DEPARTMENT OF
Biomedical Engineering
UNIVERSITY OF WISCONSIN–MADISON

Incubator for Infant Wildlife

BME 400 - Final Report

12/13/2023

Client: Dr. Mark Stelford

Advisor: Dr. Wally Block

Team Members:

Tanishka Sheth	Team Leader
Seyoung Selina Park	Communicator
Loukia Agoudemos	BWIG
Sophia Finn	BSAC
Erwin Cruz	BPAG

Abstract

Wildlife rehabilitation is a noble cause to participate in. The process to become a rehabilitation expert requires licensing, and often everyday people do not know how to best care for wildlife they come across. Rehabilitation can be an expensive process, and many times non-profit organizations do not have the funds to buy all the necessary resources. One of the key resources that is used in rehabilitation is an incubator. An incubator is a device that is typically box-shaped. It regulates key factors necessary for health in young wildlife, such as proper humidity and temperature levels. The wildlife incubator must be low-cost, durable, modular, easy to clean, and precise in temperature control. It is essential to create an incubator that is more accessible and accommodating for those interested and passionate about wildlife rehabilitation but may lack the financial resources to purchase components currently available in the market. There are many wildlife incubators on the market today, but have a high price point that can be difficult to achieve for private parties that are passionate about saving lives. Due to the lack of budget-friendly incubators, it becomes difficult for those working in wildlife rehabilitation to provide necessary care. The team's current solution involves the division of the design into three main components: humidity, temperature, and external. The main goals for this semester include creating the different components through trial and error and finding a way to combine all of the internal components into the external design. To ensure proper functionality, the team will be conducting testing on each component to ensure longevity and accuracy. Additionally, client evaluation will be conducted frequently to ensure that the design and development match client needs. With the team's efforts, a low-cost and functional incubator will be created by the conclusion of the semester to be tested and receive critical feedback before the next semester.

Table of Contents

I. Introduction

Motivation

The broad objective of this project is to create accessibility around wildlife rehabilitation. The goal of wildlife rehabilitation is to treat sick, injured, orphaned, and otherwise distressed wildlife, and to release them back into their natural habitat [1]. Most states require that people who participate in wildlife rehabilitation are licensed, to ensure that qualified care is provided to animals in a humane way [2].

This project specifically focuses on the rehabilitation of orphaned mammals and birds. Many of these animals are neonates or nestlings who are too young to regulate their body temperature. As a result, these animals require supplemental heat to survive. There are many wildlife incubators on the market today, but have a high price point that can be difficult to achieve for private parties that are passionate about saving lives. Due to the lack of budget-friendly incubators, it becomes difficult for these people to pursue their wildlife rehabilitation efforts. However, thus far, cheaper options have posed their own challenges, as the incubator must also be easy to assemble.

Existing Devices and Current Methods

There are several wildlife incubators on the market right now, but none are at the price point expected for this project. Incubators at a lower price point do not completely satisfy the client's requirements. One of the main manufacturers of incubators is Brinsea. They offer a number of different incubators with varying capabilities and sizes. The TLC-50 Zoologica II is 25" x 18" x 14", with many electrical components [3]. These components include accurate digital temperature control with a screen for adjustments, alarms that signify temperatures that are too high or too low, automatic humidity control, air filtration and exchange, and variable fan speeds. While all of these components are very advanced and offer effective utilization, the price point is $1199.99 when buying directly. This is a very high-cost version of what the team aims to achieve. Another offering by Brinsea is the TLC-30 Eco, which is 9.5" x 9.5" x 6.5", with similar components [4]. However, this incubator is significantly smaller than what is expected to be created by the team. Additionally, this incubator does not include humidity control and is also at a higher price point of $309.99 when buying directly. This company also offers other types of incubators, however, these two were the most similar to what the team hopes to achieve with this project. The team's goal is to mimic the ease of use of a sophisticated incubator, both in set-up and everyday use, without the extra cost incurred.

Problem Statement

Wildlife rehabilitation often includes caring for neonatal wildlife who are unable to control their own body temperature, thus the incubator must provide supplemental temperature control. Although private parties frequently contribute to wildlife rehabilitation efforts, they do not have enough financial resources to purchase an incubator. As such the wildlife incubator must be low-cost, durable, modular, easy to clean, and precise in temperature control. It is essential to create an incubator that is more accessible and accommodating for those interested and passionate about wildlife rehabilitation but may lack the financial resources to purchase components currently available in the market.

II. Background

Relevant Biology and Physiology

Many of the wildlife that is brought into rehabilitation centers is infant wildlife. It has been noted that infants have physical limitations because heat loss overwhelms their heat production [5]. Heat regulation also significantly differs in animals based on gender, season, and aging [6]. Additionally humidity regulation is a large factor in the design of the incubator as well. This is because it is imperative to control relative humidity. It is not necessary to control it as narrowly as temperature for most mammals, and typically an acceptable range is between 30%-70% for most mammals [7]. Due to the infantile nature of the wildlife that will be housed in the incubator, 60%-70% humidity is preferred. For rehabilitation purposes, rehabbers must provide an adequate environment for animals which includes fresh air, and auxiliary ventilation when ambient temperature exceeds 85°F. Additionally, lighting should allow for inspection and cleaning but should not distress animals [8]. Because the incubator developed will be usable to most infant wildlife, it is not necessary to include specific physiological parameters for all species of infant wildlife that can be housed within.

Client Information

The client, Dr. Mark Stelford is the Vice President and Treasurer of a nonprofit organization– Oaken Acres Wildlife Center. This organization has been providing wildlife care for over 30 years and since its inception, has taken in more than 11,000 animals.

Design Specifications

The dimensions of the incubator should be approximately 18” x 18” x 18” and break into a box that is 20” x 20” x 8” or smaller for shipping. The incubator should also cost less than $100 per unit for the wildlife rehabilitation to both purchase and assemble.. There should be modular parts included to allow for easy replacement. To adhere to the biological needs of the wildlife, the incubator should also maintain a temperature of 95°F with a buffer of +/- 2°F. Additionally, the incubator should include the ability to increase the humidity up to 60% without the need of additional sealing. A separate sealable part can be included to allow the incubator to reach up to 70% humidity. For safety reasons, there should be no accessible electronics close to where the wildlife is housed within the incubator, and there should be no sharp edges on the interior surface. The shelf life for this product should be 10 years, but can include replaceable parts such as electronics which may not be able to withstand consistent use for the full lifetime of the product. Additionally, the product should be able to withstand regular operational use and a cleaning regime. These include the transport and regular removal of the incubator and its modular parts; sustained wait load from animals on the modular parts; scrubbing and cleaning using high temperatures and/or chemicals on the incubator and its parts; and exposure to humid conditions.

III. Preliminary Designs

Humidity Control

1. ### All-In-One Pre-Built Humidifier

   The all-in-one pre-built humidifier is a commercial-grade humidifier that has been adapted for integration within the incubator system. We have selected a specific model from HUMI-CARE, which unfortunately does not provide detailed information on the margin of error in humidity sensing. However, the manufacturer assures the accuracy of this humidifier. Compact and portable, this humidifier is designed for easy insertion and removal from the incubator, to ensure convenient maintenance and cleaning.

2. ### Team-Built Water Atomizer and Humidity Sensor Circuit

   The team-built Water atomizer and humidity sensor circuit is designed to incorporate a DHT22 humidity sensor with a margin of error of +/-5%. Humidity generation would be managed by a Grove water atomizer circuit, under the precise control of an Arduino.

3. ### Ultrasonic Nebulizer and Integrated Circuit (IC) Type Humidity Sensor

   The ultrasonic nebulizer and Integrated circuit (IC) type humidity sensor will manage and measure the relative humidity within the incubator environment. The ultrasonic nebulizer creates an aerosol under ambient conditions, while the Integrated Circuit (IC) type humidity sensor measures the relative humidity. If the measured humidity falls below a predetermined humidity value, the ultrasonic nebulizer activates, converting sterilized water into fine water particles to elevate the humidity level. The accuracy of the sensor is +/-2% at 25°C [9].

Temperature Control

1. ### Feedback Heater with Bed Detection

   The feedback heater with bed detection consists of a heating detection element embedded within the animal bed at the base of the incubator. This aims to get a more accurate reading of the wildlife's body temperature. A feedback system, integrated with a microcontroller, interprets the detected temperature. Depending on whether the temperature falls within the predetermined range, the system activates or deactivates the heating element to maintain optimal temperature.

2. ### Feedback Heater with Ambient Air Detection

   The feedback heater with ambient air detection is similar to the first design, except for the placement of the temperature sensing element. In this variant, the sensor protrudes from the interior walls of the incubator, measuring the ambient air temperature to initiate the heating feedback loop.

3. ### Modified Arduino Thermistor

   The modified Arduino thermistor utilizes our design team's existing familiarity with temperature sensing. This design is heavily based on our previous experience with thermistor fabrication coursework. We will designate an Arduino Uno as the microcontroller, using its Serial Monitor function for consistent temperature readouts. The relay Control will be performed by another robust Arduino product, the Beefcake Relay Control Hookup. This design is not only easily programmable but also compatible with various thermistors. The PTC Ceramic Heating Plate will be tasked with the execution of the heating on or off functions, further enhancing the system's efficiency and reliability. Overall, this design optimizes both ease of use and convenient sourcing of components.

Materials

1. ### 3D printing with Acrylonitrile Styrene Acrylate (ASA)

   ASA is an alternative to ABS that performs exceptionally well in various outdoor environments and climates. It exhibits robust chemical resistance, ensuring durability against bodily fluids, humidity, or cleaning supplies. Furthermore, ASA is improved with superior UV resistance, allowing for outdoor storage without compromising its integrity. Despite these advanced characteristics, ASA remains an economically priced material.

2. 3D printing with Chlorinated Polyethylene (CPE+)

CPE+ has substantial thermal and chemical resistance, ensuring durability across diverse climates. Its exceptional strength enhances its resilience, effectively withstanding potential damage caused by animals. However, the elevated mechanical properties that provide these advantages also increase the complexity of manufacturing, making CPE+ a more costly material option.

3. Injection molding with Polylactic Acid (PLA)

PLA is cost-effective and can be quickly manufactured, making it an ideal choice for prototyping and test prints. However, it lacks the resilience to diverse temperatures and chemicals compared to other materials, rendering it less suitable for the final product.

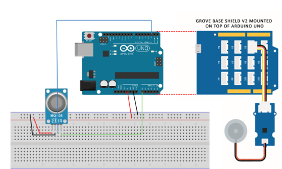
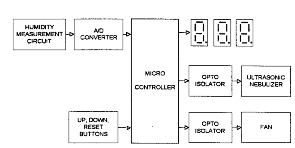
4. Injection molding with Polypropylene (PP)

PP distinguishes itself among the four materials by being recognized as a food-grade plastic, offering a more environmentally friendly option. PP is also relatively lightweight, and has very good chemical and heat resistance, making it an excellent choice for thermal insulation. In addition, PP shows extremely low water absorption, meaning it can support humidity control [10].

IV. Preliminary Design Evaluation

Design Matrix

1. Humidity Control

Criteria	Design 1: All-In-One Pre-built Humidifier 	Design 2: Team-Built Water Atomizer and Humidity Sensor Circuit 	Design 3: Ultrasonic nebulizer and Integrated circuit (IC) type humidity sensor 
Accuracy (25)	3/5 (15)	3/5 (15)	4/5 (20)
Ease of Instrumentation	4/5 (16)	4/5 (16)	3/5 (12)

(20)			
Practicality within an Incubator (20)	2/5 (8)	3/5 (12)	2/5 (8)
Usability (15)	3/5 (9)	3/5 (9)	4/5 (12)
Safety (10)	2/5 (4)	3/5 (6)	3/5 (6)
Cost (10)	1/5 (2)	4/5 (8)	3/5 (6)
Total (100)	54	66	64

Table 1: Humidity Preliminary Design Matrix. Criteria include Accuracy, ease of instrumentation, practicality, usability, safety, and cost. Overall, the Atomizer design won by having 66/100 points.

The designs were evaluated based on multiple criteria including accuracy, ease of instrumentation, practicality within an incubator, usability, safety, and cost. Accuracy is ranked the highest because minimizing the error of the humidity sensor and effective humidity control is the most important criterion emphasized by the team's client. Ease of Instrumentation is the second most important criterion, reflecting the degree of simplicity and efficiency with which the humidifier control, sensors, and humidifier itself can be implemented into the incubator system, considering the time constraints of the semester. Practicality within an incubator refers to how safe and robust the system is to regular cleaning; its ability for water level maintenance; and the realisticness that this humidifier system could be incorporated into an infant wildlife incubator. Usability refers to the ease of changing the humidity, access controls, and ease of refilling the water basin. Safety refers to the system's ability to safeguard against harm to the user and the infant wildlife it will be sustaining. Finally, cost is how affordable the system is– which while the lowest due to constraints of the semester, is important for a non-profit organization. Team-built water atomizer and humidity sensor circuit design received the highest score across most of the criteria, except for accuracy and usability. Initially, the team planned to use the ultrasonic nebulizer and integrated circuit (IC) type humidity sensor in the preliminary design. However, integrating the nebulizer with Arduino proved challenging, resulting in a complex circuit that could potentially undermine efficiency in the incubator and increase the risk of errors. Consequently, the team opted for the final design of the team-built water atomizer with a humidity sensor to address these challenges and enhance the system's overall performance.

2. Temperature Control

Criteria	Design 1: Feedback Heater with Bed Detection.	Design 2: Feedback heater with Ambient Air Detection	Design 3: Modified Arduino Thermistor

Safety (25)	3/5 (15)	5/5 (25)	4/5(20)
Temperature Control Capability (20)	3/5(12)	4/5 (16)	5/5 (20)
Durability (20)	5/5(20)	4/5(16)	4/5(16)
Cost (15)	2/5(6)	3/5(9)	5/5(15)
Feasibility (10)	4/5(8)	3/5(6)	5/5(10)
Replaceability (10)	3/5(6)	4/5(8)	5/5(10)
Total (100)	67	80	91

Table 2: Temperature Preliminary Design Matrix. Criteria included safety, control capability, durability, cost, feasibility, and replaceability. The Modified Arduino Thermistor design won by having 91/100 points.

The most important factor in our design is safety. This is ranked highly because it is essential to ensure that the heating and electronic elements are not within reach of the animals. Thus to provide the incubating function most effectively, the incubator must provide heating without injuring the animals housed inside. Temperature control is also significant as the infant wildlife requires a temperature of 95°F with a buffer of 2 degrees. This temperature range is vital to ensure that the infant wildlife is warmed to proper body temperature. The client, a wildlife rehabilitation expert with over 40 years of experience, has outlined that slight temperature deviations may cause hypothermia or overheating in some wildlife animal species. Although mature animals may be able to survive extreme temperatures, infants lack the ability to thermoregulate. Durability is important because the incubator itself must last 10 years but the electrical components can be replaced infrequently, as needed. Cost is also a significant factor because the entire incubator, including assembly, must be within $100. Feasibility is important because the prototyping should represent the actual assembly of the final product, which will be done by employees at the rehabilitation center. This requires the design to be accessible and feasibly created for people with no experience. Finally, replaceability requires that the electrical components are easy to replace during the lifetime of the incubator. The modified Arduino thermistor design received the highest score in most of the criteria, except for safety and durability. This makes the design the optimal choice for temperature control based on our criteria.

3. Materials

Criteria	Design 1: 3D Printing - ASA	Design 2: 3D Printing - CPE	Design 3: Injection Mold - PLA	Design 4: Injection Mold - PP
Temperature	4/5 (20)	5/5 (25)	3/5 (15)	5/5 (25)

Support (25)				
Water/Weather Resistance (25)	5/5 (25)	4/5 (20)	2/5 (10)	4/5 (20)
Strength/Durability (20)	3/5 (12)	5/5 (20)	5/5 (20)	3/5 (12)
Cost(15)	5/5 (15)	2/5 (6)	4/5 (12)	3/5 (9)
Weight (10)	4/5 (8)	3/5 (6)	2/5 (4)	5/5 (10)
Safety (5)	2/5 (2)	3/5 (3)	2/5 (2)	5/5 (5)
Total (100)	80	80	63	81

Table 3: Materials Preliminary Design Matrix. Criteria included temperature support, weather resistance, durability, cost, weight, and safety. The Injection Mold design won by having 81/100 points.

In contrast to the other matrices, this matrix evaluated materials rather than designs. The criteria for this matrix include temperature support, water and weather resistance, strength and durability, cost, weight, and safety. The first and highest weighted of the criteria is temperature support. This is due to the fact that the incubator must maintain a constant temperature to support the body temperature of the animal that the incubator is housing. The second criterion, which is tied for the highest weight is water and weather resistance. This is because not only should the incubator support humidity control, but it could be used around the world, and may be stored in places where climate is not controlled. The next criterion is strength and durability. Not only must the incubator be able to withstand the weight of infant wildlife, but it must also be resistant to damage from the animal. The incubator should also be able to be used for a long period. The cost criterion simply refers to the cost of the material itself. While the incubator must be a reasonable price, its effectiveness in nurturing infant wildlife is of higher importance. The second to last criterion is weight. When choosing a material and creating a design, weight will play a factor in ergonomics when handled by people and shipping costs. The final criterion is safety. While the safety of the animal is of utmost importance, the safety of the material itself does not make a significant difference, as it will not be used as a food storage device. With a high Vicat Softening Point and low moisture absorption, polypropylene scored exceptionally in the two highest weighted criteria, temperature resistance and water/weather resistance [10]. In addition, PP is reasonably priced, and has a good Shore hardness, meaning it will handle scratches from incubated wildlife well. Due to these evaluations of polypropylene, it has been chosen by the team as the material to be used for the apparatus shell.

Proposed Final Design

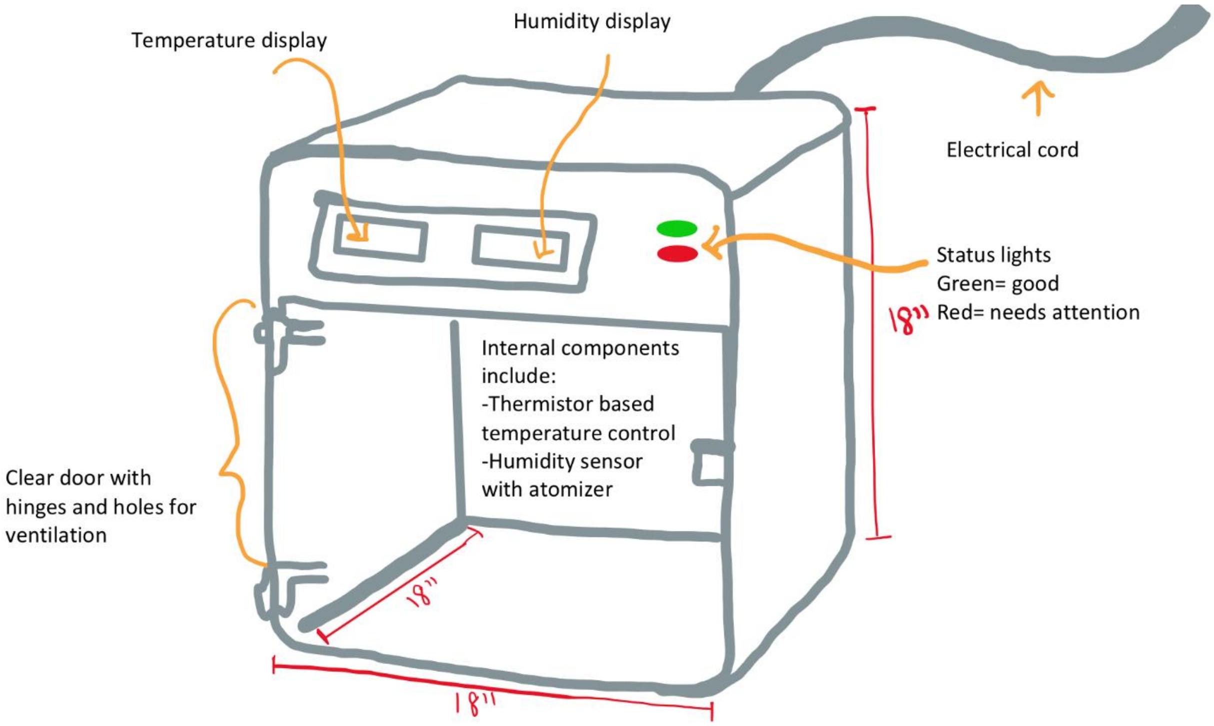


Figure 1: Proposed Final Design combining all three parameters; humidity, temperature, and materials

The dimension of the incubator is 18” by 18” X18” X18”. The design will be made of injection-molded PP, which received the highest score in our material's preliminary design matrix. Two displays will be incorporated to show measured temperature and humidity values respectively, enhancing the ease of monitoring. Status light, specifically red light, will indicate if attention is needed, ensuring timely interventions. The incubator will feature a clear door to facilitate easy visibility of the infant wildlife inside. It will also be equipped with hinges and holes to ensure proper ventilation, promoting a safe environment. Internally, the incubator will integrate a thermistor-based temperature control system and an atomizer with a humidity sensor to maintain optimal conditions.

V. Fabrication/Development Process

Materials

The team has plans to primarily focus on fabricating working electrical components, before making the physical structure of the incubator. Some materials that will be needed for the creation of the humidifier component are an Arduino microcontroller, compatible humidity and temperature sensors, an atomizer, and other typical electronics components such as a breadboard, resistors, and wires. The microcontroller will allow the design team to communicate with the circuit and control it with software. The humidity and temperature sensors will allow for the detection of these variables and correction. The atomizer is the humidifying mechanism that will add water vapor to the incubator environment. Finally, the typical electrical components will allow for proper instrumentation.

Materials needed for the temperature system include a sensor if the humidity sensor we get does not have temperature-sensing capabilities and has the same basic electrical components as the humidifier. Additionally, a ceramic heating element is also needed.

Finally, for the materials needed for the outside of the incubator, the team will use a dog cage as temporary use until the external components can be fabricated through injection molded polypropylene or T-Slot 80/20.

Methods

Fabrication methods involved the assembly of circuits on breadboards. Since the design included two main circuitry systems, there was a method for assembly for each circuit system.

The temperature circuit system was assembled using a beefcake, 12V DC adaptor, 147k ohm resistor, DS18B20 temperature sensor, and a ceramic heating element. These elements were all connected to an Arduino microcontroller which included written code that would control when the heating element would turn on and off. The code also allowed the microcontroller to receive input from the temperature sensor so it could govern the heating element using a feedback system.

The humidity circuit system was assembled using a beefcake, power supply, DHT11 humidity sensor, and an atomizer. The elements were connected to an Arduino microcontroller which included code that involved a feedback loop. This loop is what determines when the atomizer would turn on or off. This was also governed by input from the humidity sensor.

There were no methods for the external design of the incubator, though there was a design created. This was because the team determined it was necessary to test and validate the electrical components by themselves prior to including them within a shell. Thus for temporary purposes, the shell was “created” by using a popup dog cage with ventilation and sufficient insulation.

Final Prototype

Figure 2: Image of final prototype. For this semester, the electronics were housed within a dog cage that provided an adequate testing environment by having appropriate ventilation and insulation.

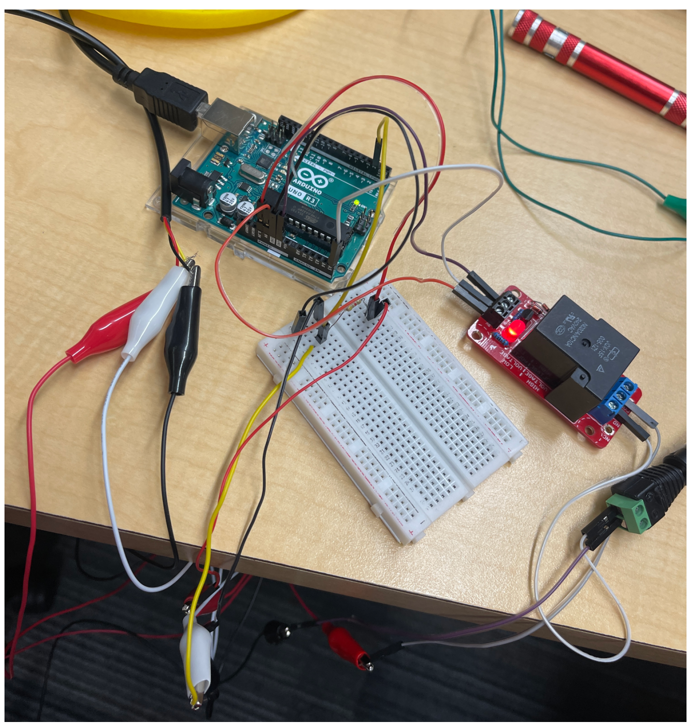


Figure 3: Image of final temperature circuit. Includes beefcake, 12V DC adaptor, 147k ohm resistor, DS18B20 temperature sensor, and a ceramic heating element.

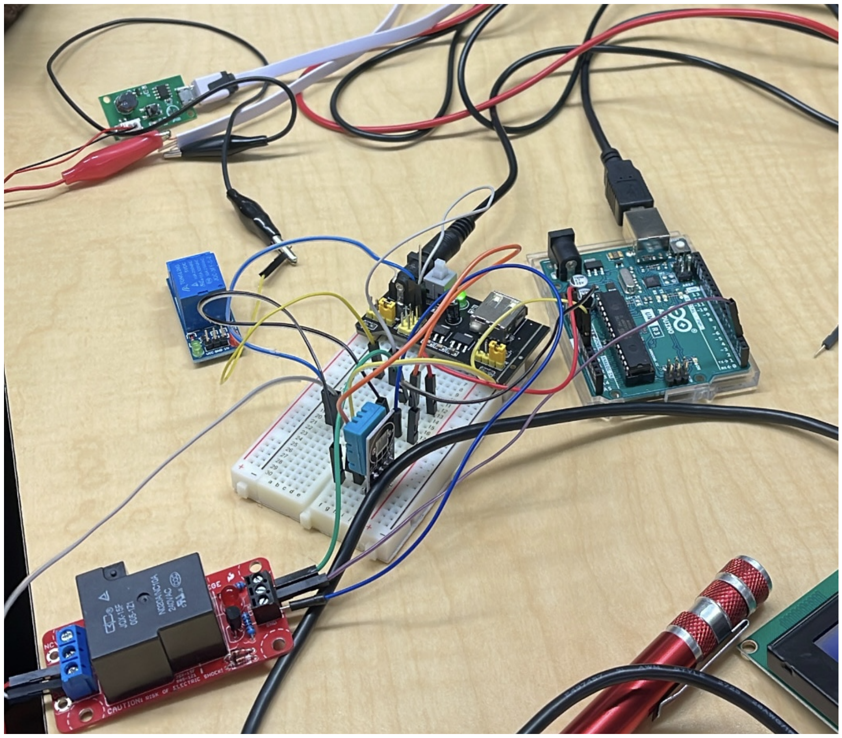


Figure 4: Image of final humidity circuit. Circuit includes, beefcake, power supply, DHT11 humidity sensor, and an atomizer.

Testing

This semester, testing focused on ensuring proof of concept. The goal was to ensure that all of the electrical components worked as desired in a similar environment as to what they will be housed in. This was done prior to creating the external shell design to ensure that no material was wasted in case components did not work properly.

To test the temperature circuit, the team uploaded the code into the Arduino microcontroller, and waited for the element to heat up. Testing was done at room temperature, to mimic the conditions that the actual incubator would be in. To ensure that the element came back down, the team placed the sensor on the heating element so it would measure the higher temperature, rather than remain at room temperature, like the surroundings. A successful test would see the heating element turn on and heat until it fell into the range of 93-97℉. Once the temperature was at 97℉, the team should see the heating element turn off and the sensor should read cooler temperatures. This was also tested via tactile feedback as team members ensured that the ceramic heating element was indeed getting hot/cold when necessary. To ensure that the results of this test were reproducible, the team completed multiple cycles. These cycles were defined as oscillations between a baseline temperature, increasing to reach threshold, decreasing to reach baseline, and finally reaching baseline again. The team aimed to conduct 5 of these tests and plot the data received through the Arduino Serial Monitor to see how the oscillations changed over time.

To test the humidity circuit, the team uploaded the code into the Arduino microcontroller. The team ensured that the humidity in the room was around 50% to ensure that the atomizer would initially turn on. Once it was visually verified that the atomizer was able to turn on and spray water, the team covered the device and placed it into the dog cage to mimic the incubator environment. A successful test would see that the atomizer turns on and increases the humidity in the environment when the humidity drops below 60%, and turns off and stops spraying water vapor into the air when it reaches 70%. This was also checked via visual and auditory cues to ensure that when the Serial Monitor was reading that humidity was below the threshold, the sound of the atomizer turning on and spraying water vapor was heard. The same was true for making sure that when the Serial Monitor was reading that the humidity was above or at threshold, the atomizer was turning on. The team aimed to conduct 4 of these tests and convert data into graphs that visualize the data

VI. Results

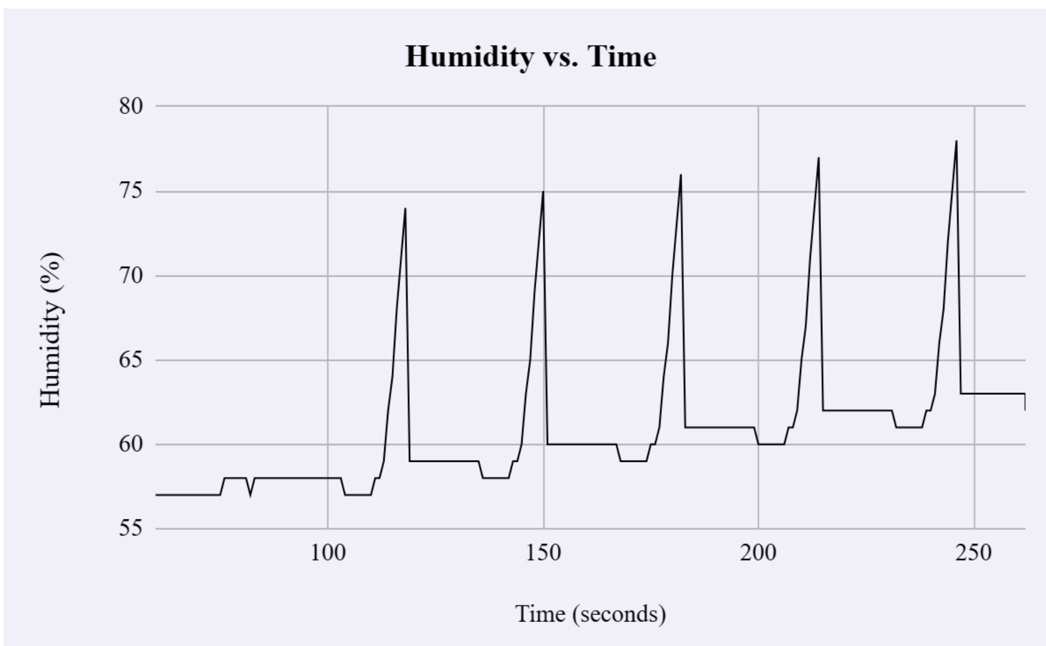


Figure 5: Image of humidity vs time graph that was developed via testing. There is a slight upward trend that can be seen over time, but overall the humidity stays mostly within the range that was expected and desired.

The humidity data was found to have a standard deviation of 1.15. The team found that 23.6% of data points are outside of the desired range by the client (60-70% humidity). Of these points, 79.66% are due to humidity that exceeds the desired range. Thus, the team will focus on ways to decrease humidity with regard to the feedback regulation process.

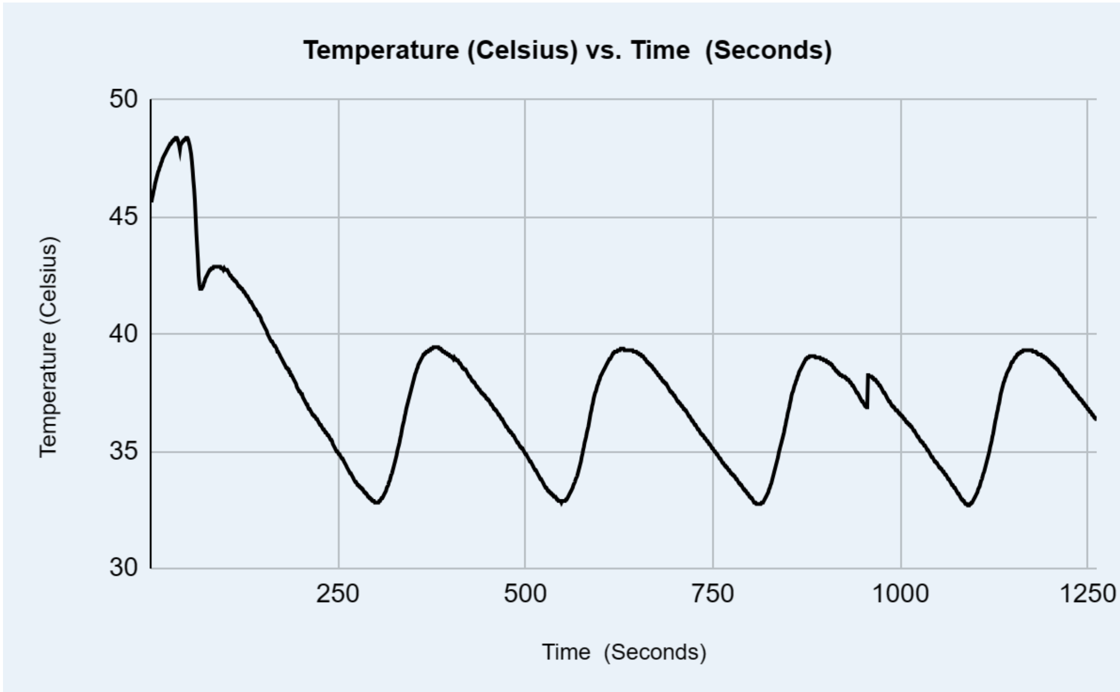


Figure 6: Image of Temperature vs Time that was obtained through testing data. There is a brief spike that was the calibration period but the temperature feedback system behaved as expected. However, the range is slightly wider (89-104℉) than what would have been desired (93-97℉).

The team found a standard deviation in the temperature data of 3.37 degrees Celsius and a median of 37.3 degrees Celsius. Out of 1263 data points, 783 are out of the specified range by the client (93 to 97 degrees Fahrenheit). That is about 62% of the data points, indicating a significant need for improvement on this measure in future work. 74% of the data points that are out of range are due to the temperature being above the specified range by the client, which is further solidified as the main error by the fact that the median temperature is slightly above the client's desired range. Of the points that are outside of the desired range, only 76 (about 9.7%) are greater than 10% outside the desired range. Thus, although the feedback system does waver outside the range frequently, it rarely goes much lower or much higher than the range.

VII. Discussion

The team was able to interpret the results in the context of key determining factors of success in this project. In the humidity data, it is easily observed that the humidity maximum and minimum (located in the peaks and troughs of each oscillation) slowly trend upward over time. Long-term, this may pose an issue if testing results over a longer period of time reveal that the humidity feedback loop does not eventually self-correct (or, does not self-correct in a way that is satisfactory enough). Overall, there is not too much deviation in the results already obtained. The humidity feedback loop does take approximately 100 seconds to initiate (beginning the oscillations that regulate humidity levels).

Over the course of the group's research and logistics meetings concerning the use and fabrication of this incubator, it was found that there is a main ethical concern. For human infants, incubators are designed especially for their needs. In contrast, a wildlife incubator may be used for infants of several species. There is concern that the lack of specificity for certain species may lead to poorer recovery results than if the incubator was made with certain species in mind. Additionally, it is unethical to test these devices on animals, as supported by the Animal Welfare Act of 1966 [11].

The team saw errors such as the temperature of humidity systems may hover outside the desired ranges. The reason for this was likely because of the feedback system not being precise enough. This will require changes in the feedback system. This could involve the introduction of a PID controller. The fundamental concept of a PID controller is to read a sensor, calculate the derivative, integral, and proportional responses, and then add these three components to get the desired actuator output [12]. This will allow for faster and more stable responses through the device. This should ideally reduce the error that is seen.

Another change that should be incorporated into the future design would be the introduction of fans, which would increase the airflow within the incubator. This would spread the heat that is generated by the heating element throughout the incubator. The same would be seen with the humidity. Additionally, creation of the external shell will create more insulation that will prevent heat and humidity from leaking out of the incubator.

VIII. Conclusions

The wildlife infant incubators on the market today are too expensive for many of those who run nonprofit wildlife rehabilitation centers, such as the team's client. Despite the high price, the client has found that the incubators purchased did not have reliable and accurate temperature control. The team was tasked with creating an incubator that is durable, safe, precise in its temperature and humidity controls, and affordable. This project aims to improve accessibility to wildlife infant treatments.

The team was able to prototype a design that met the client's criteria. The design utilizes simple and affordable Arduino controls. These controls read the temperature within the incubator, report it back to a microdevice that records these readings in a serial monitor, and trigger a heating element. The heating element will turn on if the temperature has fallen below 93℉, and will turn off if the temperature has risen above 97℉. The incubator is also equipped with a humidity control system. The team selected the water atomizer circuit with a humidity sensor. The atomizer creates a mist at ambient conditions and a humidity sensor measures the relative humidity of the incubator environment. If the predetermined relative humidity value is higher than the measured values, the atomizer converts water into fine water particles. The accuracy of the sensor is +/-2% at 25°C. Finally, the team selected a commercial dog cage for a proof of concept of the external shell. The benefit of the dog cage is that it has similar dimensions to the incubator and has plenty of ventilation like our incubator–ideally. Both the temperature and humidity circuits were successful in their testing cycles at moderating temperature and humidity; however, the results could be improved through additional work.

Future work includes improving the regulation of temperature and humidity through a proportional integral derivative control system (PID). The team also wants to implement changeable temperature and humidity using a dial. Additionally, the external shell will be created via 3D printing or T-Slot 80/20. Finally, the team wants to test the whole system over multiple-hour periods rather than the individual components and to test the shell for modularity and durability.

IX. References

[1] A. Moran, “What is wildlife rehabilitation?,” Urban Utopia Wildlife Rehabilitation, https://www.urbanutopiawildlife.org/wildlife-rehabilitation (accessed Sep. 28, 2023).

[2] “How to get a wildlife rehabilitation license,” How to get a wildlife rehabilitation license | | Wisconsin DNR, https://dnr.wisconsin.gov/topic/WildlifeHabitat/permitting (accessed Oct. 8, 2023).

[3] “TLC brooders/Intensive Care Units,” /Hospital Cage, https://www.brinsea.com/p-682-tlc-50-zoologica-ii-parrot-brooderintensive-care-unitrecovery-incubator.aspx (accessed Sep. 21, 2023).

[4] “TLC brooders/Intensive Care Units,” Home, https://www.brinsea.com/p-615-tlc-30-eco-parrot-brooderintensive-care-unitrecovery-incubator.aspx (accessed Sep. 21, 2023).

[5] M. S. Blumberg and G. Sokoloff, “Thermoregulatory competence and behavioral expression in the young of Altricial species?revisited,” *Developmental Psychobiology*, vol. 33, no. 2, pp. 107–123, Dec. 1998. doi:10.1002/(sici)1098-2302(199809)33:2<107::aid-dev2>3.0.co;2-n

[6] J. Terrien, “Behavioral thermoregulation in mammals: A Review,” *Frontiers in Bioscience*, vol. 16, no. 1, p. 1428, Jan. 2011. doi:10.2741/3797

[7] *Guide for the care and use of Laboratory Animals*, 2011. doi:10.17226/25801

[8] E. A. Miller, *Minimum Standards for Wildlife Rehabilitation*. St. Cloud, MN: National Wildlife Rehabilitators Association, 2012.

[9] I. Güler, M. Burunkaya, “Humidity control of an incubator using the microcontroller-based active humidifier system employing an ultrasonic nebulizer,” J Med Eng Technol, Mar 2002, doi: 10.1080/03091900110115478.

[10] “How to Choose the Right 3D Printing Material,” Formlabs, https://formlabs.com/blog/how-to-choose-the-right-3D-printing-material/ (accessed Sep. 28, 2023).

[11] “Animal Welfare Act,” Animal Welfare Act | National Agricultural Library, https://www.nal.usda.gov/animal-health-and-welfare/animal-welfare-act#:~:text=The%20Animal%20Welfare%20Act%20(AWA,USDA%20%2C%20APHIS%20%2C%20Animal%20Care. (accessed Dec. 12, 2023).

[12] “The PID Controller & Theory explained,” NI, https://www.ni.com/en/shop/labview/pid-theory-explained.html (accessed Dec. 12, 2023).

X. Appendix

A. Product Design Specification (PDS)

Wildlife Incubator: PDS

9/22/2023
Client: Mark Stelford
Advisor: Dr. Wally Block
Team Members: Loukia Agoudemos, Erwin Cruz, Sophia Finn, Seyoung Selina Park, and Tanishka Sheth

Function:

Wildlife rehabilitation often includes caring for neonatal wildlife who are unable to control their own body temperature, thus the incubator must provide supplemental temperature control. Although private parties frequently contribute to wildlife rehabilitation efforts, they do not have enough financial resources required to purchase an incubator. As such the wildlife incubator must be low cost, while also durable, modular, easy to clean, and precise in temperature control. It is essential to create an incubator that is more accessible and accommodating for those interested and passionate about wildlife rehabilitation but may lack the financial resources to purchase components currently available in the market.

Client requirements:

I. Dimensions should be 18" x 18" x 18" and break down into a box that is 20" x 20" x 8" or smaller for shipping purposes
II. The incubator must be under $100/unit to manufacture
III. The incubator should involve modular parts that allow for easy replacement
IV. The incubator must maintain a temperature of 95°F with a buffer of +/- 1-2 degrees
V. Compatible with common indoor outlets, as the incubator is for indoor use only.

Design requirements:

1. Physical and Operational Characteristics

a. *Performance requirements*:

I. The incubator should be durable enough to easily withstand regular operational use and cleaning regimen. This may include:
   A. Transport/regular removal of the incubator and its modular parts.
   B. Sustained weight load from animals on the modular parts.
   C. Scrubbing and cleaning using high temperatures and/or chemicals on the incubator and its parts.
   D. Exposure to humid conditions

II. Incubator door:
   A. Should be large enough to insert and remove modular parts.
   B. Should allow for easy access for cleaning.
   C. Should allow for easy access to the water basin for humidity control.
   D. Should allow for easy access to the animal inside.
   E. Should be transparent to allow for observation of the animal inside.

III. The bottom of the incubator should be a 4 inch deep "tray" with smooth sides to make it easy to clean.

IV. The base of the incubator should have indentations that will allow secure placement in a rack, enabling stacking of multiple incubators.

V. Humidity control
   A. There must be a spot to put water for humidity control.
   B. There should be an obvious alert system to indicate when water needs to be added to the system, or if the humidity level is outside of desired ranges.
   C. Should have the ability to increase humidity up to 60% without additional sealing on the door.
      1. The ability to increase to 70% humidity is ideal.

b. *Safety*:

I. There should be no sharp edges on the interior surface to ensure the safety of the wildlife inside of it.

II. The incubator should be assembled with seals / bolts that are smooth on the inside of the incubator for easy cleaning and safety of the wildlife inside of it.

III. Temperature and humidity control within specified range by client for the safety of the wildlife.

IV. Should have failure alerts and fail-safes.

c. *Accuracy and Reliability*:

I. Accurate temperature control inside the incubator with a typical range of 90°F to 100°F and temperature of the incubator needs to be within 1 to 2 degrees of the target temperature set by the user.

II. Humidity control should have a maximum error of 5% of the displayed humidity.
   A. A 3% error is ideal.

d. *Life in Service*:

I. It is preferred that the incubator has a life in service similar to current products on the market. This is typically defined as 1-3 years.

e. *Shelf Life*:

I. The incubator will be stored in a storage unit that does not include climate control and thus the components should be able to withstand being in a variable environment.

f. *Operating Environment*:

I. The user should be able to store this incubator in a storage unit that isn't climate controlled in Arizona or Minnesota and they should expect it to work when they bring it into a climate controlled building.

g. *Ergonomics*:

I. The incubator should allow for easy access to the animal, as employees will be checking on the animals frequently.

II. The incubator should be easy to carry and be lightweight such that employees can move it from the shelves that it will be stored on.

III. Electronics must be housed within the incubator at a height such that the animals cannot reach them.

h. *Size*:

I. The outside assembled dimensions of the incubator should be 18" x 18" x 18".

II. The unit should ideally be able to be broken down into a box that is 20" x 20" x 8" or smaller for shipping.

i. *Weight*:

I. OSHA requirements typically recommend that workplaces do not allow carrying of equipment over 35 lb. Many kinds of newborn livestock, such as sheep, weigh about 15 lb. Therefore, the incubator should not exceed 20 lb. [1]

j. *Materials*:

I. Materials for the outside should be made of injection molded plastic or a similar lightweight plastic.

k. *Aesthetics*, *Appearance, and Finish:*

I. The design should incorporate a see-through door.

II. The temperature monitor should be able to be set to display the temperature in fahrenheit or celsius.

III. The external portions of the incubator can be "angular" if needed.

2. Production Characteristics

a. *Quantity*:

I. At this time, only one prototype is required. The client would like to be able to replicate the product in the future.

b. *Target Product Cost*:

I. The incubator must cost less than $100 per unit to produce including labor and materials.

3. Miscellaneous

a. *Standards and Specifications*

I. The incubator would ideally be able to accommodate changes in the power cord/power supply so a second mold is not needed (for example, international power cord requirements versus the standards for the US).

II. Need appropriate electronics approved for sale in the United States.

b. *Customer*:

I. The users of this incubator would likely be private parties that feel passionately about wildlife rehabilitation.

II. These users would require a low cost and easily accessible incubator to allow for the highest impact in wildlife rehabilitation.

c. *Patient-related concerns*:

I. The device should be thoroughly cleaned between uses to ensure that all animals are being safely handled and that no mixing of environments is occuring

d. *Competition*:

I. Brinsea Incubators [3] come in a variety of sizes and are often used at wildlife rehabilitation centers [4].

References

[1] “NIOSH sets 35-lb limit as the max for safe lifts,” Relias Media. https://www.reliasmedia.com/articles/9596-niosh-sets-35-lb-limit-as-the-max-for-safe-lifts

[2] “Overview of Medical Device Classification and Reclassification,” U.S. Food and Drug Administration. https://www.fda.gov/about-fda/cdrh-transparency/overview-medical-device-classification-and-reclassification

[3] “TLC-40 Eco Series II Parrot Brooder/Intensive Care Unit/Recovery Incubator,” TLC Brooders/Intensive Care Units, https://www.brinsea.com/p-679-tlc-40-eco-series-ii-parrot-brooderintensive-care-unitrecovery-incubator.aspx (accessed Sep. 20, 2023).

[4] “The incubators,” BabyWarm, https://www.babywarm.org/about-the-incubators/ (accessed Sep. 20, 2023).

B. Expenses and Purchases

Item	Description	Manufacturer	Part Number	Date	QTY	Cost Each	Total	Link
Component 1								
Atomization Disc, 5V Module USB	It Is A 108KHz 20mm Micro USB Humidifier With Driver. It Will Keep Work after Power-ON.	tingbowie	B095MZDD1Z	10/30	1	7.99	7.99	link

Humidifier Atomization Plate Circuit Board								
Component 2								
150 * 28.5mm PTC Heating Plate	Ceramic Electric Heating Plate, with High Temperature Resistance PTC Thermostat Heating Element (12V 220℃) Component Heater	Marhynchus Store	1	10/26	1	8.99	8.99	link
Component 3								
DS18B20 Temperature Sensor Waterproof Stainless Steel Prob	Power supply range: 3.0V to 5.5V Wide temperature Measurement range of -55 ℃ ~ +125 ℃	DIYables	B0BPFYQT8C	10/26	1	9.99	9.99	link
Component 4								
Liquid Level Controller	This liquid level controller has LED indicators, large contact capacity, ultra-wide voltage, and flame-retardant materials. Stable operation, 35MM standard track installation.	Hilitand Store	Hilitand8a1b23u0ys	10/26	1	18.23	18.23	link
Component 5								
MakerFocus 4pcs 3D Printer Fan	Size: 40 mm x 40 mm x 10 mm; Working Voltage: DC 12V; Working Current: 0.08A; Air Flow: 5.75±10% CFM; Power: 0.96w; Cable length: 280mm; Certification: CE,UL,CUL	MakerFocus	B07CH6YC32	10/26	1	10.99	10.99	link
Component 6								
5V Relay Module	5V indicator light LED 1 channel relay module works with arduino boards	DAOKI	B00XT0OSUQ	11/14	1	7.89	7.89	link
Component 7								
DC 12V 2A power supply adapter	AC 120V to DC 12V, 5.5mm*2.1mm plug 12V 2A power supply	CENTROPOWER store	B0C2J2M3GL	11/29	1	9.99	9.99	link
Component 8								
Pop up travel pet kennel	Size: 32.5” * 19.5”* 19.5”	Beatrice home fashion store	SLOPPKOOBLK	12/5	1	17.76	17.76	link
TOTAL:								**$91.83**

C. Arduino code for the humidity circuit

```
#include "U8glib.h"
U8GLIB_SSD1306_128X64 u8g(U8G_I2C_OPT_NONE);//Set the device name:
I2C-SSD1306-128*64 (OLED)

#include "DHT.h"

#define DHTPIN A0

#define DHTTYPE DHT11

#define jiashi 2

#define button 12


DHT dht(DHTPIN, DHTTYPE);

void setup() {

  Serial.begin(9600);
  pinMode(jiashi,OUTPUT);
  pinMode(button,INPUT);
  dht.begin();

}

void loop() {
  float Humid = dht.readHumidity();
  float Temp = dht.readTemperature();

  Serial.print("Temp");
  Serial.println(Temp);
  delay(1000);
  Serial.print("Humid");
  Serial.println(Humid);
  delay(1000);


  u8g.firstPage();
  do
  {
    u8g.setFont(u8g_font_gdr14r);
```

```
    u8g.setPrintPos(25,18);
    u8g.print("DKARDU");
    u8g.setFont(u8g_font_9x18);
    u8g.setPrintPos(1,40);
    u8g.print("Temp: ");
    u8g.print(Temp);
    u8g.print("'C");
    u8g.setPrintPos(1,60);
    u8g.print("Humid: ");
    u8g.print(Humid);
    u8g.print("%");
  } while(u8g.nextPage());

if(Humid<80) {
  digitalWrite(jiashi,LOW);
} else
{
  digitalWrite(jiashi,HIGH);

}


}
```

D. Arduino code for the temperature circuit

```
/*
 * Created by ArduinoGetStarted.com
 *
 * This example code is in the public domain
 *
 * Tutorial page: https://arduinogetstarted.com/tutorials/arduino-heating-system
 */

#include <OneWire.h>
#include <DallasTemperature.h>

#define SENSOR_PIN  2   // Arduino pin connected to DS18B20 sensor's DQ pin
#define RELAY_PIN   A5  // Arduino pin connected to relay which connected to heating
element

const int TEMP_THRESHOLD_UPPER = 36.1; // upper threshold of temperature,
change to your desire value
```

```
const int TEMP_THRESHOLD_LOWER = 33.9; // lower threshold of temperature,
change to your desire value

OneWire oneWire(SENSOR_PIN);         // setup a oneWire instance
DallasTemperature sensors(&oneWire); // pass oneWire to DallasTemperature library

float temperature;    // temperature in Celsius

void setup() {
  Serial.begin(9600); // initialize serial
  sensors.begin();    // initialize the sensor
  pinMode(RELAY_PIN, OUTPUT); // initialize digital pin as an output
}

void loop() {
  sensors.requestTemperatures();             // send the command to get temperatures
  temperature = sensors.getTempCByIndex(0);  // read temperature in Celsius
  Serial.println(temperature);
  if(temperature > TEMP_THRESHOLD_UPPER) {
    digitalWrite(RELAY_PIN, LOW); // turn off
  } else if(temperature < TEMP_THRESHOLD_LOWER){
    digitalWrite(RELAY_PIN, HIGH); // turn on
  }

  delay(1000); // spits out a temp every second.
}
```