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## Self-regulating heating/cooling blanket using the Peltier effect: Temperature Automated Blanket System (TABS)

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## **Temperature Automated Blanket System (TABS)**

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### **Abstract**

Currently, hospitals need to constantly monitor hyper/hypothermic patients when trying to return a patient's core body temperature to safe value. The temperature automated blanket system (TABS) constantly monitors a patient's temperature, through a medical rectal probe (proven to be the most accurate way of reading a patient's core body temperature), and adjusts the heating/cooling blanket accordingly. The need for this product is evident by the fact that, currently, hospitals with non-automated systems designate a nurse to constantly monitor a patient, which is inconvenient for effective/efficient personnel use. Systems that automate the process of heating and cooling a patient do exist as complete packages, but these systems are large in size, require water, and are very expensive (\$5,000 to \$10,000). TABS is a cheap and smaller alternative to the large expensive packages that are available.



# ***Self-Regulating Heating/Cooling Blanket Using the Peltier Effect***

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# Abstract

Currently, hospitals need to constantly monitor hyper/hypothermic patients when trying to return a patient's core body temperature to safe value. The temperature automated blanket system (TABS) constantly monitors a patient's temperature, through a medical rectal probe (proven to be the most accurate way of reading a patient's core body temperature), and adjusts the heating/cooling blanket accordingly. The need for this product is evident by the fact that, currently, hospitals with non-automated systems designate a nurse to constantly monitor a patient, which is inconvenient for effective/efficient personnel use. Systems that automate the process of heating and cooling a patient do exist as complete packages, but these systems are large in size, require water, and are very expensive (\$5,000 to \$10,000). TABS is a cheap and smaller alternative to the large expensive packages that are available.

The blanket portion of the system uses the peltier effect to heat or cool the blanket to be placed on the patients. The peltier effect occurs when a current is passed across two dissimilar metals. In the case where a positive current is applied across the two dissimilar metals, one side of the peltier pad, or thermoelectric module (TEM), will heat and the other side will cool. When a negative, reversed current is applied across the same two dissimilar metals, the side that was heating will begin cooling. When placing a heatsink on the non-patient side of the TEM, you can draw heat away from the module allowing the cooling side to be controlled more effectively.

TABS integrates temperature sensors, a Programmable Logic Controller (PLC), heatsinks, peltier pads, and aluminum plates. During testing we found that using a generic Proportional Integral Derivative (PID) temperature control function would not suffice using the peltier effect. We handled the issue by making our own timing function for both heating and cooling activities, allowing the peltier units to be powered on for a given amount of time and then shut off; the heat transfer between both sides of the peltier pads was the cause for this need.

We made the user interface for the controller easy and useful for optimal friendliness and simplicity. We have a manual set point option, in addition to an automatic option, allowing a medical employee to set the optimal temperature they wish the patient to attain. Through research, we found that at different ages the average core body temperature differs by about 1 degree F give or take a degree. For automatic mode, we gave the user the option to select the age of the patient which has automatic set points in the program for each age range.

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# Introduction

For our senior capstone design project, we decided that we would tackle a problem that affected nurses, doctors, and hospitals in general. After researching and interviewing hospital staffs throughout Boston, we found a great need in their hyper-hypothermic care systems. At the time the systems implemented were bulky, overpriced, and constant needed monitoring. Nurses would have to constantly monitor the core body temperature of the patient and adjust the temperature of the blanket accordingly.

Our goal was to remove any possibility of human error, as well as automate a system that takes valuable time from the hospital staff. Another very important aspect we focused on was the patient's safety. Whenever a medical system is implemented it needs to be flawless. In order to have a flawless system we had to take many precautions and look into all error handling techniques available. We also looked into making a more light weight, easy to use, portable product that would be reusable without any added agent, such as water. When researching ways of cooling without outside agents we quickly realized there would not be an easy solution or way of going about it. We then learned of the Peltier Effect.

The peltier effect is an inefficient way of cooling using a reverse current across two dissimilar metals. The peltier effect will be explained in more detail later in this report. Using TEMs, thermoelectric modules, which use the peltier effect we were able to harness both the heating and cooling qualities to heat and cool our blanket. We found this to be not only a smaller, more cost efficient, but also a mobile way of manipulating a patient's temperature by using thermoelectric properties.

Once we received our materials needed for the TEMs we realized that the heatsink would be one of the most important portions of our project. We dedicated a lot of time on finding a lightweight but efficient heatsink that would pull energy from one side of the TEM to the other. We then realized that we need to make a comfortable blanket. So we then researched different types of gel and clay packs testing them numerous times in different conditions to find the type that had the best thermal properties for our application, which in the end was the clay pack.

The following sections of this paper go into greater detail of the material we tested, test results, and explanations of the system we developed to successfully create a lightweight, cost efficient, portable system that would be marketable and obtainable to hospitals all over the world.

# Problem Formulation

## Needs

Although the need for an automated heating and cooling blanket system may seem novel at first, one may wonder why hospitals would be interested in such a product if there were available solutions already on the market. The products that are on the market currently are actually rather inconvenient, both financially and functionally. If hospitals are supposed to treat a larger and larger quantity of individuals, as is expected in the coming decades, then the current solutions will not suffice. The current options for heating and cooling a patient are systems utilizing air or water as the medium for thermal regulation.

The current air systems on the market, Faw and the Bair Hugger models, happen to be somewhat convenient in terms of size. While the size may not be a factor in their case, they have outdated functionality. The systems require constant airflow into the accompanying blanket, with the need of dangerous heating coils and mechanical devices to create air pressure. Because they use heating coil technology as their basis for thermal regulation, they are only able to create hot air and thus, only useful for hypothermic patients. The air systems are temperature controlled by manual operation. This makes them rather tedious for hospital staff to have precise control over the heating of the patient, having to regularly check to verify a patient's temperature has not dramatically increased. For staffs that are constantly overworked, which are predicted to be the vast majority in the future, it will be nearly impossible to be so closely monitored.

Some of the current water systems on the market, while comprising the same functionality as our self-regulating heating and cooling blanket, are rather bulky in size. This bulkiness creates problems when trying to transport the units. It prevents them from quickly moving around a hospital. Although the systems are created with wheels in tow, they are still very heavy, making them impossible to move throughout the hospital without aid of an elevator and making them impossible to use inside of an ambulance. Also, the current self-regulating water systems, the Blanketrol or the Normo-temp for example, are quite expensive. With the financial problems hospitals face today and will inevitably face tomorrow, it is difficult to imagine such systems are economically feasible.

## Medical Background

The normal body temperature averages 98.6°F, but some variations as large as 1°F occur during the day. The extreme cases of body temperature require medical attention, in order to stabilize it back to a normal range. When the body temperature is abnormally low, the condition is called hypothermia. Conversely, hyperthermia is a condition that occurs when the body temperature is abnormally high. Hypothermia occurs as a result of cases such as diabetes, excessive alcohol use, drug use, shock, as well as hypothyroidism. This is a condition where the thyroid hormones used in regulating the way the body uses energy are not produced enough by the thyroid gland. Hyperthermia on the other hand is as a result of the body failing to regulate its temperature. It is usually caused by heatstroke(3).

Knowledge of a patient's body temperature is very important in determining how fast and how long they would need the blanket to regulate their temperature back to normal. Temperature

is normally measured one of five ways: orally, rectally, aurally (through the ear), under the armpit, or on the forehead. Reading temperature through the ear, orally, and rectally are the most accurate ways. Our system would be designed to read the temperature in a conducive and non-invasive way (3). Table 1 describes the upper limit of the body temperature with respect to the age of the person (4).

<b>Age</b>	<b>Upper Limit of Body Temperature</b>
0-2 Months	100.7°F (38.1°C)
3-47 months	100.3°F (37.9°C)
4-9 years	100.1°F (37.8°C)
10-18 years	100.1°F (37.8°C)

**Table 1: Upper Limit of Body Temperature**

Hypothermia and hyperthermia are conditions that involve complicated solutions. Even though these methods are sufficient, they take time away from nurses and hospital staff that may be spent on other patients. Interviews of hospital workers, such as nurses, technicians, and doctors, resulted in a recommendation for finding an improved approach for treating hypothermia and hyperthermia. Hypothermia occurs when the body temperature falls below 95°F (3).

Hyperthermia occurs when the body's core temperature rises above 100°F. When patients suffer from hyperthermia caused by fever or by participating in demanding activities in environments where the ambient temperature is greater than body temperature, they have to be treated in a delicate manner; this usually involves a cold compressor to the neck, head, or groin (3). Doctors also use intravenous methods to cool patients if the cold compressor is ineffective. A last resort is application of ice and cold water, but the downfall is introducing the patient to hypothermia. Ice and cold water are only used when there are means to monitor the patient's temperature continuously (3).

# Analysis

## Basic Setup

The setup of the TABS system is divided into two separate sections; the Human Interface and the Control System. The Human Interface consists of the Person whose temperature is being monitored, and the Blanket that heats and cools that person. The Control System consists of the Programmable Logic Controller (PLC), the power supplies for both the blanket and TEMs and the PLC. There are two relays, one to turn on the heating power supply and another to turn on the cooling power supply. There are two fuses to protect the blanket and PLC from any possible power surges and diodes on the negative and positive outputs of each power supply to eliminate any reverse current flow from the other power supply.

The temperature of the patient and the blanket are fed into the PLC as raw voltages, and then they are converted to degrees in the code on the PLC. These temperatures are then used to establish what the blanket should do and how fast it should do it. The blanket temperature is used to establish that the blanket is doing what it is supposed to do, and will shut it off when it reaches the prescribed value. The patient temperature is used to monitor the progress of the patient as they are heated and cooled.

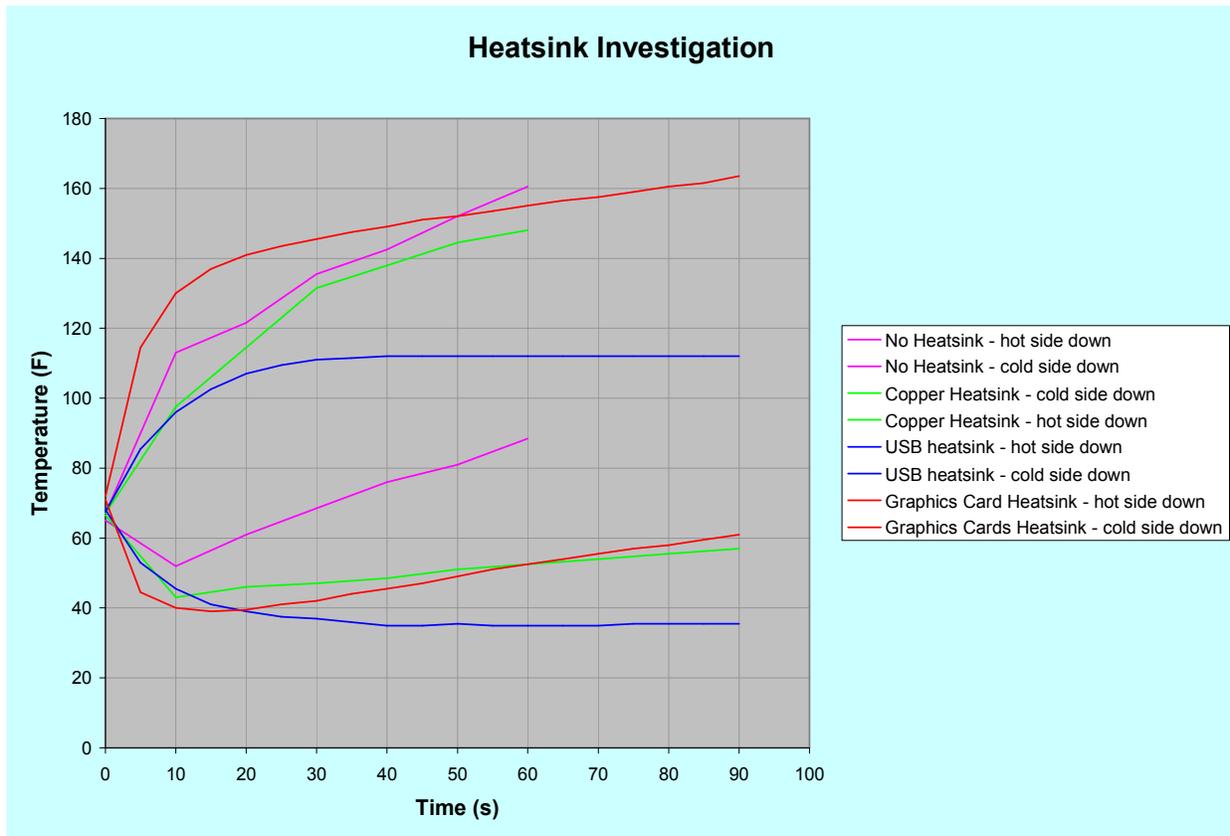
Once the PLC “decides” the proper course of action, it sends a signal to the appropriate relay. This turns on the relay and allows AC to flow into the power adapter for the needed application (heating or cooling). Once the relay is on, the power adapter will output the required power to the blanket. The current will flow through a diode and through the TEMs in the blanket. It then returns to the power supply where it needs to go around the safety diode that limits flow from the other supply when it is on. In order to achieve this, a switch is turned on by the PLC during this power supplies time of operation to create a complete circuit from the power supply to the blanket. While one power supply is on, its switch to bypass the diode is closed, and the other switch to bypass the other power supplies diode is open. Hence, no current will be allowed to flow into the other power supply and therefore the power supplies will not short each other out.

Once the PLC begins the heating or cooling process of the blanket, all of the control is turned over to the code, which establishes when to turn the heating and cooling on and off and uses a basic timing algorithm to level out the heating and cooling curves and makes the process as smooth as possible. Once the person is at the required temperature, the blanket turns off and on to keep them at that temperature for as long as is necessary. At this point the patient will stabilize to an appropriate core body temperature.

## Data Analysis

### Heatsink investigation

We opted to use heatsinks to increase the differential of the temperatures between each side of the TEMs. By increasing the differential, we could cool the patient-side of the blanket and draw away the energy generated on the opposite side of the TEM so that the temperature will have less of an impact on the properties of the TEM.



**Figure 1: Heatsink Investigation**

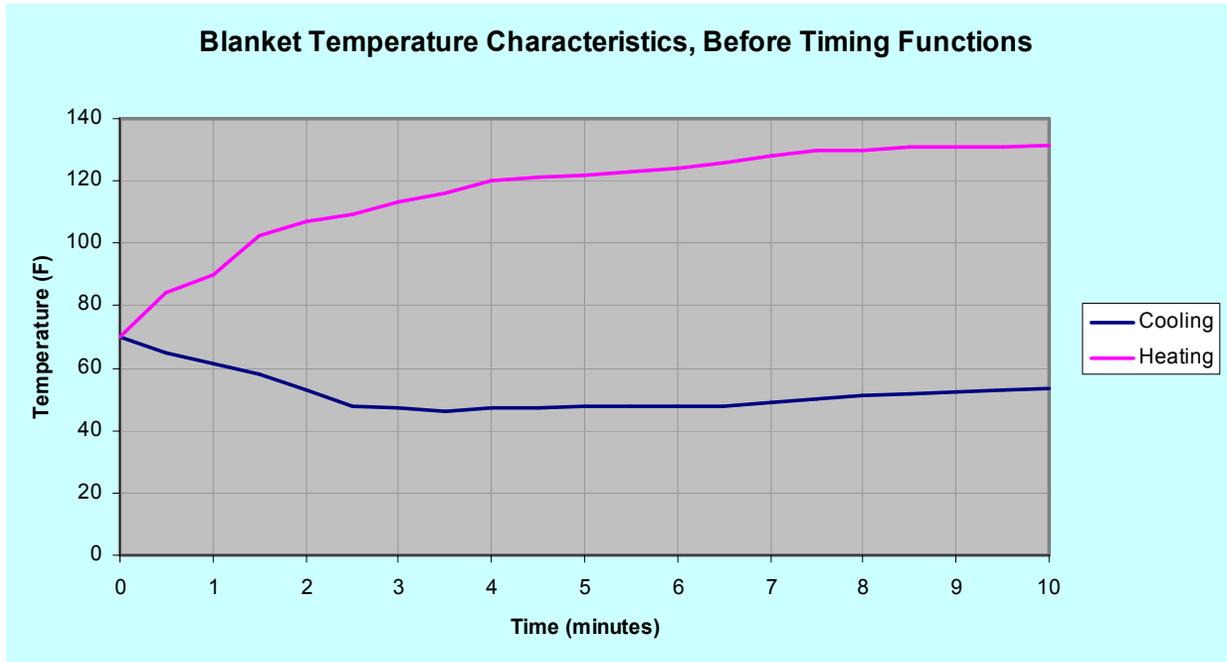
While cooling without a heatsink, the TEMs were not able to maintain their cooling properties after a short period of time because the opposite side would heat and the heat would not have anyplace to dissipate. Therefore, we experimented with various heatsinks to dissipate the heat produced on the non-patient side of the TEM and to absorb the cold produced on the non-patient side of the TEM as well when heating a patient. We proceeded by testing each heatsink, characterizing their properties for better understanding of their operation with the TEMs. The heatsinks we used included copper sheeting to serve as a heatsink, a PC card heatsink, and an aluminum heatsink.

The copper sheet and PC card heatsinks showed satisfactory heating properties but suffered in regards to cooling. The minimum temperature, about 40°F, would be reached after a brief moment, but then the temperature of the TEM would gradually increase, thus displaying poor cooling properties, but still significantly better than TEMs without heatsinks. The aluminum heatsink was able to help the TEMs maintain a low temperature around 40°F over an extended period of time without compromising the cooling properties. As for heating with the aluminum heatsinks, the TEMs were able to maintain a high temperature over an extended period of time.

After characterizing the heatsinks, we concluded that the aluminum heatsink was the optimal one to use for our purposes. As previously stated, the aluminum heatsinks allowed the TEMs to maintain their high and low temperatures over extended periods of time, thus meeting our criterion.

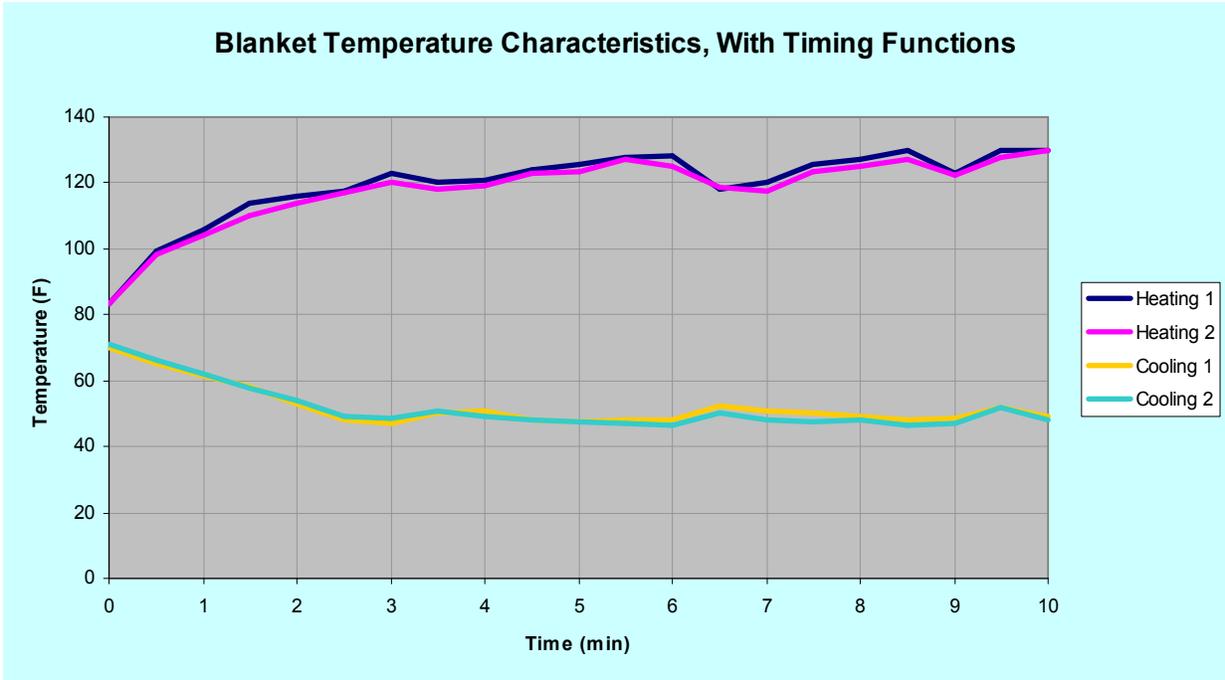
# Actual Blanket Temperature

The highest temperature to safely heat a patient is 110°F but over time, the blanket would exceed this temperature. Our method for counteracting this effect was to add timing functions to the code in order to stabilize the maximum and minimum temperatures.



**Figure 2: Blanket Temperature Characteristics, Without Timing Functions**

Without the timing functions, the maximum temperature of the blanket would drift higher. The blanket would also begin to slightly drift higher away from the minimum temperature that we desired because the heatsink would heat the blanket. With the timing functions implemented in the software, the TEMs would be shut off, thus allowing the heatsink to lose heat when the patient side of the TEM resumes cooling. The heatsink would be able to absorb more heat from the non-patient side of the TEM, in effect stabilizing the minimum temperature of the blanket.

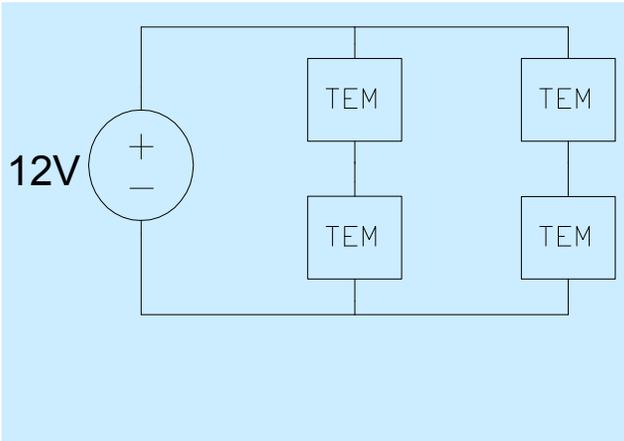


**Figure 3: Blanket Temperature Characteristics, With Timing Functions**

## Power Requirements

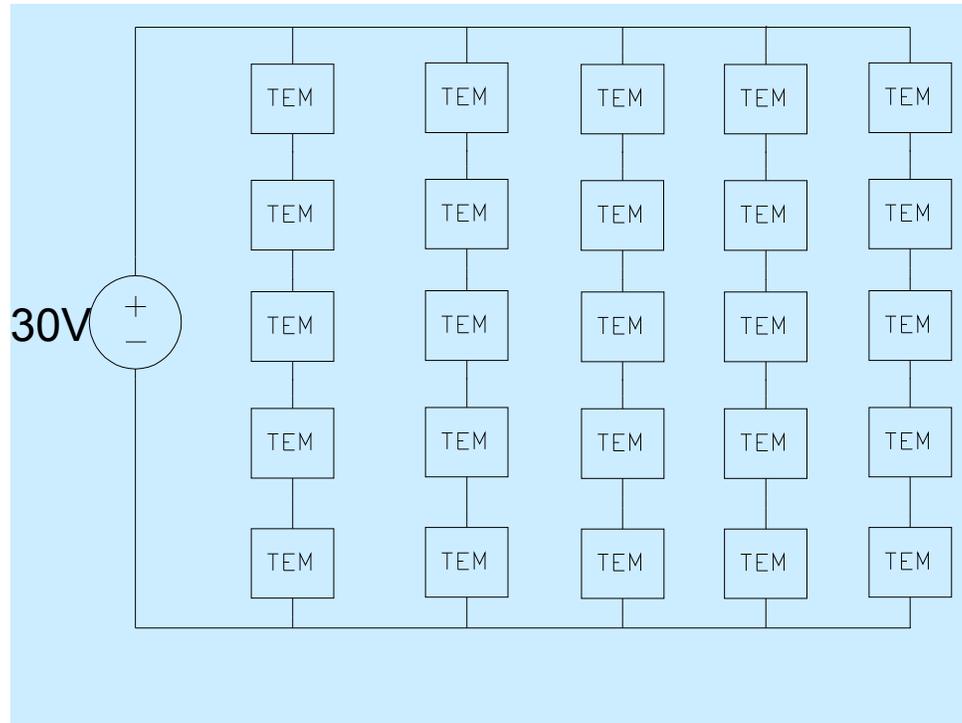
Primarily, the TABS prototype uses 60 watts of power harnessed through 3 AC-DC voltage sources;  $12\text{v} \times 5\text{ amps} = 60\text{ watts}$ . Two voltage sources, which run at 12 volts and a maximum of 5 amps, are used to power the heating/cooling regulation of the blanket while the voltage source to power the PLC runs at 12 volts and a maximum of 2 amps. Our final design using a 25 TEM configuration would need about 300 watts of power;  $30\text{v} \times 10\text{ amps} = 300\text{ watts}$ . This power usage for our final design is on par with the power usage of refrigerators.

The optimal design for our prototype uses a 4 TEM configuration shown in Figure 4.



**Figure 4: Prototype TEM Configuration**

Each TEM has a resistance of  $2.5 \Omega$  at normal operating temperature and tends to increase as temperature increases, causing a smaller current and resultant power draw. The TEM configuration for our final design has 5 TEMs in parallel with 5 TEMs in series as seen in the diagram below.



**Figure 5: Final Product TEM Configuration**

If the TEMs were instead connected all in series, there would be a significant increase in power draw of about 33 percent. So, this parallel/series configuration was chosen as an optimal design. This final TEM configuration would provide a heating/cooling cover of about a 4 foot by 2 foot area, regulating temperature by interfacing on the core or torso of the patient.

## Protecting the Patient

TABS has many features to ensure the safety of the patient amidst the heating/cooling process. Primarily, the heating and cooling behavior is done through a gradual change rather than a sudden abrupt change. This helps ensure that the patient is not brought into shock by an extreme temperature shift. By adding a timing function where the controller allows for heating/cooling for three minutes, turns off for thirty seconds and repeats, this not only allows for a gradual temperature change, but helps the heatsink dissipate stored energy with less strain. The timing of the regulation, three minutes on then thirty seconds off, was tested to be the optimal control and interval time.

Further measures to protect the patient were also taken in the software. For example, if the condition exists where the blanket temperature sensor goes above 110 degrees Fahrenheit or the sensor gets disconnected, the heating/cooling activity will automatically stop, protecting the safety of the patient. Aside from these software checks, there were also limits on entering the set-

point manually. These limits, 110°F upper and 50°F lower, (11) protect the patient's safety should a user try and enter a set-point that is too high or low.

In selecting mechanical features of the actual blanket components, safety was considered to be of the up-most importance. For example, the cloth covering was made of a porous material that allows for maximum air flow, with the heatsink in mind, and also provides an optimal interface between the patient and the clay pack to allow for gradual and comfortable temperature (energy) transfer. If there was no cloth covering, the clay pack would potentially be exposed directly to the patient's skin, which would not only be uncomfortable, but unhygienic; the covering can be washed on a per patient basis. A final step in ensuring the safety of the patient can be seen in the design of the TEM. By encasing these modules in RTV Silicon sealant, possible TEM corrosion due to condensation (in cooling) is minimized. Also, this step protects TABS from the consequences of spilling water on the device and possibly producing a short circuit or electrical failure. These steps help to make the TAB system reliable for the safety of the patient, which is of primary importance for our design.

## Lifetime

The lifetime of the TABS final product is based upon three main factors. The first and most important is the TEMs. The lifetime of a thermoelectric module is indefinite as long as the TEM is not put under any undue stress. The TEMs are protected from power surges with fuses in the control system and they are protected from corrosion from condensation by being sealed by Silicone Sealant. This means that the only cause for failure of a TEM is if it were to be bent, removing any of the solder joints (5). In order to make this not possible, the TEMs are sturdily attached between the heatsink and an aluminum plate so that it is not possible for them to be put under any stress.

The next factor affecting the lifetime of the system is that of the power supplies that power the blanket and PLC. The power supplies used are rated for 60,000 hours (12) of full load usage. This comes to a lifetime of approximately 40 years if the blanket is used on average for 4 hours a day. The power supplies, like the TEMs, are protected from surges with replaceable fuses inside the control system.

The last factor that effects the lifetime of the product is the clay packs. The clay packs have a lifetime of 7 years, after which they cannot be guaranteed to replicate the same heating and cooling properties as originally advertised. It is due to this factor that the blanket portion of the system can be replaced separately from the entire system.

The cloth encasement will wear over time, but since the blankets inner workings can be removed from the cloth covering, it can easily be separately replaced and/or washed. The PLCs lifetime is indefinite as well and it is protected from surges by fuses in the control system as well.

Due to the lengthy lifetime of this product's components, if marketed, the product could be sold with a lifetime guarantee and the only replacement needs would be the cloth covering and a rare clay pack replacement.

# Design Comparison

TABS has many advantages compared to current blanket temperature regulation (BTR) designs on the market in such categories as cost, total bulk, and general system design. The following will provide a comparison of our system versus current BTR units, highlighting the pros and cons of our system.

A primary feature of our system allows for minimal patient monitoring while in operation. Because our blanket self-regulates temperature based on user inputs, the nurse or attendant to the hyperthermic/hypothermic patient is allowed to tend to other patients without having to worry that the patient is reaching an extreme hot or cold temperature, potentially causing further physical ailments. Many BTR models only do either heating or cooling, like the Bair Hugger or the FAW 750, and thus require regular attention from a nurse or staff member. Although there are a select number of models on the market today which regulate the patient's temperature, including the Medi-therm III, our system offers many other benefits that these systems cannot offer. One such example is a relatively low and affordable price.

Current BTR units can range anywhere from \$5,000 to \$10,000, putting a fairly large strain on hospitals. Examples of this include the Medi-therm II and III systems which cost \$9,500 and \$6,200 respectively; this does not include the cost of blankets. Systems which only deal with hyperthermia or hypothermia, like the Bair Hugger or the FAW 750, start off at \$1,000 and progressively get more expensive. Our design in mass production, which executes both heating and cooling activities, would cost only about \$923. This is a savings of about 88% versus current designs which conduct bidirectional BTR. This would be a savings which cannot be ignored, and adds yet another advantage to the TABS.

Because our system does not require constant air or water flow, this proves to be yet another advantage over our competitors. Our system has no moving parts which could break or require maintenance over time because we use the unique peltier electrical effect and corresponding TEM configuration. Having no moving parts not only means less maintenance, but also a longer life than the normal system because of a smaller probability of failure. This factor combined with the precision temperature control allotted to our system makes for a very attractive alternative to air and water BTR treatments.

A simultaneous pro and con of our system would be its weight. The drawbacks will be examined first. The estimated weight of our final blanket design would be about 21 pounds; this is mainly due to the inflexible heatsinks incorporated in our design to dissipate the resultant energy of our system. Although this weight is fairly high, on a full sized adult, this weight would be spread across the patient's torso causing minimal discomfort; the patient would more than likely be in a critical hyperthermic or hypothermic condition anyway, and may be rendered incapacitated, causing the blanket to be the least of their worries. This weight, undoubtedly, is unacceptable in dealing with infants and new-born babies. With this being said, further prototypes would be designed to be lighter and more flexible, perhaps incorporating copper sheeting as heatsinks, to dissolve concerns of blanket weight.

Even though the weight of the blanket is fairly large, the total system weight is small compared to current refrigerator-like bidirectional BTR designs. For example, the Medi-therm III weighs in at 141 pounds and has to be wheeled around, undoubtedly using elevators to gain access to various levels in a health facility. With our compact controller piece and blanket, a weight of about 25 pounds for the total system makes our design on par with systems that only do either a heat or cool function. TABS, being compact, also frees up valuable hospital space for other

equipment. This design provides for an optimal storability and portability option scarce in current BTR systems.

Our design displays many improvements over current systems in aspects including price, portability, temperature regulation and limited maintenance. The main drawback, blanket weight, could be reduced in further prototypes using more efficient temperature regulation and heat dissipation properties. By using the Peltier Effect, our unique and innovative prototype stands as a building block in which future BTR systems could be based. As the TABS currently stands, however, it offers a never before seen degree of versatility, architecture and design which opens a whole new world for BTR systems.

# Design and Implementation

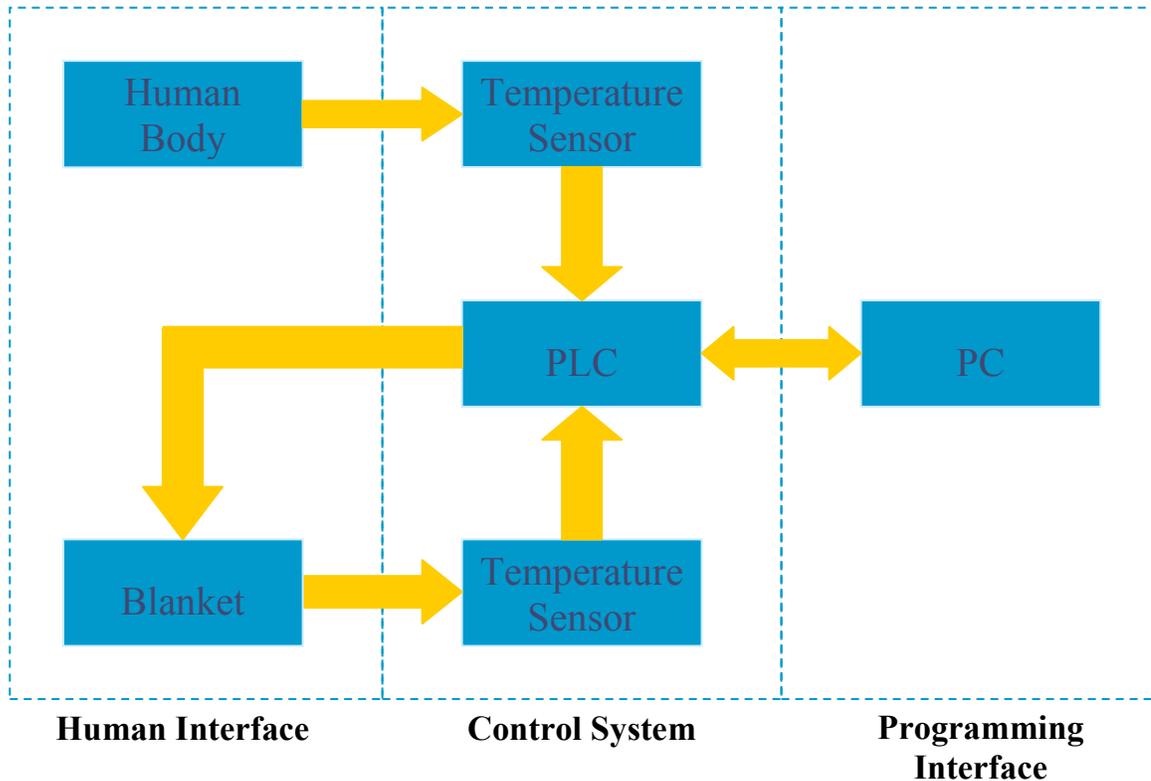


Figure 6: System Configuration

## Hardware

### Blanket

TEM: Thermoelectric Module, or the heating and cooling pad.

Heat-sink: Absorbs energy to counteract patient side of TEM.

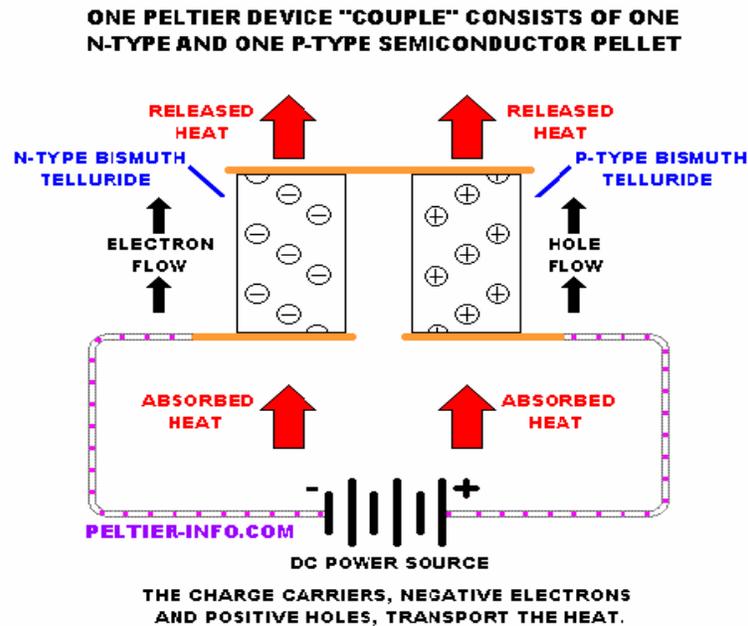
Clay-based pack: Stores energy for gradual changes in temperature on patient side.

Cloth covering: Encases the components, made from porous material that allows air flow.

### Thermoelectric Modules

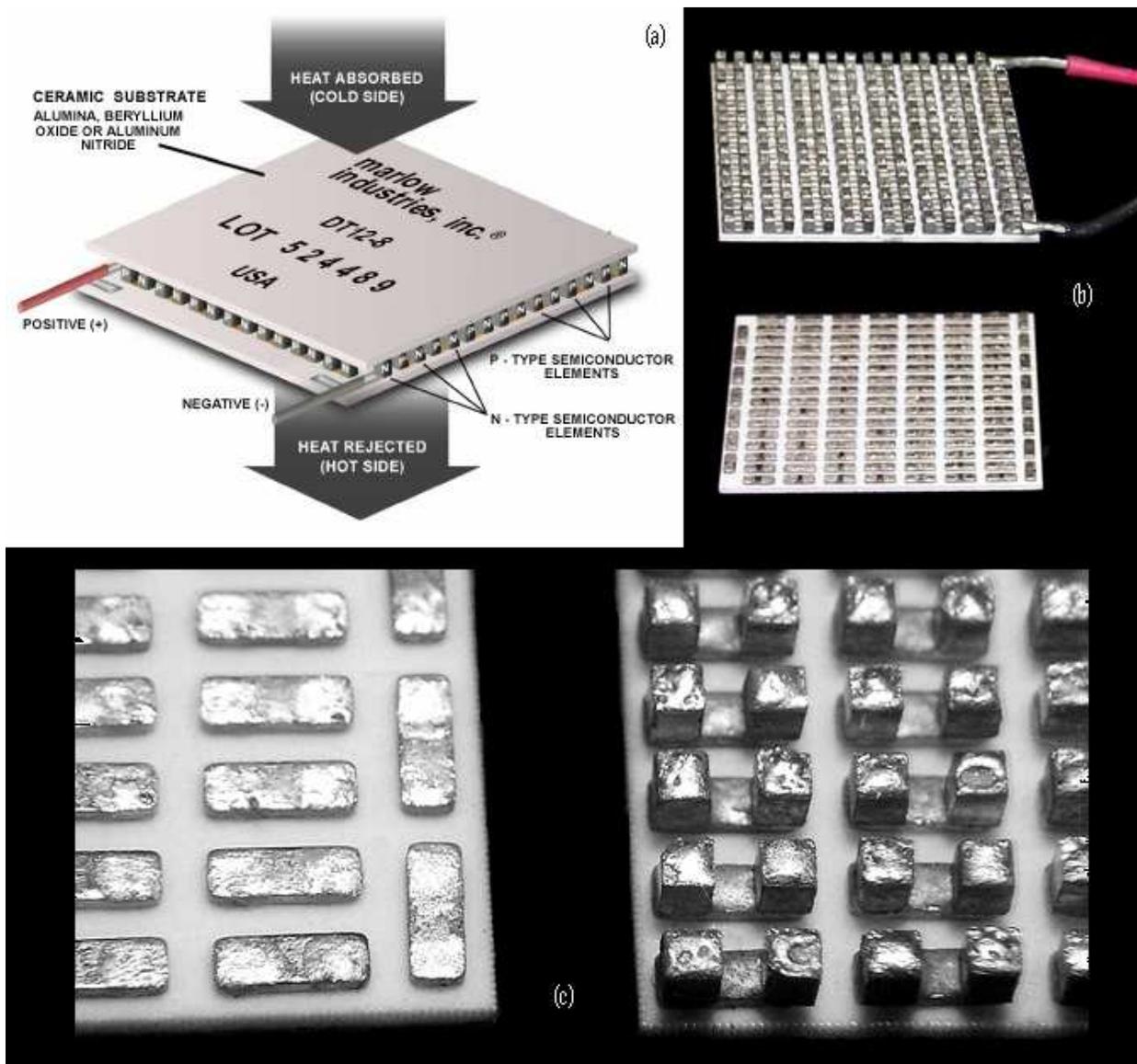
The thermoelectric modules (TEMs) used in the blanket portion of our system utilize a phenomenon known as the Peltier Effect. The basis for this effect is that when a current is applied across two conductors, there is a heating/cooling effect (5). This heating/cooling effect occurs due to the heat being transferred along with the flow of electrons and holes through the

conductors. The TEMs consist of two ceramic plates with an array of small Bismuth Telluride Cubes between them. The cubes are arranged in an alternating pattern of N and P type doped cubes, electrically in series and thermally in parallel, and when a current is applied across the entire array, heat is moved from one side of the device to the other creating a “hot” and a “cold” side (5). The thermal capacity of the TEM is proportional to the current applied across the device and the number of cubes in the array.



**Figure 7: Peltier Effect**

Figure 7 shows the process of utilizing the Peltier Effect. The DC power source applies a current clockwise around the circuit and because the left cube of Bismuth Telluride is N-type doped it transfers heat along the path of electrons. The other cube is P-type doped and therefore transfers heat along the path that the holes are traveling in. This creates a “hot” side on top of the device and a “cold” side on the bottom of the device. Each TEM is a few millimeters thick and can range from a few millimeters to a couple of centimeters squared (5).



**Figure 8: Thermoelectric Modules (TEMs)**

Figure 8(a) shows a TEM or Peltier Pad and the wires that create the series electrical connection between the the cubes. Figure 8(b) is a picture of a TEM that has been taken apart, showing the array of N and P-type doped Bismuth Telluride cubes. Figure 8(c) is a close-up of the array of cubes between the two ceramic plates.

The advantages of TEMs are that they require a simple DC current to operate, contain no moving parts and hence do not require maintenance, do not cause any vibration, do not require any freon refrigerant, do not produce noise, are very small, have a long lifetime, and can be used to precisely control temperature by amount of current supplied (5). The disadvantages of the TEMs is that they are not very efficient and hence require a large amount of power, are susceptible to corrosion do to condensation during cooling, and have limited flexibility. The corrosion issue can be solved by sealing the TEM in a paste of RTV Silicone Sealant or Polyamide Epoxy Sealant. The limited flexibility is due to the soldering of the Bismuth Telluride cubes into the array between the ceramic plates. If the solder joints are broken when

the TEM is bent, it will break the electrical series connection and cause the TEM to fail (5). The main disadvantage of TEMs is their low efficiency. They have an efficiency of approximately ten percent; this is the reason that they require so much power in order to have significant heating and cooling properties. The lack of efficiency, however, is offset by the numerous advantages and the efficiency is constantly being improved (5).

The factor that controls the efficiency of the TEMs is known as the “Figure of Merit” (ZT). This factor follows the relationship:

$$ZT = (a^2/kr) T$$

$T$  is the temperature difference between the “hot” and the “cold” sides of the device,  $a$  is the Seebeck coefficient,  $k$  is the thermal conductivity and  $r$  is the resistivity or electrical conductivity. In order to achieve a high Figure of Merit (more efficient device), a high Seebeck coefficient, small thermal conductivity, and a high electrical conductivity (low resistivity) are needed. The issue is that these three factors, seebeck coefficient, thermal conductivity, and resistivity are connected in such a way that improving one tends to lower another. New methods to improve the Figure of Merit are being investigated (5).

One way to improve the Figure of Merit of TEMs is to vacuum seal them. Vacuum sealing the TEM lowers the thermal conductivity and raises the electrical conductivity which raises the Figure of Merit. There is still a need for large amounts of power though and even more investigation into the efficiency is needed. There have been significant advancements in the field of Quantum Dots that promise vast improvements for the thermoelectric cooler efficiency issue. Creating low-dimensional systems composed of custom tailored quantum dots raises the electrical conduction of the device while lowering the thermal conduction which lowers inefficient waste heat. These new TEMs are utilizing the nanometer scale and are able to overcome the limitations of traditional thermoelectric devices like Beryllium Telluride Cubes (5).

## Controller

- Horner PLC OCS Controller: Programmable Logic Controller used with 2 temperature analog inputs, with 2 digital outputs to switch the relays on or off. The front screen and keypad are user friendly and allow user input to set parameters for heating and cooling the patient.
- 12 Volt, 5 Amp power supplies: 1 flows current in the positive direction to the blanket when turned on, the other flows current in the negative direction to the blanket when turned on. \*\*\*Neither can be turned on at the same time, handled in software.
- 12 Volt, 2 Amp power supply: Powers the PLC as well as the digital outputs of the controller to turn the relays on one at a time.
- Solid State Relays: Turn the two 5-amp power supplies on, one at a time according to the digital output of the PLC.
- 8 Amp Fuses: Used for safety, in case of a surge of energy, or in the case where both relays were to turn on at the same time shorting the power supplies.
- 6 Amp Diodes: Used to protect the power supply not being powered from receiving a current into its output from the power supply switched on.

- Temperature Probes
  - Rectal (Patient): most accurate medical way to read patient's core body temperature.
  - Thermocouple (Blanket): J thermocouple attached to interior of the blanket to read the blanket's temperature at all time.

## Size and Weight

The size of the TABS system will be 25 inches by 50 inches. 25 inches is equal to the average width of a patient and 50 inches is the length from a 6 foot mans shoulder to his knees. This is large enough to accurately and efficiently heat and cool any variation of body size. The size of this blanket is comparable to the other heating/cooling blankets available and is more than sufficient to heat and cool a patient until they reach a desirable core body temperature.

The weight of the blanket is a larger issue. Due to the use of heatsinks in TABS, the blanket weighs a significant amount. The prototype weighed approximately 3.33 pounds and a full blanket would weigh in the range of 20 to 25 pounds. This means that the blanket will not be very comfortable. Other blankets that offer the ability to heat and cool (water pumped systems) are relatively heavy as well. The difference is that the weight of water pumped systems is in the water, not metal heatsinks. This makes the water pumped systems inherently more comfortable, but they lack all the other advantages of the TABS system. Options to reduce the weight and comfort issue are alternate heatsinks. One such idea is a flexible heatsink that is spread throughout the entire blanket and acts as the heatsink for all the TEMs, for example a thin copper sheet. This would reduce the weight of the blanket, and make it more comfortable. In the future when larger TEMs are available, an option to increase the size of each "mini" blanket that makes up the blanket could be available and then a thin sheet heatsink for each section could be utilized and this would offer the same quilt like option with less weight and better heat dissipation with separate heatsinks per TEM. Because the TEMs are lightweight and small, the main factor in weight that needs to be improved is the heatsinks.

## Software

### User Interface

The user interface available on TABS, via the PLC, has two main modes of operation; these include manual and automatic mode. Manual mode allows the user to manually enter a set-point temperature which the nurse or health official wishes the patient to achieve. The temperature range allowed to be entered manually has been programmed to only allow temperatures between 50°F and 110°F (11). This safety feature ensures that the patient's set-point exist within a normal range. Manual mode ensures optimal temperature configuration on a per patient basis giving the health care professional a flexible option of a custom temperature regulation setting. The other mode allowed by the PLC is automatic mode. In this mode, the user selects the age of the patient, and the system automatically enables a pre-established set-point

temperature for the individual. The list of ages and their corresponding temperatures can be seen below:

Age	Normal Body Temperatures ( $\pm 1^{\circ}\text{F}$ )
0-3 Months	99.4 $^{\circ}\text{F}$
3-6 Months	99.5 $^{\circ}\text{F}$
6 Months -1 Year	99.7 $^{\circ}\text{F}$
1-3 Years	99.0 $^{\circ}\text{F}$
3-5 Years	98.6 $^{\circ}\text{F}$
5-9 Years	98.3 $^{\circ}\text{F}$
9-13 Years	98.0 $^{\circ}\text{F}$
>13 Years	98.6 $^{\circ}\text{F}$

**Table 2: Normal Core Body Temperatures**

Automatic mode gives the health care professional another option in choosing the set-point and conveniently regulates the temperature for individuals in all stages of life based on their age. This can help to take the guess work out of setting an optimal temperature, especially if the patient is a child; more than half of the set-points in this mode are specific for babies, toddlers and children. Please note that while in either mode, the health care professional can view and change the current set-point with a few pushes of a button.

## Code Specifics

Cscape ladder logic was used with the Horner XLE 105 PLC. The software is free with the PLC, and is specifically given for use with any Horner PLC. Ladder logic is a method of drawing electrical logic schematics horizontally and vertically.

Below you will find an example of our pseudo code for our heating timing function. Below the pseudo-code is the implemented version of the heating timing function using ladder logic run on the PLC. Full version of the pseudo-code showing all algorithms and error controls is shown in the Pseudo-code Appendix. A full screen shot of Cscape Ladder Logic showing all algorithms and error control logic is shown in the Ladder Logic Appendix.

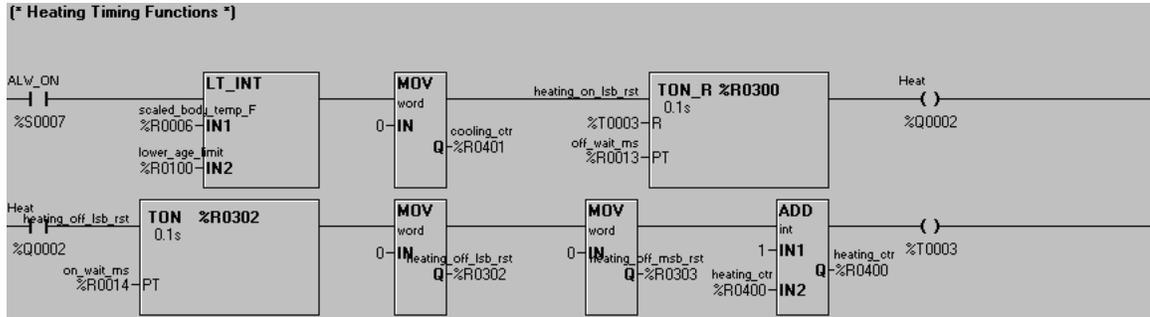
- Example of pseudo code:

### //Heating Timing Function

```
If scaled_body_temp_value_F < lower_age_limit
    cooling_ctr = 0
    wait 30 seconds
        heating off
    end wait
    heating on
    wait 3 minutes
    end wait
```

heater\_ctr = heater\_ctr + 1  
end if

- Example of Cscape Ladder Logic:



**Figure 9: Code Example**

# Cost Analysis

The cost of the TABS prototype was approximately \$700. This price represents the cost of all of the materials present in the final prototype and not the cost of the materials that were eventually not used. If a full size blanket were to be produced using the same materials as those used in the prototype, the cost would amount to \$ 1,657. One third of that cost is due to the controller and the other two thirds is the cost of the blanket. If one were to mass produce TABS, the cost of a full blanket would fall to \$923. The cost of the controller in a mass produced blanket would rise to about 40% of the total amount with the cost of the blanket falling to 60%. The controller would cost \$381 and the blanket would cost \$541. Mass producing TABS offers a 45% improvement in the cost over the system cost with prototype components.

In comparison with the price of competitor systems, TABS is extremely cheap. A mass produced system offers an 87% cost improvement over the \$7500 competitor option. Breaking the system cost into two separate sections offers a significant improvement over competitor prices as well, because if any part of the system needs to be replaced during its lifetime, the system can be sold as a separate blanket, or a controller. The competition offers a single system at eight times the price that can only be purchased as one single unit and does not offer the same functionality as TABS.

Prototype Cost					
QTY	Decription	Manufacturer	Cost	Shipping	Total Price
<b>Controller</b>					
1	PLC	Horner	332.5	\$0.00	\$332.50
1	4 Pack Of Fuses	Radioshack	\$1.99	\$0.00	\$1.99
1	2 Fuse Holders	Radioshack	\$1.99	\$0.00	\$1.99
1	12V 3Amp	12vadapters.com	\$14.99	\$5.99	\$20.98
2	12 Screw Terminal	Radioshack	\$3.45	\$0.00	\$10.35
2	12V 5amp	Ituner Networks	\$24.95	\$7.70	\$57.60
1	Controller Enclosure	In - House	\$23.00	\$0.00	\$23.00
1	Misc Wires	In - House	\$10.00	\$0.00	\$10.00
Controller SubTotal:					\$458.41
<b>Blanket</b>					
4	2X2 TEM	Melcor	\$19.50	\$8.50	\$86.50
2	Clay Packs	ThermaPaq	\$20.64	\$0.00	\$41.28
4	Heatsink	Alpha Novatech	\$16.30	\$11.00	\$76.20
1	Hardening Grease	Artic Silver	\$10.99	\$4.99	\$15.98
4	3X3 Aluminum Plate	In - House	\$4.00	\$0.00	\$16.00
Blanket SubTotal:					\$235.96

**Total Costs:** \$694.37

**Table 3: Prototype Cost**

<b>Single System Cost</b>					
<b>QTY</b>	<b>Decription</b>	<b>Manufacturer</b>	<b>Cost</b>	<b>Shipping</b>	<b>Total Price</b>
<b>Controller</b>					
1	PLC	Horner	\$332.50	\$0.00	\$332.50
1	4 Pack Of Fuses	Radioshack	\$1.99	\$0.00	\$1.99
1	2 Fuse Holders	Radioshack	\$1.99	\$0.00	\$1.99
2	30V 10Amp	PowerSuppliesDepot.com	\$48.99	\$5.99	\$103.97
2	12 Screw Terminal	Radioshack	\$3.45	\$0.00	\$6.90
1	12V 3amp	Ituner Networks	\$14.99	\$7.70	\$22.69
1	Controller Enclosure	In - House	\$23.00	\$0.00	\$23.00
1	Misc Wires	In - House	\$10.00	\$0.00	\$10.00
Controller SubTotal:					\$503.04
<b>Blanket</b>					
25	2X2 TEM	Melcor	\$19.50	\$8.50	\$496.00
6	Clay Packs	ThermaPaq	\$20.64	\$0.00	\$123.84
25	Heatsink	Alpha Novatech	\$16.30	\$11.00	\$418.50
1	Hardening Grease	Artic Silver	\$10.99	\$4.99	\$15.98
25	3X3 Aluminum Plate	In - House	\$4.00	\$0.00	\$100.00
Blanket SubTotal:					\$1,154.32

**Total Costs:** \$1,657.36

**Table 4: Final Product Cost**

## Mass Production Of System (QTY:50)

QTY	Decription	Manufacturer	Cost	Shipping	Total Price	Single Price
<b>Controller</b>						
50	PLC	Horner	\$250.00	\$150.00	\$12,650.00	\$253.00
100	12 Screw Terminal	Radioshack	\$2.00	\$0.00	\$200.00	\$4.00
25	4 Pack Of Fuses	Radioshack	\$1.00	\$0.00	\$25.00	\$0.50
50	2 Fuse Holders	Radioshack	\$1.00	\$0.00	\$50.00	\$1.00
100	30V 10Amp	PowerSuppliesDepot.com	\$35.00	\$150.00	\$3,650.00	\$73.00
50	12V 3amp	Ituner Networks	\$12.00	\$75.00	\$675.00	\$13.50
100	Controller Enclosure	In - House	\$18.00	\$0.00	\$1,800.00	\$36.00
1	Misc Wires	In - House	\$10.00	\$0.00	\$10.00	\$0.20
Controller SubTotal:					\$19,060.00	\$381.20
<b>Blanket</b>						
1250	2X2 TEM	Melcor	\$12.00	\$125.00	\$15,125.00	\$302.50
300	Clay Packs	ThermaPaq	\$8.00	\$0.00	\$2,400.00	\$48.00
1250	Heatsink	Alpha Novatech	\$5.00	\$125.00	\$6,375.00	\$127.50
5	Hardening Grease	Artic Silver	\$8.00	\$25.00	\$65.00	\$1.30
1250	3X3 Aluminum Plate	In - House	\$2.50	\$0.00	\$3,125.00	\$62.50
Blanket SubTotal:					\$27,090.00	\$541.80

<b>Total Costs:</b>	\$46,150.00	\$923.00
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<b>Current Mass Produced System:</b>	\$375,000.00	\$7,500.00
<b>Our Mass Produced System:</b>	\$46,150.00	\$923.00
<b>Savings Difference:</b>	\$328,850.00	\$6,577.00

**Table 5: Mass Produced Final Product**

# Customer Survey

To better gauge our target market's perspective on our product, we used a brief survey consisting of five questions we believed to be most relevant in illustrating a medical personnel's awareness and demand. We passed the survey to 80 personnel, including those in charge of finances, doctors, and nurses, and tallied the results. Although we tried as best we could to distribute the surveys equally across a wide spectrum of occupations, we were left to settle with a great majority of nurses, and a minority of doctors and financial individuals.

To assess whether medical personnel were already familiar with products similar to ours, we asked in our first question, "Have you heard of and/or seen a product like this before?", having already referred to the functionality of the product at the heading of the page. The answer to this question was approximately split, with 52.5% of respondents stating they were unfamiliar with such a product, or products. This, we felt, was somewhat disconcerting, since we were not exactly positive of the reasoning that half of the respondents had chosen to ignore purchasing similar products. We concluded, since reasoning was not asked within the survey itself, that their logic was similar to ours when we chose to initially create the product. The price was excessively steep for any hospitals' budget and difficult to maneuver around different areas of the building. This was apparent from the results of our next question.

Our next question dealt with the importance of our product to health care facilities. On a scale from one to five, one being "not important at all" and five being "extremely important", we averaged our results to obtain 4.2, verifying our assumption from the first question. Since the majority of respondents, 68%, replied to our last question, the price they would be willing to pay, circling the range \$1,000-5,000, this again confirmed our theory. It was quite obvious from this result that there will be a strong market for our product.

The third and fourth questions were actually rather surprising for us, as we were solely attempting to determine whether our product would garner enthusiasm for widespread sale. In our third question, 92.5% of respondents felt as though our blanket should be available to the general public, or for use in their home. On a scale from one to five, five being "extremely likely", this question averaged 4.8. From these results, we felt as though our target market was much larger than originally thought.

# Future Improvements

The future improvements on TABS fall into 6 topics; Cost, Portability, Safety, Efficiency, Comfort, and functionality. The most important improvements are in the fields of comfort and efficiency. The PLC that the system uses has much more functionality than required and so a simpler version would help lower the cost of the final product and the size and weight of the system section of the final product. Another way to lower the cost and size is to fabricate the circuit on a PCB instead of at the device level. Currently our system is bulky because each circuit component is large and heavy. Another way to lower the cost would be to buy the components used in the system in bulk. In order to increase the safety of the product, more error detection and robustness must be added into the code to handle every possible situation that could occur.

The efficiency of the blanket can be improved by improving the heatsinks, sealing the system, and using the TEMs to help power themselves. The heatsinks are the largest factor in the lack of efficiency. Improving the thermal properties of the heatsinks would directly improve the heating and cooling of the blanket and increase the efficiency. Vacuum sealing the TEMs would increase the electrical conductivity and hence create a more efficient device.

The temperature from the TEMs during their heating and cooling cycles can be used to power other TEMs by harnessing a phenomenon called the Seebeck Effect. The Seebeck Effect is the opposite the Peltier Effect in that instead of applying a voltage and getting heat transfer, the Seebeck Effect creates a voltage when there is a temperature difference across a conductor (5). By stacking the TEMs and only powering one half of them and then using the voltage generated by their heat to help power the ones that are being used, the efficiency of the system can be increased. This system would not be able to power the TEMs by itself, but it would be able to take a little of the strain off of the power supplies and hence increase the efficiency and provide more heating/cooling per watt of power supplied to the blanket (5). Because these added TEMs would not require heatsinks, there would not be a significant increase in the weight of the blanket because the TEMs are relatively small and lightweight.

An aspect of functionality that could be improved in the future would be to add a heart-rate monitor to make sure that the patient is reacting appropriately to the heating or cooling process. It could sound an alarm if the patient were to go into shock due to being heated or cooled too rapidly and would offer another safety feature to the system.

# Appendix

## Pseudo-code

### //Start Screen

Select Set by Age

    Go to Age case screens/statements

Select manually set

    Go to set-point screen

### //Temperature Input Values

scaled\_body\_temp\_value\_C = [(unscaled\_body\_temperature\_value)/20]

    scaled\_body\_temp\_value\_F = [((scaled\_body\_temp\_value\_C)(9/5)) + 32]

scaled\_blanket\_temp\_value\_C = [(unscaled\_blanket\_temperature\_value)/20]

    scaled\_blanket\_temp\_value\_F = [((scaled\_blanket\_temp\_value\_C)(9/5)) + 32]

### //Blanket overheating control

If scaled\_blanket\_temp\_value\_F >= 130

    heating\_on\_lsb\_rst = 0

    heating\_on\_msb\_rst = 0

end if

### //Blanket Disconnection Detection

If scaled\_body\_temp\_value\_F >= lower\_age\_limit

    If scaled\_blanket\_temp\_value\_F <= upper\_age\_limit

        heating\_ctr = 0

        cooling\_ctr = 0

    end if

end if

disconnection\_error\_value = heating\_ctr + cooling\_ctr

If disconnection\_error\_value > 25

//25 because the run cycle for heating and cooling is 3 minutes, so doing that 25 times = //75 minutes without changing the blanket temperature means there is a bad connection //somewhere.

    Display “[Error Code A0001] see manual, then click top left corner”

### //Heating Timing Function

If scaled\_body\_temp\_value\_F < lower\_age\_limit

    cooling\_ctr = 0

    wait 30 seconds

        heating off

    end wait

        heating on

        wait 3 minutes

```
        end wait
        heater_ctr = heater_ctr + 1
    end if
```

### //Cooling Timing Function

```
    If scaled_body_temp_value_F > upper_age_limit
        heating_ctr = 0
        wait 30 seconds
            cooling off
        end wait
        cooling on
        wait 3 minutes
        end wait
        cooling_ctr = cooling_ctr + 1
    end if
```

### //Age Temperature Limits Case Statement

```
    Case1: 0-3 Months
        lower_age_limit = 98 F
        upper_age_limit = 100 F
    Case2: 3-6 Months
        lower_age_limit = 99 F
        upper_age_limit = 101 F
    Case3: 6 Months – 1 Year
        lower_age_limit = 99 F
        upper_age_limit = 101 F
    Case4: 1-3 Years
        lower_age_limit = 98 F
        upper_age_limit = 100 F
    Case5: 3-5 Years
        lower_age_limit = 98 F
        upper_age_limit = 100 F
    Case6: 5-9 Years
        lower_age_limit = 97 F
        upper_age_limit = 99 F
    Case7: 9-13 Years
        lower_age_limit = 97 F
        upper_age_limit = 99 F
    Case8: 13+ Years
        lower_age_limit = 98 F
        upper_age_limit = 100 F
```

# Ladder Logic

(\* April 10, 2007

-Self Regulating Heating/Cooling Blanket Using the Peltier Effect-

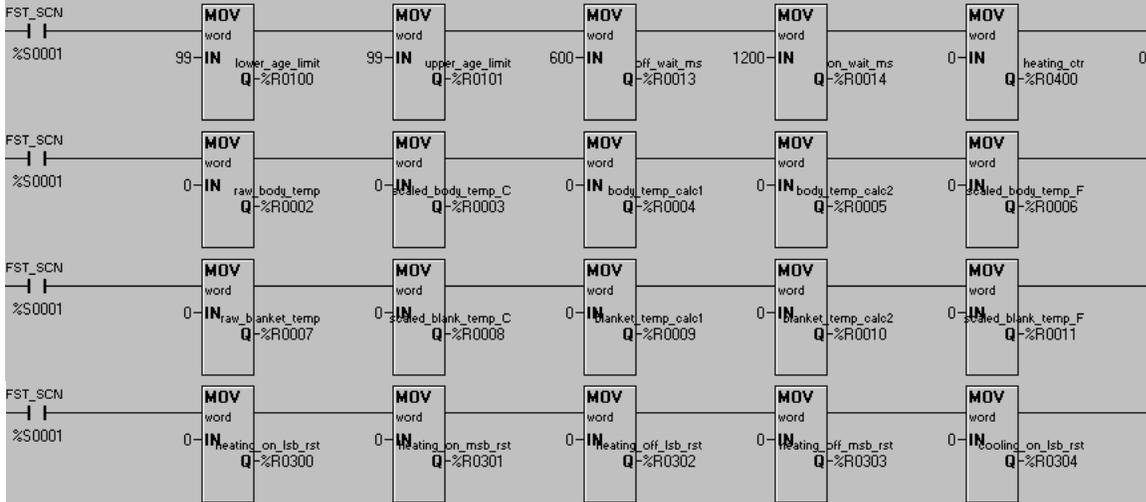
MEMBERS

- Brian Langlais - Stephen Segalla - Chidinma Okebalama - Stanley Cantave - Jonathan Crider - Dino Buro -

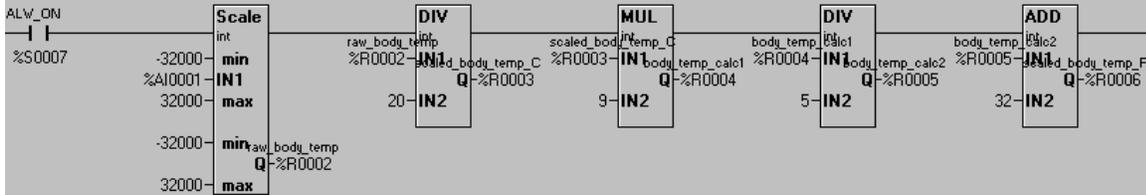
PROFESSOR

-Masoud Salehi- \*)

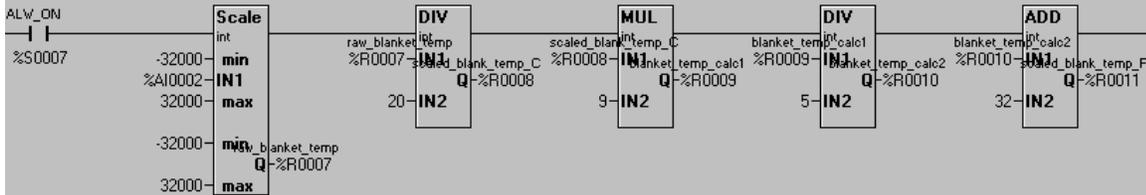
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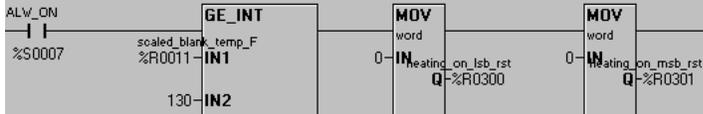
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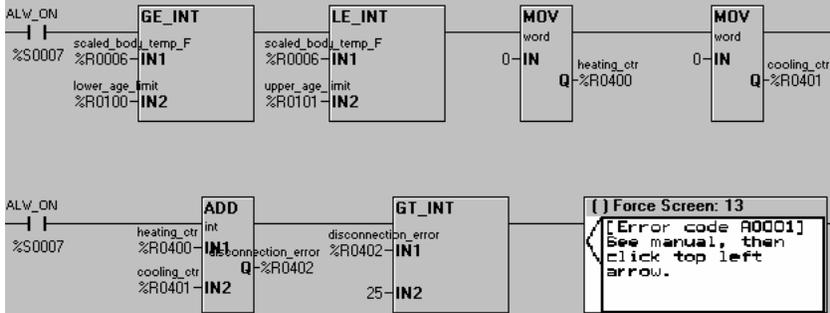
(\* Blanket Temperature \*)



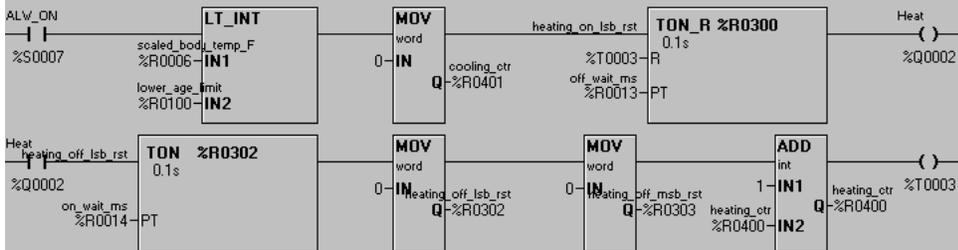
(\* Blanket overheating control \*)



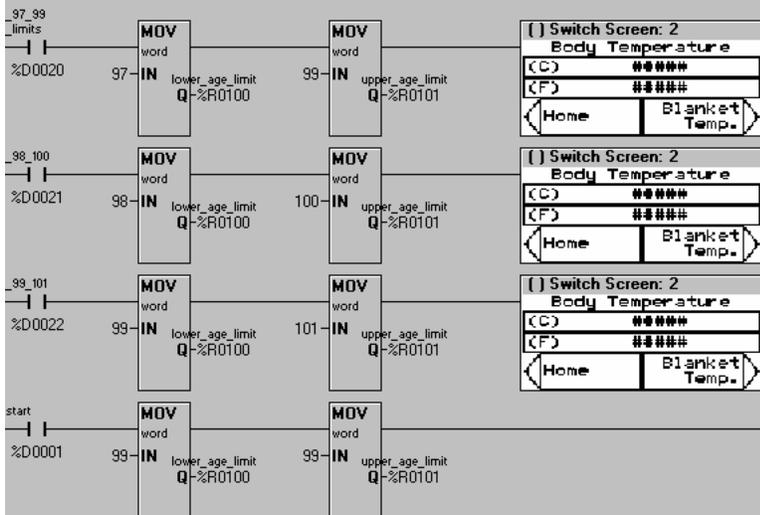
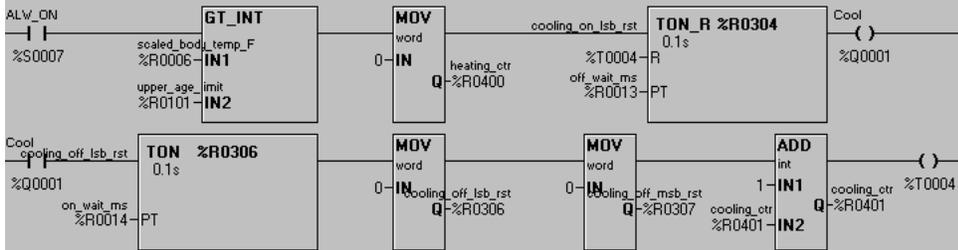
(\* Blanket Disconnected Detection \*)

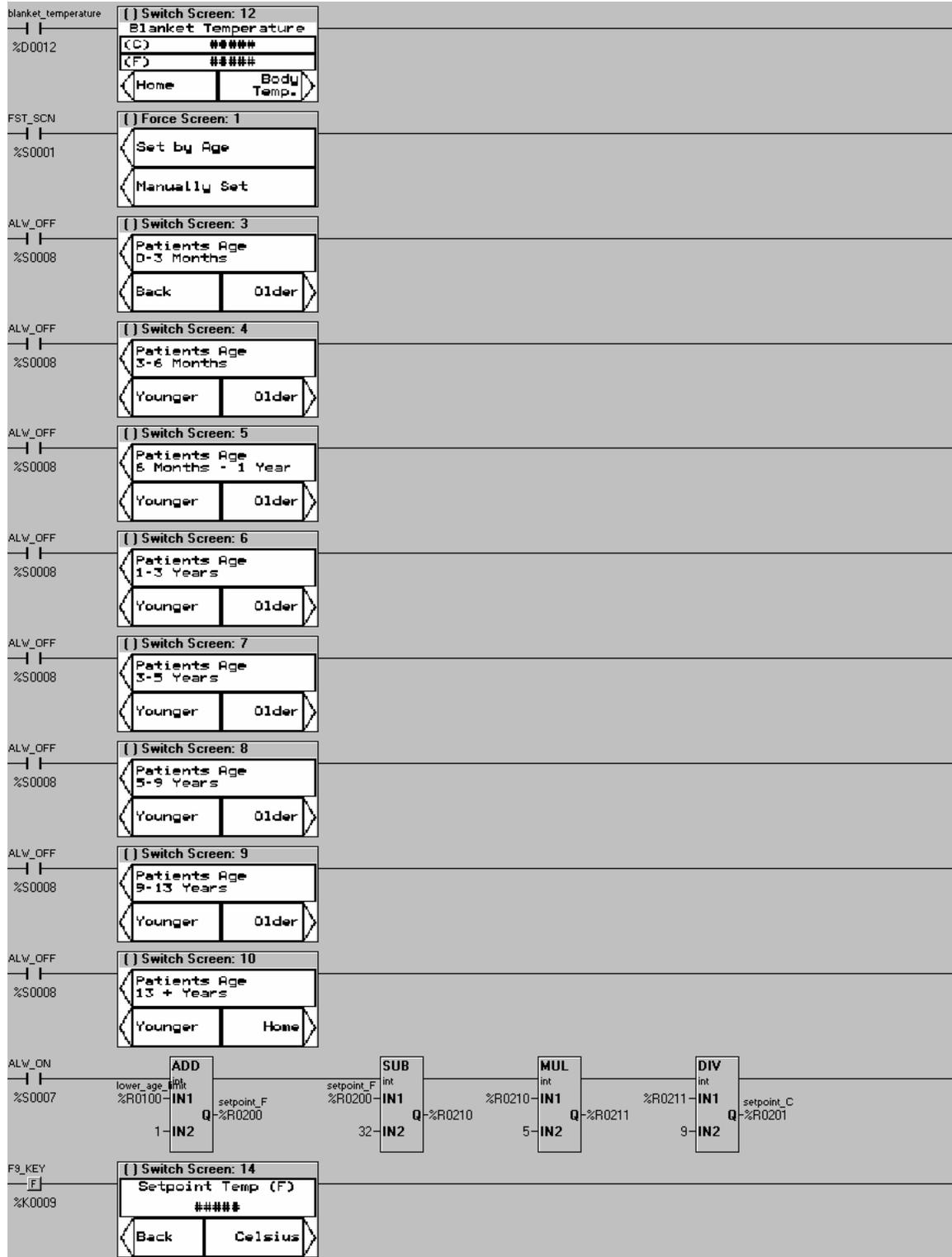


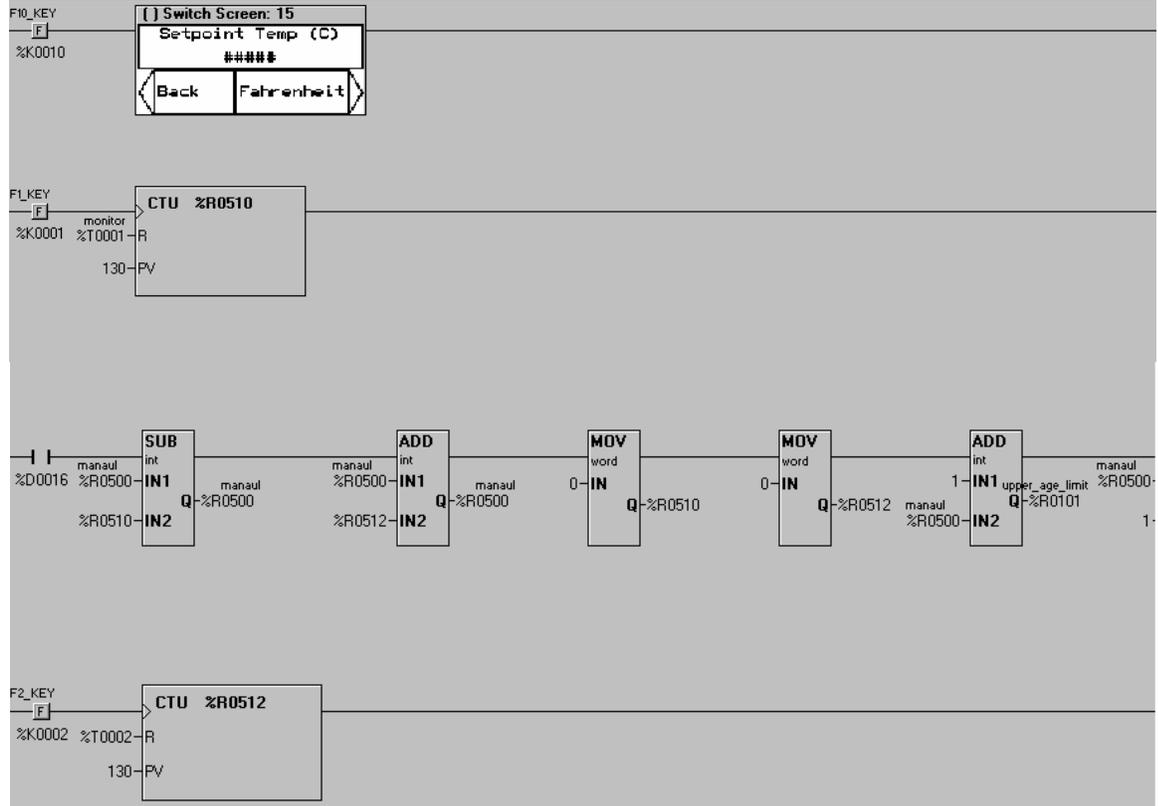
(\* Heating Timing Functions \*)



(\* Cooling Timing Functions \*)







## Code Setpoints

Screen Number	Operation 1	Pointer	Operation 2	Pointer	Operation 3	Pointer
1	Set by Age	3	Manually Set	16	-	-
2	Body Temp	-	Home	1	Blanket Temp	12
3	0-3 Months	21	Back	1	Older	4
4	3-6 Months	22	Younger	3	Older	5
5	6Months - 1 Year	22	Younger	4	Older	6
6	1-3 Years	21	Younger	5	Older	7
7	3-5 Years	21	Younger	6	Older	8
8	5-9 Years	20	Younger	7	Older	9
9	9-13 Years	20	Younger	8	Older	10
10	13+ Years	21	Younger	9	Home	1
-	-	-	-	-	-	-
12	Blanket Temp	-	Home	1	Body Temp	2
13	Error Code A0001	1	-	-	-	-
14	Setpoint Temp (F)	-	back	2	Celsius	15
15	Setpoint Temp (C)	-	back	2	Farhenheit	14
16	Set Temperature	2	-	-	-	-
-	-	-	-	-	-	-
20	97F-99F_limits	2	-	-	-	-
21	97F-99F_limits	2	-	-	-	-
22	99F-101F_limits	2	-	-	-	-
-	-	-	-	-	-	-

PLC Screen Addressing

## Code Register Values

<b>Register Number</b>	<b>Name</b>	<b>Default Value</b>
-	-	-
%R0002	raw_body_temp	0
%R0003	scaled_body_temp_C	0
%R0004	body_temp_calc1	0
%R0005	body_temp_calc2	0
%R0006	scaled_body_temp_F	0
%R0007	raw_blanket_temp	0
%R0008	scaled_blank_temp_C	0
%R0009	blanket_temp_calc1	0
%R0010	blanket_temp_calc2	0
%R0011	scaled_blank_temp_F	0
-	-	-
%R0013	off_wait	600
%R0014	on_wait	1200
-	-	-
%R0100	lower_age_limit	99
%R0101	upper_age_limit	99
-	-	-
%R0300	heating_on_lsb_rst	0
%R0301	heating_on_msb_rst	0
%R0302	heating_off_lsb_rst	0
%R0303	heating_off_msb_rst	0
%R0304	cooling_on_lsb_rst	0
%R0305	cooling_on_msb_rst	0
%R0306	cooling_off_lsb_rst	0
%R0307	cooling_off_msb_rst	0
-	-	-
%R0400	cooling_ctr	0
%R0401	heating_ctr	
-	-	-

PLC Registers Used

# Consumer Survey

## Survey Questions

### *Self-Regulating Heating/Cooling Blanket Using the Peltier Effect*

A system that automates the process of heating and cooling patients whose symptoms are consistent with that of hyperthermia or hypothermia

1. Have you heard of and/or seen a product like this before?

Yes

No

2. On a scale from 1 – 5, 5 being the most important, how important do you think this blanket is in health care facilities?

1

2

3

4

5

3. Do you think this blanket should be available for purchase for the home

Yes

No

4. On a scale from 1- 5, 5 being the most likely, how likely are to buy this blanket for your home?

1

2

3

4

5

5. How much are you reasonably willing to pay for this blanket (for hospital use)

Below \$1000

\$1000-\$5000

above \$5000

# Bibliography

- [1] Vacca, Vincent M.RN. Brigham and Womens Hospital. Neurology ICU
- [2] <http://www.gaymar.com/catalog.asp?id=48&pid=189>
- [3] [http://www.webmd.com/hw/health\\_guide\\_atoz/hw198785.asp](http://www.webmd.com/hw/health_guide_atoz/hw198785.asp)
- [4] <http://www.exergen.com/medical/PDFs/tat2000instrev6.pdf>
- [5] [www.peltier-info.com](http://www.peltier-info.com)
- [6] <http://www.aacn.nche.edu/Media/Backgrounders/shortagefacts.htm>
- [7] <http://www.aamc.org/newsroom/pressrel/2005/050222.htm>
- [8] <http://www.yisi.com/extranet/TEMPKL.nsf/447554deba0f52f2852569f500696b21/9d35c1d2df30a1d6852569fa00622cab!OpenDocument>
- [9] <http://www.kronosrobotics.com>
- [10] [http://www.yisi.com/extranet/TEMPKL.nsf/447554deba0f52f2852569f500696b21/dadf8ddc215cefd985256a0300795a84/\\$FILE/Power.pdf](http://www.yisi.com/extranet/TEMPKL.nsf/447554deba0f52f2852569f500696b21/dadf8ddc215cefd985256a0300795a84/$FILE/Power.pdf)
- [11] <http://www.paragonmed.com/warmsys.shtml#MTA6900>
- [12] [www.12voltageadapters.com](http://www.12voltageadapters.com)