Electric Hot/Cold Wrap

Design Team
Daniel Jordan, Tseten Lungjangwa
Thomas Mullaney, Rahman Nabulsi
Blake Sama

Design Advisor
Prof. Gouldstone
Email: a.gouldstone@neu.edu

Abstract
The goal of this project was to create a device that can cyclically heat and cool an area of the body utilizing a thermoelectric module. This summary covers the design and development of this device that can cyclically heat and cool the human skin from temperatures ranging between $8 \pm 5^\circ C$ and $42 \pm 5^\circ C$. The problem was further specified to be: physically flexible, home-user affordable, home-user controllable, and variable in operating parameters. This cycling procedure is most commonly referred to as contrast therapy, and is used primarily within the sports and physical therapy fields. In contrast therapy, the cyclic heating and cooling provides benefits including: quicker recovery from injury or exercise bouts, pain relief, decreased swelling, and increased range of motion post-exercise. Proof of concept and module selection was based on initial heat transfer calculations. This led to the evaluation of multiple thermoelectric modules within theoretical required operating ranges, and selection for final design. In addition to selection of the module, different interface materials, control options, and heat sink options were investigated analytically, computationally, and experimentally. Conclusions based upon calculations and test results of individual components led to final component selection and optimization of design.
The Need for Project

An all-inclusive device provides the user with an easy to use, cost effective, controllable product to perform contrast therapy treatments without limitations and inconveniences of the current practices. Hot and cold therapy, including the combination of the two, is currently used frequently by people spanning a wide range of athletic activity and/or ability. These therapies are used for pain relief, relaxation, and have several other benefits. Therefore, there is a drive and market for such a therapy system. Addressing current application methods, several shortcomings are apparent. In particular, methods for cyclical hot and cold therapy, known as contrast therapy, can be cumbersome, non-controllable, costly, and require user attention. Contrast therapy is growing in popularity, especially in the physical therapy and sports fields, therefore a user controlled, convenient method of application would be a great improvement on current methods. In addition, the team’s IRB approved survey results confirm the need for this type of all-inclusive product.

The Design Project Objectives and Requirements

Design Objectives

An electrically powered, user-controlled wearable wrap device that cyclically heats and cools an area of the human body. The product must be a self-contained wrap including a thermoelectric module (TEM) as the driving force for energy transfer. Additional objectives include the inclusion of a passive heat sink and controller for user controllability. The wrap should be flexible, comfortable, and have a protective outer layer to eliminate injury risks. The unit will be plugged into a standard 120V wall outlet.

Design Requirements

The wrap must utilize a TEM to perform the cooling and heating. The required area of effectiveness of the wrap must be 40cm$^2$. This area must be controlled between a minimum of 8 ± 5°C to a maximum of 44 ± 5°C. The device will need to accommodate ratios of 1:1 to 1:5 hot to cold. Lastly, the production cost of the unit cannot exceed $50.

Design Concepts Considered

Several options were evaluated within design requirements for each category: TEM, heat sink, and other materials. The range of design concepts was limited by the problem statement and design requirements. The necessity of using a thermoelectric module dictated much of the design stack up, as the operation of such a device requires most of the included layers. Therefore, much of the design and creativity included in the product were based on TEM requirements, the synergy of required layers, and
material selection. The material and component options provided several potential concepts that were evaluated. These can be separated into the following categories:

**Thermoelectric Module (TEM)**

The TEM, the driving force of the device, was a required component of the design. Selection was non-trivial based on the range of TEM’s available, varying in size, cost, life, and other parameters. The parameters were prioritized and an affordable and effective choice was made based upon a decision matrix.

**Heat Sink**

The second most important element of the design was the heat sink. This heat sink must pull out all of the heat required to run the TEM as well as that being absorbed from the body. Concept considerations included both active (e.g. fans), as well as passive techniques. Passive techniques were favored and included fin/pin models as well as phase change materials.

**Other Materials**

Other elements of the design included wrap material, heat spreading material, and thermal interfaces/insulation.

Wrap materials considered included terry cloth, polyester, as well as a spandex blend. Heat spreaders included copper, copper meshes, graphite sheets, and copper tapes. Thermal interfaces and insulation options included foam insulation, neoprene, pipe insulation, Artic Silver™ thermal paste and thermally conductive tape.

Each permutation of each of the above components provided a design “concept.” It was through testing and creativity that the optimal combination of synergistic material effects was chosen and the most advantageous design formulated.

**Recommended Design Concept**

The product is comprised of a Tellurex TEM sandwiched between an insulated copper energy spreader and a phase change heat sink. The enclosure is spandex and is also used as a skin.

**Design Description**

The final design consists of five layers that achieve a self-contained, electrically powered hot/cold wrap. The final product is a combination of the best solutions for each of the individual elements mentioned above. Best is characterized differently for each element, but all decisions were based on both analysis and experimental
interface. The design layers consist of a wrap material, energy spreading material, thermoelectric module, heat sink, and an insulating material. A pair of Velcro straps will be used to secure the product to the arm. The passive cooling heat sink features a phase change material that allows flexibility and uniqueness. The heat spreader provides a larger coverage area without compromising flexibility and more efficiently using the thermoelectric module.

**Analytical Investigation**

Extensive theoretical heat transfer calculations were performed to ensure that the device could theoretically meet specifications. Both analytical and finite element analysis (FEA) was completed for human arm heat transfer, while FEA was completed on energy spreader materials as proof of concept and conceptualizing limitations. Based on the results of the calculations; the power ratings of the thermoelectric modules were set. A Tellurex TEM was selected based on wattage, size, and cost.

Though analytical modeling was robust and extensive, it required several simplifying assumptions. As a result, numerous experiments were necessary for verification.

**Experimental Investigation**

Testing was performed in a variety of configurations to examine which combination of materials would maximize the effectiveness of the device. Using both thermally loaded and unloaded testing setups, the effectiveness of heat spreaders was analyzed with and without an insulator, such as neoprene. It was found that 0.006” thick flexible copper insulated with adhesive pipe insulation performed the best within cost and flexibility parameters.

The thermally conductive, interface and thermally insulated layers were selected based on materials properties. After all of these materials were tested, the best materials for each layer were then incorporated into the design.

The heat sink materials were the last of the stack up elements to test. A variety of heat sink options were compared. It is currently hypothesized that a phase change material is most fitting for the current application, both satisfying the passive cooling design objective, as well as uniqueness of design.

The controller element was selected primarily based on cost.
parameters and the number of functions required. A testing controller was ordered that required a large overhead cost to interface with the testing software, but this controller is not part of the final product and its cost is not reflected in the final product. Instead, a microcontroller was designed and is used to perform all functionalities necessary within our user limitations and design specifications.

**Key Advantages of Recommended Concept**

The final design is the best of each design element and therefore provides the best solution based on the testing results. The novelty of the phase change heat sink has its advantages in its patentability as well as its flexibility. Advantages also include the insulation and use of the copper temperature spreader that quadruple the area of effectiveness while not compromising flexibility. Overall the inclusion of a passive heat sink and effective device operation with user controllability sets this product apart from anything currently in practice.

**Financial Issues**

The prototype cost, in materials alone, was about $45. According to available bulk pricing and material estimates, if this device was to be mass produced, the cost would amount to about $28. This reduction estimate is based heavily on the two big ticket items: TEM and controller costs being reduced by 30% respectively. This cost meets our design requirement of under $50.

**Recommended Improvements**

The next step is to scale the device to accommodate other parts of the body. The IRB survey has given information that will guide the future areas of application (back, knee, shoulder, head). The current wrap utilizes a phase change heat sink, which works well for a cycling application. However, should the user request constant heating or constant cooling, a metallic heat sink may provide a better solution. With slight modifications to the controller and its limitations on how long the user can use the device for, the device could potentially be scaled to provide just hot or cold therapy in addition to its cyclical capacity.