ECE 445 Design Document Team 44

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Contents

1 Introduction

1.1 Problem

Maintaining an optimal sleeping temperature is essential for restful and uninterrupted sleep. Traditional methods of temperature control, such as adjusting thermostats, using fans, or adding layers often fail to provide personalized comfort or involve considerable energy costs [4]. This discomfort not only affects the quality of sleep but also contributes to daytime fatigue, decreased productivity, and long-term health consequences such as stress and weakened immune function [5].

As such, a field has arisen to target climate specifically while one is sleeping. Competitors in this field consist of water-based temperature regulation systems, which, while effective, come with significant drawbacks [6]. They pose a risk of leaks that can damage mattresses and bedding, particularly with more expensive or delicate materials like memory foam. These systems are also prohibitively expensive, both in terms of upfront costs and ongoing maintenance.

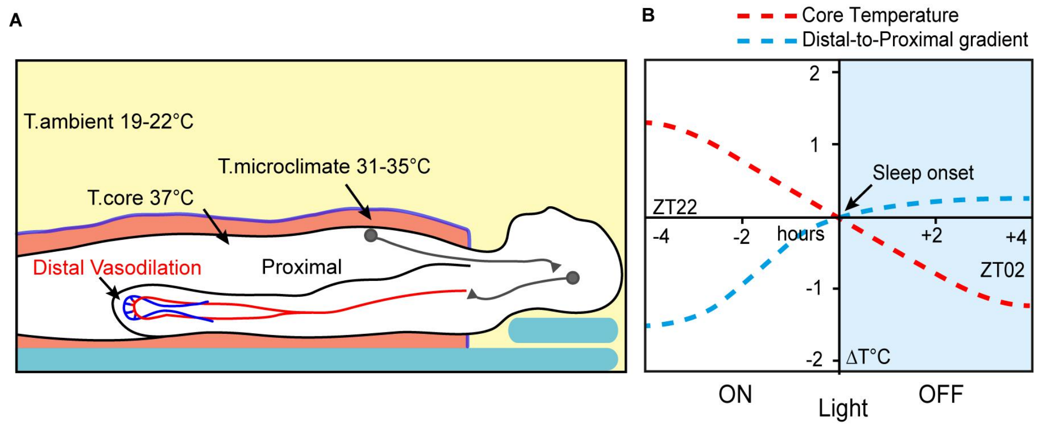

Figure 1: Optimal Temperatures While Sleeping

1.2 Solution

A heated bed, through ventilation, is our answer to the many who feel uncomfortable with frigid temperatures in the middle of winter. The system consists of a central heating system stored underneath the bed, attached to a vent that clamps onto the foot of the bed and allows for circulation through a fan unit in the central heating system. This creates a modular system that may be used for heating or cooling by circulation, subject to the user. The vent exhausts air underneath your blanket, over one's sheets, generating an area under the sheets to create a warmer, more comfortable environment. The project is divided into three subsystems:

1. Heating
2. Ventilation
3. Control

Each will be expanded on below. Additionally, a brief overview and interactions between the subsystems is provided. Below is also our visual aids to help understand what our enclosure will look like.

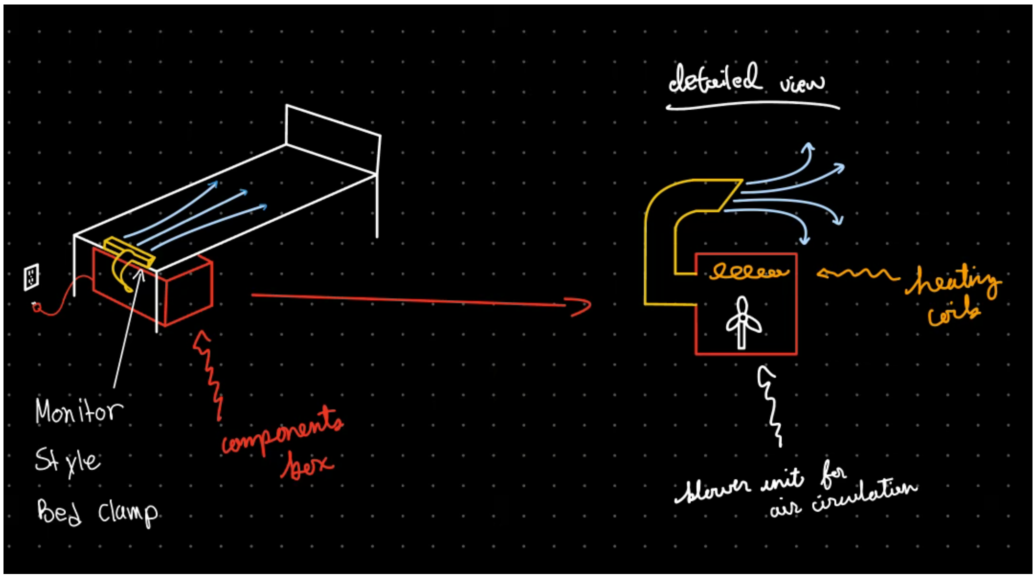

Figure 2: System Setup + Flow

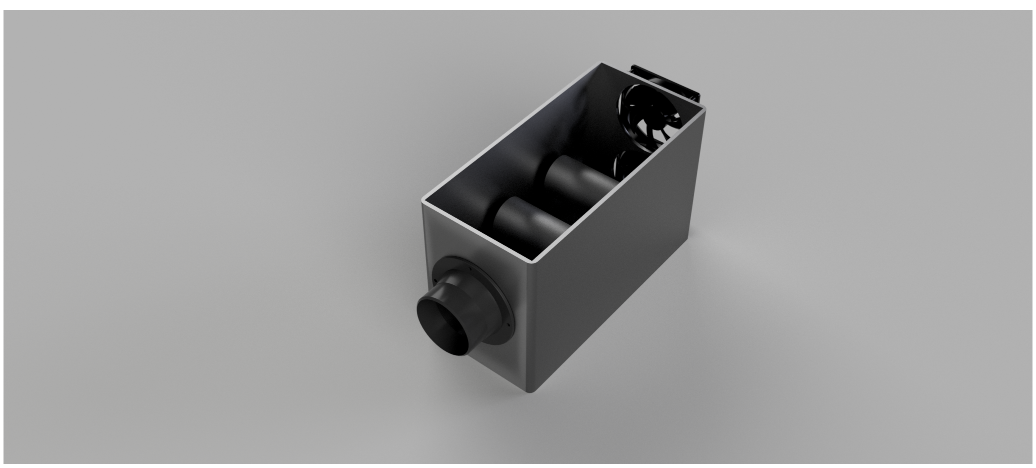

Figure 3: 3D Design of Enclosure with Heating Elements

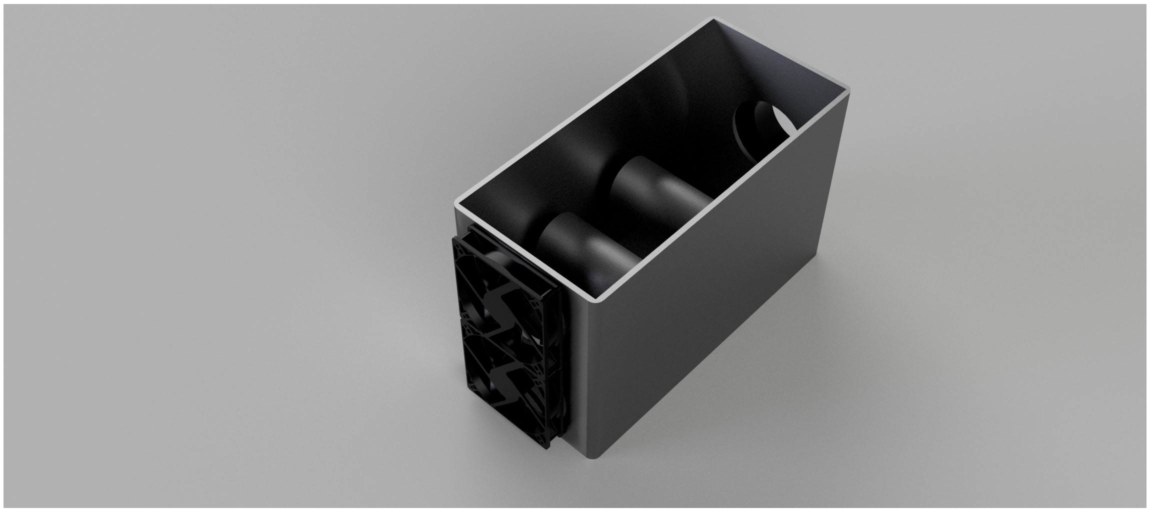

Figure 4: Alternate Enclosure View

1.3 High-level Requirements

As a mark of success, the project should be able to fulfill these three requirements:

1. Be able to modulate the temperature of its surroundings (defined as the temperature within a square box of the bed) within 3 degrees Fahrenheit of what the user inputs
2. Have a quiet air ventilation system, measured around 50-60 decibels (when sleeping, noise around one should not exceed 60)
    (a) To assess this system, we will use our phone microphones at head level on a bed, checking the decibels at night when only the system is in use.
3. Not power hungry and able to subsist off of the wattage of a normal fan and heater (1000-1500W).

(a) To assess this system, we can check the input through power monitoring at the AC Input through a smart plug

2 Design

2.1 Block Diagram

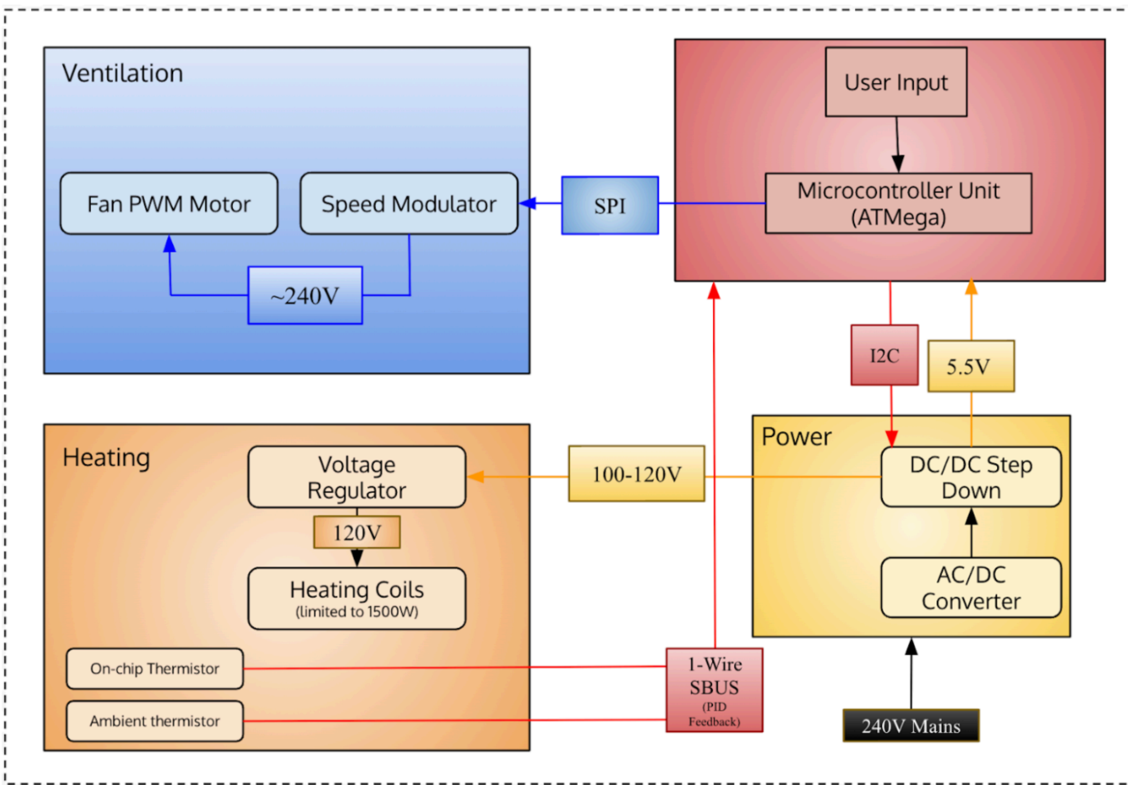

Figure 5: Block Diagram

2.2 Subsystem 1 - Heating

After researching available heating options, we believe that nickel-chromium (nichrome) wires, which can be found in hair dryers and toasters, are the ideal way to create our heating element. Nichrome is a metal alloy primarily composed of nickel and chromium, with various grades available. The most common types are nichrome-80 and nichrome-60, containing approximately 80% and 60% nickel, respectively. Both have a maximum operating temperature between 1100°C and 1200°C and melting points above 1400°C. [1] The chromium in nichrome forms an oxide layer on the surface, providing protection against corrosion. Its corrosion resistance, high melting point, and higher resistivity compared to other metals make nichrome an ideal material for electrical heating elements. The flexibility of the nichrome wire solution is appealing to us, as it allows us customize the heating element to our own needs. Additionally, it is far more cost effective than the pre-built heating coils from McMaster-Carr. [1] To heat the coil, voltage is applied on both sides of the wire. The switch to turn this voltage on or off will be controlled by our control system, using a MOSFET such as the TSM170N06CH [5] for modulation.

To measure the temperature, we will use three separate sensors: one measures the temperature of the ducted air, one will monitor ambient temperature in the room, and a thermistor on the board (inside a separate enclosure).

Considering we are choosing to heat the nichrome wires with a constant voltage supply, the steady-state voltage/temperature relationship looks like the following:

$$\Delta T = \theta * \frac{V^2}{pL^2}$$

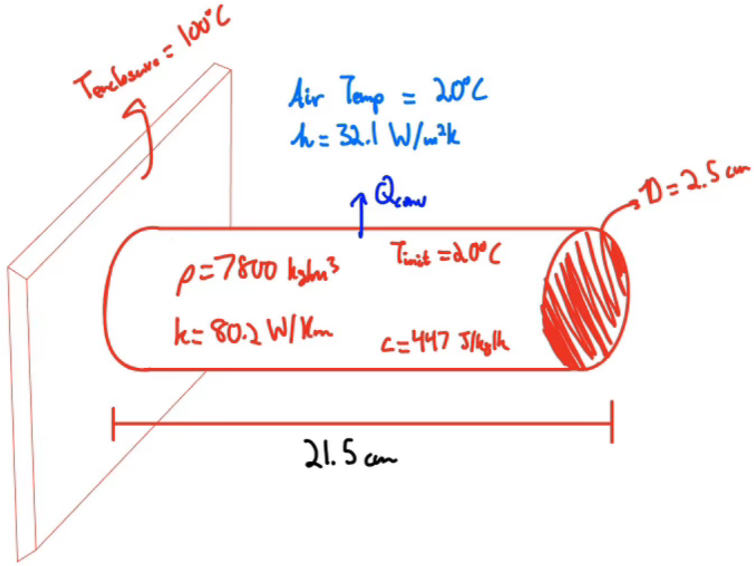

Figure 6: Model of Insulation

$\rho =$ resistivity or resistance per unit length $(constant)$

L = length of the wire

$\theta =$ the radial thermal resistance of the wire to ambient per reciprocal unit length

In addition, we have to consider that thermal resistance for the nichrome wire will have two components - from the wire to ambient temperature in the enclosure as well as from the wire to the contraption holding it in place. [3]

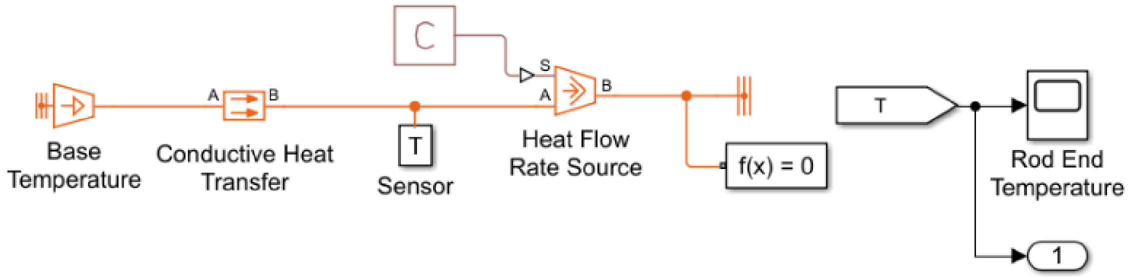

Figure 7: Steady State Heat Conduction Flow Diagram

2.2.1 Subsystem 1 - Requirements and Testing

Requirement	**Verification**
We need to study how different temperatures that the nichrome wire is set to affects ambient temperature. The temperature in the enclosure needs to be under 200F, while the temperature in our circuitry enclosure should be under 100F. Additionally, we are measuring the temperature for the air ducted to the user; this should be clamped at 80F.	The DS18S20 is an extremely efficient and precise temperature sensor, and will be used as our feedback sensor to the ATMega. It will also be used as our testing mechanism for our heating subsystem, as it is designed to work within temperatures between -55C to 125C.

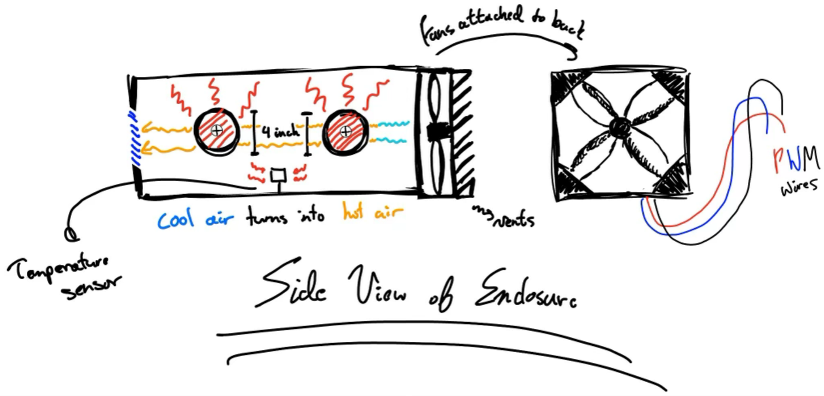

Figure 8: Side View of Enclosure (including Ventilation)

2.3 Subsystem 2 - Ventilation

Circulation is an issue even in conventional air conditioning systems, which makes its implementation all the more pertinent in our project. Through a fan or air blower, we can circulate air under the blankets and bed sheets to increase the temperature of the bed without having the problems of Eight Sleep (leakage issues, temperature mismatches, etc.). Additionally, we intend on giving the user control of this function through a motor control system and receiver implemented on our PCB. Easy access and variability through an app or remote of some sort will most certainly satisfy user expectations and leave a good experience. An ATMega328 will be used as a microcontroller for control and communication through PWM (expanded on below). We will have our ventilation unit situated under the bed, feeding into the heating subsystem.

2.3.1 Subsystem 2 - Requirements and Testing

Requirement	Verification
We need to be able to observe and monitor changes in temperature to make sure it operates within safe/desired limits.	Sensors placed inside and outside the enclosure will monitor ambient temperatures. The system must read and respond (PID Controller) to these sensors to adjust power to the heating or ventilation system, depending on temperature feedback.
We need to ensure that the PWM signals generated from the MCU to drive the fans are not attenuated	We will use an oscilloscope to monitor the PWM signals sent from the ATMega328 microcontroller to the fan motor. Ensure the signals are consistent and adjust airflow according to the set duty cycles.

2.4 Subsystem 3 - Control System

We are using the ATMega328 on our PCB, in order to control our PWM based systems, as well as the feedback loop for PID to make sure that we are establishing the proper temperatures that we need and the coils are at the appropriate temperature. This control system will also include the input areas, which will have a physical dial/knob so that the user can control the temperature and behavior of the device. As a stretch goal, we may try to implement some kind of wireless control system, such as having the device communicate to an app or web page of some kind, so the user can control the system remotely.

2.4.1 Subsystem 3 - Requirements and Testing

Requirement	**Verification**
The system must be capable of controlling power delivery to both the heating coils and ventilation fan. Power adjustments must be regulated to stay within safe operational limits	We will use a multimeter to measure the actual voltage and current supplied to both the heating coils and ventilation fan. By varying the control signals (via PWM from the MCU), we will ensure that the power output adjusts accordingly, and remains within defined safety limits.
We need to be able to observe and monitor changes in temperature to make sure it operates within safe/desired limits.	Sensors placed inside and outside the enclosure will monitor ambient temperatures. The system must read and respond (PID Controller) to these sensors to adjust power to the heating or ventilation system, depending on temperature feedback.
With ATMega328 serving as the MCU responsible for managing sensor inputs and adjusting power levels to both the heating and ventilation systems. Communication protocols between sensors and MCU must ensure real-time feedback control to not over/under shoot required temperature levels	We will verify communication integrity by testing our sensors in a separate environment with simulated temperatures that are known and, if necessary, normalize to desired settings

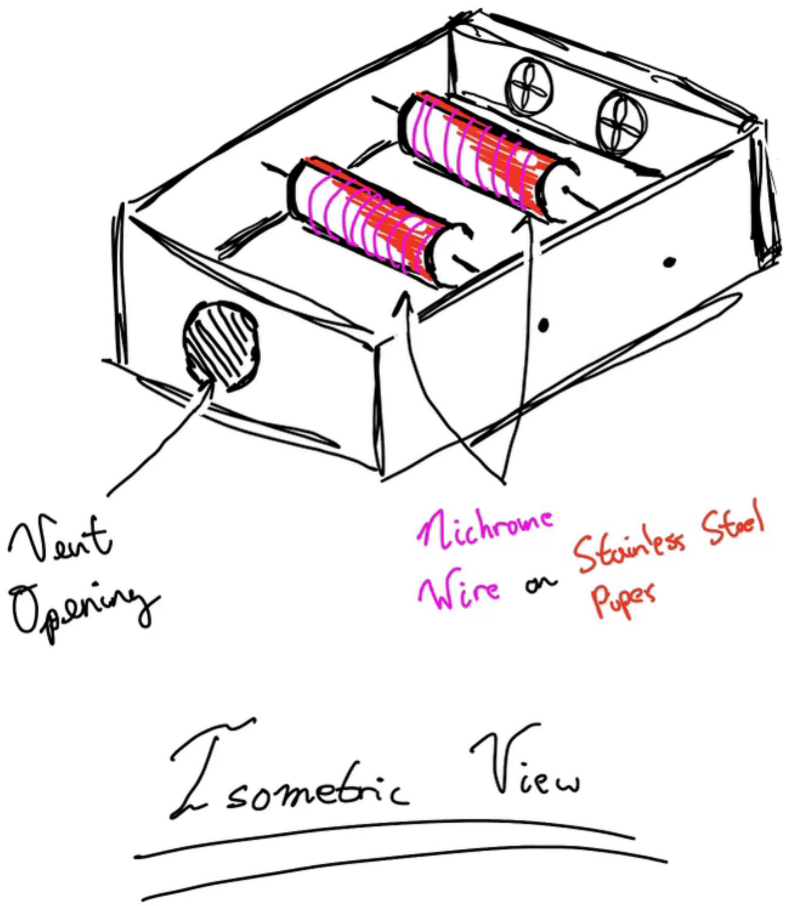

Figure 9: Isometric View

2.4.2 Subsystem Interactions

As a fundamental requirement, power will be provided through a 120V/60Hz AC outlet, and converted into DC through our rectifier. A step down DC/DC converter will take the 120V and provide 5V for the ATMega (MCU) as well as 20V for the heating coils, feeding power to the separate subsystems. Our ATMega will be the main controller for our system, receiving signals from the user's interface. This is intended to be a simple knob to regulate temperature, along with a switch to turn off the heating and use the system purely as ventilation. The heating subsystem will be located within an enclosure, thermally isolated from the rest of the system so as to prevent overheating of the circuitry.

Below is the visual aid for one's convenience — the heatings coils will be suspended using viable materials, similar to acrylic that does not warp under thermal transfer. A blower unit mounted behind the coils will now vent air over these heated tubes, similar to what happens in a hairdryer, but on a larger scale. With only one intake(for the blower) and one exhaust(insulated tubing up to the vent), the air will be pushed out of the exhaust, and be carried by the tubing upwards to the vent. Once the air arrives at the vent, it will be exhausted underneath the blanket and onto the sheets as previously explained.

2.5 Tolerance Analysis

1. Hysteresis Control:
   (a) Target Temperature: 30°C (assumed comfortable for the self-heating bed).
   (b) Hysteresis Range: ±2°C.
   (c) The heating coils would turn off when the temperature reaches 32°C and turn on again when it falls below 28°C. This ensures smoother transitions and prevents rapid cycling.
2. Fan Speed Adjustment:
   (a) Below 28°C: Fan speed is minimal (30% of max speed) to retain heat.

(b) 28°C - 32°C: Fan speed at moderate levels (50-70%) to help circulate the warm air.

(c) Above 32°C: Fan runs at full speed (100%) to dissipate excess heat and protect the components.

3. Current Monitoring for Nichrome Wire:

   (a) Operating Current: Assume 2 amps as the nominal operating current (depending on wire gauge and length).

   (b) Max Allowable Current: 2.5 amps.

   (c) If current exceeds 2.5 amps, this will signal a short or fault in the nichrome wire, prompting a system shutdown. This will be either through fuses or the ATMega monitoring the current.

3 Cost and Schedule

3.1 Bill of Materials

Table 1: Schedule

Part #	Description	Manufacturer	Quantity	Cost
1	ATMega328	Microchip Technologies	1	$2.42
2	LM7805	SparkFun	1	$0.75
3	ToolkitRC ADP AC Power Supply	NewBeeDrone	1	$19.99
4	XT60 Female Connector	MCIGICM	10	$7.99
5	DC Buck Converter	Drok	1	$12.15
6	Nichrome Wire	Amazon	1	$6.99
7	MAX1464	Mouser	1	$17.42
8	DS18S20	Digikey	4	$40.00
9	Wathai 12038 120MM Fan	Wathai	1	$19.99
10	3-Pin Screw Mount	Mikroe	2	$2.28
11	Steel Piping	Machine Shop	1Ft	$3.99
12	Enclosure	Confote	1	$60.99
13	Enclosure Insulation	Machine Shop	1	$13.99
14	Insulated Tubing	Yijuhou	1	$9.99

3.1.1 Labor Costs

$16 x 2.5 x 80 = $3200

3.2 Schedule

Week	Agenda
9/29	Finish Design Document/Proposal Regrade, start PCB
10/6	Finish first iteration of PCB, order ICs for PCB, get enclosure from shop/amazon
10/13	Order first iteration of PCB (Monday), revise for next iteration, start signal coding for ATMega and fans
10/20	Test PCB (if board arrives), start tests for nichrome wire heating, check PID feedback system and tolerance checks
10/27	Order second iteration of PCB if revision needed, finalize voltage settings for heating elements, start design doc with feedback
11/3	Finalize design doc regrade, finalize interaction of sensors with PID system, start assembly of venting to the enclosure
11/10	Finalize fan system signals, finalize assembly for mock demo
11/17	Bonus/App Building Week (Mock-Demo Week)
11/24	Break
12/2	Final Demos, make presentation for next week
12/9	Final Presentations

4 Ethics and Safety

The user will not be interacting with any high power systems in their use of the device. However, there are two areas that we need to ensure are fault tolerant and can withstand failures, safely shutting down in case of emergency. The power system monitoring will be done through multiple voltage valuations and current examinations, feeding back to the main controller on the PCB and allowing us to monitor the system at all times. We will also have multiple fuses in place to ensure that we do not exceed rated amperage so that the system is either controlled or off. As previously mentioned, we will also have multiple temperature sensors, which will be automatically monitored, and if we exceed what we deem to be acceptable, safety logic will be executed to either cut power to the heater, or to the unit as a whole. The last but most important consideration for safety will be the heating coils that we use. In our research we have come upon nichrome wire as what we believe is the ideal DIY heater coil mechanism. We will be controlling the voltage to the nichrome wire through our ATMega controller as previously mentioned in the controls subsystem. Along with this, we are investigating a proportional-integral-derivative (PID) based feedback system, as it provides the most flexibility and has been tested numerous times in other projects. The feedback system will be core to how we control our fan and heating, and will require fine tuning at the end of our project to ensure that we stay within safe operating temperatures. The heater will NOT be allowed to be on if the blower is not on. This way the heater is never on without airflow. Furthermore, the entire box will be wrapped in fireproof insulation and made of plastic, rather than something flammable like wood. This serves two reasons, it allows the heat to stay within the box so that less voltage is needed to heat and maintain the temperature of the nichrome wire, and second so that the electronics, which will be placed outside the enclosure, in a space of their own, will always be in safe operating temperatures. We'll be following the IEEE standards (62395-1-2024) for heating elements and fire safety.

5 References

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6. Moyen, Nicole E., et al. ‘Sleeping for One Week on a Temperature-Controlled Mattress Cover Improves Sleep and Cardiovascular Recovery’. Bioengineering (Basel, Switzerland), vol. 11, no. 4, Apr. 2024, https://doi.org/10.3390/bioengineering11040352.