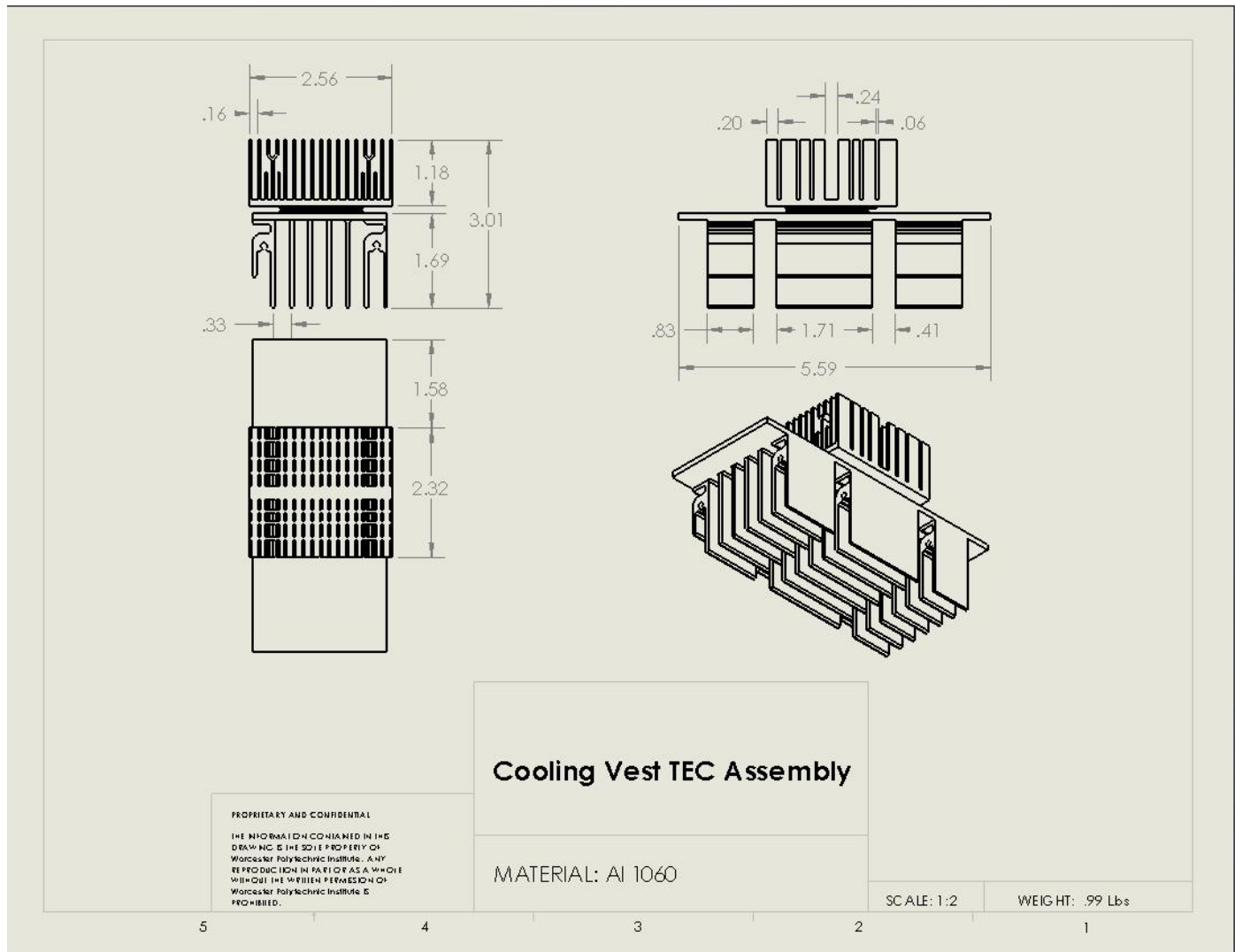


Figure 7: Cooling Vest TEC Assembly in SolidWorks

CosmosXpress was then used to analyze the air flow over the heat sinks. With CosmosWorks (pro edition) the system may include heat transfer included in the flow, but this package was not currently available.

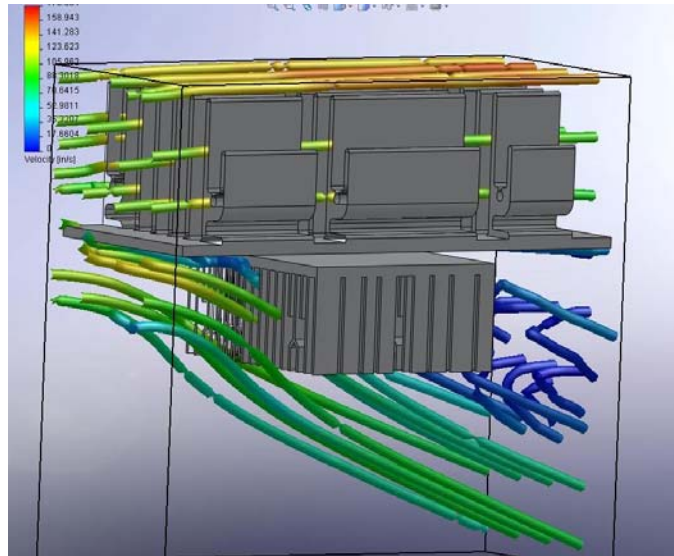


Figure 8: TEC Assembly Flow Model

# Experimental Approach

## Assumptions:

The overall model system contains some assumptions and values that are held constant; this overall system is viewed as a steady state environment. A steady state system is one in which all variables remain constant. This means that when demonstrating the changes of temperature that the temperature gradient line is straight and not varying.

Since testing on an actual human is not plausible because of non constant variables, a replica model was built. The model represented the parts of the torso that were to be tested. These parts are the skin, core temperature, sweat rate, and amount of evaporative cooling. This means that for the experiments and calculations some assumptions were accepted. The skin which facilitates the sweat from the core body to the outside to be evaporated was replicated by silicone sheets. These sheets fit the specification of human skin. Many mannequins utilize silicon sheets to replicate the skin, one such company is Mannequin Store (Mannequin Store 2008).

Variation of the size of the human torso was held to a certain constant. The torso dimension was 24" tall by a 40" circumference. This creates a constant area, allowing for the equations to always use the same value for area. A changing variable, such as area, would create a difficult process for creating a cooling vest. An area of larger or smaller surface may create a change in experimental data and cooling effects. For creating a workable/testable model, the area of the torso was set to a constant. The body will be assumed to produce 100 watts and sweat 2L/h. The 2L/h is a constant, it is plausible that a human body may sweat more or less due to the level of hydration, which could affect the overall evaporative cooling, but for the experimental tests, sweat rate was held constant.

The second challenge arose from making the model system from physical components. As an engineer designing and running test procedures there is an understanding that not everything will be completely predictable and feasible. Due to time and material constraints one is not able to design the perfect model system. It must be understood that due to the set, up not all energy, heat, ect., could be conserved. This is unlike the model system and equations done previously when the steady state and perfect conservation was assumed.

## Human Torso Design:

The process of building began with designing the human replica torso. The replica torso was formed by metal duct work. Two pieces were fastened together by riveting them together. Three rivets line each side of the torso replica. On the inside of the torso the rivets

were lined with duct tape in order to remove the possibility of material catching on the inside. This formed the base shell for the human torso of 24" height and 40" in circumference. The human skin was replicated by 3mm sheets of silicone that line the aluminum shell. The skin was sewn together, in a shell that fit the specifications of the torso cylinder (Figure 9). The skin was then slid down over the metal cylinder and held tightly to the rimming. In order to heat the cylinder to the correct core temperature 98.6°F (outlined by the model system), water was contained inside the cylinder, and heated to the correct temperature. Inside the cylinder a smaller solid shape was created, in order to reduce the amount of water that has to fill the inside of the cylinder. This allowed for an easier design parameter. A water-proof lining filled the rest of the space in the cylinder, in order to establish a container in which the water would be placed.



**Figure 9: Inner cylinder and water proof lining of replica torso**

Since testing of the heat properties are mainly desired out of the sides of the cylinder, the top and bottom were fitted with thermally non conductive material in order to reduce heat loss from these locations. The water was heated with an immersion heater, which was contained inside the cylinder (Appendix B picture 33). The temperature of the torso was held at an average temperature of  $98.0^{\circ} \pm 0.6^{\circ}\text{F}$  by means of heating hot water to the specified temperature.

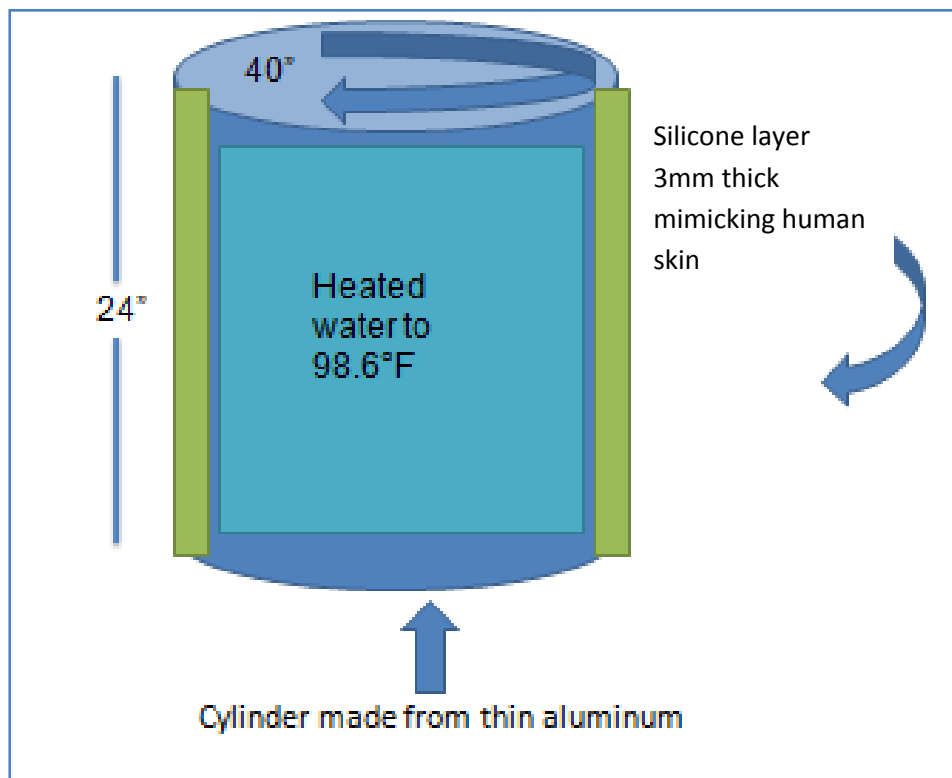
Data collection from human torso:

It was important to test the torso on its own to find out the temperature of the water inside the torso and the temperature difference transferred to the outside of the cylinder skin. Therefore, numerous tests were conducted in order to create a baseline temperature that could be expected for the inside and outside temperatures. This would give an idea of a constant variable for the model torso, and allow the other changes due to the vest and evaporation to be noted. The procedure for testing of the human torso is outlined in the following paragraph.

The solid inner cylinder was inserted into the torso replica, and fastened in place. Tap water was added to the space in between the two cylinders. The water was filled to the top of the cylinder to where the line of skin was seen. This allowed for a consistent temperature throughout the whole torso. The immersion heater was submerged into the water. There was an inside water temperature reading instrument that was contained in the water system to make sure that the water reached a uniform temperature of the desired parameter(97.0-98.6°F). The water was constantly mixed in order to reach a uniform temperature throughout the whole cylinder. This allowed for all sections of the outer torso to be within similar temperature ranges. The temperature of the water would be taken from the torso using a IR temperature gun. These temperatures were recorded in the data tables found in Appendix (C). By means of an IR temperature gun the temperature of the outside skin was recorded until it reached the desired temperature of the skin. The skin was measured at the top, bottom, and middle of the outer torso to give a temperature range for the whole structure. Mixing of the water was done in a consistent pattern, and the temperature of the core slowly became uniform through the structure. This experiment was conducted 4 times with 10 measurements each. The delta from the inside core to the outer skin was measured to be around an average of 5.21 degrees. It took 1.5 hours to fully reach a uniform skin temperature on the outer torso. The skin temperature was measured to be  $98.0 \pm 0.6$  °F (Table 4).

**Table 4: Example of data collection for the human torso**

Inside Core Temperature Degrees Fahrenheit	Outside Core Temperature Degrees Fahrenheit	Delta T	Delta T
103.8	98.1-98.8	5.7	5
104	98.3-98.2	5.7	5.8
103.1	98.3-98.8	4.8	4.3
			31.3
		average	5.21667



**Figure 10: Picture represents model of human torso**





**Figure 11: Outer skin of human torso**

The measurement and heat transfer from the inside of the torso to the outside of the replica torso was successful. It demonstrated the heat exchange and simulated the skin and body temperature accurately with the material at hand.

#### Perspiration Model Design:

A perspiration system was designed and fabricated into a physical model. Wicking material was used as a way to introduce water (sweat) into the system. In our model, perspiration accumulated on the wicking material and not on the skin. This is similar to the way a cooling system would be used in the field. Evaporative cooling took place from the wicking material and allowed us to control the volume of water. This made it easier to evaporate the water because the wicking material provided an air path.

#### Data Collection for the wicking material:

The wicking material (Shamwow) was placed on the mannequin without the vest. A large container of water was placed around the mannequin and the body of the human torso or

T.E.D (Thermoelectric Evaporating Device). The water contained the sweat rate predetermined as to the amount that a human soldier sweats during moderate activity (Tiburon) , a rate of 2L/h. The container was filled with 2 liters of water. The experiment was to see how well the wicking material would absorb the water from the container, in order to make sure that the right amount of water would be getting evaporated for the cooling. Measurements were taken every 10 seconds, to determine how much of the water was absorbed by the wicking. The conclusion was that the wicking material was able to hold the full two liters of water which was described as the average sweat rate of a soldier at peak performance; therefore during the tests performed 2 liters of “sweat” was present for evaporation.

**Table 5: Data Collection of wicking material**

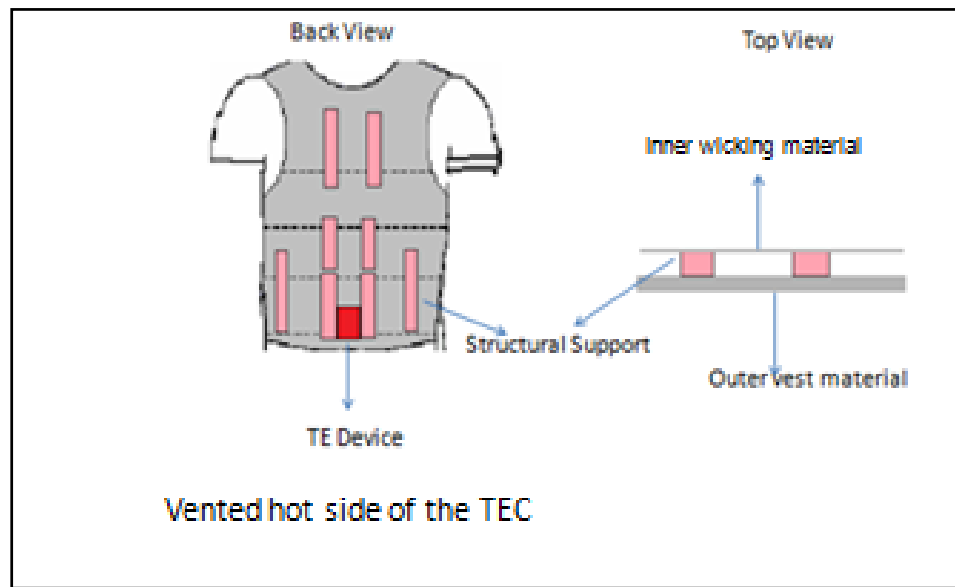
Experiment							
Time Elapsed (seconds)	0	20	20	30	40	50	60
Amount of water remaining	0.2	0.2	0.25	0.2	0.25	0.25	0.25



**Figure 12: Outer Shell of Cooling Vest**

Design of the Cooling Vest:

The development and design of the vest resulted from alteration of a normal jacket. The jacket was altered to fit the specifications outlined for the most advantageous vest design. A light weight jacket with mesh inner lining was altered. The sleeves were cut away and sewn in to create a large opening for the arms and armpit area, in order to be able to vent the air through these openings. The neckline was sewn down slightly from the original, which created a second means of escape for the air passing through. Figure 13 shows the way in which the jacket was altered to fit the desired parameters.

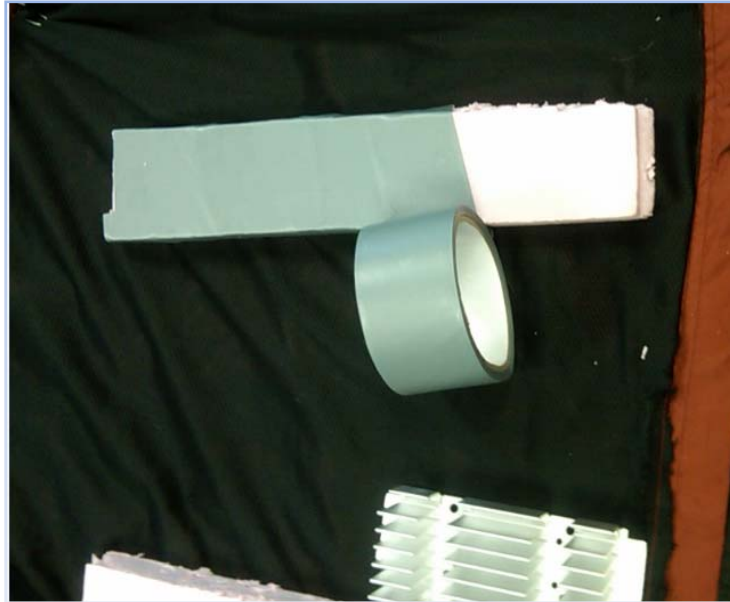


**Figure 13: Inside airflow for Vest**

Figure 13 depicts the way in which the airflow will be contained inside the vest. The TEC and the blower are to be installed at the back of the vest. The air will be directed upward by the two chamber enclosure on its sides. The inner wicking material will be touching directly to the torso's skin. The air will be directed upward and flow out in left and right directions. By means of the channels the air flow rate can be controlled to vary the air distribution.

The cooling vest was designed to the following specifications: The vest was light weight and comfortable. The vest contained 3 layers. The layers were the outer shell of the vest, the inner mesh lining and the wicking material. Each layer serves its own purpose in the vest. The outer shell of the jacket helped to protect the human torso from the harmful effects of the sun. The inner mesh lining provided a pathway allowing for air flow upward and out over the wicking material. The wicking material removed the sweat from the human body by absorption and allowed for evaporative cooling to take place. The structural system of the air flow of the vest, which was described in the previous schematic (Figure 14) was created by using thick Styrofoam, coated in a layer of duct tape. This allowed for a light weight, strong backbone to the vest alignment. The duct tape was used

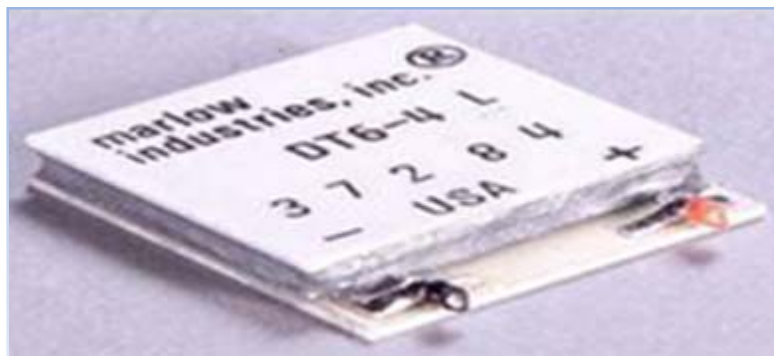
to prevent any cracking from occurring so that the structure would not collapse completely and the Styrofoam would not flake. The channels and cooling unit as placed in the vest, as seen in Figures 14 -17, created the air flow distribution system.



**Figure 14: Shows the wrapping of the Styrofoam backbone**

### Design of the TEC System

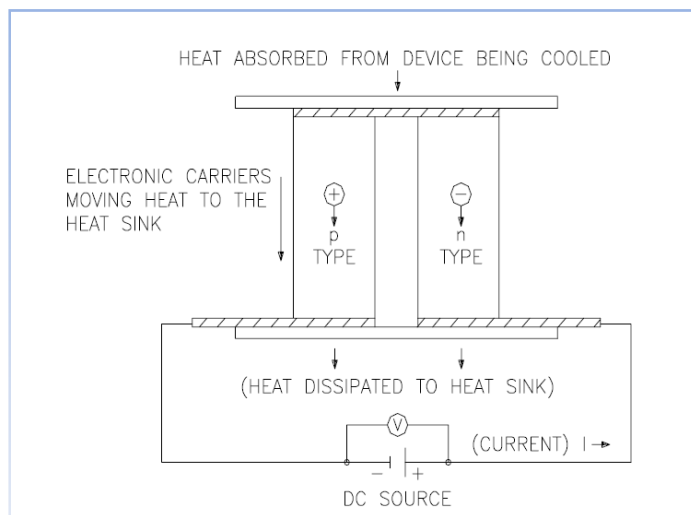
A TEC is a cooling/heating device based on Peltier-Seebeck effect. It can be considered a small heat pump that contains no moveable parts, which can be extremely advantageous (Marlow Industries 2007). Figure 14 is a picture of the TEC that was utilized in the design process, more information can be found in Figure 24, Appendix B.



**Figure 15: A Thermoelectric Cooler by Marlow Industries**

Inside is a heat flux created between the junctions of the two metals. Two wires are attached to one side of the TEC to allow for a power supply to run a current into the system.

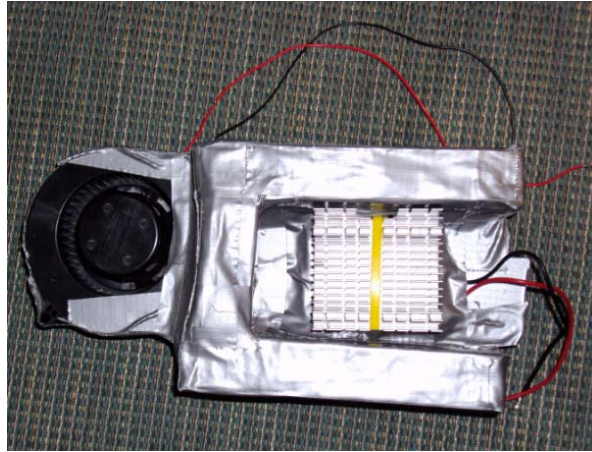
This transfer of heat from one side to the other is produced by the electric current that is supplied through the wires. The TEC used in this lab is a single stage cooler which contains two ceramic plates with p and n type semiconductor material (Bismuth Telluride). The elements of the semiconductor material are connected in series and are thermally parallel (Marlow Industries 2007). Figure 17 below demonstrates how and where the current of the TEC flows, and the way in which it is constructed.



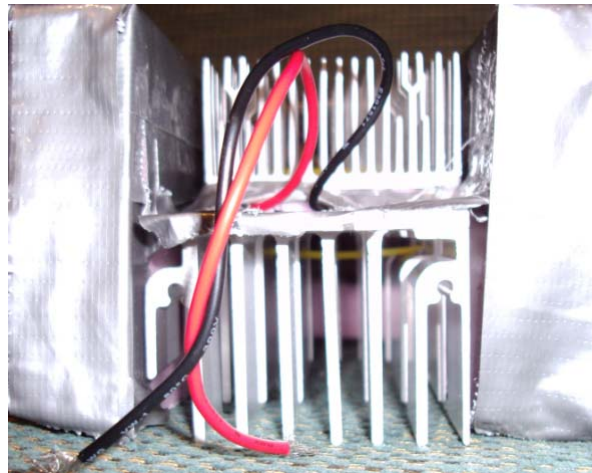
**Figure 16: Single stage TEC**

The temperature gradient creates a hot side and a cold side. Over the cold side, air will be blown from the outside environment before it is channeled into the vest. The cold heat sink system will lower the temperature of the air as it passes through the fins. Heat sinks were added to both sides of the thermoelectric cooler. The heat sinks allow for the thermal energy to be transferred from the hot object to another object with a lower temperature. Fins provide a greater allowance for heat transfer. They were attached by applying thermoelectric grease to the surfaces in order to create a better contact surfaces to conduct the heat. The two heat sink fans (Figure 18) were fastened together by a tightly attached binding wire wrap that ran through and around the centers of both heat sinks. The apparatus can be seen in Figures 17 and 18. Next insulation was added around the TEC and the heat sinks, to try and alleviate the transfer of air from one side to the other or to the environment.

The fan was fitted up against the two heat sinks, so that the air flow would be divided between the hot and cold heat sinks. More air flow was directed towards the cold side of the TEC so that the cooler air could be blown up into the channels of the vest. In Figure 17 a top aerial view of the TEC and blower setup can be seen.



**Figure 17: View of the TEC with blower attached,**



**Figure 18: View of Heat Sinks and Fins**

The blower located on the backside of the TEC apparatus is able to supply 10 Cfm of cooled air into the vest. Since the air flow is split between the hot and cold fin and experiment was designed to measure the portion of the 10 Cfm that was actually being blown into the vest.



Figure 19: TEC setup with attached channels for airflow

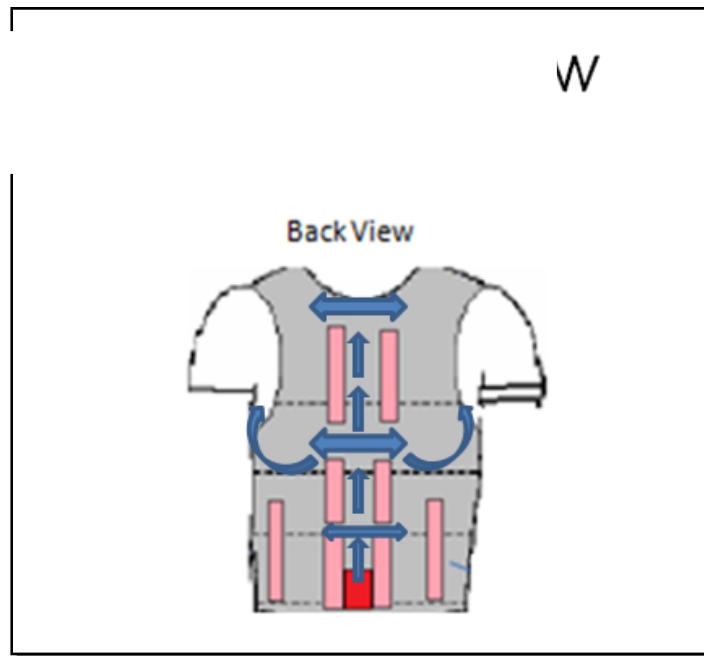


Figure 20: Direction of airflow

The direction in which the air flows into the vest is very important. Since the air will dissipate through the holes at the armpits, the concentration of air will be directed to that location. The human body contains certain locations where if cooled can trigger the brain into believing that it is regulated at a correct temperature level. This information caused the design of the air flow to be altered to avoid the back of the neck which is one of the



main trigger points for perceived cooling. Therefore in the airflow chamber design, the air will flow up from the TEC and outwards towards the armpits and the upper shoulders. The TEC device is equipped with a slanted exit ramp in the back of the vest for the removal of hot air from the body more easily, so the individuals do not feel the effect of the hot air disposal as much. The mesh from the jacket was lifted up and the two chambers were sown in place to hold the apparatus still. The back of the jacket was removed so that the blower and the hot side of the fins were exposed.

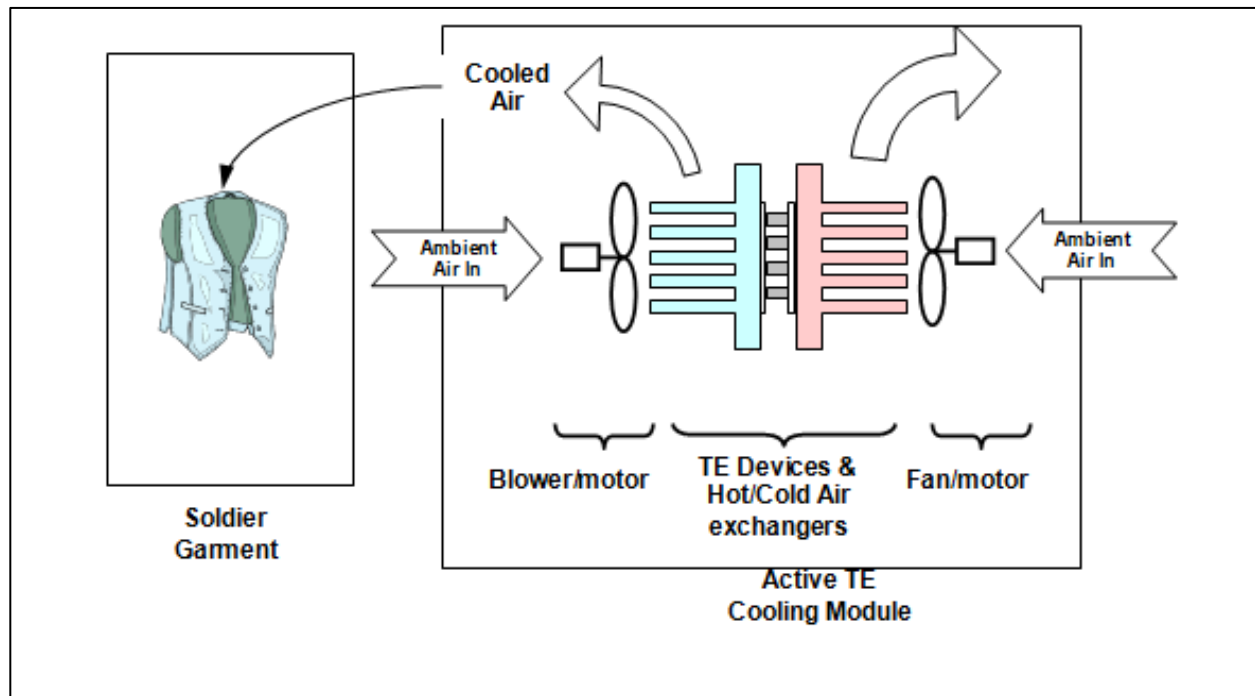


Figure 21: Schematic of the location for the TEC



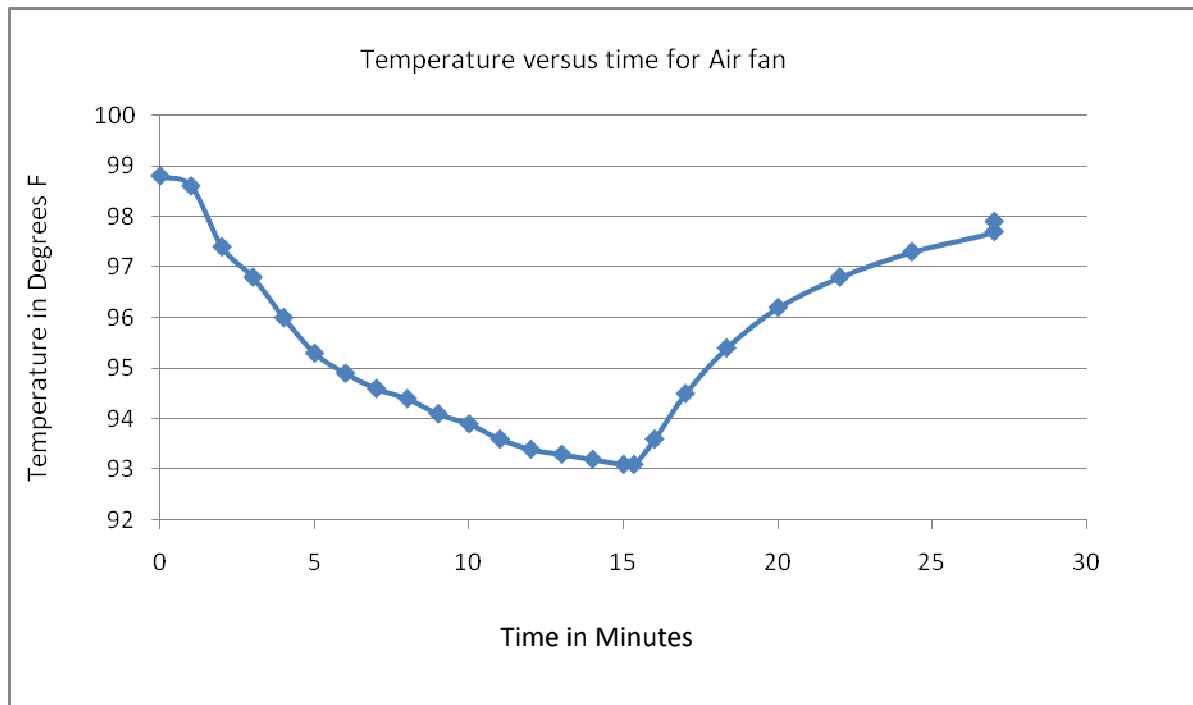


**Figure 22: Back of the vest with TEC application device in place**

*Data Collection for T.E.D wearing the cooling vest:*

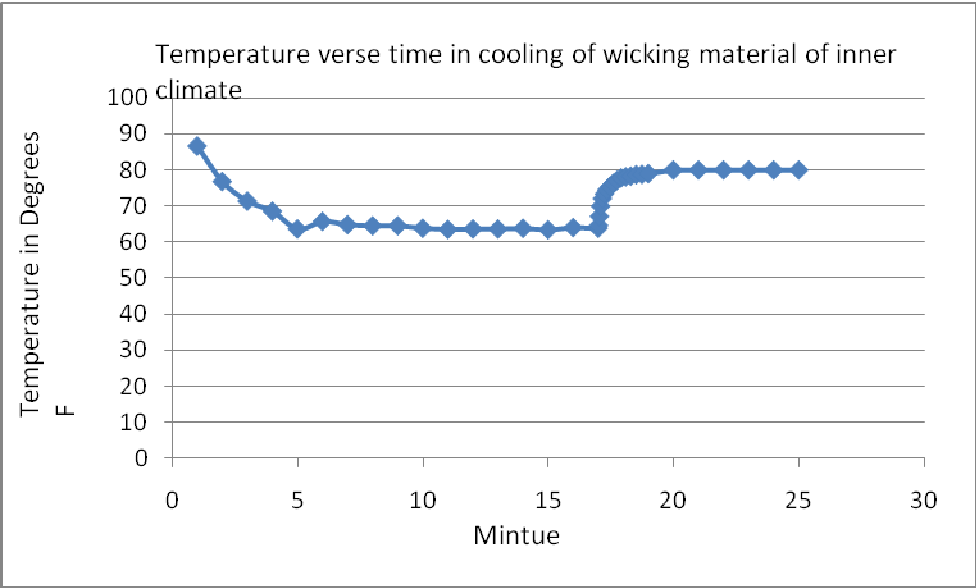
The next series of tests were made with the torso wearing the designed cooling vest. Measurements were collected to see if the vest would result in a decrease of temperature of the core. This temperature was taken without the effect of the TEC, to determine if just blowing air colder than the environment would have a significant effect on the cooling of the core. The following data table shows the data collection from the experiment.

**Table 6: Data collection for cooling vest mounted on mannequin without TEC cooling**



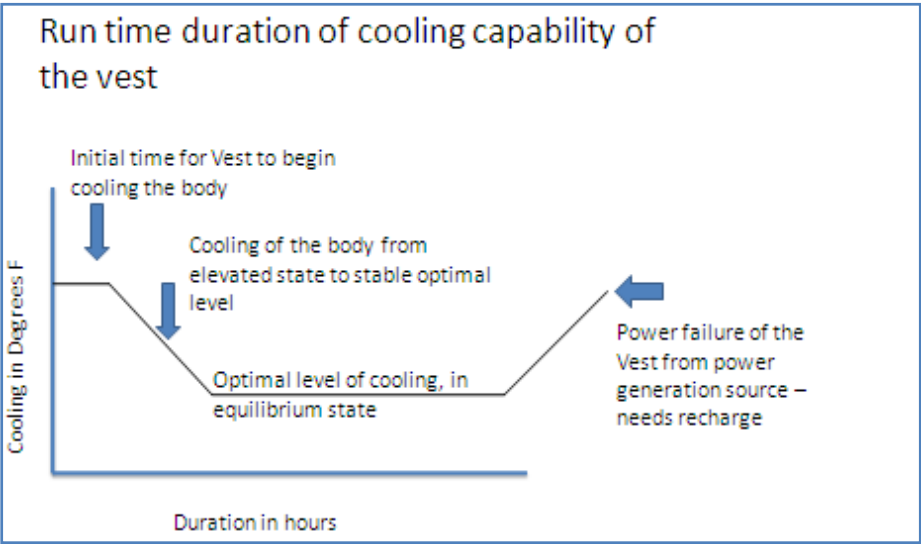
The next experimental step was to immerse the wicking material so it evaporated the amount of water perspiration that was produced every hour by the human torso. Evaporative cooling was being tested. The same data information was collected, and the change in temperatures was compared. All data using the Psychometric Charts were calculated and compared.

**Table 7: Data collection taking advantage wicking system showing temperature decrease inside the microclimate vest**



Design of a duration run:

The system was designed to be rugged and long lasting. The operation time is determined by the available power from a battery. A TEC uses a great deal of power and limits the duration of operation. Figure 23 is an example chart of a cooling cycle.



**Figure 23: Duration of Cooling**

Duration run of stability of Vest Cooling:

An essential design aspect of this research was the length of time that the vest was able to cool the individual and allow them to operate at a safe core body temperature. One of the last experiments run on T.E.D was a duration test. The vest was situated on the mannequin and allowed to run for an hour. The temperature of the skin was taken every minute to see if there was any fluctuation in the system, temperature. Observing at the data collected in Table 7, one can see that the skin temperature reached a comfortable equilibrium and was only disturbed when the power supply was shut off to represent a battery failure and to see how quickly the body's skin temperature would rise back to the starting temperature.

**Table 8: Experimental Run 1**

Time in Minutes	Temperature of Skin in Degrees F	Temperature of inside core water in F	Room Temperature
0	91.4	108.5	74.8
1	91.4	108.5	74.8
2	91.1	109	74.8
3	90.8	109.6	74.8
4	90.6	110	74.8
5	90.3	110	74.1
6	89.7	111	74.4
7	89	111	74.1
8	88.8	112	74.2
9	88.4	112	74.1
10	88.3	111	74.2
11	88.3	112	74.1
12	88.3	112	74.1
13	88.3	112	74.1
14	88.3	112	74.2
15	88.3	111	74.1
16	88.3	112	74.1
16.33333333	88.6	112	74.1
16.5	89.1	112	74.1
16.66666667	90	112	74.1
17	90.9	112	74.1
17.33333333	91.6	112	74.1
17.66666667	92.6	112	74.1
18	93.4	112	74.1
18.33333333	94.1	112	74.1
18.66666667	94.8	112	74.1
19	95.3	112	74.1
20	96.2	112	74.1
21	96.8	112	74.1
22	97.1	112	74.1
27	98.3	112	74.1

# Results Section

The 10 cfm air flow was enough air to cool the human torso to the needed body temperature. Although the entire 10 cfm of airflow was not directly blown into the vest, airflow into the vest was maximized for ultimate temperature control. The power supply was run at 5 volts, and was deemed to supply an appropriate amount of current when the 12 volt change made no significant alteration in data values (Appendix C, Figure 34). The ambient air of  $\sim 74^{\circ}\text{F}$  was cooled around an average of 10 degrees, with a relatively high humidity. This high humidity affected the cooling rate, and established that cooling in a humid environment was still attainable. With this information the predetermined calculations for an aired environment of  $120^{\circ}\text{F}$  are substantial in that an individual would be properly cooled by the TEC cooling vest device.

Since the resources to create a hot environment of  $120^{\circ}\text{F}$  were not available the experiments were conducted in an environment of  $74^{\circ}\text{F}$  and 24-26% relative humidity. The humidity would adversely affect the desired result, since more humidity and water contained in the air makes it harder to evaporate the water produced by sweat. Although this is the case, it did not seem to adversely affect the data received by experimental procedures. The calculations pertaining to the model system showed that evaporation cooling is possible with the environmental temperature and the relative humidity. The preliminary tests showed at the current testing conditions that evaporation was still possible. The preliminary hypothesis was that the only failure would come from the battery power. Instead of waiting for the battery system to fail, a failure was simulated by removing the power supply. The engineering group's original prediction of a graph for evaporative cooling is found in figure (24).

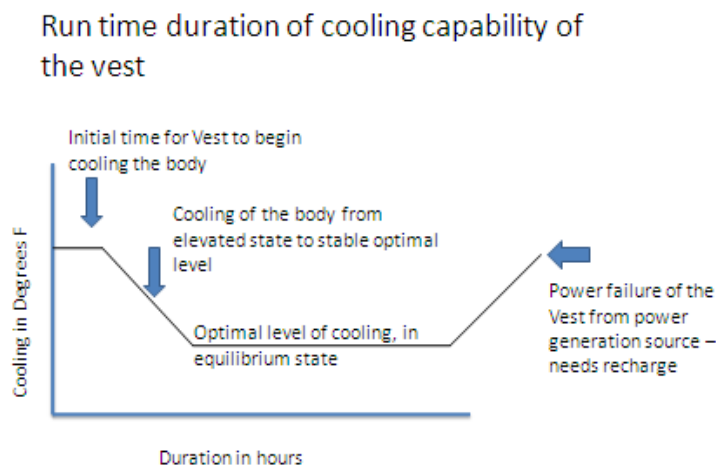
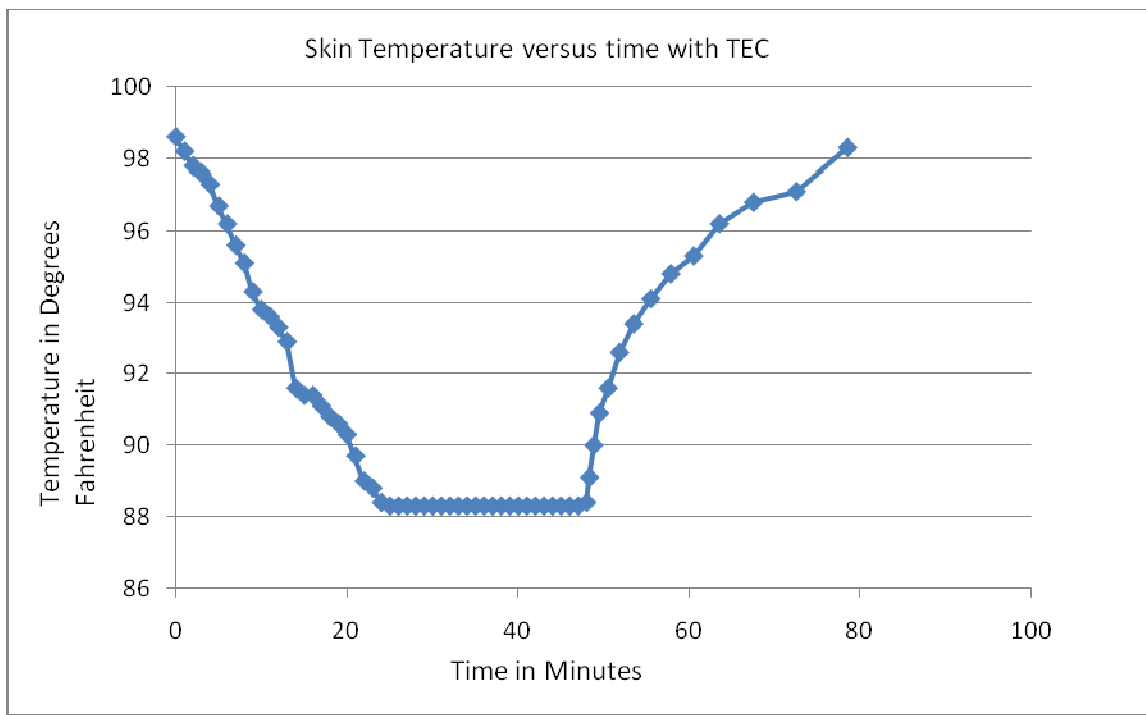


Figure 24: Graph prediction the evaporative cooling curve

The predicted graph assumed that the situation was steady state. The experimental data of course showed otherwise, but still followed the pattern of the predicted graph. Also the numerical values collected show that evaporative cooling was a plausible way of establishing core body temperature in the microclimate. The following graph, Figure 24 is an example of an experimental run. Actual results (Figure 25) were similar to those results predicted in the graph (Figure 24).



**Figure 25: Graph of cooling vest evaporation for experimental runs**

Other graphs and numerical data charts can be found in Appendix C. The data values from trial runs do not vary significantly and all the graphs are similar in shape. This data illustrates that evaporative cooling does work and once steady state is achieved, the cooling is constant. This method of cooling is more advantageous than current applications because T.E.D allows a longer lasting cooling effect on the human body temperature with a lighter weight vest option.

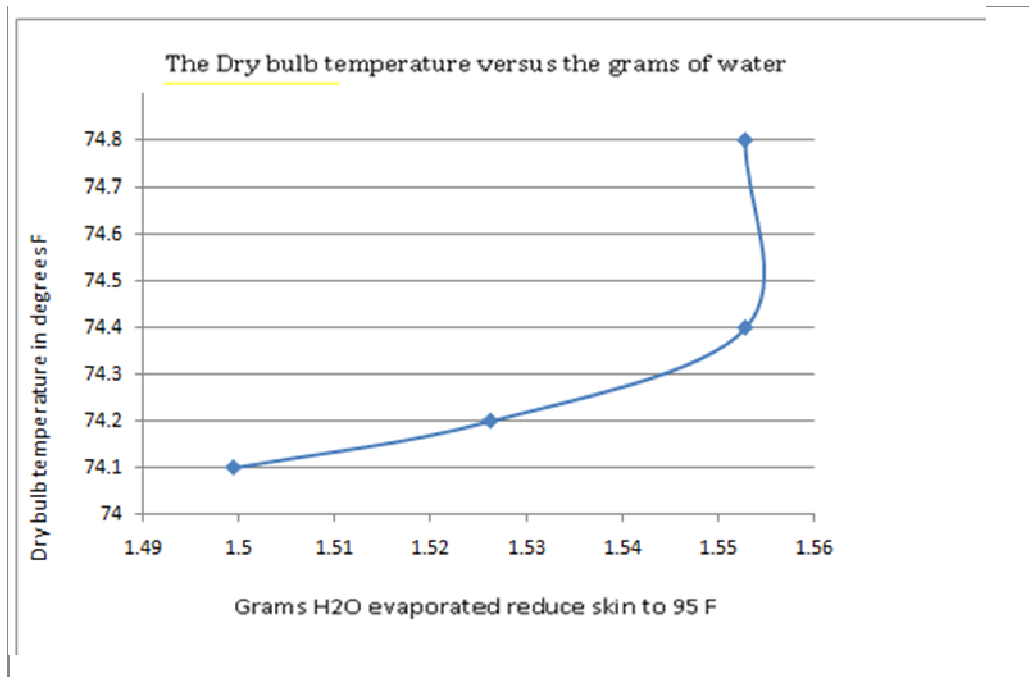
Using the Psychrometric calculator the values of the humidity for the environment in which the experiments were conducted can be calculated. Below in Table's 8, 9, the data can be observed.

**Table 9: Psychrometric Chart Data**

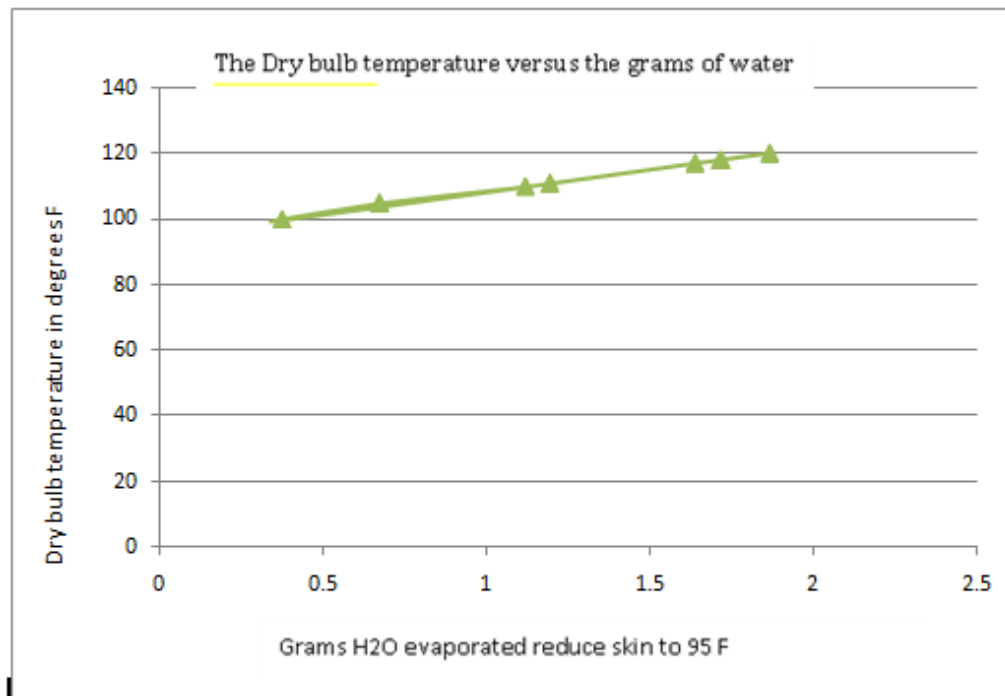
Dry Bulb		Relative Humidity	Wet Bulb		Dew Point		H <sub>2</sub> O/Dry Air
°C	°F	Percent %	°C	°F	°C	°F	g/kg
23.38889	74.1	24.8	12.33333	54.2	2.14	35.8	4.42
23.44444	74.2	24.57	12.33333	54.2	2.07	35.7	4.4
23.55556	74.4	26.94	12.83333	55.1	3.46	38.2	4.86
23.77778	74.8	26.7	12.94444	55.3	3.53	38.4	4.88

**Table 10: Psychrometric Chart Data continued**

Enthalpy	Watts to reduce skin to 95 0F	Grams H2O evaporated reduce skin to 95 0F
	10 CFM	
kJ/kg		10CFM
34.68	62.21766248	1.552853473
36.68	62.21766248	1.552853473
35.97	61.14987286	1.52620315
36.25	60.07814413	1.499454512



**Figure 26: Dry Bulb Temperature of ~74 °F versus the grams of water needed to be evaporated**



**Figure 27: Dry Bulb Temperature of 100-120 °F versus the grams of water needed to be evaporated**

In the above graphs, though the temperatures and the relative humidity's differ, one is able to see that the evaporative cooling is still possible due to the amount of water that is assumed as a flow rate of sweat.

The overall weight of the vest was calculated to be 4.2 pounds using a lithium battery. This is advantageous to the wearer because in comparison to current market application the newly designed vest is lighter.



# Conclusions

Our results indicate that for a hot dry environment, evaporative cooling is a viable solution for controlling body core temperature. The application of a TEC device to create a temperature gradient is important to the success in lowering the core body temperature in a hot environment. The use of a TEC precooler lowers the amount of water that has to be evaporated and extends the humidity range over which the cooling will occur. The experimental data verifies the predetermined equations and predictions. The application of the cooling vest can be utilized in many functions: soldier, fireman, patients, and construction workers.

The effect of heat stress on our armed forces is significant enough that steps must be taken to maintain and enhance the performance of those fighting in combat settings. The TEC vest gives a viable option as a cooling system and by changing the airflow direction of the current and minor electronics it can also be a heating system. Therefore we are giving the armed forces more than one type of protection, as well as expanding the application to other occupations and individual needs.

We feel that the vest was designed in a manner suited to individuals' as the customer. The TEC device and cooling garment were light weight, durable, portable, and maintained the ability to be worn under protective armor.

The idea, design, and construction of T.E.D was innovative, and focused on solving a problem that facilitated technology, science and engineering to aid society and needs of other individuals. The transition of engineering principles and basic theory into a practical prototype culminated the engineering education of the authors. The project fulfills the MQP requirement as defined.

# Recommendations

The primary recommendation of this effort is to extend the research and demonstration to a preproduction prototype that can be fully tested to customer requirements. The implementation of many design features were excluded from this project due to financial constraints. Even with the constraints, the outcome of the hardware was positive and the prototype creative and inventive.

Based on the current construction of TED new design and material selection is needed to make a flexible backbone and shell for the air distribution system within the vest and comfort for the wearer. This will improve the use in portable or self contained mission applications and extend to enable individuals in motor vehicles to wear the garment without impeding their performance.

The TEC system was built with available parts and can be redesigned to be smaller and lighter. The efficiency of the TEC system can also be improved through material selection such as carbon fiber heat exchangers and better insulation. This would help to manage the cooling capacity and possibly extend run times; as the battery life would be extended in portable systems.

With the design and material changes the MQP engineers feel that the vest can be used in many applications. This system can be redesigned to be smaller, lighter and use less power. We feel that the garment/TEC system is extremely versatile and its application can be advantageous to many fields of interest. Although the goal is to design one vest for all applications, the MQP engineers realize that in near term, specific design features will have to be constructed to the specific applications. Potential applications in addition to soldiers are discussed.

## Hospitals

The thermoelectric cooling vest would be extremely beneficial in a medical setting. In many hospital situations patients need to be stabilized in a colder environment, often during surgery or for the reduction of fever. The vest would be an optimal solution for these conditions. Since most patients are not mobile in such environments, it would be easy to revise the power system of the vest. Instead of a battery power system needed for mobile transportation the vest could be connected up to a stationary power supply that would allow for continuous cooling. The vest may also have to be redesigned to allow for comfort for the individual positioning in a reclined or sitting position. This could be accomplished by moving the blower and TEC system to the side instead of the back location. An adjustment of the air distribution system would have to be redesigned in order to still allow full access to the body for cooling.

### Fire Fighters:

Fire fighters are exposed to extremely hot environments for short periods of time. The vest could be redesigned to create more cooling over a shorter period of time. The battery system could be recharged using a vehicular device. If one increases the CFM of the blower, than the individual could benefit from more evaporative cooling over a shorter time. It would be advantageous for the fire fighter to have a lighter power system since their equipment itself is cumbersome.

### Civilians with health Problems:

There are many individuals who have health related issues that make it difficult to live and perform daily routines in a hot environment. An example of such would be individuals who have no sensory heat regulation capabilities such as individuals with Multiple Sclerosis.

### Police:

The people who protect us are very mobile in their day to day activities and many times the activities create an increase in their body temperature. The increased temperature from their protective vests creates an uncomfortable situation for the individuals. A portable cooling device would be beneficial to their work. The design of the current cooling vest would work well for the police academy. One beneficial design would be a portable, car adaptor type vest system.

### Construction workers:

These individuals have a similar situation to the soldier personnel. They are out in the sun for long durations of time, with moderate activity levels. Some of these individuals may wear less protective clothing than that of the soldiers. They are more susceptible to heat from radiation from the sun. These individuals also have the opportunities to recharge their system via a vehicle, and therefore a car unit system may be advantageous for this application. This can be extended to heavy equipment operators and truck drivers.

### Sports Industry:

The sports industry spends millions of dollars yearly to make sure that their athletes are in peak performance. Current applications of cooling devices have been seen in the racing industry. These cooling devices are personal coolers, most commonly the ice pack. Although the drivers do not have to worry about the weight of the phase change as

much as a mobile person, the phase change system still has its disadvantages to the drivers. The packets for the phase change are bulky, unlike the TEC system, as well if the TEC system was redesigned, it would be able to continuously run on the car adaptor, taking up little power and supplying continuous cooling to the individual, allowing them to be comfortable and maintain their quick reflexes.

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# Appendices

## Appendix A

List of equations used in report and experiments

*List of Equations used:*

$$T_{sk} = T_{core} + T_{activity} + T_{surrounding}(R_{th}C_{th}CD)$$

$$T_{sk} = T_{core} + T_{activity} + T_{surrounding} + T_{Env}$$

$$Total\ heat\ stress = [(heat\ generated\ in\ the\ body(metabolic\ heat)) + (heat\ gained\ from\ the\ environment(environmental\ heat))]$$

$$C = 7.0Va^{0.75}(t_a - t_{sk})$$

$$\left(\frac{22}{12}\right)^2 - \left(\frac{20}{12}\right)^2$$

$$R = 6.6(T_w - T_{sk})$$

$$\frac{Q}{t} = \epsilon \sigma A (T_{hot}^4 - T_{cold}^4)$$

$$E = 14Va^{0.75}(P_{sk} - P_a)$$

$$Flow\left(\frac{m^3}{s}\right) * density\ final\left(\frac{kg}{m^3}\right) * specific\ heat\left(\frac{J}{kgC}\right) * \Delta T$$

$$\left(\frac{watt}{2404}\right) * 60$$

# Appendix B:

Reference Figures referred in text document

## Evaporative Cooling-Submission



- Heat is expended to change water from liquid into vapor
- The hotter and dryer the air, the greater evaporative cooling effect, the relative humidity becomes lower and evaporative cooling efficiency increases
- RH decreases as air temperature increases
- For every 20° F (11° C) rise in temperature, the moisture-holding ability of air doubles
- Relies on water for evaporation to cool – continuous supply of water in Iraq?
- Must remove garment to reactivate product
- Low efficiency when worn below garments

**Figure 28: Evaporative Cooling System**

### Phase Change System (solid-liquid)

- Very common in public
  - Duration limited to one melt, then need access to cooler
- ↓
- Means one must remove outer garments
  - Heavy cooling packs

Pockets where  
phase change  
material pouches  
are held



Figure 29: Phase Change System

### Personal Ice Cooling System

- Powered by three D-cell batteries (housed in the pump unit)

- Maximum of 4 hour cooling capabilities

- Controlled by a three-position toggle switch (off/low flow/high flow)



- System circulates cold water through a tube-lined shirt

- Collects metabolic heat from the user's body by conduction

- Water is at an elevated temperature when exiting the shirt

- The water is brought back to a cool temperature when it passes over ice contained in a bottle

Ice bottle needs replacement every 30-60 minutes

Figure 30: Personal Cooling System



### Compressed Air System

- Must have access to compressed air
- Limited mobility to hose length
- Need a way through garments to run house outside of body
- Cooling rate constant over time
- Smaller design of larger systems



Conclusion: Not an advantageous system

**Figure 31: Compressed Air System**

# DC San Ace

## Blower

97mm  
San Ace B97

### High air flow type

#### General specifications

Material.....Frame, Impeller: Plastics  
Motor protection system.....Current cut system (with reverse polarity protection)  
Dielectric strength.....50/60 Hz 500 VAC 1 minute (between lead conductor and frame)  
Operating temperature.....-20℃ to +60℃ (Non-condensing)  
Life expectancy.....40,000 hours (survival rate 90% at 60℃,  
rated voltage and continuously run in a free air state)  
Fan power lead.....⊕ Red, ⊖ Black

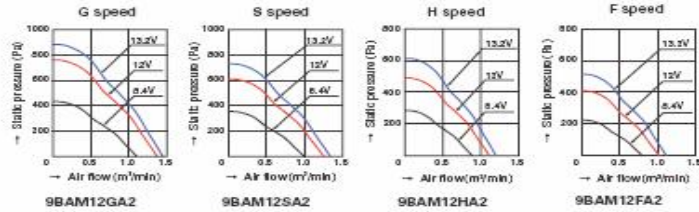


Blower

### 33mm thick Specifications

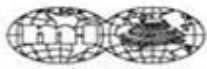
Model No.	Rated voltage (V)	Operating voltage range (V)	Rated current (A)	Rated input (W)	Rated rotating speed (min <sup>-1</sup> )	Air flow (m <sup>3</sup> /min) (CFM)		Static pressure (Pa) (InchH <sub>2</sub> O)		Noise (dB [A])	Mass (g)
9BAM12GA2	12	9.4~13.2	1.95	22.2	5,800	1.37	48.4	760	3.05	62	170
9BAM12SA2		9.4~13.2	1.45	17.4	5,300	1.25	44.2	610	2.45	60	
9BAM12HA2		9.4~13.2	1.20	14.4	4,700	1.10	38.9	490	1.97	58	
9BAM12FA2		9.4~13.2	0.99	11.9	4,300	1.00	35.3	410	1.65	56	
9BAM24GA2	24	12.0~26.4	0.90	21.6	5,800	1.37	48.4	760	3.05	62	
9BAM24SA2		12.0~26.4	0.71	17.0	5,300	1.25	44.2	610	2.45	60	
9BAM24HA2		14.4~26.4	0.60	14.4	4,700	1.10	38.9	490	1.97	58	
9BAM24FA2		14.4~26.4	0.49	11.9	4,300	1.00	35.3	410	1.65	56	

#### Typical air flow and static pressure characteristics



97mm

Figure 32: Specifications on Blower



**Thermoelectric Cooler**

**DT6-4**

**Performance Values**

Hot Side Temperature (°C)	27 °C	50 °C
$\Delta T_{max}$ (°C-dry N <sub>2</sub> ):	65	73
$Q_{max}$ (watts):	20	22
$I_{max}$ (amps):	3.7	3.7
$V_{max}$ (vdc):	8.2	9.2
AC Resistance (ohms):	1.8	



**Mechanical Characteristics**

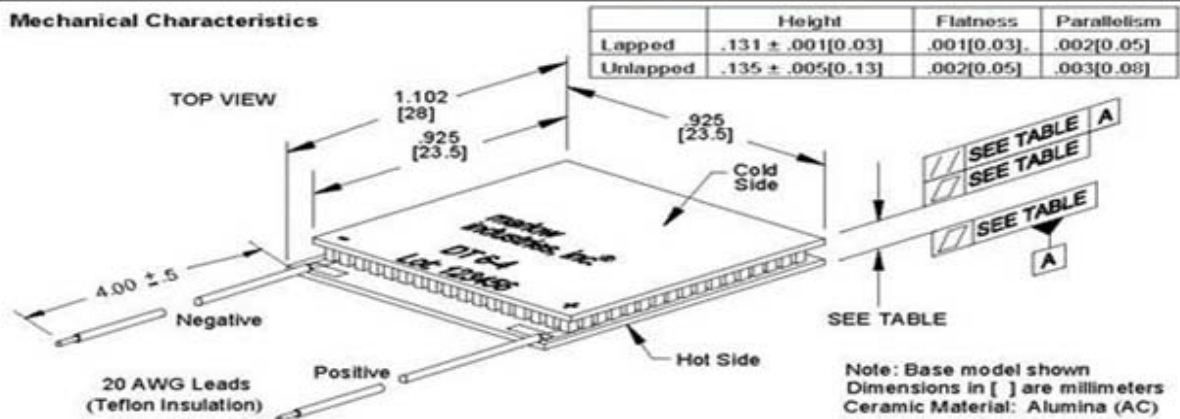


Figure 33: Specifications on Thermoelectric Cooler



Figure 34: Picture of Submersible Heater

# Appendix C

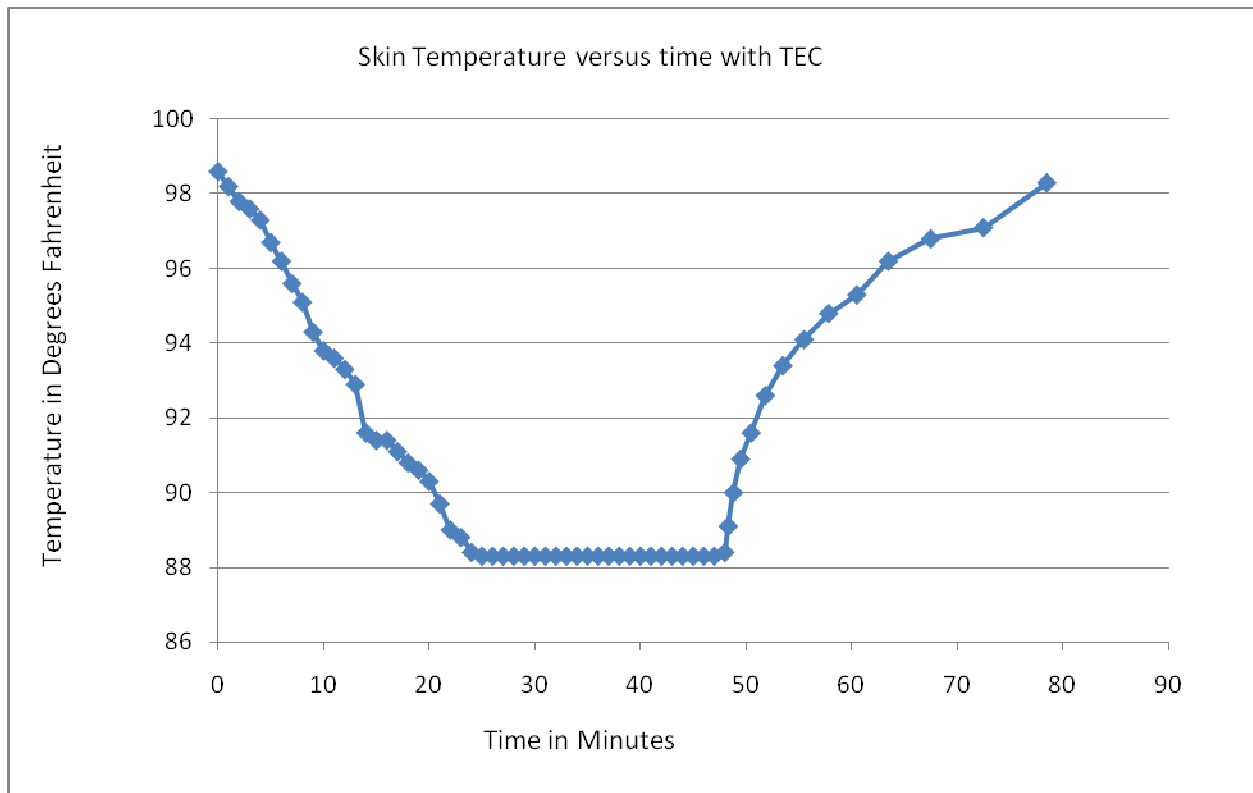
## Experimental Data Collections

### Skin Temperature versus time with TEC Data and Graphs

#### Data Run 1 (Table 7)

Time in Minutes	Temperature of Skin in Degrees F	Temperature of inside core water in F	Room Temperature
0	91.4	108.5	74.8
1	91.4	108.5	74.8
2	91.1	109	74.8
3	90.8	109.6	74.8
4	90.6	110	74.8
5	90.3	110	74.1
6	89.7	111	74.4
7	89	111	74.1
8	88.8	112	74.2
9	88.4	112	74.1
10	88.3	111	74.2
11	88.3	112	74.1
12	88.3	112	74.1
13	88.3	112	74.1
14	88.3	112	74.2
15	88.3	111	74.1
16	88.3	112	74.1
16.33333333	88.6	112	74.1
16.5	89.1	112	74.1
16.66666667	90	112	74.1
17	90.9	112	74.1
17.33333333	91.6	112	74.1
17.66666667	92.6	112	74.1
18	93.4	112	74.1
18.33333333	94.1	112	74.1
18.66666667	94.8	112	74.1
19	95.3	112	74.1
20	96.2	112	74.1
21	96.8	112	74.1
22	97.1	112	74.1
27	98.3	112	74.1

Graph for Test Run 1

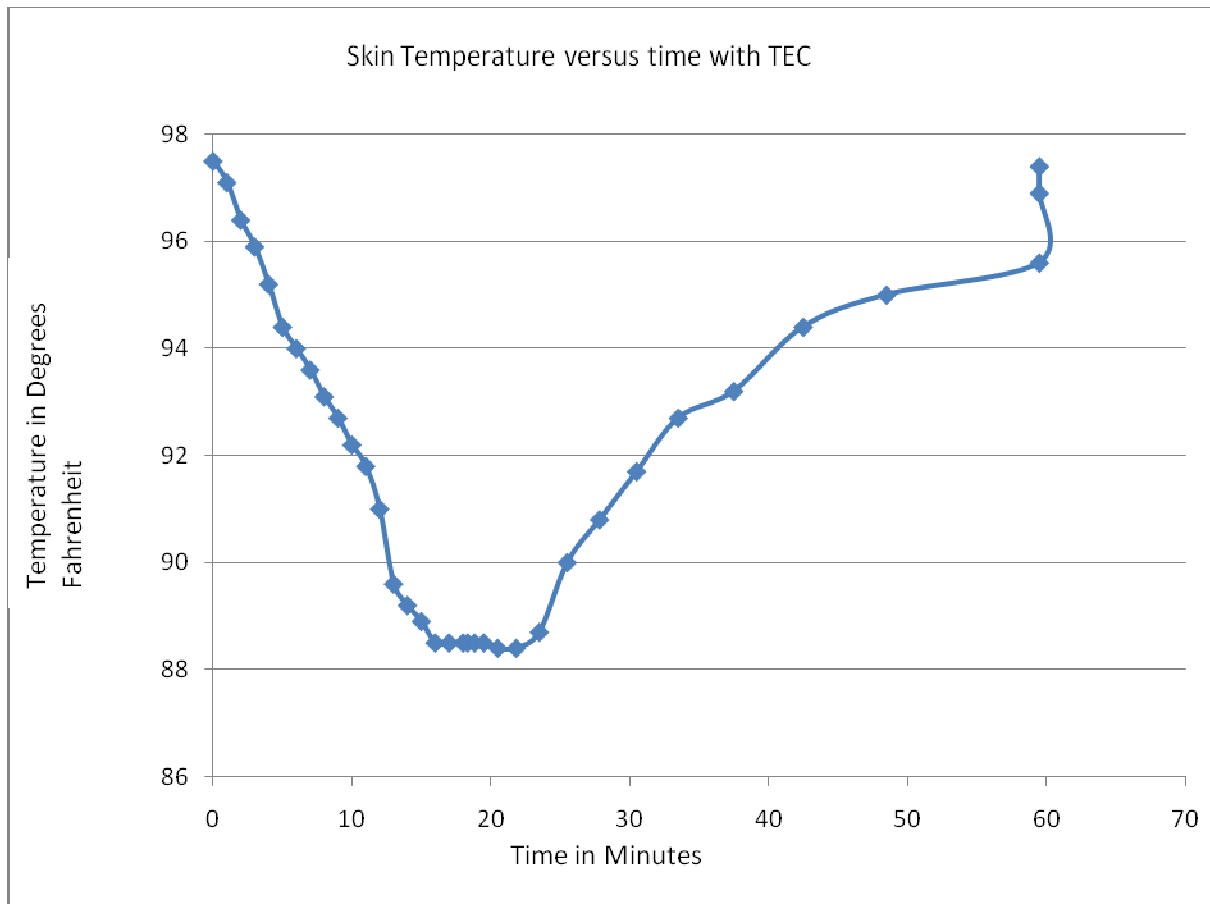


Data Run 2

Time in Minutes	Temperature of Skin in Degrees F	Temperature of inside core water in F	Room Temperature
0	97.5	110.2	74.1
1	97.1	110.4	74.2
2	96.4	110.4	74.1
3	95.9	110.5	74.2
4	95.2	110.4	74.1
5	94.4	110.8	74.1
6	94	110.9	74.1
7	93.6	111	74.2
8	93.1	111	74.1
9	92.7	111	74.1
10	92.2	111	74.1
11	91.8	111	74.1
12	91	111	74.1
13	89.6	111	74.1

14	89.2	111	74.1
15	88.9	111	74.1
16	88.5	111	74.1
17	88.5	111	74.1
18	88.5	111	74.1
18.33333333	88.5	111	74.1
18.83333333	88.5	111	74.1
19.5	88.5	111	74.1
20.5	88.4	111	74.1
21.83333333	88.4	111	74.1
23.5	88.7	111	74.1
25.5	90	111	74.1
27.83333333	90.8	111	74.1
30.5	91.7	111	74.1
33.5	92.7	111	74.1
37.5	93.2	111	74.1
42.5	94.4	111	74.1
48.5	95	111	74.1
59.5	95.6	111	74.1
59.5	96.9	111	74.1
59.5	97.4	111	74.1

Graph for Data Run 2



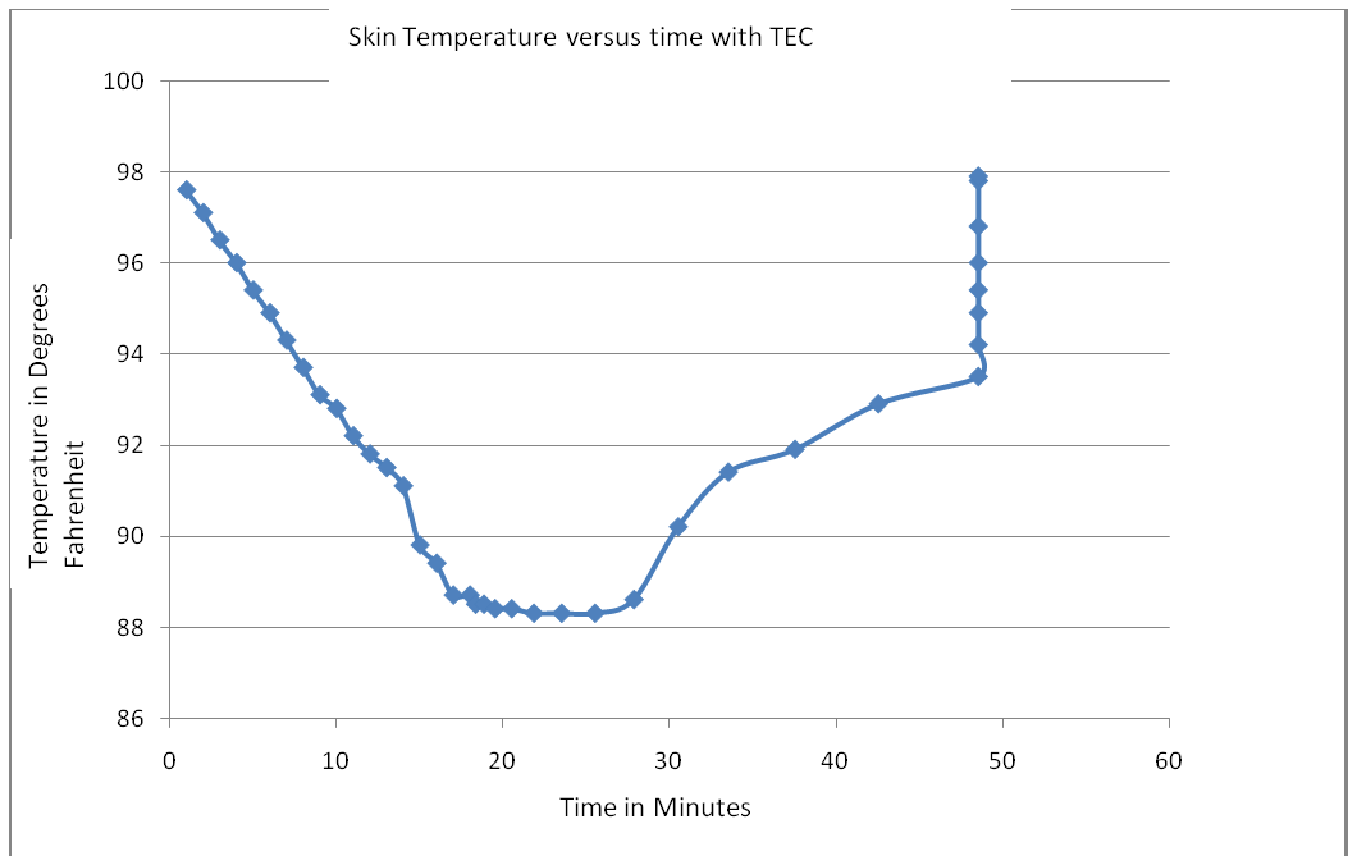
Data Run 3

Time in Minutes	Temperature of Skin in Degrees F	Temperature of inside core water in F	Room Temperature
1	97.6	111	74.1
2	97.1	111	74.2
3	96.5	111	74.1
4	96	111	74.2
5	95.4	111	74.1
6	94.9	111	74.1
7	94.3	111	74.1
8	93.7	111.5	74.2
9	93.1	111.5	74.1
10	92.8	111.5	74.1
11	92.2	111.5	74.1

12	91.8	111.5	74.1
13	91.5	112	74.1
14	91.1	112	74.1
15	89.8	112	74.1
16	89.4	112	74.1
17	88.7	112	74.1
18	88.7	112	74.1
18.33333333	88.5	112	74.1
18.83333333	88.5	112	74.1
19.5	88.4	112	74.1
20.5	88.4	112	74.1
21.83333333	88.3	112	74.1
23.5	88.3	112	74.1
25.5	88.3	112	74.1
27.83333333	88.6	112	74.1
30.5	90.2	112	74.1
33.5	91.4	112	74.1
37.5	91.9	112	74.1
42.5	92.9	112	74.1
48.5	93.5	112	74.1
48.5	94.2	112	74.1
48.5	94.9	112	74.1
48.5	95.4	112	74.1
48.5	96	112	74.1
48.5	96.8	112	74.1
48.5	97.8	112	74.1
48.5	97.9	112	74.1



Graph for Data Run 3

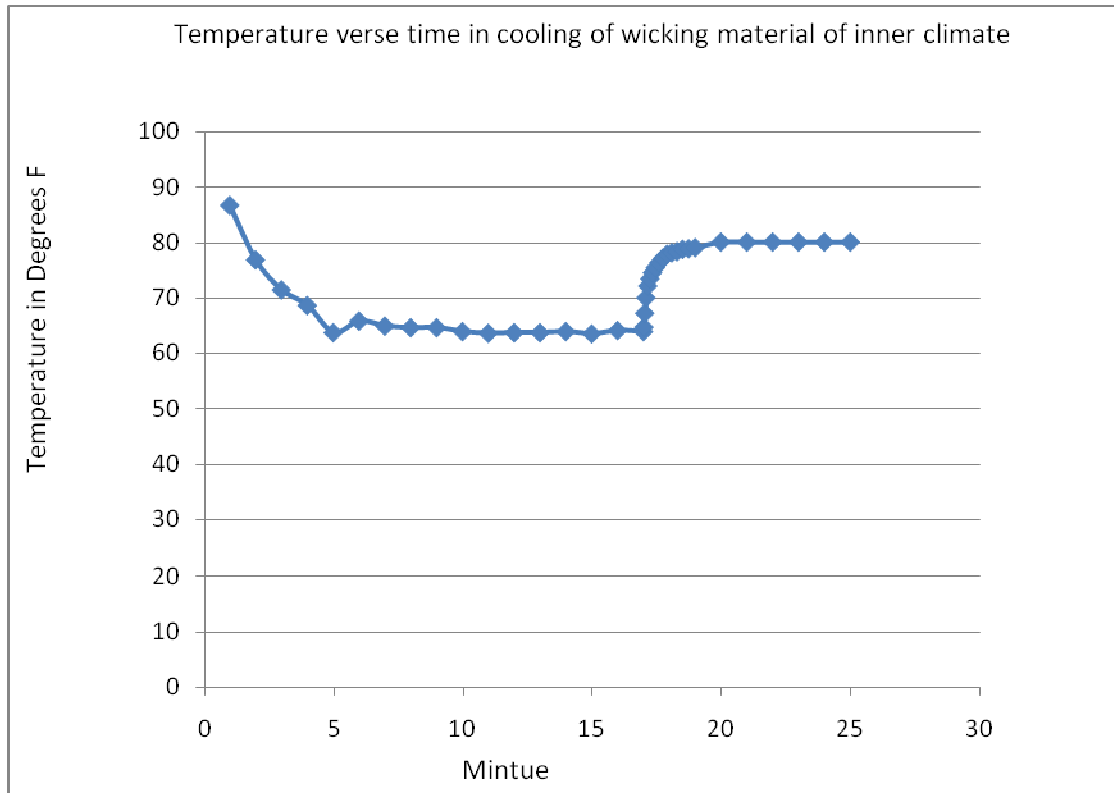


Cooling of the Wicking material inside the microclimate environment

Run 1

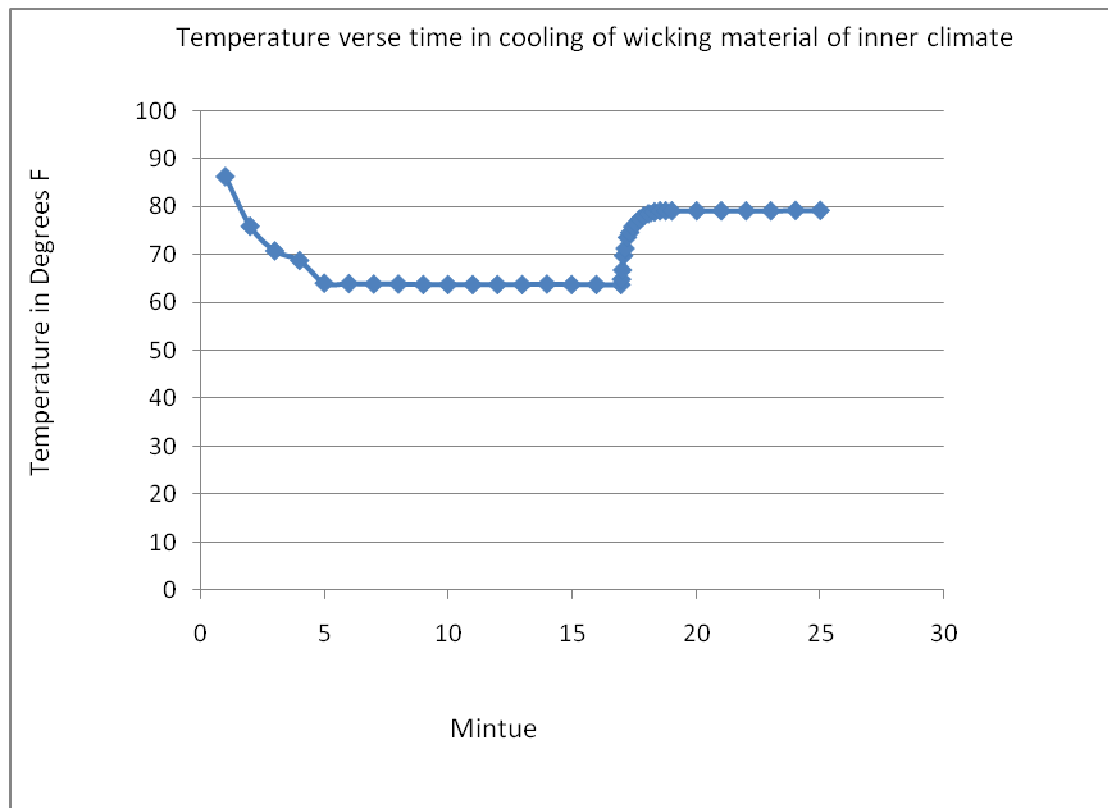
Run in minutes	Temperature of inside vest outer evaporative layer
1	86.6
2	76.8
3	71.4
4	68.6
5	63.7
6	65.8
7	64.9
8	64.6
9	64.6
10	63.9
11	63.6

12	63.7
13	63.7
14	63.9
15	63.5
16	64.1
17	63.9
17.01666667	64.7
17.05	67.2
17.1	70
17.16666667	72.1
17.25	73.4
17.35	74.5
17.46666667	75.4
17.6	76.3
17.75	77.1
17.91666667	77.8
18.1	78.1
18.3	78.3
18.51666667	78.7
18.75	78.8
19	79
20	80
21	80
22	80
23	80
24	80
25	80



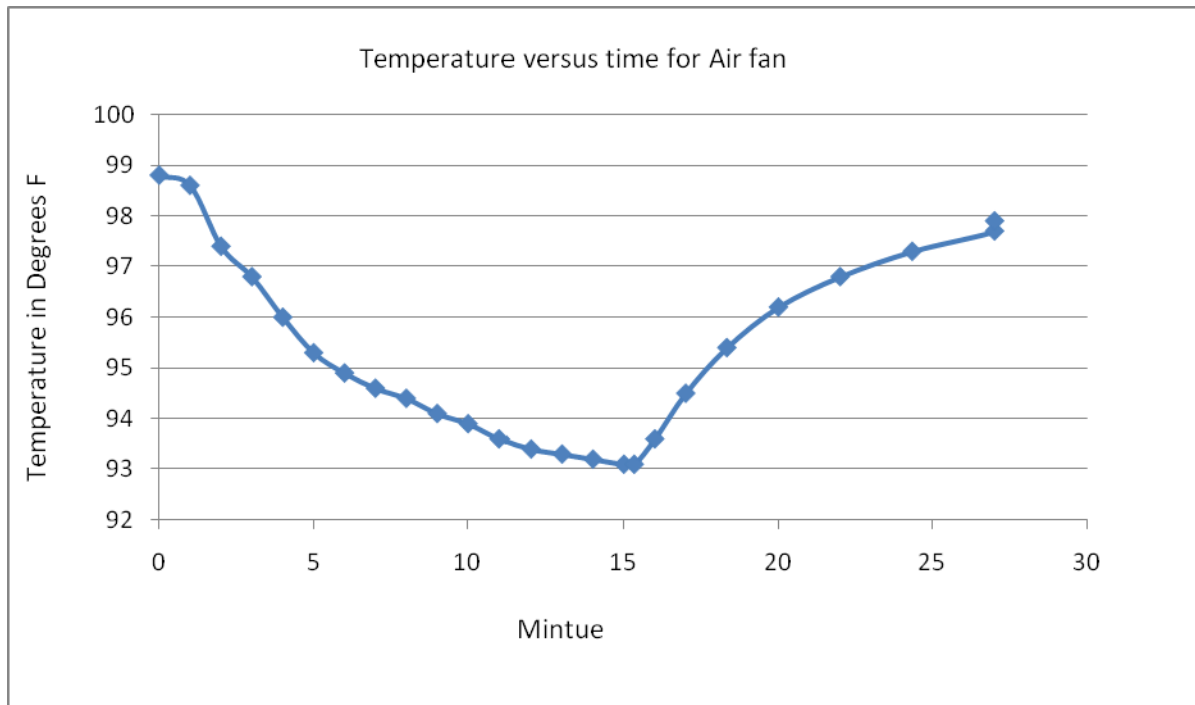
Run in minutes	Temperature of inside vest outer evaporative layer
1	86.2
2	75.9
3	70.8
4	68.8
5	64.1
6	64
7	63.9
8	63.9
9	63.8
10	63.8
11	63.8
12	63.8
13	63.8
14	63.9
15	63.8
16	63.8
17	63.8
17.01666667	64.9
17.05	66.8
17.1	69.8

17.16666667	71.3
17.25	73.6
17.35	74.6
17.46666667	75.8
17.6	76.5
17.75	77.4
17.91666667	78
18.1	78.5
18.3	78.9
18.51666667	79.1
18.75	79.1
19	79.1
20	79.1
21	79.1
22	79.1
23	79.1
24	79.2
25	79.2



Run without the TEC, only using the air blower fan

Run in Minutes	Cooling with TEC turned off and running fan
0	98.8
1	98.6
2	97.4
3	96.8
4	96
5	95.3
6	94.9
7	94.6
8	94.4
9	94.1
10	93.9
11	93.6
12	93.4
13	93.3
14	93.2
15	93.1
15.33333333	93.1
16	93.6
17	94.5
18.33333333	95.4
20	96.2
22	96.8
24.33333333	97.3
27	97.7
27	97.9



Run in minutes	Temperature of the skin in F
0	98.7
1	98.3
2	97.3
3	96.2
4	95.2
5	94.5
6	93.9
7	93.3
8	93.1
9	92.8
10	92.8
11	92.8

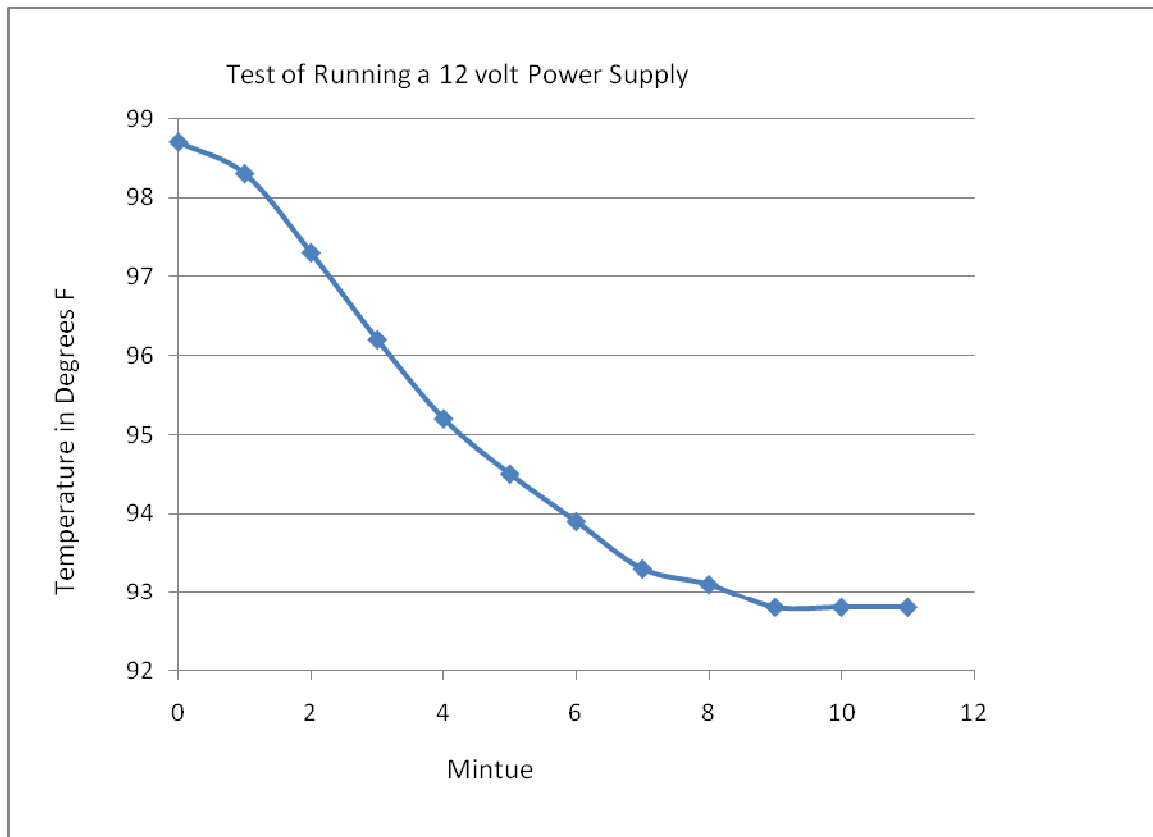


Figure 35: 12 Volt

Data for an environment of 100-120 with relative humidity of 9-11 %

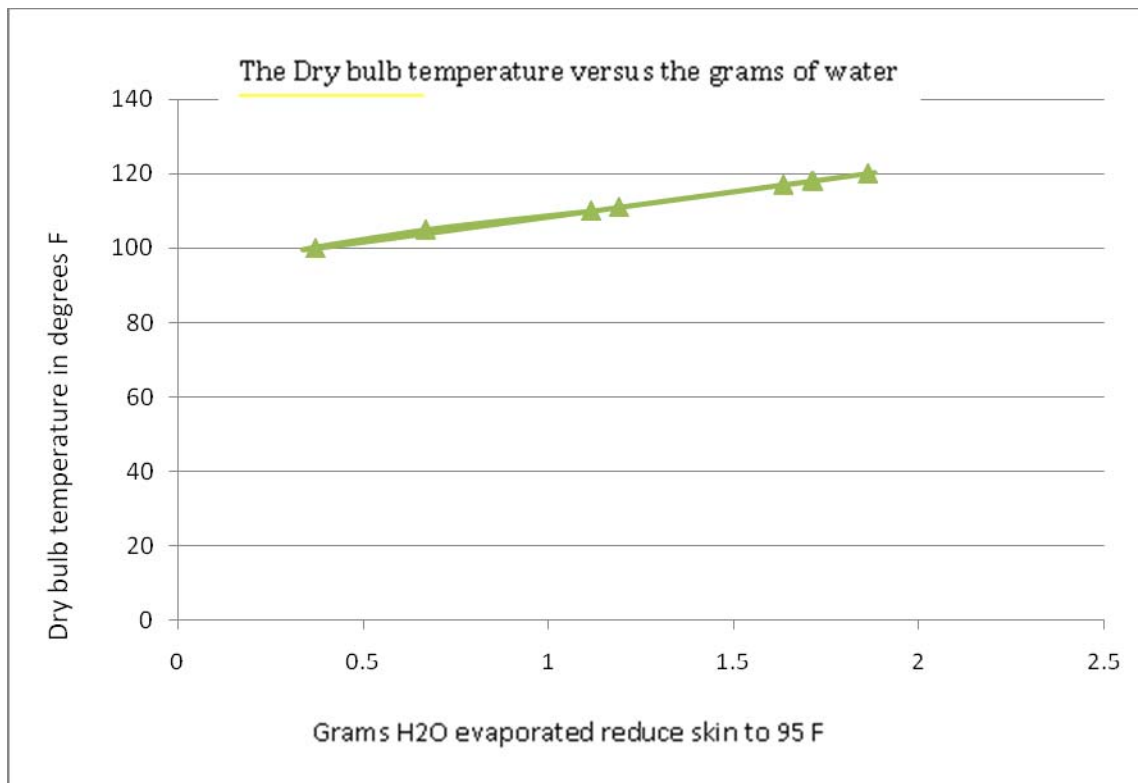
Dry Bulb		Relative Humidity	Wet Bulb		Dew Point		H <sub>2</sub> O/Dry Air	Enthalpy
°C	°F	Percent %	°C	°F	°C	°F	g/kg	kJ/kg
37.8	100.0	10.0	17.3	63.3	1.0	33.8	4.1	48.4
40.0	105.0	10.0	18.5	65.3	2.6	36.7	4.6	51.9
43.3	110.0	10.0	20.3	68.5	5.1	41.3	5.5	57.6
43.9	111.0	10.0	20.6	69.0	5.6	42.0	5.6	58.6
47.2	117.0	10.0	22.3	72.1	8.1	46.6	6.7	64.6
47.8	118.0	10.0	22.6	72.7	8.5	47.2	6.9	65.8
48.9	120.0	10.0	23.2	73.7	9.3	48.7	7.3	68.0
37.8	100.0	9.0	17.0	62.7	-0.4	31.3	3.66	47.32
40.0	105.0	9.0	18.2	64.7	1.2	34.1	4.12	50.74
43.3	110.0	9.0	19.8	67.7	3.6	38.5	4.91	56.12
43.9	111.0	9.0	20.2	68.3	4.1	39.3	5.07	57.13
47.2	117.0	9.0	21.8	71.3	6.5	43.7	6.01	62.29
47.8	118.0	9.0	22.1	71.8	6.9	44.5	6.2	64.02
48.9	120.0	9.0	22.7	72.8	6.6	43.8	6.56	66.06
37.8	100.0	11.0	17.7	63.9	2.3	36.2	4.48	49.43
40.0	105.0	11.0	18.9	66.0	4.0	39.2	5.05	53.12
43.3	110.0	11.0	20.7	69.2	6.5	43.7	6.02	58.96
43.9	111.0	11.0	20.99	69.8	6.94	44.5	6.21	60.07
47.2	117.0	11.0	22.75	73.0	9.43	49.0	7.73	66.42
47.8	118.0	11.0	23.07	73.5	9.89	49.8	7.6	67.63
48.9	120.0	11.0	23.66	74.6	10.71	51.3	8.03	69.89
23.38889	74.1	24.8	12.33333	54.2	2.14	35.8	4.42	34.68
23.44444	74.2	24.57	12.33333	54.2	2.07	35.7	4.4	36.68
23.55556	74.4	26.94	12.83333	55.1	3.46	38.2	4.86	35.97
23.77778	74.8	26.7	12.94444	55.3	3.53	38.4	4.88	36.25

Watts to reduce skin to 95 °F	Grams H <sub>2</sub> O evaporated reduce skin to 95 °F
10 CFM	
	10CFM
14.92289722	0.372451678
26.84461905	0.669998812
44.73610041	1.116541608
47.74564485	1.19165503
65.54085175	1.635794969
68.57900545	1.711622432
74.6841702	1.863997592
14.92207458	0.372431146



26.84314909	0.669962124
44.73278712	1.116458913
47.74241629	1.19157445
65.53589365	1.635671222
68.76229077	1.716196941
74.67828083	1.863850603
14.92373321	0.372472543
26.84639166	0.670043053
44.73876546	1.116608123
47.74887341	1.191735609
65.54570435	1.635916082
68.77280533	1.716459368
74.69005956	1.864144581
62.21766248	1.552853473
62.21766248	1.552853473
61.14987286	1.52620315
60.07814413	1.499454512

Graph showing the dry bulb temperature versus the amount of grams of water needing to be absorbed



Data for an environment of ~73°F-74 °F with relative humidity of ~24-27 %

Dry Bulb		Relative Humidity	Wet Bulb		Dew Point		H <sub>2</sub> O/Dry Air
°C	°F	Percent %	°C	°F	°C	°F	g/kg
23.38889	74.1	24.8	12.33333	54.2	2.14	35.8	4.42
23.44444	74.2	24.57	12.33333	54.2	2.07	35.7	4.4
23.55556	74.4	26.94	12.83333	55.1	3.46	38.2	4.86
23.77778	74.8	26.7	12.94444	55.3	3.53	38.4	4.88

Enthalpy	Watts to reduce skin to 95 °F	Grams H <sub>2</sub> O evaporated reduce skin to 95 °F
	10 CFM	
kJ/kg		10CFM
34.68	62.21766248	1.552853473
36.68	62.21766248	1.552853473
35.97	61.14987286	1.52620315
36.25	60.07814413	1.499454512

