Project Proposal: Self Heating Bed

Team Members: Team 44

- Siddharth Kaza (**kaza3**)
- Amaan Rehman Shah (**arshah6**)
- Hari Gopal (**hrgopal2**)

Problem

Maintaining an optimal sleeping temperature is essential for restful and uninterrupted sleep. Many individuals struggle with temperature regulation throughout the night, either feeling too hot or too cold, which can disrupt sleep cycles and negatively impact overall health and well-being. Traditional methods of temperature control, such as adjusting room thermostats, using fans, or adding or removing blankets, often fail to provide personalized comfort or involve considerable energy costs.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. Sleep scientists set out to study the conditions that affect one's sleep, one key factor that emerged as directly affecting the quality of sleep that a person gets is their temperature not just when they sleep, but throughout the night.

We are not the only ones who want to provide a solution to this problem. There are competitors like the Eight Sleep Mattress, however the Eight Sleep is a Water based mattress. Water-based temperature regulation systems for beds, while effective, come with significant drawbacks. They pose a risk of leaks that can damage mattresses and bedding, particularly with more expensive or delicate materials like memory foam. Additionally, they are bulky and require cumbersome setup and regular upkeep, detracting from their convenience. These systems are also prohibitively expensive, both in terms of upfront costs and ongoing maintenance, making them inaccessible for many consumers. The Eight Sleep costs an astounding 4,998$(pre-tax), on top of which, the user **must** pay 25$/month(300$/year) in order to be able to adjust and manage the temperatures of their Eight Sleep mattress from the accompanying app. In contrast, we aim to build a vented bed system that is more affordable, user-friendly, and does not require the user to pay a continuous subscription fee.

Solution and Overview

A heating mattress is our answer to the many who feel uncomfortable with frigid temperatures in the middle of winter. The system would include a vent attachment to one's bed frame (through clamps), creating a modular and universal system. The vent then exhausts hot/room temperature air underneath your blanket, over your sheets, circulating under the sheets to create a warmer, and more comfortable environment. We are dividing the project into three systems, heating, ventilation, and control. Each will be expanded on below. Additionally, a brief overview of the overall system and interactions between the subsystems is provided in the next paragraph.

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.

Visual Aid:

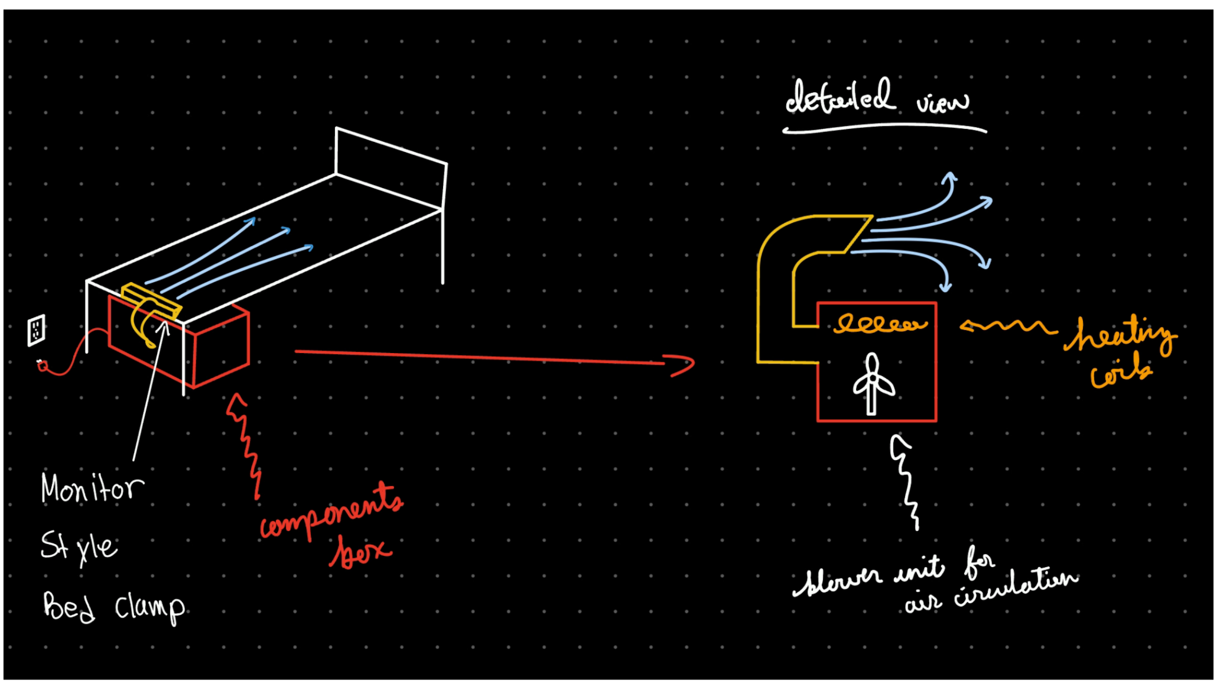


Figure 1: Visual Diagram of Project

Solution Components

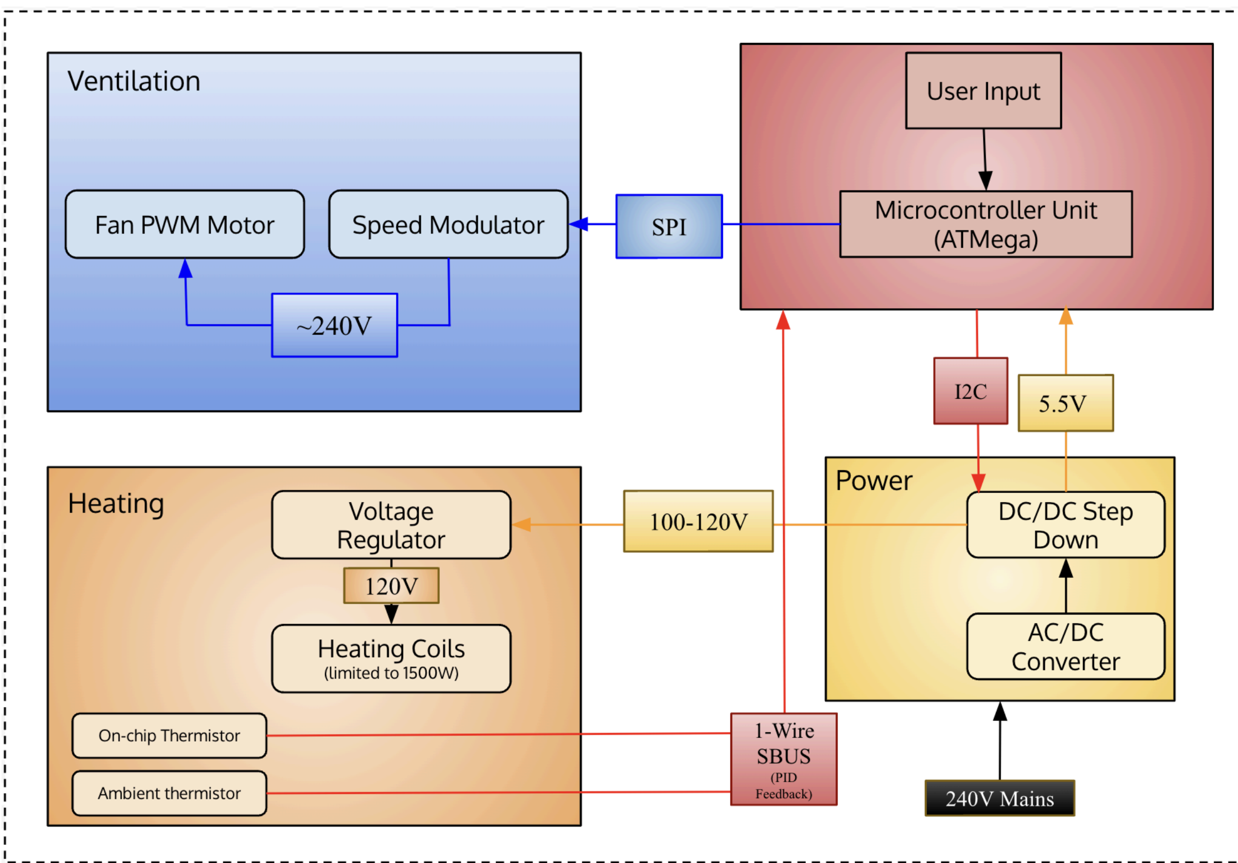


Figure 2: Block Diagram of Project

Subsystem 1 - Heating

We intend on implementing heating using independent and smaller heating coils, due to their cost effectiveness compared to the circulatory system in most apartments and houses. This coil is usually a resistor in most heating systems, coupled into an electric system where more power sent through the resistor results in more heat being dissipated. After researching available heating options, we believe that nichrome wires, which can be found in hair dryers and toasters, are the ideal way forward to create our heating subsystem. The flexibility of the nichrome wire solution is appealing to us, since it allows us to create a custom designed heating element, which is more cost effective than an off the shelf solution. We intend on using a solid state switch for current control via the heating element. This allows us to control its power using PWM, which is essential for ensuring the coil temperature remains below a certain prescribed level. Ideally, we'll have an N-channel power MOSFET such as the TSM170N06CH[5] to modulate the power. To measure the temperature, we will use three temperature 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).

Nichrome Wires:
https://morelectricheating.com/coilhd10332-20-ga-ni60-25id-20-09-ohm-cln-cut-coil

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. 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.

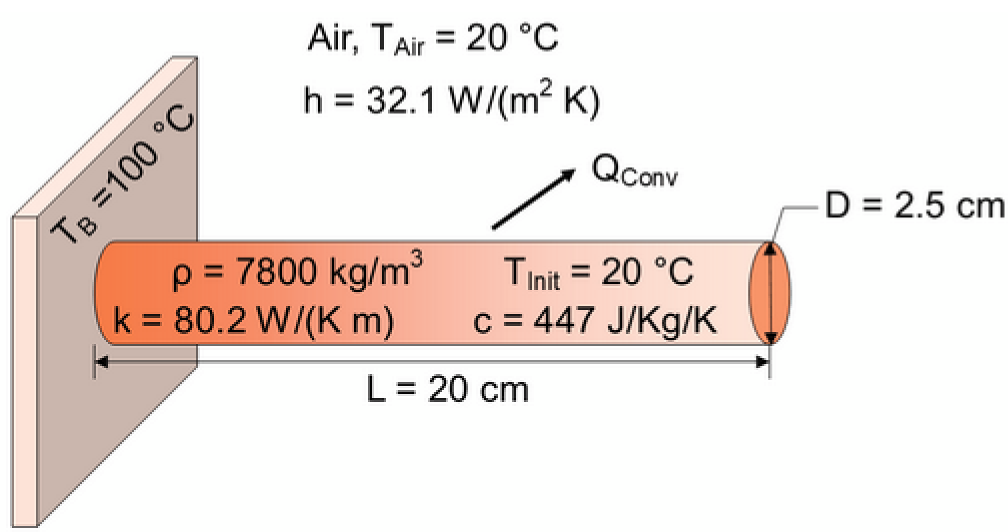
Considering we are choosing to heat the the nichrome wires with a constant voltage supply, the steady-state voltage/temperature relationship looks like the following:

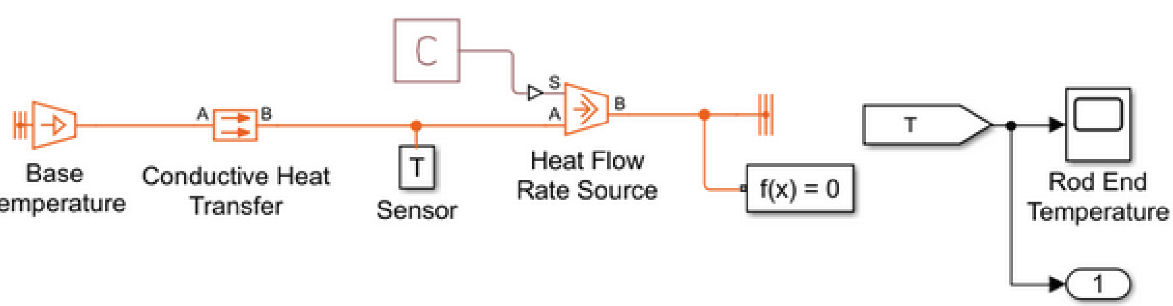
$$\Delta T = \theta * \frac{V^2}{\rho * L^2}$$

Where,
ρ = resistivity or resistance per unit length. (This is a constant)
L = length of the wire.
θ = 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.

Tool for heat conduction calculation through nichrome wire:





Subsystem 1 - Requirements and Testing

The temperature in the enclosure will 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.

Benefits and Features

- Unique 1-Wire® Interface Requires Only One Port Pin for Communication
- Maximize System Accuracy in Broad Range of Thermal Management Applications
  - Measures Temperatures from -55°C to +125°C (-67°F to +257°F)
  - ±0.5°C Accuracy from -10°C to +85°C
  - 9-Bit Resolution
  - No External Components Required

Figure 3: Thermal Conditions for DS18S20

In terms of power requirements, the equation is simply:

$$V = IR$$

Our resistance for the nichrome wire is 150.2 ohms/m, which translates to 1.5 ohms/cm. Considering that we are going to use around three meters of wire, the resistance is around 450 ohms. The temperature desired for the wire is around 800F on nichrome 60 wire, which we can use:

$$W = I^2R$$

to find that our wattage is 85W from inputting 20V and 2.8amps.

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. Since most fans use PWM, we'll use an ATMega328 as a microcontroller for communication (expanded on below). We will have our ventilation unit situated under the bed.

Subsystem 2 - Requirements and Testing

Our requirement for the ventilation system lies in whether or not the user feels cooler when the heat is not on. We will use a focus group to test this requirement, perhaps multiple TAs or fellow peers that can honestly assess whether the ventilation system is cooling them or providing a circulation that creates an impact in comfort. Although fans do not have a condenser, it may help alleviate the heat due to the wind chill effect, and its displacement of stale air.

Subsystem 3 - Control System

We are using the ATMega328 microcontroller onto a 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.

ATMega Pinouts are listed here.

Subsystem 3 - Requirements and Testing

The requirements will be being able to control the power delivery to the heating and ventilation systems. It will be responsible for monitoring the various sensors that we place around the enclosure and the system, as well as regulating the power appropriately to stay within the safe limits. The main way to test this system are control points on the IC to track the communication protocols, with use of an oscilloscope in the lab. Additionally, we can check if this is working in conjunction with the ventilation or heating systems - turning up the heating should provide a significant increase in temperature. Since we are also monitoring the sensors, we can use an external heat source to test the sensor output. A space heater will be used to shift the temperature higher and allow our MCU to read the temperature from the sensor (that should be changing the longer it is close to the space heater).

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.

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.

Criterion For Success

Our project should:

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)

3. Not power hungry and able to subsist off of the wattage of a normal fan and heater (1000W), the pulled power will be lower when the heater coils are not being used.

Parts List:

Potential PID system: **kr4fty/PID-temperature-control**
ATMega328 (Microcontroller)
DS18S20 (Ambient Temperature sensor)

- 1 Wire Bus
- https://www.analog.com/media/en/technical-documentation/data-sheets/ds18s20.pdf

MAX1464 (On chip temperature sensor)

- MAX1464 Datasheet and Product Info | Analog Devices
- 4-20mA current loop
- Calibration for outside temperature sensors (could grab ambient sensor readings and feedback to ATMega)

Nichrome Wire

- Talk to machine shop for ordering
- Nichrome 80-100' - 28 Gauge Wire - 100ft - 0.32mm - 0.013in - Made in USA - Master Wire Supply: Amazon.com: Tools & Home Improvement (Amazon option)
- Nichrome wire and transformer selection.
    - 10.8 V at 2.6 Amps for 500C (18” wire)

Steel-tubing:

- We require tubing with a moderate diameter and sufficient wall thickness to prevent warping when heated by Nichrome wire. The tube must have adequate thermal capacity to maintain heat without constant reheating. We plan to consult with the machine shop to gauge and buy the appropriate tubing that will suit our needs.

- Potential Tubing Options outside of Machine Shop: https://www.aliexpress.com/i/3256803591605778.html?gatewayAdapt=4itemAdapt

Power conversion (AC/DC)

- https://a.co/d/6YuQppb
  - 20V/3A converter, covers nichrome wire and ATMega powering (can grab a DC step-down from 20V/3A to 5V/1.5A)
- DC Buck Converter - 20V-72V to 5V 5A
  - Potential option for 20/5 DC buck converter
- https://www.grainger.com/product/808FR6?gucid=N:N:PS:Paid:GGL:CSM-2295:4P7A1P:20501231&gad_source=1&gclid=Cj0KCQjwjNS3BhChARIsAOxBM6r1zvEEQV4p3nhtZ9GAPMrAYaWaa8LqQCUENJ4TA4NoLNCam5CBh2caAuldEALw_wcB&gclsrc=aw.ds
  - Female connector for board (DC)

Enclosure:

- Generic plastic storage container will work, we will have thermal insulation on the inside of it to prevent the box from warping
- Insulation Material Box: https://t.ly/K4pUT
  - Material to have inside the box to stop warping and maintain temperature in the coil

Blower Unit:

- #1 Fan Choice:

  https://www.amazon.com/Wathai-5300rpm-Airflow-Brushless-Cooling/dp/B07SGWNV5J/ref=sr_1_3?

- #2 Blower Choice:

  https://www.amazon.com/SEAFLO-Line-Marine-Bilge-Blower/dp/B0166S2PA2/ref=sr_1_6

- Wide Flow Blowers: Link

- Fan Based Blower: Link, https://dannermfg.com/products/pondmaster-air-pumps

Citations

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