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The Feasibility of a Heated Box for Clothing Items

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Abstract

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This study concerns the feasibility of a heated box for clothing items, as a precursor to a heated closet. Suitable materials for the box are examined, along with the resistive heating elements (RHEs). Namely: a parallel resistor connection, copper, nichrome and nikrothal wire. Lastly, the heating of the wire is controlled through the use of an Arduino 2560 microcontroller, operating a pulse width modulation (PWM). The purpose of the study was to increase the temperature within the box to the degree that clothing items placed within the box during the heating process could then be worn by the user, and keep them warm in colder environments.

Initially, the assumptions were that a 25°C increase in air temperature would be sufficient and would require 4W of power. Testing commenced with the parallel resistor connection as a first safe step, to determine if the assumed resistance, voltage, current and power values were correct. However, intial assumptions were found to be incorrect, as the temperature increase was not attained and the voltage, current and power values were insufficient.

Although theoretical values were calculated for all the wire types, practicality demanded that only nikrothal wire could be physically tested. Throughout the process, the wire length and resultant resistivity was adjusted, along with the applied voltage and subsequent current and power values.

Ultimately, the best results were attained when the air temperature increase was approximately 45°C, which required that the nikrothal wire be heated to 100°C. These results were obtained by applying 17V over a 2 minute period to 4.4Ω of parallel connected wire. At the latter stages of testing, a 75% PWM was implemented to keep within a 1°C error margin of the maximum RHE temperature.

Once the box was deemed to be working as desired, clothing items were confined to the box , heated, and worn in 3°C weather. They were found to keep the user warm for a period of at least 15 minutes, though results could vary.

Although the voltage and current required to power the box were larger than expected, indicating that an easily purchasable battery pack would be insufficient, the heating box was still determined to be feasible and the goal of warming clothing items was achieved.

Keywords: RHE, PWM, Heating box, nikrothal wire.

Contents

List of Abbreviations

AWG:	American Wire Gauge. Signifies a wire size in a North American standard starting from 40 AWG and reaching the largest value of 0000 AWG. This is contrasted with the European metric system, utilized for determining wire size or cross-sectional area.
DUT:	Device Under Test. A device or equipment undergoing testing, either initially by a manufacturer or later during its life cycle as part of ongoing functionality testing.
PCB:	Printed Circuit Board. A typical medium utilized within electronics to connect electrical components together in a controlled manner.
PID:	Proportional, Integral Derivative. A controller loop mechanism which employs feedback to adjust an output, which in this case is voltage.
PWM:	Pulse Width Modulation. This is a digital signal which moderates an electrical voltage and reduces the average power supply, by breaking into parts. These parts are described in its duty cycle, which may take the form of 25%, 50% 75% or 100%.
RHE:	Resistive Heating element. This refers to an object which generates heat when electrical current passes through itself, due to its resistive nature. They are usually comprised of metallic alloys, ceramic materials/metals and are rated in Ω or Ω/m.

1 Introduction

The purpose of this study is to determine the feasibility of a heated box for clothing items as a precursor to a heated closet. Therein the feasibility of different materials as a resistive heating element or RHE, namely copper, nichrome and/or nikrothal wire, will be examined along with the benefit that may be accrued to the user of the box.

The ideal temperature of the clothing items within the box is estimated to be 45°C and is based on the average person’s body temperature being 37°C, as temperatures that exceed 40°C cause people to feel uncomfortable [1]. However, as items heated in the box would lose their heat rapidly when removed and placed into much cooler environments, the clothing items need to be warmed above the accepted comfortable temperature. Additionally, as the clothes may not warm as fast as the surrounding air, it is possible that the box may need to be heated above the 45°C assumed threshold.

The elements to the heated box are as follows: Firstly, an Arduino (Mega 2560 microcontroller) has been decided upon as the PID controller which would be programmed to operate the voltage applied to the RHE.

Secondly, the resistive heating elements that may be utilized as a DUT within the heated box are copper, nichrome and/or nikrothal wire. However, initially a resistance ladder is to be utilized as a safer first test of the circuit as the resistors would simply burn out if the power is beyond the (resistor) manufacturer specifications, whereas copper and nichrome may increase their heat into a range of hundreds of degrees.

Lastly, the box is required to have reasonable dimensions, being large enough to hold small clothing items but small enough that it does not require massive amounts of power to heat, thereby limiting the necessary voltage and current.

Once the box is constructed and its operation tested, the feasibility to the user will be examined.

2 Theoretical Background

The basis for creating heat within the box hinges on Ohm's law and its variations (such as Joule's Law), namely that the current through a conductor between two points is directly proportional to the voltage across those points. This may be expressed by the known formula below:

$$I = \frac{V}{\mathrm{R}} \qquad (1)$$

Where *I* refers to current, *V* is voltage and R is resistance.

When the above formula (1) is reworked in terms of heat, it is considered Joule's heating or Joule's law and is expressed as:

$$P = I^2R \qquad (2)$$

Where *P* in formula (2) refers to Power and may be further expanded upon to determine heat and time taken where:

$$H = I^2Rt \qquad (3)$$

In the above formula (3) *H* refers to heat and *t* refers to time taken.

These three equations inform the basis for heating the box and can be examined in terms of the RHE in use.

2.1 Resistors in Parallel

The first type of heating element or RHE that will be tested is the resistors in parallel, which is a parallel combination of resistors repeated together that will resemble a ladder when completed, as shown below.

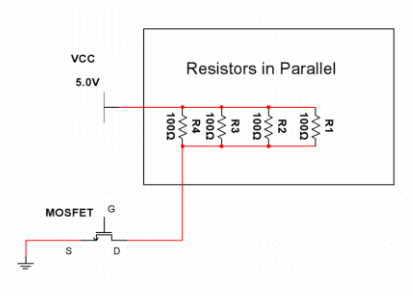

Figure 1. Resistors connected in parallel configuration.

The above Figure 1 shows four resistors of 100Ω value connected in parallel. The parallel connection of resistors creates a new total resistance value through the known formula:

$$\frac{1}{R_T} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots \frac{1}{R_n} \tag{4}$$

The above formula (4) shows the method for calculating the sum of resistors in parallel, and if all the values of R_1 to R_4 from figure 1 are inserted into the formula then R_T would total 25Ω.

As shown in the above in figure 1, the resistance ladder will be connected to a voltage source and a MOSFET transistor, which will be expanded upon in further chapters. Additionally, the calculated value of R_T will be placed into formulas 1,2 and 3 to determine a suitable heating value, which will also be discussed in subsequent chapters.

A parallel resistors configuration is not suitable as a long term solution as the resistors would burn out over time. How much power the resistors can tolerate and for how long would be determined by the resistor’s wattage rating, normally being either a ¼ Watt rating or ½ Watt rating.

2.2 Copper Wire

Another RHE that will be examined is copper wire. There are a few components to examine when dealing with wire as a heating element, namely: Resistivity, conductivity, malleability, safety and its overall suitability. Suitability in this instance refers to the fit for purpose, as for example a wire used in a water heater needs to be non-corrosive and non-conducting. The features of copper would be best expressed in a table format as shown below.

Table 1. Properties of copper

Copper	**Values**	**Suitability**
Resistivity	$1.68*10^{-8}$ (ρ/m)	Not good
Conductivity	$59.6*10^{6}$	Not good
Malleability	High	Good
Safety	Poor due to high current	Not good

As per the above table 1, it is shown that copper has a very low resistivity and a very high conductivity [2]. In fact, conductivity is the inverse of resistivity, and the above values make sense. Unfortunately, if resistivity is low, when placed in formula (3) for heat, then the value of heat (H) is equally low, unless current is proportionally high. Having an exceeding large current would be deemed unsuitable as it is impractical and falls particularly low in the safety category. This will be further expanded upon in subsequent chapters.

However, in terms of copper wire, the gauge or the width of the wire needs to be accounted for, as resistivity varies with the diameter and length of the wire. Table 2 below shows some values of different AWG Gauge wires, with the complete table placed into appendix 1, table 1.

Table 2. Copper wire resistance values at various gauges. Data gathered from Engineering toolbox (2008) [3].

AWG	**Area (Circular Mils)**	**European standard: Diameter (mm)**	**Resistance at 25°C (Ω/m)**	**Resistance at 65°C (Ω/m)**	**Weight (kg/m)**
0000	212000	11.684	$0.164*10^{-3}$	$0.187*10^{-3}$	0.954
10	10400	2.5908	$3.35*10^{-3}$	$3.87*10^{-3}$	0.0467
30	101	0.254	0.344	0.397	$0.452*10^{-3}$
40	9.9	0.07874	3.510	4.035	$0.298*10^{-4}$

As per the above table 2, it is shown that electrical resistivity increases the smaller the wire’s diameter, as well as an increase in resistivity with temperature. Thus, as formula (3) indicates, heat (H) will increase with a larger resistivity and practicality would demand that a lower gauge wire be utilized (40 being the lowest) to achieve the highest resultant heat.

As it relates to the suitability of copper; copper is extremely malleable and may be fitted by wrapping the wire into a coil shape, thus saving space length wise and has the added benefit of adding heat unto itself (as the layers of wire leave less surface area exposed to air and heat dissipation). Additionally, copper is extremely durable as it normally does not corrode or deteriorate over its lifetime and has a high level of heat conductivity with a melting point of 1084°C [4].

2.3 Nichrome and Nikrothal Wire

The second heating RHE to be investigated is Nichrome wire. Nichrome also known as nickel chrome is a composite alloy consisting of nickel and chromium (possibly also iron) and can be found in two types, A and C. Type A consists of 80% Nickel and 20% Chromium, while type C consists of 60% Nickel, 16% Chromium and 24% Iron. Both types however, come in various gauges ranging from between 0 – 46 Gauge wire, the properties of which will be expanded upon in the following tables. [5;6.]

Table 3. Properties of Nichrome wire.

Nichrome wire	**Value**	**Suitability**
Resistivity	1 to $1.5*10^{-6}$ (Ω/m)	Can be quite good
Conductivity	$1*10^{6}$ (Ω/m)	Good
Malleability	High	Good
Safety	Medium	Medium

Table 3 above shows the basic properties of nichrome wire in the same format as the previous copper wire table 1 but cannot be taken into full context without specifying the gauges of wire, as shown in the following table 4 [7].

Table 4. Nichrome wires A and C resistance values. Data gathered from WireTronic Inc. (2017) [8].

AWG	**European standard: Diameter (mm)**	**NiCrA Resistance at 20°C (Ω/ft)**	**NiCrA Resistance at 20°C (Ω/m)**	**NiCrC Resistance at 20°C (Ω/ft)**	**NiCrC Resistance at 20°C (Ω/m)**
6	4.1148	0.02477	0.007549896	0.02572	0.007839456
10	2.5908	0.06248	0.019043903	0.06488	0.019775423
30	0.254	6.5000	1.981199937	6.75	2.057399934
46	0.039878	263.70	80.37575743	273.84	83.46642933

Table 4 above shows the various resistance values for both types of nichrome wire at an assumed room temperature of 20°C, with a more complete table placed into appendix 1, table 2. Similar to copper wire, as the diameter of the wire decreases or the gauge decreases, the resistance increases. However, as can be seen from table 4 and table 2, the resistance value for nichrome is much larger than that of copper and thus when placed in formula (3) produces a greater value for heat (H) given the same current. Proper calculations for this material will follow in subsequent chapters.

As concerns the suitability of nichrome, it is also malleable and may be fitted by wrapping the wire into a coil shape. Additionally, nichrome is extremely durable as it is protected from oxidisation. As the temperature of the wire increases nichrome wire develops an outer layer of chromium oxide making it impervious to oxygen, unlike other types of metal. Lastly, nichrome A wire may be heated to 1400°C before melting with a maximum operating temperature of 1180°C, while nichrome C melts at 1350°C and has a maximum operating temperature of 1150°C. [6;7.]

Lastly, Nikrothal wire is an austenitic nickel-chromium alloy (nichrome) which can be implemented up to temperatures of 1200°C and found in many home appliances, such as flat irons or ironing machines. The term austenitic refers to an alloy which consists primarily of austenite, which is a commonly used stainless steel, containing a high percentage of nickel and chromium. Owing to superior adhesion properties of the surface oxide, Nikrothal has a better service life than regular nickel-chromium alloys. [9;10.]

Nikrothal, like the other RHEs come in a variety of sizes and resistance values, starting from nikrothal 20 and ending at nikrothal 80. The resistance information is presented below in table 5.

Table 5. Nikrothal 20-80 Resistance values. Data gathered from Kanthal [11].

Type	Diameter (mm)	Resistance @20°C (Ω mm^2/m)	Operating temperature (°C)	Melting point (°C)
Nikrothal 20	1 – 4	0.95	1050	1380
Nikrothal 30	1 – 4	1.03	1050	N/A
Nikrothal 40	1 – 4	1.04	1100	1390
Nikrothal 60	1 – 4	1.11	1150	1390
Nikrothal 70	1 – 1.5	1.18	1250	1380
Nikrothal 80	1 – 4	1.09	1200	1400

Table 5 above illustrates the resistance values for various types of nikrothal wire, along with its operating temperature and melting point. It is worth mentioning that the Resistance values as quoted from their data sheets are given as Ω mm^2/m and thus total resistance is based on the thickness of the wire attained, as well as the length [9].

2.4 MCP9701 and LM35 Temperature Sensor

The heated box requires a minimum of two temperature sensors to determine the satisfactory operation of the box. One sensor would be attached to the RHE to provide feedback to the PID controller, and the second sensor would be placed to the top of the box to determine the temperature within the box. This study will utilize two types of temperature sensors, as those are the types available, namely the MCP9701 and the LM35 temperature sensor.

The MCP9701 can measure temperature ranges between -10°C to +125°C and is a linear active thermistor, whose output voltage is directly proportional to the measured temperature. Its linear slope changes at a rate of 19.53mV/°C, which signifies that for every increase of 1°C the sensor outputs 19.53mV [12]. The MCP9701 comes in a 3-pin package and is illustrated below in figure 2.

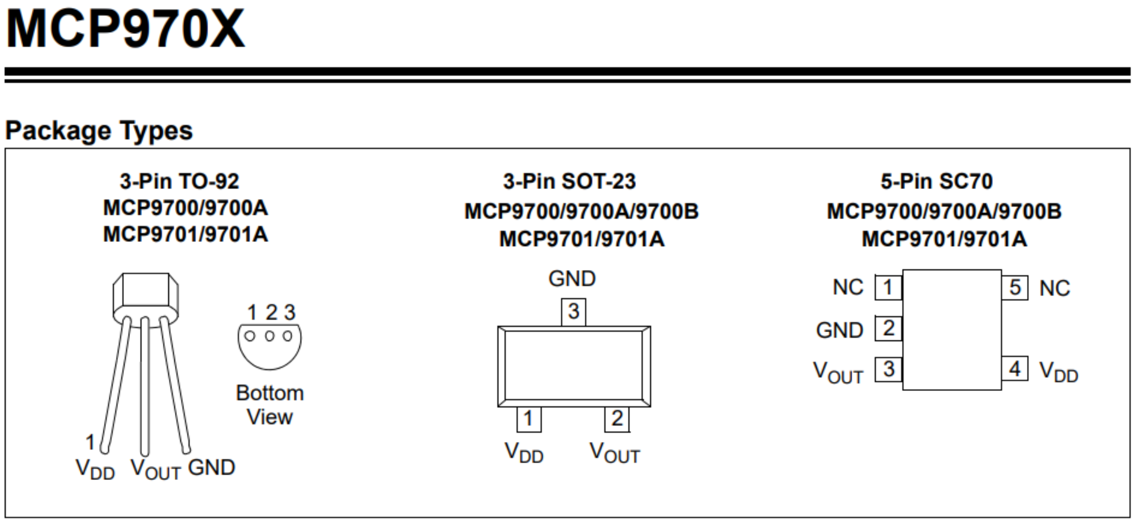

Figure 2. MCP9701 layout reprinted from data sheet [12].

The above figure 2 shows the MCP9701’s 3-Pin package where pin 1 is V_{DD} or the positive supply voltage, pin 2 is V_{OUT} or the voltage out, and pin 3 is connected to ground.

The LM35 temperature sensor, like the MCP9701, has an output voltage that is directly proportional to the temperature. However, the LM35 has an output voltage of 10mV/°C, thus for every 1°C of temperature rise its output voltage increases by 10mV. The measurement range, however, is slightly better than the MCP9701, as it can measure between -55°C to +150°C. The LM35 also comes in a 3-pin package and is only discernible from the MCP9701 by the manufacturer’s markings. The pinout of the LM35 is presented below, figure 3. [13.]

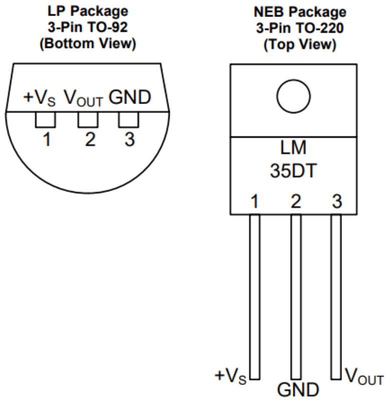

Figure 3. LM35 pinout from datasheet [13].

The above figure 3 shows the LM35 pin assignments from pin 1 to pin 3. The first pin is assigned to $+V_S$ or voltage supply, while the second and third pin can either be V_{OUT} or GND, depending on the LM35 version. In this study the LM35DZ is utilized and V_{OUT} or voltage out is assigned to pin2, while pin 3 is grounded.

A comparison between the features of the two temperature sensors are best represented in a table which is presented below.

Table 6. Temperature sensor comparison.

Name	**MCP9701**	**LM35**
Temperature range	-40°C to +125°C	-55°C to +150°C
Accuracy	±4°C	±0.75°C
Accuracy at 25°C	±1°C	±0.25°C
Voltage range	3.1V to 5V	4V to 30V
Max supply current	12µA	56.2µA
Linear scale	19.53mV/°C	10mV/°C

The above table 6 compares the MCP9701 and LM 35 temperature sensor features and illustrates that the LM35 is more accurate than the MCP9701 with an easier to use scale and a much wider voltage supply range. However, for the purposes of this study, both sensors will be utilized as they both fall within acceptable parameters.

2.5 MOSFET

MOSFET stands for Metal Oxide Semiconductor Field Effect Transistor and may be described as a semiconductor device which is applicable for either switching or amplification purposes. A MOSFET is a four terminal device containing a gate (G), source (S), drain (D) and body(B), but typically three electrical leads- S, G and D. The structure of the device is depicted below, figure 4. [14.]

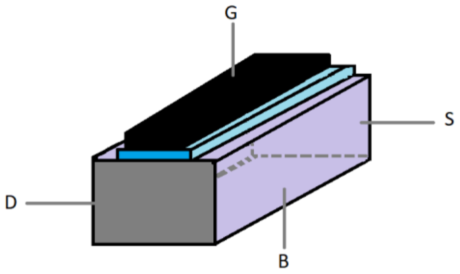

Figure 4. Structure of a MOSFET device.

Figure 4 above depicts the structure of a MOSFET, and its function depends on electrical variations that occur along the channel width as well as the flow of carriers (holes or electrons). The channel width is located between the source and the drain and is determined by the voltage from the gate. This operation is depicted below, figure 5.

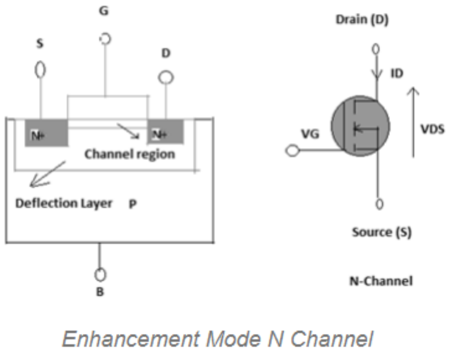

Figure 5. N-Channel MOSFET electron flow. Reprinted from Elprocus [14].

The above figure 5 depicts the electron flow in an n-channel MOSFET from source (S) or input (pin 3), to drain(D) or output (pin2), as voltage is applied to the gate (G) or control (pin 1).

Within this study, the MOSFET to be used is the 055N03L model and will be utilized as a switch, connected between the microcontroller and the heating element. The microcontroller sends a “high” signal to the gate, which switches the transistor on, connecting the drain and source which completes the circuit.
The 055N03L is an n-channel MOSFET, implying that the mobility of electrons is greater than holes, which are found in the p-channel device. Due to this superior mobility, n-channel MOSFETs are faster than p-channel MOSFETs and thus ideal for switching. [14.] More information concerning this model MOSFET is shown below, table 7.

Table 7. 055N03L MOSFET data gathered from datasheet [15].

Type	**N-channel MOSFET 055N03L**
V_{DS}	30V
$R_{DS\ (on)\ max}$	5.5mΩ
I_D	50A
Gate source voltage	±20V

Table 7 above shows that the voltage that may be applied at the gate could reach a value of 20V. The $R_{DS\ (on)\ max}$ value of 5.5mΩ represents the resistance at drain to source when the channel is completely open. An $R_{DS\ (on)\ max}$ value of less than 0.01Ω allows the MOSFET to run cooler and extend its lifespan. [15.]

2.6 Wood vs Plastic

The type of material that the box will be made of is important, as it needs to withstand temperatures of at least 45-50°C and 100°C at the RHE, or possibly higher in the event of malfunction. Additionally, the box would need to be sturdy enough that it does not wobble, as the heating element should be affixed in such a way that if the box were to move, the heating element would not touch the clothing items held within.

To explore this, it would be possible to first consider plastic as a housing element, due to the lowest melting point of any plastic being polystyrene at 170°C. However, the lowest recommended operating temperature for any plastic belongs to Ionomer at 34°C [16].

There is also the additional consideration of its size or fit for purpose. While there may be a ready-made solution that can be purchased, the most ideal scenario is to mould the plastic to the dimensions deemed most suitable for the heated box. This may be achieved through 3D printing of an ABS material which has an operating temperature value of between 75°C and 110°C at maximum [16]. A list of 3D printing materials is presented below to illustrate their operating temperatures.

Table 8. Popular 3D printed materials and their maximum operating temperature. Data gathered from RYD Tooling, form labs [16;17].

Material	**Maximum operating temperature**
ABS (high heat)	110°C
PLA (Polylactic acid)	80°C
PETG (Polyethylene terephthalate Glycol)	63°C
Nylon (Polyamide)	280°C (melting point)
TPU (thermoplastic polyurethane)	100-163°C (melting point)
PVA (polyvinyl alcohol)	180-190°C (melting point)
HIPS (high impact polystyrene)	80°C

Table 8 above describes various popular 3D printing materials along with their heat capacity. From the above values it may be determined that only Nylon and a PVA material will be suitable for a heated box that contains an RHE that reaches 100°C. Although, 3D printing allows for exact dimensions to be achieved, most plastics would be deemed unsuitable for the purpose of a heating box, though some may be feasible.

Another option for creating a housing element is that of wood. As with plastic, it may be possible to find a ready-made solution, however building a wooden box that fits within the given dimensions may be the most ideal scenario. Generally, wood would need to be at a temperature of 250 °C before a spark or flame can ignite it, but this is not the only consideration [18]. Wood contains moisture, and the adjustment of environmental temperature may cause wood to expand and contract and thus lose its shape [19]. The type of wood is thus important in determining its suitability for withstanding high temperatures and some examples of these are listed in table 9.

Table 9. Types of wood and their ignition temperature. Data gathered from Long Shi, Chew. (2012) [20].

Wood type	**Thickness (mm)**	**Time (s)**	**Temperature (°C)**
Pine	20	11	306.6
Beech	20	13	270.4
Cherry	20	11	334.4
Oak	20	24	353.7
Maple	20	26	399.2
Ash	20	19	340.9

The above table 9 identifies various wood types and their thickness to show time taken and at what temperature the type of wood would ignite. This is not an exhaustive list of every type of wood, but from the sample group shown in table 9, it may be seen that various types of wood withstand higher temperatures than the plastic varieties found in table 8.

A contrast between the most suitable plastic and wood type is presented below, table 10.

Table 10. A suitability comparison between plastic and wood.

Features	**Plastic**	**Wood**
Maximum temperature	280°C	399.2°C
Sturdiness	Flexible	Inflexible
Ability to mould	Extremely high	High
Electrical conductivity σ(S/m) @ 20°C	$1.5*10^{-15}$	$1*10^{-3}$ to $1*10^{-16}$ (Dry to wet)

The above table 10 shows a comparison between wood and plastic for the purposes of a heated box. The table illustrates that wood can withstand higher temperatures than plastic, while also being sturdier. Plastic can be easier to mould than wood, provided it is constructed utilizing a 3D printer. However, wood is also easy to shape without the need for such specialized equipment. Additionally, both materials are deemed to be safe, as they are considered insulators rather than conductors [21]. The determining factor concerning which material should be used would therefore be cost and availability.

3 Methods and Materials

The way the heated box operates is determined by the type of PID controller in use (and its coding), the circuit that is built and the heating element chosen, as well as the box dimensions.

There are a few calculations that need to be made before construction of the circuit can begin, namely: the resistance values for the resistors in parallel and the gate resistor of the transistor, the resistance values for both the copper and nichrome wire, as well as the expected heat dissipation within the air in the box.

3.1 Resistors in Parallel and 055N03L MOSFET

Taking the resistors in parallel as the first RHE, the values of the resistors need to be calculated. This will be done by reworking formula (1) and (2) from chapter 1, where the new formula is as shown below:

$$R = \frac{V^2}{P} \qquad (5)$$

From formula (5) above, it can be seen that R is the total resistance of the connected parallel resistors. V^2 refers to the square of the voltage supplied, and P refers to the power to dissipate in the connected resistors. At this point there needs to be an assumption made, namely the amount of power to dissipate, which is unknown and the voltage supplied.

Once total resistance is known, the current required to operate at the power rating can be calculated utilizing formula (1). The best illustration of these values shall be presented below, table 11.

Table 11. Resistance and current values at given voltage and power.

Voltage	Assumed power	Total Resistance	Current
5V	3W	8.33Ω	0.6A
	4W	6.25Ω	0.8A
	5W	5Ω	1A
9V	3W	27Ω	0.33A
	4W	20.25Ω	0.44A
	5W	16.2Ω	0.55A
12V	3W	48Ω	0.25A
	4W	36Ω	0.334A
	5W	28.8Ω	0.41667A

Table 11 above illustrates the required current necessary to drive the power from a given voltage, utilizing various resistance values.

These resistance values, however, only show the total resistance value (R_T). To acquire the individual resistor values from the parallel resistors, formula (4) from chapter 2.1 is required, along with the rating of each resistor. As an example, assuming that 4W is the desired power output, table 12 below shows the corresponding R_T values along with the usual power rating of resistors.

Table 12. Quantity of parallel resistors in connection and their individual values.

R_T (Ω)	Power rating (W)	Individual values (Ω)	Quantity of resistors
6.25	¼	100	16
	½	50	8
20.25	¼	324	16
	½	162	8
36	¼	576	16
	½	288	8

The above table 12, illustrated the quantity of resistors needed to dissipate 4W of power between ¼ and ½ Watt rated resistors, based on a 5V (6.25Ω R_T), 9V (20.25Ω R_T) and 12V (36Ω R_T) voltage supply respectively.

For the purpose of testing the heated box, the parallel resistors RHE will first be implemented as sixteen 324Ω resistors (or as close a resistance value as possible) connected to a 9V supply through the transistor. As it relates to formula (3), heat (H) is now equal to 4W as a multiple of time. How much this value actually is will be discussed in the section titled measurements and results.

An additional consideration regarding resistors concerns the gate resistor needed for the transistor. It is considered proper practice to connect a resistor to the base or the gate of the transistor, to prevent an excessive flow of current [22]. In most cases a 1kΩ resistor is considered sufficient, as, if there are 5V through a 1kΩ resistor, the resultant current would be 5mA. In this study a 10kΩ resistor will be utilized, providing an even smaller current. However, in both cases the level of current is handled well by the microcontroller (Arduino).

3.1.1 Nichrome and Nikrothal Wire

The method for calculating the necessary values for the nichrome wire are the same as that for the resistance ladder. Applying formula (5), R is obtained based on an assumed power value. If power is taken as, for example, an assumed 4W with a 5V supply, then total resistance will be 6.25Ω, as calculated prior and illustrated in table 11. The closest value of nichrome wire that matches this resistance is 1m of the 35-gauge wire shown in table 4. Further examples of the necessary values for the wire are calculated and presented below, table 13.

Table 13. Nichrome wire length and resistance values (R) to maintain 4W of power with a 5V supply.

AWG	Diameter (mm)	Nicr A R values (Ω/m)	Length to maintain 4W @ R (m)	Nicr C R values (Ω/m)	Length to maintain 4W @ R (m)
25	0.45466	0.61843918	10.10608	0.642213579	9.7319648
26	0.40386	0.783640775	7.975593	0.813815974	7.6798689
27	0.36068	0.982675169	6.360189	1.020470367	6.1246266
28	0.32004	1.24785116	5.008610	1.296009559	4.8224952
29	0.28702	1.55143195	4.028536	1.611172748	3.8791619
30	0.254	1.981199937	3.154653	2.057399934	3.0378148
31	0.22606	2.50118872	2.498114	2.597505517	2.4061546
32	0.2032	3.096767901	2.018233	3.215639897	1.9436255
33	0.18034	3.928871874	1.590787	4.081271869	1.5313853
34	0.16002	4.99262384	1.251846	5.184647834	1.2054820
35	0.14224	6.318503798	0.989158	6.55929579	0.9528461

Table 13 above displays the length of nichrome wire, between gauges 25-35, required to maintain 4W of power with a 5V supply and 0.8A of current drawn. As can be seen from the table, the lower the gauge (35 being the lowest) – the smaller the length of wire required. Depending on the exact size of the heated box, a shorter length would be the most suitable. Additionally, this shorter length also corresponds to a smaller diameter, which is easier to accommodate in a small space.

Assuming the voltage supply comes through a battery back at either 9V or 12V, the following values for nichrome wire are calculated and listed below in table 14, where 9V requires 20.25Ω of resistance and 12V requires 36Ω of resistance for 4W.

Table 14. Nichrome wire length and resistance values (R) to maintain 4W of power with a 9V and 12V supply.

AWG	Diameter (mm)	NicrA (Ω/m)	Length @9V,4W (m)	NicrC (Ω/m)	Length @9V,4W (m)
25	0.45466	0.61843918	32.74372	0.642213579	31.531566
26	0.40386	0.783640775	25.84092	0.813815974	24.882775
27	0.36068	0.982675169	20.60701	1.020470367	19.843790
28	0.32004	1.24785116	16.22789	1.296009559	15.624884
29	0.28702	1.55143195	13.05245	1.611172748	12.568484
30	0.254	1.981199937	10.22107	2.057399934	9.84252
31	0.22606	2.50118872	8.096150	2.597505517	7.7959410
32	0.2032	3.096767901	6.539075	3.215639897	6.2973469
33	0.18034	3.928871874	5.154151	4.081271869	4.9616885
34	0.16002	4.99262384	4.055983	5.184647834	3.9057619
35	0.14224	6.318503798	3.204872	6.55929579	3.0872216
AWG	**Diameter (mm)**	**NicrA (Ω/m)**	**Length @12V (m)**	**NicrC (Ω/m)**	**Length @12V (m)**
25	0.45466	0.61843918	58.21106	0.642213579	56.056118
26	0.40386	0.783640775	45.93941	0.813815974	44.236045
27	0.36068	0.982675169	36.63469	1.020470367	35.277849
28	0.32004	1.24785116	28.84959	1.296009559	27.777573
29	0.28702	1.55143195	23.20436	1.611172748	22.343973
30	0.254	1.981199937	18.17080	2.057399934	17.497813
31	0.22606	2.50118872	14.39315	2.597505517	13.859451
32	0.2032	3.096767901	11.62502	3.215639897	11.195283
33	0.18034	3.928871874	9.162935	4.081271869	8.8207797
34	0.16002	4.99262384	7.210637	5.184647834	6.9435767
35	0.14224	6.318503798	5.697551	6.55929579	5.6975514

The above table 14 lists the lengths of nichrome A and C wire necessary to maintain 4W of power with a 9V supply and a 12V supply respectively. As was demonstrated in table 11 previously, assuming that 4W is not a large enough power value for the desired heat, an increase in power would demand a decrease in resistance and a concurrent decrease in wire length. In the interest of clarity, the following table 15 is presented below to represent the idea.

Table 15. Changes to resistance based on desired power and voltage.

Voltage (V)	Power (W)	R_T (Ω)	R_T change	Wire length (Assuming same gauge)	Current (A)
5	3	8.33	New (V)	Value N/A	0.6
5	4	6.25	Decrease	Decrease	0.8
5	5	5	Decrease	Decrease	1
9	3	27	New (V)	Value N/A	0.33
9	4	20.25	Decrease	Decrease	0.44
9	5	16.2	Decrease	Decrease	0.55
12	3	48	New (V)	Value N/A	0.25
12	4	36	Decrease	Decrease	0.334
12	5	28.8	Decrease	Decrease	0.41667

The above table 15 illustrates the necessary wire length adjustments needed, at a given gauge, to achieve the total resistance necessary for a desired power rating at 3 voltage levels: 5V, 9V and 12V. The “value N/A” represents the fact that the wire length is different at different gauges/thicknesses and thus there is no one set length.

In addition to the properties of nichrome wire described above it is important to note that nichrome wire is not necessarily easily available and comes at a higher cost than copper wire, or other alternatives.

As concerns the nikrothal wire RHE type. It follows the same parameters as previously discussed, and thus only a brief illustration shall be presented below in table 16. In this instance, there will be an assumed 5Ω total resistance contrasted with various nikrothal wire types, which will be compared to various voltage levels with its power output values.

Table 16. Nikrothal wire length to achieve desired Power.

Type	Length (m)	Resistance (Ω)	Voltage (V)	Current (A)	Power (W)
Nikrothal 20	5.26	5	5	1	5
Nikrothal 30	4.85	5	5	1	5
Nikrothal 40	4.81	5	9	1.8	16.2
Nikrothal 60	4.50	5	9	1.8	16.2
Nikrothal 70	4.24	5	12	2.4	28.8
Nikrothal 80	4.59	5	12	2.4	28.8

Table 16 above shows the changes in wire length required for a set resistance value of 5Ω, at various voltage levels and its resultant current and power levels. It should be noted that this information assumed a fixed wire thickness of 1mm, however, actual available values will differ.

Both nichrome and nikrothal wire follow the same guidelines, with the results of use varying only through the total resistance value utilised while in operation.

3.1.2 Copper Wire

Copper as an RHE follows the same principles as previous RHEs. The tentative aim is to achieve 4W of power with a 5V power supply with 0.8A of current. As was shown with nichrome, copper provides more resistance the smaller the diameter, the lower the gauge and the longer the wire. However, unlike nichrome there is no copper wire gauge that would provide 6.25Ω of resistance within 1m of wire, making it less practical than nichrome wire as a heating element.

For completeness, some values of copper wire resistance along with their required length to maintain 4W of power is shown below, table 17.

Table 17. Copper wire length needed to maintain 4W of power with a 5V supply.

AWG	**Area (Circular mills)**	**Diameter (mm)**	**Resistance @25°C (Ω/m)**	**Length required to maintain 4W of power @5V (m)**
30	101	0.254	0.344	18.16860465
32	63.2	0.2032	0.548	11.40510948
34	39.8	0.16002	0.873	7.15922107
36	25.0	0.127	1.388	4.50288184
38	15.7	0.1016	2.208	2.83061594
40	9.9	0.07874	3.510	1.780626

Table 17 above illustrates that even at the lowest gauge copper wire, there needs to be more than 1m of wire to achieve 4W of power, which in this context (the wattage) is not a lot. The exact heat (H) that can be obtained from the copper wire, as is with nichrome and nikrothal wire, will still be based on formula (3), where heat is equal to power (I^2R) multiplied by time (t).

As with nichrome and nikrothal wire, as the voltage increases, the total resistance increases to achieve the same power level, but as the power level increases at the same voltage, the total resistance decreases. When total resistance decreases, the necessary wire length decreases, while the reverse is also true. As this was thoroughly examined in the nichrome and nikrothal wire chapter, only a short example will be provided below, table 18.

Table 18. Copper wire length required for 3W, 4W and 5W of power at 5V and 9V respectively.

AWG	**Diameter (mm)**	**Wire length @ 3W, 5V (m)**	**Wire length @ 4W, 5V (m)**	**Wire length @ 5W, 5V(m)**
38	0.1016	3.772644028	2.83061594	2.264492754
40	0.07874	2.373219373	1.780626	1.424501425
AWG	**Diameter (mm)**	**Wire length @ 3W, 9V (m)**	**Wire length @ 4W, 9V (m)**	**Wire length @ 5W, 9V (m)**
38	0.1016	12.22826087	9.171195652	7.336956522
40	0.07874	7.692307692	5.769230769	4.615384615

The above table 18 demonstrates that, as with nichrome and/or nikrothal wire, as the diameter decreases total resistance increases. As the total resistance increases, the wire length required decreases. When the power desired at a given voltage increases, the total resistance and therefore wire length decreases. The table also illustrates that the higher the voltage, the more resistance and the longer the wire necessary to achieve the same power requirement, as was shown with nichrome wire.

3.1.3 Heating of Air (Based on Box Dimensions)

The decision on which material to utilize for the creation of the heated box is based on the factors described in the chapter 2.6. Ultimately, wood was decided upon, as the availability and ease of manufacture were considered superior. Specifically, this would be birch wood, which burns at between 250°C-300°C.

The measurements of the box are based on a plank of birch which measures 18mm thick and 145mm wide and could be sectioned off easily and evenly. The length of the box is designed to be 300mm externally and 264mm internally when accounting for the thickness of the wood joined at the ends. The height is then 163mm externally and 145mm internally, again accounting for the thickness of the wood joined at the base. The width of the box is taken as 250mm internally, plus 18mm on each side, totalling 294mm externally.

An example of this is depicted below in figure 6.

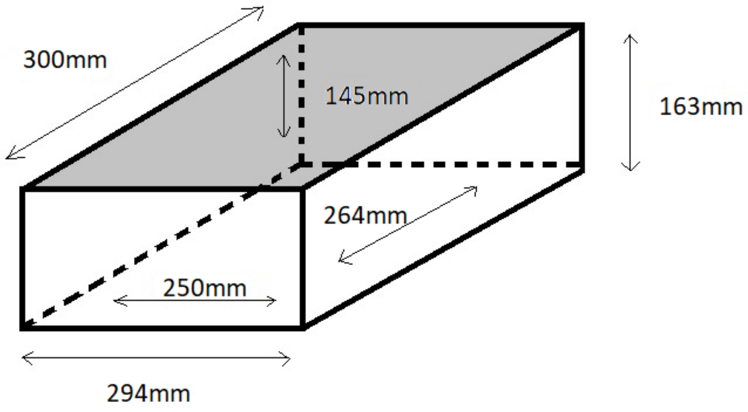

Figure 6. Box dimensions.

Figure 6 above shows the proposed dimensions for the heated box exclusive of the lid- which is to be connected with two hinges and firmly clasped into place, with nothing inside. In practice, the box would contain the RHE, temperature sensors, wires, a tray for holding the clothing items as well as a clothing item. Additionally, there would be a small hole toward the back to accommodate the wires, and at least four screws placed internally at the bottom for affixing the RHE. However, as is stands, from the image above, the volume of air contained within the box would be 0.00957m^3. To determine the power required to heat this air, requires usage of the heat capacity formula shown below, formula (6).

$$c = \frac{\mathrm{Q}}{\mathrm{m} * \underline{\Delta}\mathrm{T}} \qquad (6)$$

In the above formula (6), c refers to the specific heat, Q refers to energy added to increase the temperature, m to the mass of the object and $\underline{\Delta}$T is the change in temperature.

If the heat capacity of the material is known, then the energy required to cause a change in temperature can be determined by rewriting the formula as:

$$Q = \mathrm{c} * \mathrm{m} * \underline{\Delta}\mathrm{T} \tag{7}$$

The above formula (7) is simply a rephrasing of formula (6), with energy required to change the temperature as the subject.

Lastly, to determine the power required, both sides of the equation may be divided by time, shown below formula (8).

$$W = \frac{\mathrm{Q}}{\underline{\Delta} t} = \frac{c * m * \underline{\Delta}T}{\underline{\Delta} t} \tag{8}$$

The formula (8) above shows the power necessary to heat any material (inclusive of air), providing the specific heat, mass and change in temperature over a given time is known.

The density of air is 1.293kg/m^3, and within the box the volume is, as stated prior, 0.00957m^3. Thus, the mass of air is 0.01237401kg. The specific heat capacity for air is 1.012 J/(kg*K) with a required change in temperature of 25°C (assuming a need to move from 20°C, at room temperature, to 45°C).

Assuming a target of 4W, as stated earlier, the time taken to heat the air within the box should be 78.259 seconds.

However, there are many other factors to consider with heating the box, such as how the heat is transferred. In the above equations (6) through (8), the assumption is total energy required without consideration of the medium or method of transfer. As the box is to be sealed with no air flow, the transfer of heat would be due to radiation. Additionally, the wire to be used has a very small surface area, which means that it would take longer for heat to be transferred. To calculate the energy required for radiation heat transfer, formula (9) shown below is used.

$$Q = \varepsilon * \delta * \left({T_H}^4 - {T_C}^4\right) * A_H * t \tag{9}$$

In the above formula (9), Q is the heat energy transferred during radiation. ε refers to the coefficient of emissivity, which can be taken for example as 0.65 for

nichrome wire. The value of ε varies depending on the medium in use. σ is the Stefan-Boltzmann constant and is $5.6703*10^{-8}W/m^2K^4$ (Watts per square metre multiplied by Kelvin to the fourth power). T_H refers to the temperature of the hot object, which in this case is the RHE, rated in Kelvin. T_C refers to the temperature of the cool environment and is also rated in Kelvin degrees. A_H represents the area of the hot object or RHE.
Thus, utilizing the above formula (9) and assuming nichrome wire to be the RHE reaching a temperature of 100°C, with the environmental temperature assumed to be 25°C. The calculated energy released every second is 0.9693J, which equates 0.9693W.

Utilizing formula (7) directly with the mass of air as 0.01237401kg. The specific heat capacity of air being 1.012 J/(kg*K) and a required change in temperature of 25°C, the total energy absorbed would be 30.4612J. Then utilizing formula (9), this would require a time of 31.43 seconds. Formula (8) suggests that 4W is enough to heat the air within approximately a minute and a half, while formulas (7) and (9) suggest it requires 30W of power to be absorbed in 30 seconds to reach the desired temperature.

Ultimately, the actual power required is unknown and can only be determined though measurement and testing. However, what is known at this point, is that provided that the box is to be heated quickly, from approximately 30 seconds to a minute and a half would require between 4W and 30W of power (a huge difference).

3.2 Circuit Analysis and Additional Components

The circuit for the heated box includes the items mentioned above, namely: The microcontroller, MOSFET transistor, two temperature sensors, a 9V battery pack and the resistive heating element. The battery pack contains six, 1.5V AA batteries, which output a total of 9V. These components are connected via wires, firstly on a breadboard for testing and then permanently on a PCB, the general basis of which is depicted below in figure 7.

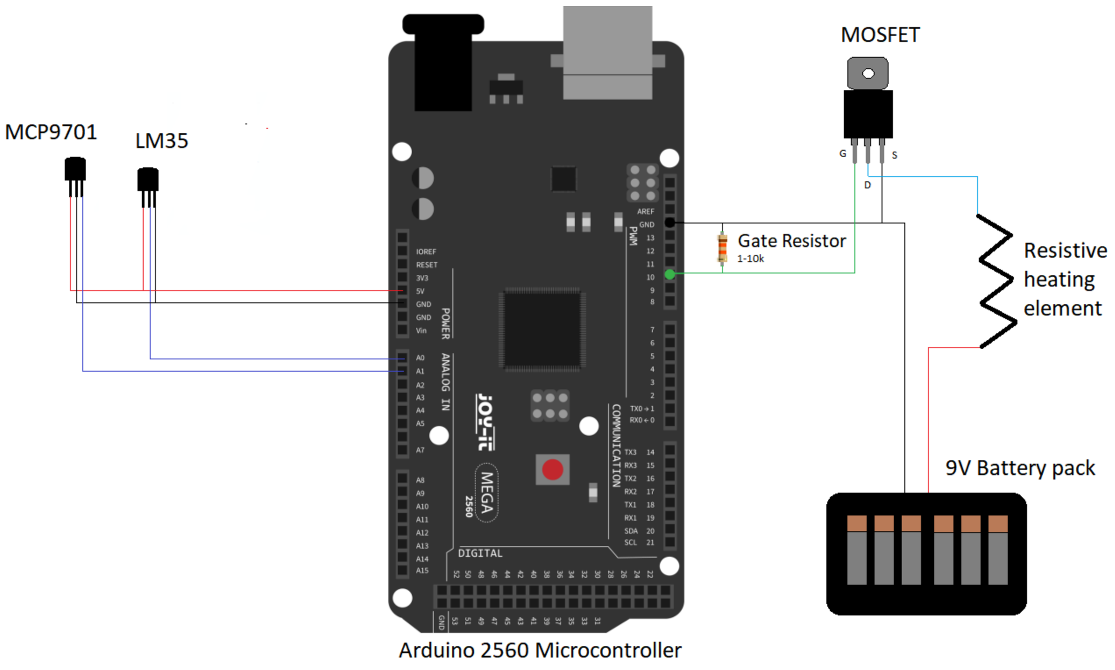

Figure 7. Circuit diagram for heated box. Figure Copied from ARD Manual [23].

Figure 7 above depicts the connections within a circuit diagram for the heated box. From this image the temperature sensors may be seen to be connected to ground, analogue inputs A0 and A1 and the 5V out pin from the Arduino.
The Gate pin from the MOSFET transistor connects to PWM pin 10 on the Arduino, which is also connected a gate resistor, which goes to ground. The transistor's drain pin is connected to the resistive heating element, which in turn is connected the 9V battery pack's power out line. Lastly, the transistors source pin is connected to the battery pack's ground line, which in turn is connected to a ground source on the Arduino. In the image, the resistive element is not stated, but represents either the resistor ladder, copper wire, nichrome or nikrothal wire.

The PCB layout for this circuit is rather simple but contains an additional component, namely a 2-pin connector nicknamed the "green monster" and needs to be designed utilizing KiCad software before the board can be milled. The PCB design and layout is depicted below, figures 8 and 9 respectively.

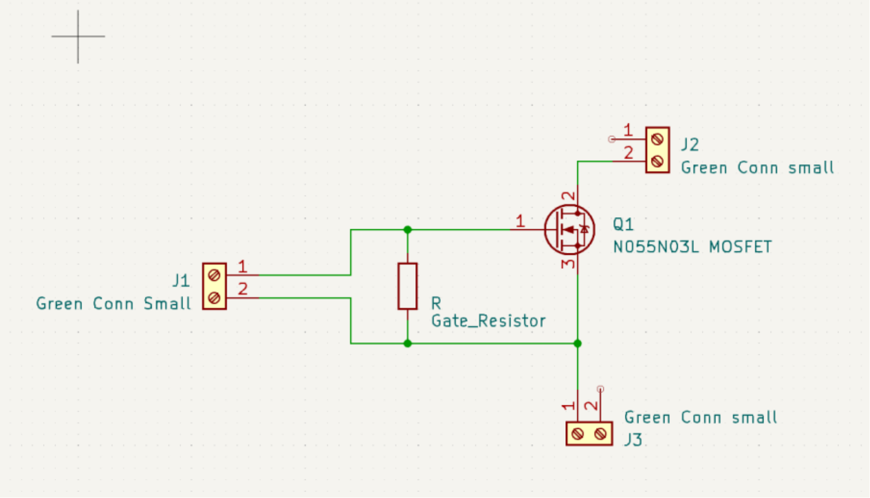

Figure 8. PCB design.

The above figure 8 shows the PCB design for the heated box circuit. It includes three 2-pin green monsters as well as the gate resistor and n-channel MOSFET.

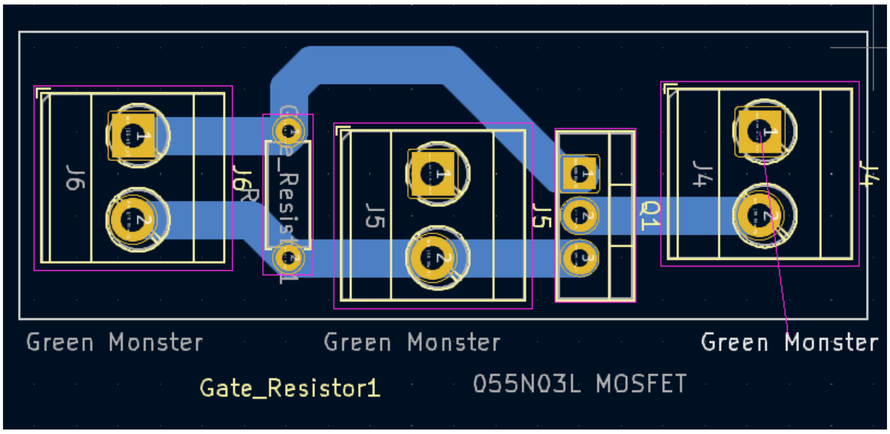

Figure 9. PCB Layout.

Figure 9 above depicts the PCB layout for the heated box, as illustrated through the PCB design. The size of the trace width and clearance is larger than normal but will be discussed in the safety concerns chapter.

3.3 Arduino as a PID Controller

The Arduino MEGA 2560 depicted below, figure 10, is the microcontroller being utilized for the heated box.

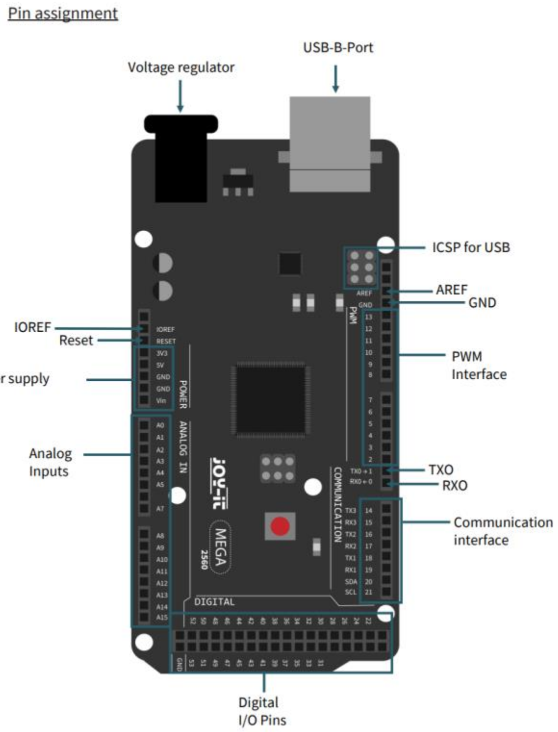

Figure 10. Arduino MEGA 2560, figure copied from ARD manual [23].

The above figure 10 depicts the microcontroller that is utilized as a PID controller in the operation of the heated box, the features of which are presented below in table 19.

Table 19. Arduino Features, data gathered from ARD Manual [23].

ATmega2560R3 Features	**Values**
Controller bits	8-bit
Memory	256kB (8k Bootloader)
SRAM	8kB
EEPROM	4kB
Clock speed	16MHz
Input voltage	7-12V
Input voltage (max)	6-20V
Digital IO	54 (14with PWM)
Analogue IO	16 (A0-A15)
DC Current IO	40mA
DC Current 3.3V	50mA
Additional pins	5V, GND and 4 serial ports

The above table 19 presents the features of Arduino ATmega2560R3 microcontroller and their values [23]. Additionally, this microcontroller was purchased as part of a set and was accompanied with a 9V battery pack which will be utilized in this study.

The battery pack requires an attachment to be connected to the breadboard, or the PCB board for testing. A depiction of both items is shown below, figures 11 and 12.

Figure 11. Standard 2.1mm pin, 9V battery pack.

The above figure 11, shows the battery pack utilized for this study, which holds six 1.5V, AA batteries for a total of 9V. The voltage out pin is a standard 2.1mm sized pins, which must match the attachment.

Figure 12. 2.1mm DC power plug attachment.

Figure 12 above shows the attachment necessary for the battery pack to connect to either the breadboard or the PCB. From the female 2.1mm DC power plug the wires extend to two alligator clips, one for ground and one for voltage.

It may also be noted that the Arduino contains a voltage in pin, which allows for the battery pack to power the Arduino as well as the RHE. However, for the microcontroller to function as desired, it must be programmed either through a desktop application or online. The code that was implemented for the Arduino is presented in appendix 2 in two formats. Firstly, for testing the maximum temperature attainable from the RHE device, and secondly, as a PWM. The PWM code only varies with the “if-else” statement and thus, only these differences will be shown below in listing 1 and 2.

```
// Regulation (Cut off)
     if (c > target)
      {
           digitalWrite(PIN_SWITCH, LOW);
           Serial.print("\tHeater OFF");
      } else {
          digitalWrite(PIN_SWITCH, HIGH);
          Serial.print("\tHeater ON");
     }

  delay(5000);
}
```

Listing 1. Maximum Temperature.

As listing 1 illustrates, the MOSFET is set to either on (HIGH) or off (LOW), based on the target temperature.

In contrast to this binary output (HIGH/LOW), the PWM contains a duty cycle, as presented below in listing 2.

```
  if (c > target)
  {
     digitalWrite(10, HIGH);
     delayMicroseconds(100); // Approximately 10% duty cycle @ 1KHz
     digitalWrite(10, LOW);
     delayMicroseconds(1000 - 100);
     Serial.print("\tHeater at 10 % PWM\n");
  } else {
    digitalWrite(PIN_SWITCH, HIGH);
    Serial.print("\tHeater ON\n");
  }

  delay(1000);
}
```

Listing 2. PWM.

Listing 2 above illustrates the change in the “if-else” statement, where instead of a simple on (HIGH) or off (LOW) function, the microcontroller now operates with a 10% PWM. It may be noted that for this type of PWM to function correctly, the delay between collecting temperatures has shifted from 5 seconds to 1 second. Additionally, at this point it is unknown whether a 10% PWM is suitable for maintaining the desired temperature.

3.4 Safety Concerns

When constructing a new design, it is important to analyse the various risks this design may pose to the intended user. Thus, implementing a best practice/routine, is the safest way to avoid an accident or injury.
Unfortunately, the design of the heated box does not incorporate a shield for the RHE, leaving the RHE exposed to human touch during operation. This is a terrible best practice, and in the event of malfunction, possibly very dangerous to the user. Theoretically however, the grounding of the RHE and having the box closed during operation limits the safety concerns, providing the user operates the box as intended.
In the event of miscalculation and the power is too high, the resistors in the resistor ladder could burn or even explode. This is unlikely to cause any damage, even less so if the box is closed, but is still a concern. It is considered appropriate for this study, that when testing the box, the user closes the box while voltage is being applied and shields their eyes if necessary.

As concerns the nichrome wire, in the event of miscalculation, the wire can reach a maximum temperature of 1200°C. In the event of serious miscalculation, it is almost impossible to reach anywhere close to this temperature, as the voltage applied is limited to 9V from the battery pack. However, damage may be caused to both the clothing item and the box itself at temperatures of 200°C and over. As all items in this test can be ignited, the user needs to consider the possibility of fire and a C02 fire extinguisher and/or fire blanket should be close at hand. One of the fire safety items utilized in this study is depicted below, figure 13.

Figure 13. Fire blanket.

Figure 13 above depicts the fire blanket utilized in this study and may be deemed suitable for small electrical fires, though this is not its main purpose, as it is more suited for small kitchen fires.

Additionally, it would be considered best practice to add a thermal fuse to the design between the positive voltage line and the RHE. This would function as an insurance protocol, disconnecting the RHE in case of malfunction. Thus, if the voltage is not taken from a limited power supply and exceeds the designed threshold, or perhaps the temperature sensor malfunctions, the voltage to the RHE would be disconnected.

Silicone covered electrical wires are used for the connection between the circuit and RHE via the hole to the back of the box. These wires were coloured red and black to separate power and ground and were chosen due to its higher resistance to heat. The wires need to be either soldered or crimped, and the ones utilized in the study are pictured below, figure 14.

Figure 14. Red and black coloured silicone wire.

The above Figure 14 depicts the two silicone wires that were used to connect the circuit to the RHE. They are colour coded to avoid incorrect connection and possible mishaps that may arise. Silicone covered wires were chosen as all items, once possible, should be as heat resistant as possible to avoid potential fire hazards.

An additional consideration regarding the electrical wire concerns their thickness. Previous assumptions suggested, for example, a 4W output with 9V and thus a current value of 0.44A. This value places little constraint on wire thickness, and thus almost any size wire is acceptable. However, if the power is insufficient and needs to be increased, the wire thickness will also need to be increased. The wire depicted above, figure 14, is 0.25mm^2 thick. This translates to a current carrying potential of 5A and should be suitable for this study without the risk of fire, but its limits should be noted to prevent any mishaps [24]. Some Wire sizes and their current rating are presented below in Table 20.

Table 20. Wire Size and Current Rating. Data gathered from Cable tester [24].

Max Current	AWG	Diameter	Cross Section Area	Current Capacity
0.1A	NA	NA	NA	NA
0.3A	NA	NA	NA	NA
0.5A	30	0.3mm	0.05mm^2	0.8A
1A	28	0.36mm	0.08mm^2	1.25A
3A	26	0.46mm	0.14mm^2	3.5A
5A	24	0.61mm	0.2mm^2	5A
25A	17	0.92	0.5mm^2	29.2A

Table 20 above demonstrates the current carrying ability of wire based on wire thickness, where values below half an amp are negligible and wire thickness increases from half an amp upward.

Lastly, as the wire is limited in its ability to carry current, so too is the breadboard. Thus, with a small current the breadboard is adequate, but with a larger current it will be deemed unsuitable, hence the need for a PCB. When designing the PCB, the trace width is to be adjusted to 2.79mm to account for a maximum of 5A of current, in the event that the projected 9V and 4W is deemed inadequate [25]. Table 21 below provides some examples of the trace width required for their relevant current.

Table 21. IPC Track width recommendation. Data gathered from MCL [25].

Current (A)	Trace Width (mil)	Trace Width (mm)
1	10	0.25
3	50	1.27
5	110	2.79
10	300	7.62

Table 21 above presents the IPC recommended track width for a PCB board that is 1oz thick with a 10°C temperature rise. As can be seen from the table, the trace width increases as current capacity increases. However, as not noted in the table, as the temperature rise increases, the required trace width thickness decreases.

Constant monitoring of the temperature within the box, while the box is in operation, is necessary throughout coding and testing to limit any potential issues. However, once the microcontroller’s code is operating as intended and the length of wire is correct, the safety concerns decrease dramatically.

4 Measurements and Results

Firstly, the box was built to the dimensions as described in chapter 3.1.3 and is depicted below in figure 15.

Figure 15. Image of heating box from all sides.

Figure 15 above shows the heated box post construction, matching the dimensions described previously. In addition to the box dimensions, as can be seen from the image, the lid is affixed to the top of the box with two hinges placed on the back of the box. The Box can be sealed as tightly as possible utilizing the two latches placed on the front of the box. The pieces of wood were joined using nails and glue to prevent air from passing through. However, there is a hole to the back of the box for wires to pass, which may allow for some air flow.

After construction of the box was completed, components were placed in the box for testing and the results are the subject of this chapter. Notably, it was decided not to test the copper wire, as suitable copper wire was not available. This issue will be included in the discussion chapter.

4.1 Parallel Resistors Results vs Expected

To achieve the 20.25Ω of resistance required for 9V required the usage of 16, 324Ω resistors in a parallel connection, as described in chapter 3.1.1. However, a 324Ω resistor is not available for use and the closest values are either 220Ω or 470Ω. Therefore, the connection of resistors was achieved utilizing ten 470Ω resistors and six 220Ω resistors.

According to formula (4), this would give a total resistance of 20.59760956Ω. Subsequently, utilizing formula (5), given the calculated $R_{T,}$ the resultant Power is 3.932495165W or approximately 4W, dissipated over 16, ¼ W resistors.

However, the actual resistance as measured from the digital multi meter for the 470Ω resistors were mostly 465Ω, the 220Ω resistors measured between 217Ω-220Ω, most being 218Ω. Actual total resistance (R_T) of the parallel resistors, as measured by the digital multi meter was 20Ω exactly.

This would provide 4.05W of power, which is slightly above the resistors rated capacity, and would mean the resistors would malfunction slightly quicker than they were designed. However, this is close enough to the intended target to proceed.

The parallel resistor construction is presented below in in figure 16.

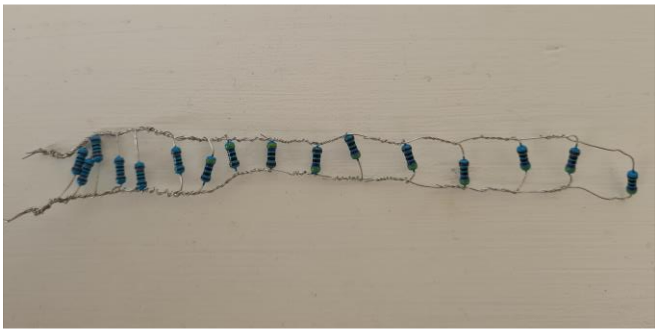

Figure 16. 20 Ω Parallel Resistor configuration.

Figure 16 above shows 16, ¼ W rated resistors, connected in parallel for use as the first RHE.

The circuit was set up as described in figure 7, and the code implemented as described in chapter 3.3, listing 1, with the following results:

- Box’s internal temperature at start was 21.48°C.
- RHE’s temperature at start was 21.48°C.
- Time for test equalled 20 minutes.
- Maximum RHE temperature was 41.99°C.
- Maximum air temperature was 24.28°C.

A graphical representation is presented below in figure17.

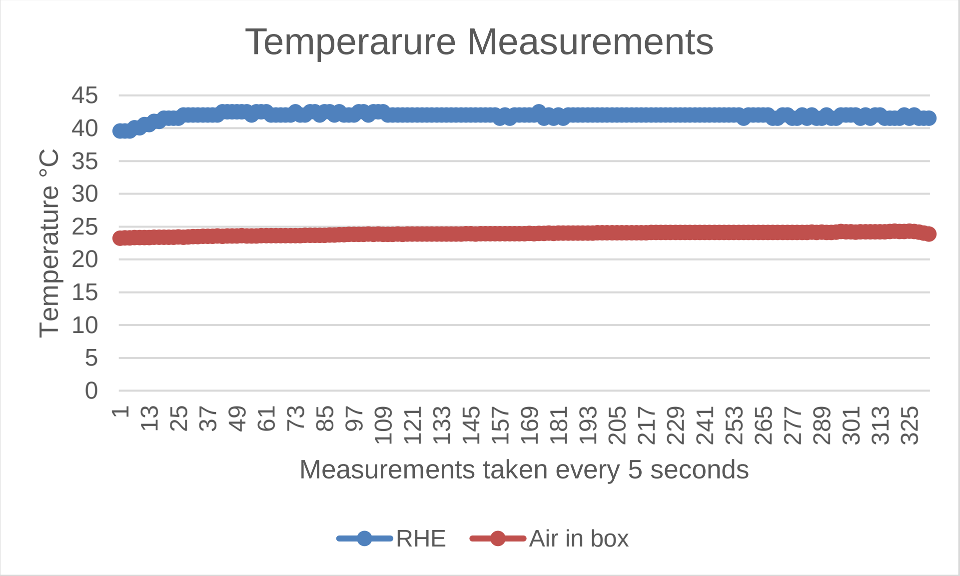

Figure 17. 20 Ω Parallel Resistor RHE temperature with a 9V supply.

Figure 17 above shows the temperature within the heated box on the y axis, as compared to the temperature of the RHE, shown on the x axis. It contains 188 data points, recorded over a 20-minute period. The maximum temperature the RHE could achieve was 41.99°C, while within this time frame the air within the box reached a maximum of 24.28°C. The target point according to the Arduino code was 50°C, indicating that with a 9V battery pack, the RHE could not heat past 41.99°C.

As this is an unsatisfactory result, a change of approach is required. Assuming all things remained as expected, a decrease in R_T should have caused an increase in power, and thus an increase in heat.

Supposing this doubling of power to 8W, then there would be a minimum of 32 resistors required. Following the guidelines shown in tables 11 and 12 above, the total resistance value (R_T) would be 10.125Ω. This would give each resistor value a total of 324Ω (the same prerequisite as the 20.25Ω R_T).
As 324Ω resistors were still not available, there needed to be a recalculation of resistor values. However, this was rather simple, as the values only needed to be doubled. Thus, in total, to achieve an R_T 10.125Ω would require 20, 470Ω resistors and 12, 220Ω resistors.
As with the first resistor connection, the total resistance accrued from this combination was exactly 20Ω. A Combination of these two parallel resistor connections measured exactly 10Ω. Thus, the new power output, given a 10Ω R_T, should have been 8.1W.

The heated circuit was connected as previously done, and the new combination of parallel resistors measuring 10Ω was connected. The listing 1 code was run as before, for a total of 20 minutes and the results are presented below, figure 18.

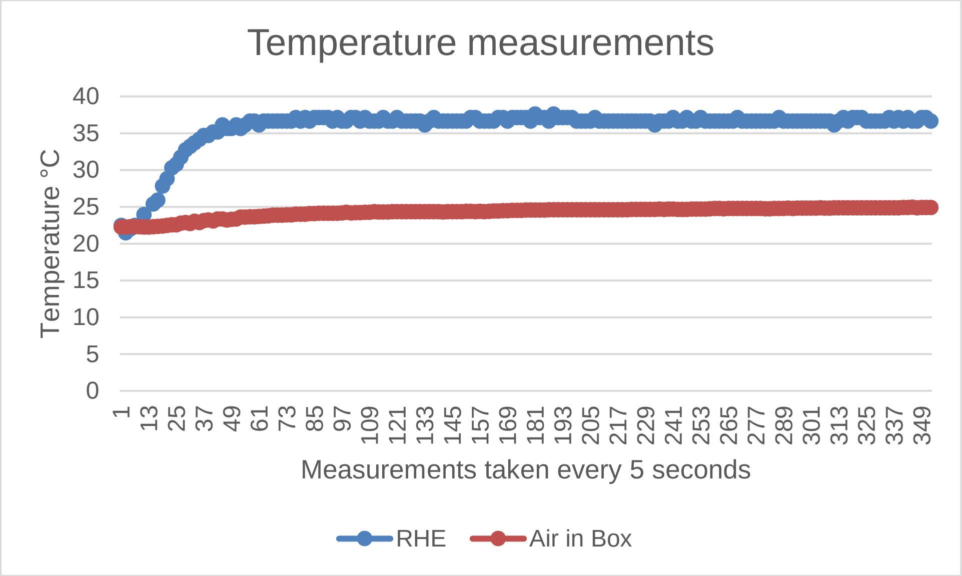

Figure 18. 10Ω Parallel Resistors RHE, with a 9V supply.

The figure above shows a total elapsed time of 20 minutes, from the starting point of 22.23°C for the air in the box, and 22.46°C for the RHE. During this time the RHE reached a maximum temperature of 37.11°C and the air within the box reached 24.89°C.

These results suggested that there was no power increase with a halving of the resistance value. As the voltage remained constant at 9V and the resistance was decreased to increase the power, the logical assumption at that point was that the current was not increasing. This was assumed to be due to a current supply limitation from the battery pack and was thus tested in the laboratory utilizing a power supply unit, the results of which are presented below, figure 19.

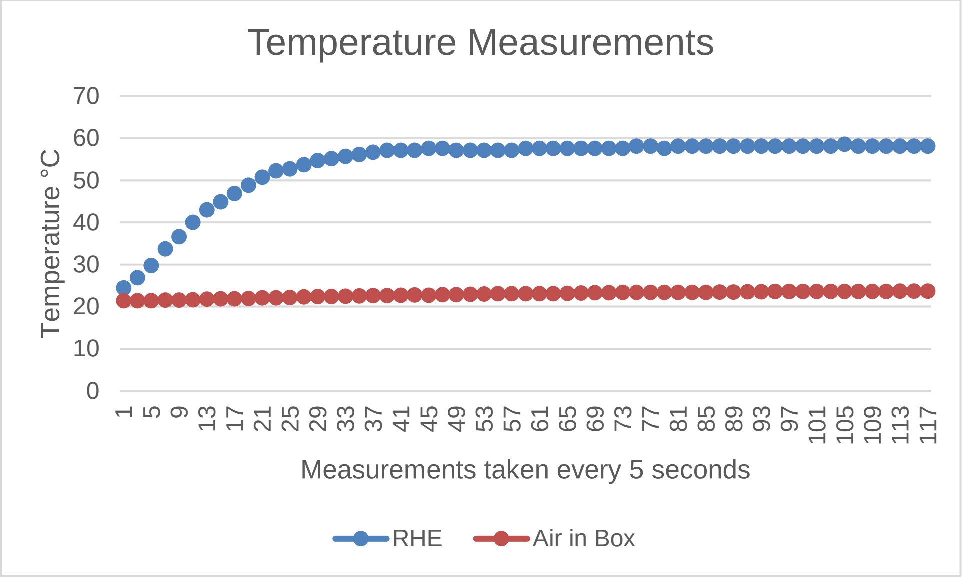

Figure 19. 20Ω Parallel Resistors RHE temperature, with a 9V supply, provided by a power supply unit.

Figure 19 above shows a 20Ω parallel resistor RHE achieving a maximum temperature of 58.11°C after 20 mins with 9V applied and no specified cut off temperature. The current drawn was correctly taken as 0.445A, and this accounted for the increase of RHE temperature, which allowed the box to reach a maximum of 23.69°C.

At this point it was known that the battery pack was insufficient for powering the box and that the assumed 4W of power through the RHE was also insufficient for achieving a heat level within the box of between 40°C - 45°C. Additionally, it was concluded that moving to an alternative RHE was safe, as resistance, power and temperature values are now known within an acceptable degree of certainty.

4.2 Nikrothal Wire Results vs Expected

Keeping the circuit unchanged but replacing the RHE with 1m of Nikrothal wire measuring 5.5Ω, which is depicted below, the box was tested utilising a 9V supply and now drawing 1.6A of current.

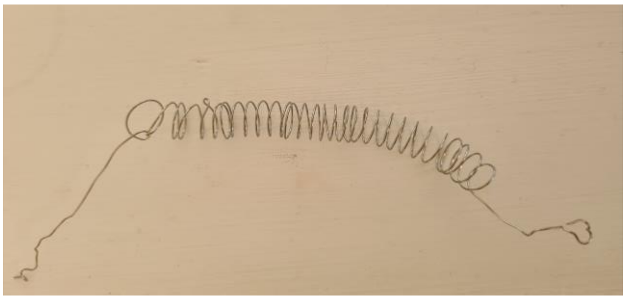

Figure 20. 1m Nikrothal wire measuring 5.5Ω.

Figure 20 above shows a meter of Nickrothal resistance wire shaped into a coil, the total resistance (R_T) of which measures 5.5Ω.

The maximum allowed RHE temperature was coded to be 70°C and the resultant maximum temperature within the box was 27.6°C. A visual representation of the results is presented below, figure 21.

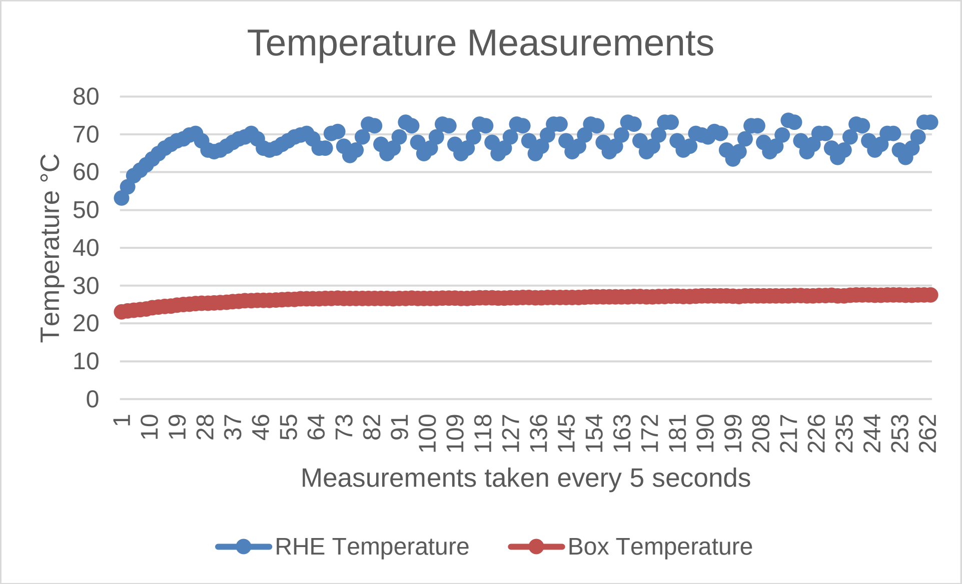

Figure 21. 5.5Ω Nikrothal wire supplied with 9V and 1.6A of current.

Figure 21 above shows that with 1m of Nikrothal wire measuring 5.5Ω, the maximum temperature of the RHE was approximately 70°C, when supplied with 9V and 1.6A of current. The resultant temperature of the box was seen to be 27.6°C. This is not a significant increase in box temperature from previous tests, though current had increased from 0.445A to 1.6A, which represented an increase in power from 4W to 14.59W.

In an attempt to keep voltage low at 9V, but increase the temperature within the box, the maximum RHE temperature was adjusted within the Arduino code from 70°C to 100°C. This resulted in a measured RHE temperature of 93.75°C, with the temperature within the box reaching a temperature of 31.32°C, the best results yielded thus far.
These operational results are illustrated below in figure 22.

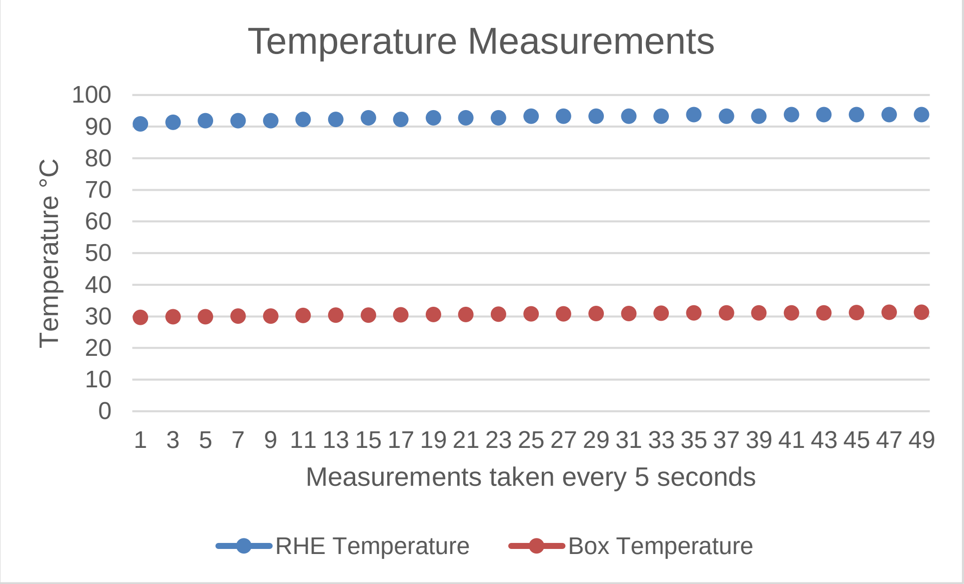

Figure 22. 1m Nikrothal wire @ 5.5Ω with 9V supply and 1.6 A of current, with a maximum RHE temperature of 93.75°C

Figure 22 above illustrates that with 1m of Nikrothal wire, keeping voltage and current unchanged, but adjusting the maximum allowable temperature of the RHE to 100°C, the RHE could reach a maximum temperature of 93.75°C. This allowed for the air within the box to heat to a maximum temperature of 31.32°C. While this represented a better result than before, it still had not reached the intended target, namely a box temperature reading of between 40°C - 45°C.

A possible reason for the inability of the air within the box reaching the desired temperature, could have been due to the surface area of the RHE within the box not being wide enough to transmit heat effectively.
The solution would have therefore been to increase the RHE surface area, but this would have caused a higher resistance value, and conversely a larger necessary voltage. However, increasing the wire length (and thus surface area) would have increased resistance and lowered the current drawn, which would have required an increase in voltage. Assuming the 100°C maximum RHE temperature is high enough once the surface area is expanded, then there would need to be a balance attained.

Some possible examples of Nikrothal wire changes and the resultant power are presented in appendix1, table 3. However, the tested increase in surface area began at 10m of Nikrothal wire measuring 55Ω, and was supplied with 9V, 12V and 15V. The results of which are presented below in Figure 23.

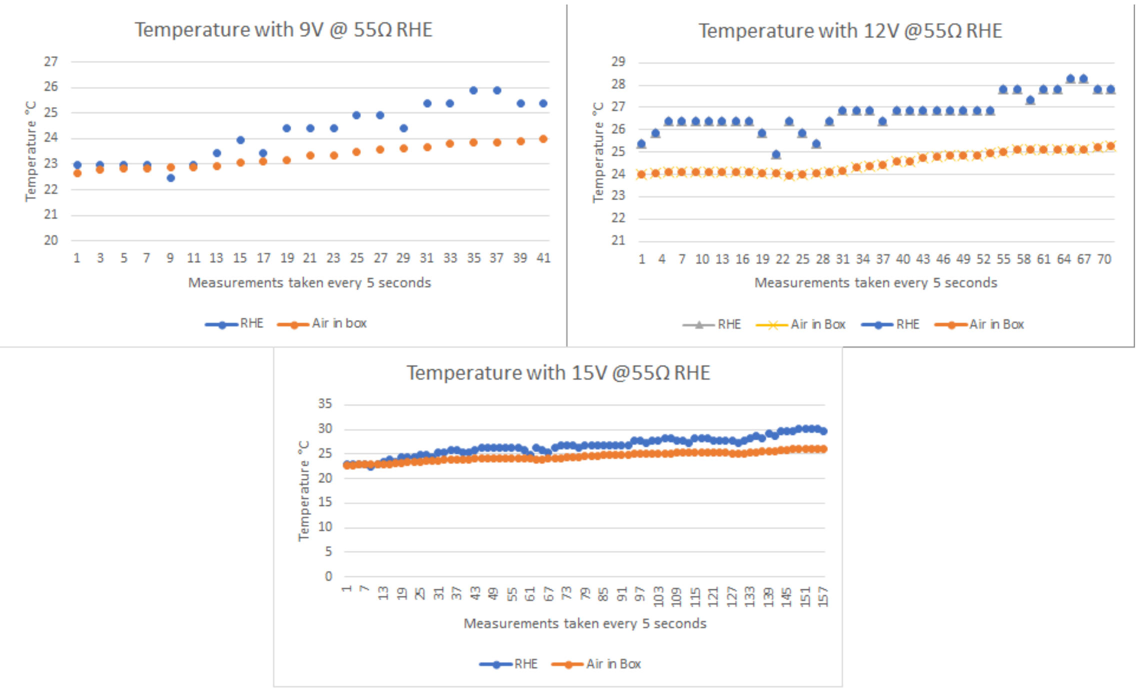

Figure 23. Temperature results with a 55Ω RHE supplied with 9V, 12V and 15V.

Figure 23 above depicts three graphs wherein the voltage was applied from 9V through to 15V. The tests were conducted with 10m of Nikrothal wire, measuring 55Ω which increased the surface area 10-fold. However, with this much resistance the resultant heat production was minimal, even considering the voltage increase. This was due to the lack of current drawn at the higher resistance value, and the subsequent lower power produced.

A more eloquent solution was required, and it was thus decided that the Nikrothal wire would be sectioned off into 4 pieces, connected in parallel. This would produce a smaller resistance value, but keep a large surface area, increasing the current consumed and consequentially the power produced.

The expected result of cutting 10m of wire into four sections would be as follows:

- Each wire section would be 2.5 m long.
- Each wire would contain 13.75Ω of resistance.
- The resultant parallel connection of wires would be 3.4375Ω.
- Current drawn at 9V, 12V and 15V would be approximately 2.62A, 3.49A and 4.36A respectively.
- The resultant Power at these voltage values would be approximately 23.56W, 41.26W and 65.45W respectively.
- As previous power output was taken as 14.59W utilizing 5.5Ω in 1m of wire, the new decrease in resistance, coupled with an increase in surface area, voltage, current and power should result in better heat production.

The wire was cut as described but could not be completed as accurately as calculations. Additionally, when the wires were connected in parallel, the total resistance value (R_T) changed, due to small areas of the wires touching each other, which could not be helped as the wires needed to touch to be connected in parallel. The measured R_T value was seen to be 3.8Ω when connected in the box and checked with the digital multi meter, which produced the following results displayed in figure 24 below.

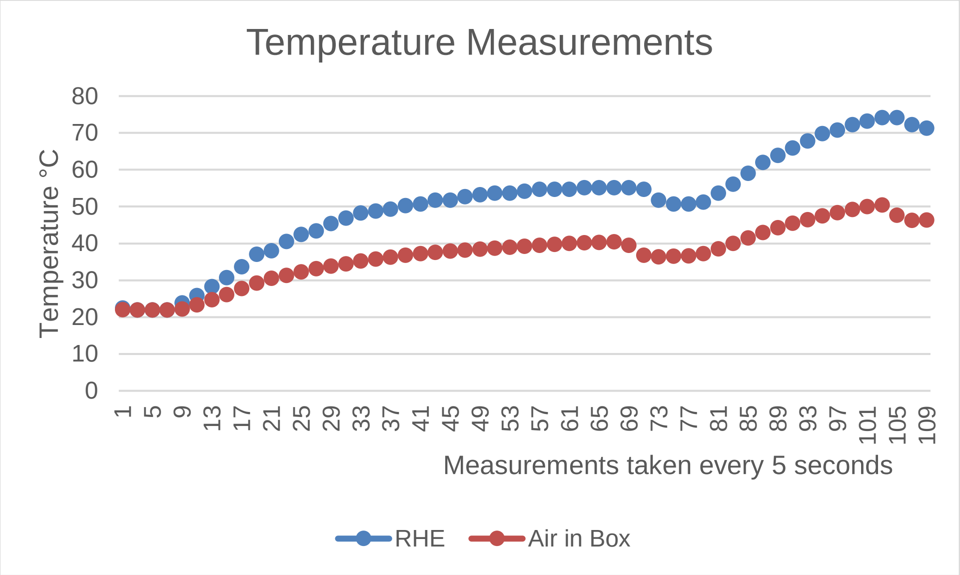

Figure 24. Temperature measurements taken with 15V and 3.8Ω of resistance.

The above Figure 24, shows that within a 10-minute period, the temperature of the RHE went from 22.46°C to 71.29°C. More significantly however, the temperature of the air within the box, went from 22.07°C to 46.42°C. This was achieved with 15V applied and a current draw of 3.9A, with a subsequent power output of 59.2W. This represented the first instance of the air within the box reaching the desired target temperature. However, the total time taken was longer than anticipated and when the box was opened, the air inside did not feel as warm as expected. Although the temperature sensor measured the correct value, the expected warmth to the touch was not attained.

Testing continued with a higher voltage supply and with the same resistance value. The results of which are shown below in figure 25.

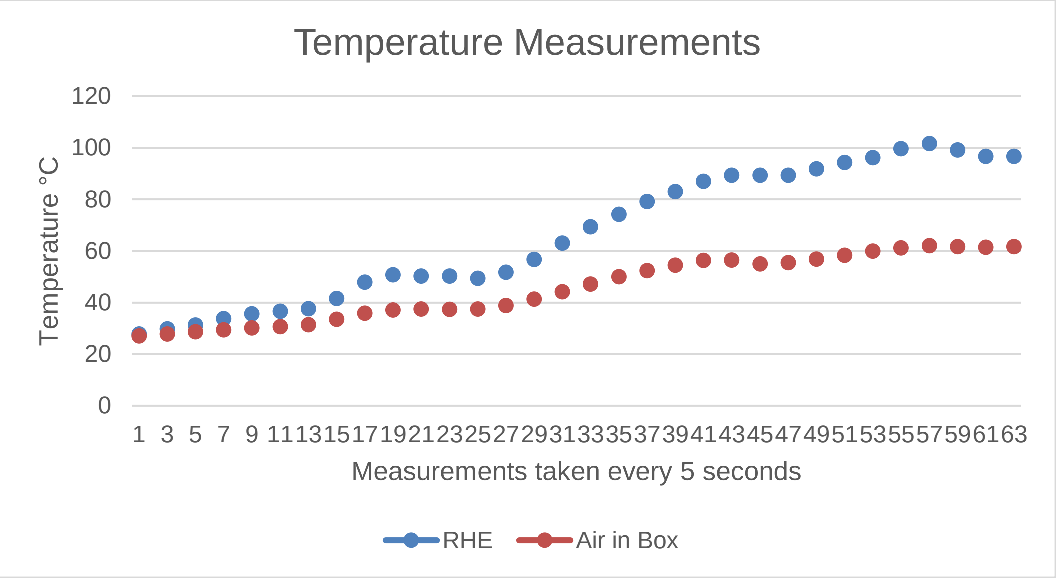

Figure 25. Temperature measurements taken with 20V and 3.8Ω of resistance.

Figure 25 above shows the temperature increase of the RHE and the air within the box when 20V is applied and a current of 5A is drawn. At this point it was noted that the power supply could not exceed 5A, as the theoretical drawn current should have been 5.26A. Additionally, testing was halted at this point as the breadboard and jumper cables started smoking, as these items could not sustain 5A of current running through them. However, from the figure above it may be seen that the RHE reached the cut off temperature of 100°C and the air within the box reached a temperature of 61.97°C. When the box was subsequently opened and a hand placed within, the air was also found to be significantly warmer.

At this point, the desired outcome within the box was achieved. The PCB was designed, manufactured and connected with the removal of any jumper cables. The resistance wires were more permanently affixed, being held stable via sixteen screws placed to the bottom of the box – 4 screws for each Nikrothal wire. As metal screws are conductive, ceramic screws being unavailable, and plastic screws susceptible to melting, insulated metallic screws were used. This outcome is pictured below, figure 26.

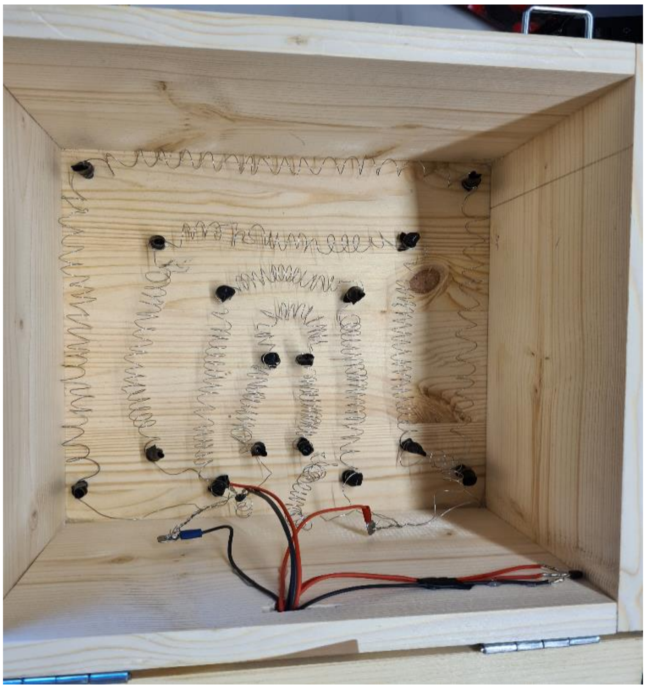

Figure 26. Internal configuration of heated box.

Figure 26 above shows the wire connection inside of the heated box, where the metallic screws can be seen to be insulated with silicone tape. The particular silicone tape utilized in the box had a dielectric strength of 8kV/mm and a maximum operating temperature of 260°C, making it suitable as a heat resistant insulator.

The Arduino and PCB were connected to the box through the hole in the back, which is depicted below, figure 27.

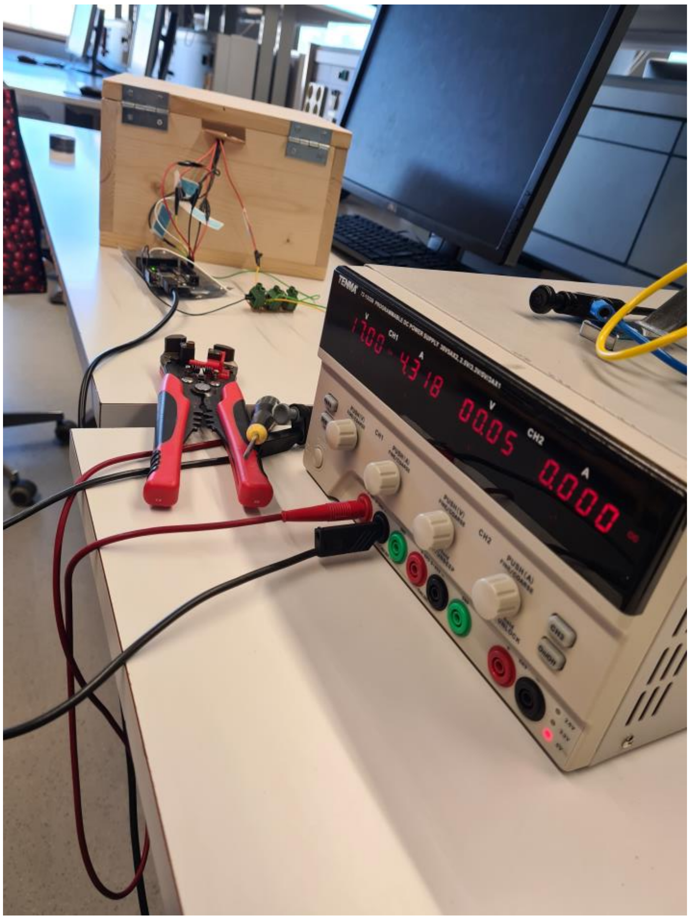

Figure 27. Heated box connected to microcontroller and PCB.

Figure 27 above depicts the rear of the box with the electrical wires connected to the Arduino, the PCB and the power supply. In this instance the power supply is set at 17V, with an accompanying 4.318A current draw.

A closer inspection of the circuit can be seen below, figure 28.

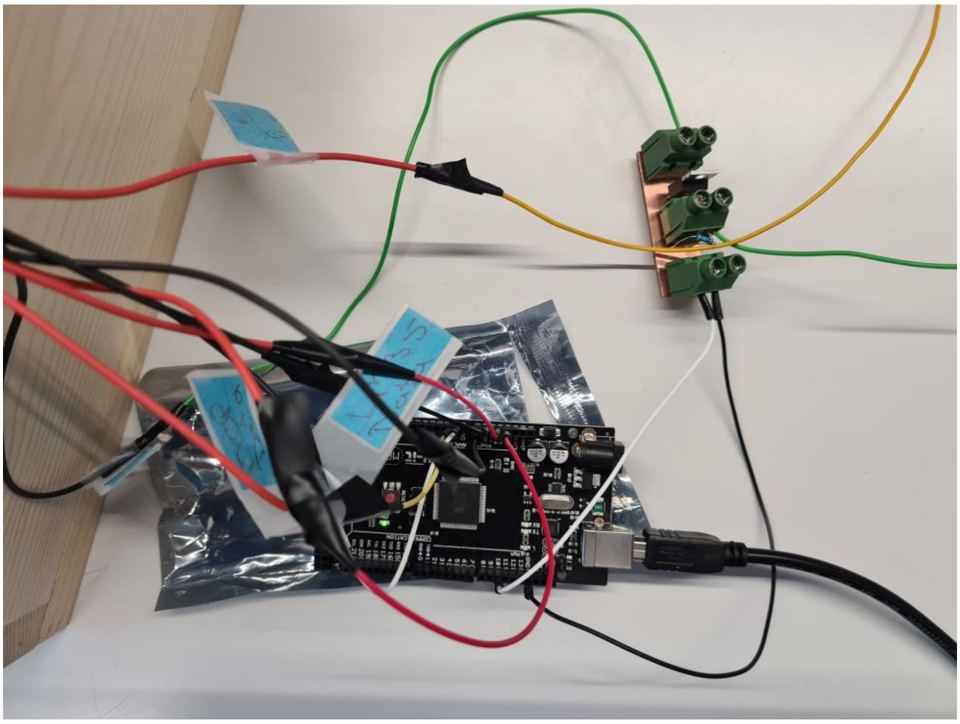

Figure 28. Arduino and PCB connection.

Figure 28 above shows the Arduino 2560 microcontroller attached to the PCB, temperature sensors (within the box), and the data cable. Soldered to the PCB are three 2-pin connectors; one 10kΩ resistor, and the MOSFET transistor. Additionally, as can be seen from the image, the cables are labelled and colour coded, to avoid incorrect connection.

The tests commenced again with the following results presented below, figures 29 through 31. Additionally, it should be noted that when the wires were more permanently connected, the R_T value changed to 4.4Ω, as the connection points were slightly altered.

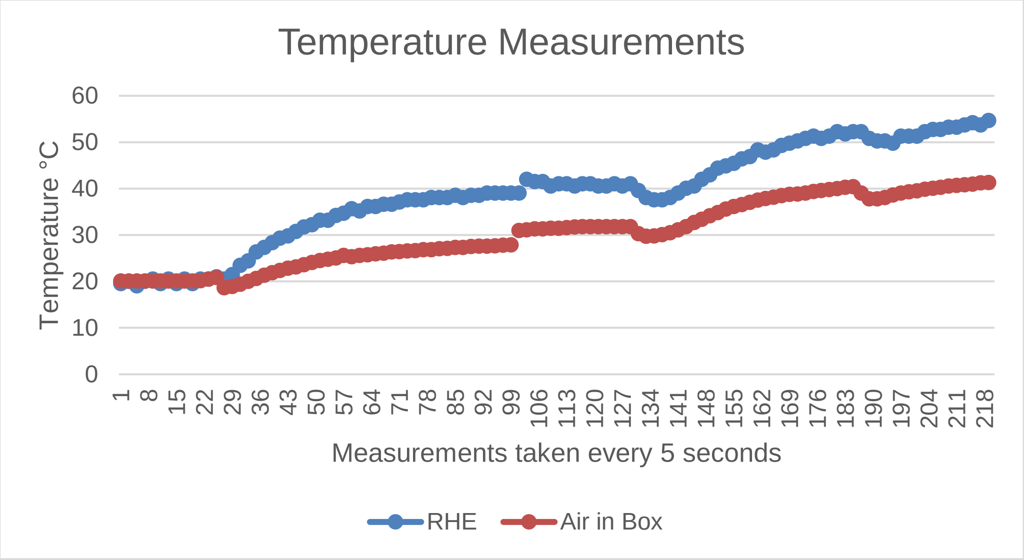

Figure 29.Temperature measurements at 9-12V with 4.4Ω of resistance.

Figure 29 above shows the temperature achieved at two voltage levels. At 9V and 2.343A of current, with 4.4Ω R_T, the RHE reached a temperature of 41°C and the air within the box measured 31.08°C. The voltage was then increased to 12V with 3.026A of current drawn, and testing continued, where the RHE increased to 54.69°C and the air within the box increased to 41.29°C.

As these values were inadequate, testing continued at higher voltage levels.

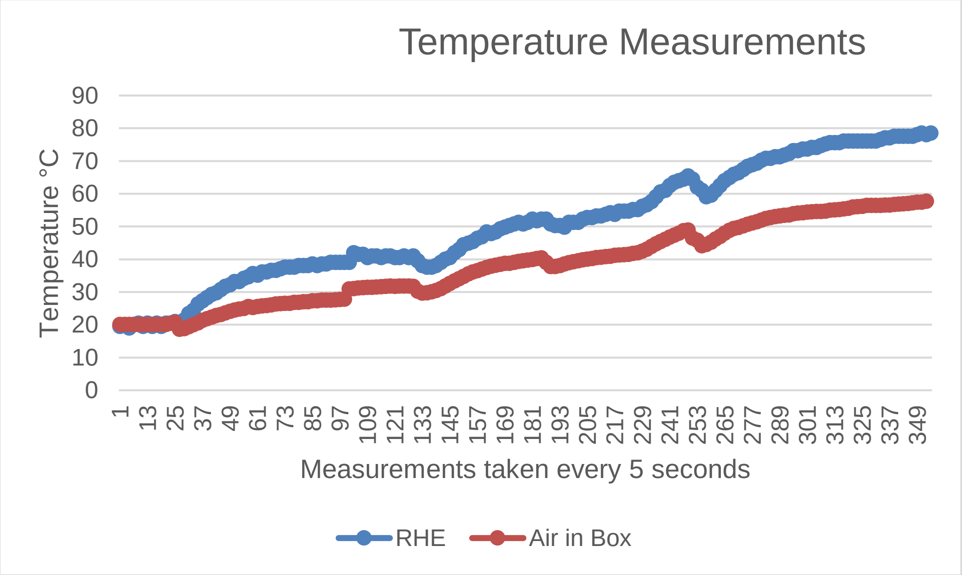

Figure 30. Temperature measurements for 15V with 4.4Ω of resistance.

Figure 30 above shows the temperature measured with 15V applied and 3.808A of current drawn. The RHE starting temperature was 20.09°C, with the air in the box being 20.11°C. The maximum temperature achieved within a 5-minute period at the RHE, was 78.61°C, with the air in the box reaching a maximum temperature of 57.71°C.

This was still lower than desired, as previously stated 60°C is the temperature at which the box felt warm, and thus voltage was increased again. 16V also did not allow for the RHE to reach 100°C in a suitable timeframe, however 17V, 18V and 20V all operated within suitable parameters. Thus, to keep the voltage and current to a minimum, the heated box containing clothing items would be tested with a 17V maximum.

The code was then adjusted to operate with a PWM, as described in listing 2, where the RHE temperature had a cut-off point of 105°C and the temperature was to be checked every second. An ad hoc shelving unit was placed within the box to support the clothing item, and the voltage adjusted to 17V, the results of both the final test and the shelving unit are shown below, figures 31 and 32 respectively.

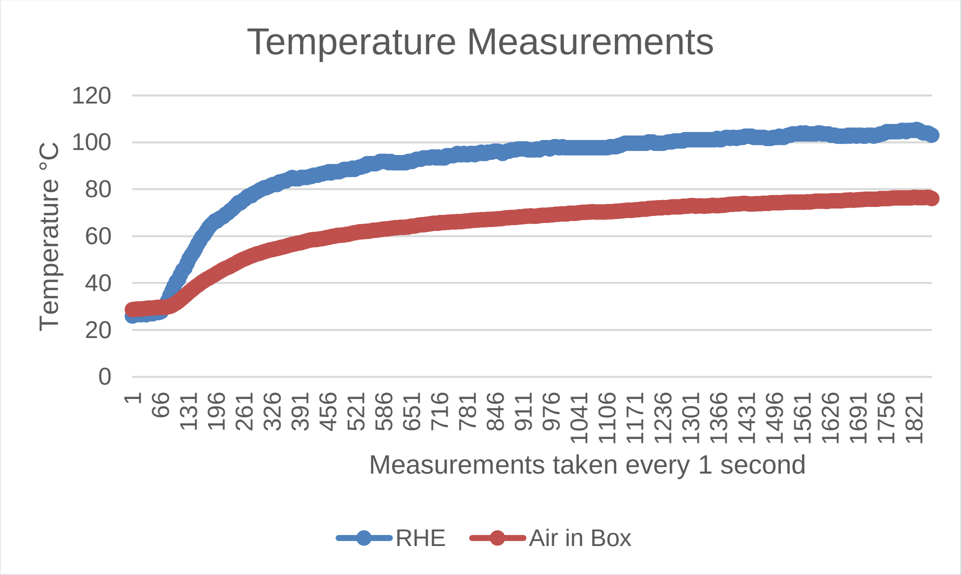

Figure 31.Temperature measurements at 17V applied with 4.4Ω of resistance.

The above figure 31 illustrates the temperature increase measured within the heated box. The voltage applied from the power supply was 17V, providing 4.320A of current, with a calculated power of 65.6W. During testing, the air in the box reached 60°C within a 2-minute time frame, with an RHE temperature of 87.4°C. This was considered warm enough for the heating of the clothing items. The test continued until the maximum of 105°C was achieved, meaning the RHE could heat past this temperature provided more time had elapsed. However, with an RHE temperature of 105°C, the air in the box was seen to be just over 75°C. While this is not harmful to the clothing, it may be slightly more than required.

The PWM operated best with a 75% PWM, as the wire cooled rapidly once the voltage was removed. Lastly, it should be noted that the PWM operated within a +/- 1°C of accuracy. Increasing the PWM, for example, to 80% would reduce the accuracy error. However, +-1°C accuracy was acceptable for this purpose.

The shelving unit on which the clothing items were placed may be seen below.

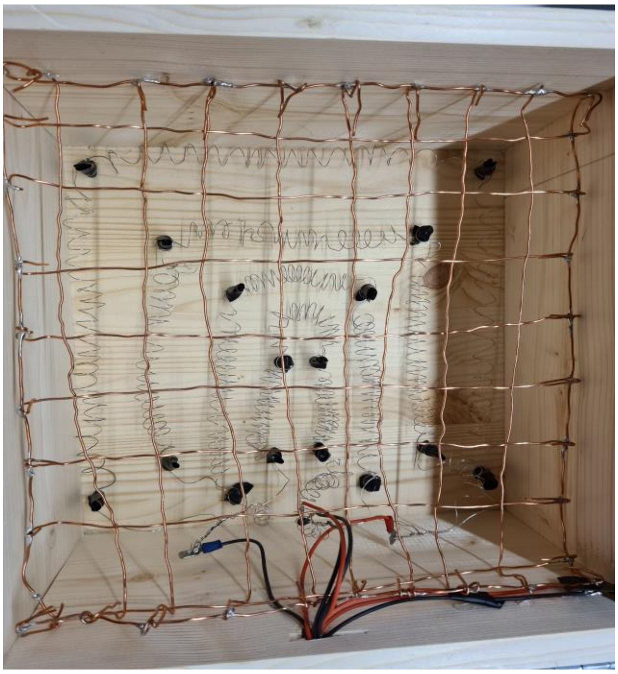

Figure 32.Shelving for clothing item.

Figure 32 above shows the temporary shelving installed for placing the clothing items within the box. When a better, more permanent grate is found, it would be permanently affixed with four screws, one on each side.

5 Discussion

Table 2 indicated that for an acceptable resistance value, the copper wire required would have needed to be approximately 0.07mm thick, or its lowest AWG value. At the time of testing, this wire was not found. However, if such a wire was available for testing, the results should have proved better than with Nikrothal wire.

Assuming the same length of 2.5m per individual wire, then the total resistance of each copper wire would have been 8.775Ω. Also, assuming there would be the same four wires to fill the box, then the total resistance (R_T) of the RHE would be 2.19375Ω. Applying the same voltage values would have resulted in a higher current consumption and power production, indicating that lower voltage values could have been applied to achieve the same results.

Although copper wire could have possibly been more effective, the results of the Nikrothal wire were deemed to be satisfactory. It may be seen however, that initial assumptions did not hold true. Namely, 4W of power was found to be inadequate for reaching the assumed temperature within the box. The assumed temperature within the box was also incorrect, as 45°C, barely felt warm. This may have been due to the design of the box, or possibly the placement of the second temperature sensor.

Additionally, the design of the box could be altered for better efficiency, for example, with the addition of a fan to circulate air. A reflective heat element could be added to the wood to better trap the heat within the box, as the wooden lid was found to absorb the heat. Also, the box could be coated with an insulating material and the wires protected in such a way as to prevent the user from accidentally coming into contact with them. Another issue to note, was that the PCB was designed poorly, as after milling it was noted that only two 2-pin connectors were required.

However, from the temperature results achieved, when the clothing item (gloves) was worn and taken outside (3°C weather), the gloves held the heat for at least 15 minutes. The tester’s hands felt warm for much longer, as their body heat gets added to the glove and heat is dissipated at a slower rate. Thus, it may be noted that there is more than an instantaneous warmth achieved with a heated item, as the user will experience a gradual decline in warmth.

The effect of the item retaining heat however, will depend on several factors. Namely, the length of time after heating the user chooses to wear the item; the material of the item being heated; the bodily location of the item, as for example, a t-shirt will lose heat at a faster rate than a hat.

6 Conclusion

The heating box was created with the aim of warming clothing items in cold climates utilizing a resistive heating element. A few resistive heating elements were explored, with testing being conducted on a parallel resistor configuration and nikrothal wire. Although initial assumptions concerning the required temperature changes and power requirements were found to be false, the goal was still achieved. Thus, the heated box, in my opinion was deemed to be feasible.

However, due to the high power consumption, the box would require a special battery to operate if it is to be a portable device. Additionally, the size of the box could be altered to change the power requirement and aid in its portability.

Beside the large power consumption, the box worked as intended, and the (heated) clothing items provided the expected benefits to the user. However, for user generated results to be valid, multiple persons would need to test the box – possibly hundreds. Additionally, those users would also need to test various clothing items in differing weather conditions, as items worn at varying temperatures would produce varying results. An example of the questions that may be presented to future test subjects is placed within the appendix, appendix 3.

Lastly, although this idea could be ported over to a closet and work as intended, there may be more efficient methods of achieving a heated closet. For example, a “heated towel warmer” design that is altered to fit within closets, but that is beyond the scope of this study.

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Appendices

Appendix 1: Resistance Values at various AWG

Table 1. Copper resistance values at various sizes. Data reprinted from Engineering toolbox (2008) [3].

AWG	**Area (Circular Mils)**	**European standard: Diameter (mm)**	**Resistance at 25°C (Ω/m)**	**Resistance at 65°C (Ω/m)**	**Weight (kg/m)**
0000	212000	11.684	$0.164*10^{-3}$	$0.187*10^{-3}$	0.954
000	168000	10.414	$0.207*10^{-3}$	$0.24*10^{-3}$	0.756
00	133000	9.271	$0.261*10^{-3}$	$0.302*10^{-3}$	0.6
0	106000	8.255	$0.328*10^{-3}$	$0.381*10^{-3}$	0.475
1	83700	7.3406	$0.413*10^{-3}$	$0.479*10^{-3}$	0.377
2	66400	6.5532	$0.522*10^{-3}$	$0.604*10^{-3}$	0.299
3	52600	5.8166	$0.659*10^{-3}$	$0.761*10^{-3}$	0.237
4	41700	5.1816	$0.83*10^{-3}$	$0.958*10^{-3}$	0.188
5	33100		$1.05*10^{-3}$		0.149
6	26300	4.1148	$1.32*10^{-3}$	$1.53*10^{-3}$	0.118
7	20800		$1.67*10^{-3}$		0.0938
8	16500	3.2512	$2.1*10^{-3}$	$2.42*10^{-3}$	0.0744
9	13100		$2.65*10^{-3}$		0.0589
10	10400	2.5908	$3.35*10^{-3}$	$3.87*10^{-3}$	0.0467
11	8230		$4.2*10^{-3}$		0.0371
12	6530	2.0574	$5.31*10^{-3}$	$6.14*10^{-3}$	0.0295
13	5180		$6.69*10^{-3}$		0.0235
14	4110	1.6256	$8.46*10^{-3}$	$9.74*10^{-3}$	0.0185
15	3260		$10.7*10^{-3}$		0.0147
16	2580	1.2954	$13.4*10^{-3}$	0.0155	0.0116
17	2050		$16.9*10^{-3}$		0.00923

18	1620	1.016	0.0214	0.0246	0.00732
19	1290		0.0269		0.0058
20	1020	0.8128	0.0341	0.039	0.0046
21	810		0.043		0.00365
22	642	0.64262	0.0541	0.0623	0.00289
23	509		0.0682		0.00229
24	404	0.51054	0.086	0.0991	0.00182
25	320		0.108		0.00144
26	254	0.40386	0.136	0.157	0.00114
27	202		0.172		$0.908*10^{-3}$
28	160	0.32004	0.217	0.251	$0.72*10^{-3}$
29	127		0.274		$0.571*10^{-3}$
30	101	0.254	0.344	0.397	$0.452*10^{-3}$
31	79.7		0.436		$0.359*10^{-3}$
32	63.2	0.2032	0.548	0.633	$0.284*10^{-3}$
33	50.1		0.692		$0.226*10^{-3}$
34	39.8	0.16002	0.873	1.007	$0.179*10^{-3}$
35	31.6		1.099		$0.141*10^{-3}$
36	25.0	0.127	1.388	1.601	$0.113*10^{-3}$
37	19.8		1.749		$0.893*10^{-4}$
38	15.7	0.1016	2.208	2.546	$0.714*10^{-4}$
39	12.5		2.782		$0.566*10^{-4}$
40	9.9	0.07874	3.510	4.035	$0.298*10^{-4}$

Table 2. Nichrome resistance values at various sizes. Data reprinted from WireTronic Inc. (2017) [8].

AWG	**European standard: Diameter (mm)**	**NiCrA Resistance at 20°C (Ω/ft)**	**NiCrA Resistance at 20°C (Ω/m)**	**NiCrC Resistance at 20°C (Ω/ft)**	**NiCrC Resistance at 20°C (Ω/m)**
6	4.1148	0.02477	0.007549896	0.02572	0.007839456

7	3.6576	0.03122	0.009515856	0.03242	0.009881616
8	3.2512	0.03937	0.011999976	0.04088	0.012460224
9	2.8956	0.04967	0.015139416	0.05158	0.015721583
10	2.5908	0.06248	0.019043903	0.06488	0.019775423
11	2.3114	0.07849	0.023923751	0.08151	0.024844247
12	2.0574	0.09907	0.030196535	0.1029	0.031363919
13	1.8288	0.12540	0.038221919	0.1302	0.039684959
14	1.6256	0.15870	0.048371758	0.1648	0.050231038
15	1.4478	0.20010	0.060990478	0.2078	0.063337438
16	1.2954	0.24990	0.076169518	0.2595	0.079095597
17	1.143	0.32100	0.097840797	0.3333	0.101589837
18	1.016	0.40630	0.123840236	0.4219	0.128595116
19	0.9144	0.50150	0.152857195	0.5208	0.158739835
20	0.8128	0.63480	0.193487034	0.6592	0.200924154
21	0.7239	0.80020	0.243900952	0.8310	0.253288792
22	0.635	1.0150	0.30937199	1.055	0.32156399
23	0.57404	1.2730	0.388010388	1.322	0.402945587
24	0.508	1.6090	0.490423184	1.671	0.509320784
25	0.45466	2.0290	0.61843918	2.107	0.642213579
26	0.40386	2.5710	0.783640775	2.67	0.813815974
27	0.36068	3.2240	0.982675169	3.348	1.020470367
28	0.32004	4.0940	1.24785116	4.252	1.296009559
29	0.28702	5.0900	1.55143195	5.286	1.611172748
30	0.254	6.5000	1.981199937	6.75	2.057399934
31	0.22606	8.2060	2.50118872	8.522	2.597505517
32	0.2032	10.160	3.096767901	10.55	3.215639897
33	0.18034	12.890	3.928871874	13.39	4.081271869
34	0.16002	16.380	4.99262384	17.01	5.184647834
35	0.14224	20.730	6.318503798	21.52	6.55929579
36	0.127	26.000	7.924799746	27.00	8.229599737
37	0.1143	32.100	9.784079687	33.33	10.15898367
38	0.1016	40.630	12.3840236	42.19	12.85951159

39	0.0889	53.060	16.17268748	55.10	16.79447946
40	0.07874	67.640	20.61667134	70.24	21.40915131
41	0.07112	82.908	25.27035759	86.10	26.24327916
42	0.0635	104.00	31.69919899	108.0	32.91839895
43	0.05588	134.30	40.93463869	139.46	42.50740664
44	0.0508	162.50	49.52999842	168.75	51.43499835
45	0.044704	209.84	63.95922995	217.91	66.41896587
46	0.039878	263.70	80.37575743	273.84	83.46642933

Table 3. Nikrothal wire lengths at varying voltage with resultant power produced.

Voltage (V)	R_T(Ω) @ length (m)	Current draw (A)	Power (W)
9	11.1 @ 2	0.81	7.29
	22.2 @ 4	0.405	3.648
	33.3 @ 6	0.270	2.432
	44.4 @ 8	0.202	1.824
12	11.1 @ 2	1.08	12.97
	22.2 @ 4	0.54	6.486
	33.3 @ 6	0.36	4.324
	44.4 @ 8	0.27	3.243
15	11.1 @ 2	1.35	20.27
	22.2 @ 4	0.675	10.135
	33.3 @ 6	0.45	6.75675
	44.4 @ 8	0.337	5.0675
18	11.1 @ 2	1.62	29.189
	22.2 @ 4	0.81	14.59
	33.3 @ 6	0.54	9.729
	44.4 @ 8	0.405	7.297
24	11.1 @ 2	2.162	51.89
	22.2 @ 4	1.08	25.9459
	33.3 @ 6	0.72	17.29

	44.4 @ 8	0.54	12.97

Appendix 2: Arduino code

Heater On/Off code

```
#define PIN_SENSOR A0 // PIN for LM35
#define PIN_SWITCH 10 // PIN for operating the MOSFET

     float target = 100; // Target for Temperature of RHE

/*
   The value of Vout is obtained by averaging 1024 values reading the voltage
on pin A0. which is connected to the sensor output.
   The value of temeprature   ta, read by the sensor is shown on the serial
monitor.
*/

     const int in = A1; // input for reading the MCP output

// set constants:
const float vout0 = 400; //sensor output   voltage in mV at 0°C
const float tc = 19.53; // mV for °C temperature constant   for the MCP

// variables:
int i, f;
     float vout, vout_avg, ta;
// MAIN PROGRAM

     void setup()
          {
                 pinMode(PIN_SENSOR, INPUT);
                 pinMode(PIN_SWITCH, OUTPUT);

            Serial.begin(9600);

                pinMode(in, INPUT);            // set pin in as input
                pinMode(13, OUTPUT);             // set pin 13 as output
                digitalWrite(13, LOW);
                analogReference(DEFAULT); //MCP
```

```
          }
      float getTemperature() { //LM 35
      float data = analogRead(PIN_SENSOR);
      return (5.0 * data * 100.0) / 1024.0; // Celsius
          }
 void loop()
      {
            vout_avg = 0; //MCP calculations
            for (i = 0; i < 1024; i++) {
             vout = analogRead(A1) * (4976.30 / 1023);
  //Serial.println(vout);
           vout_avg = vout_avg + vout;
      }
            vout = vout_avg / 1024; //MCP print
  //Serial.println(vout);
           ta = (vout - vout0) / tc;
           Serial.print("temperature ( celcius degree)   =   " );
            Serial.println(ta);
       delay (1000);




// Temperature read
           float c = getTemperature(); //LM print
           Serial.print("Temperature: ");
           Serial.println(c);
// Regulation (Cut off)
      if (c > target)
       {
            digitalWrite(PIN_SWITCH, LOW);
            Serial.print("\tHeater OFF");
       } else {
           digitalWrite(PIN_SWITCH, HIGH);
           Serial.print("\tHeater ON");
      }

  delay(5000);
}
```

Heater PWM code

```
#define PIN_SENSOR A0 // PIN for LM35
#define PIN_SWITCH 10 // PIN for operating the MOSFET

     float target = 100; // Target for Temperature of RHE

/*
   The value of Vout is obtained by averaging 1024 values reading the voltage
on pin A0. which is connected to the sensor output.
   The value of temeprature   ta, read by the sensor is shown on the serial
monitor.
*/

     const int in = A1; // input for reading the MCP output

// set constants:
const float vout0 = 400; //sensor output   voltage in mV at 0°C
const float tc = 19.53; // mV for °C temperature constant   for the MCP
// variables:
int i, f;
     float vout, vout_avg, ta;
// MAIN PROGRAM

     void setup()
          {
                pinMode(PIN_SENSOR, INPUT);
                pinMode(PIN_SWITCH, OUTPUT);

           Serial.begin(9600);

               pinMode(in, INPUT);            // set pin in as input
               pinMode(13, OUTPUT);             // set pin 13 as output
               digitalWrite(13, LOW);
               analogReference(DEFAULT); //MCP
     }
     float getTemperature() { //LM 35
     float data = analogRead(PIN_SENSOR);
     return (5.0 * data * 100.0) / 1024.0; // Celsius
     }



 void loop()
     {
           vout_avg = 0; //MCP calculations
           for (i = 0; i < 1024; i++) {
```

```
            vout = analogRead(A1) * (4976.30 / 1023);
  //Serial.println(vout);
          vout_avg = vout_avg + vout;


     }
           vout = vout_avg / 1024; //MCP print
  //Serial.println(vout);
          ta = (vout - vout0) / tc;
          Serial.print("temperature ( celcius degree)   =   " );
           Serial.println(ta);
      delay (1000);




// Temperature read
          float c = getTemperature(); //LM print
          Serial.print("Temperature: ");
          Serial.println(c);
// Regulation (Cut off)
if (c > target)
  {
     digitalWrite(10, HIGH);
     delayMicroseconds(100); // Approximately 10% duty cycle @ 1KHz
     digitalWrite(10, LOW);
     delayMicroseconds(1000 - 100);
     Serial.print("\tHeater at 10 % PWM\n");
  } else {
    digitalWrite(PIN_SWITCH, HIGH);
    Serial.print("\tHeater ON\n");
  }

  delay(1000);
}
```

Appendix 3: Questionnaire

1. What is the external temperature at the time of use?
2. Were you already warm before use, for example, because of a hot shower, sauna or exercise?
3. What clothing item have you placed in the box to be heated?
4. How long did you leave the item in the box?
5. When you initially wear the item, does the warmth feel pleasant?
6. If yes to the above question, on a scale of 1-5, 5 being the highest, how would you rate the initial effect?
7. How long after first wearing the item did you leave the house/apartment?
8. How long did the clothing item retain heat after wearing, or conversely, how long before you no longer felt warm?
9. Although the clothing item no longer retained heat, did it aid in keeping you comfortable for a longer period (does the effect of having been warm initially leave a residual warmth within the body that carries on after the item has already gone cold)?
10. If yes to the above question, on a scale of 1-5, 5 being the highest, how would you rate this residual effect?
11. Overall, on a scale of 1-5, how would you rate the experience of utilizing the box?