ThermoRevive: Low-Cost Neonatal Incubator Empowering Low-and Middle-Income Countries (LMICs) through Repurposed Hardware

Engineering World Health Design Project 2023
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Table of Contents

1. Problem Definition

The rising prevalence of global preterm births presents a substantial challenge in the healthcare sector [1, 2]. Neonatal hypothermia, characterized by a core body temperature below 36.5°C, is a major concern among low birth weight premature infants [3]. This issue is particularly pronounced in low and middle income countries (LMICs) where access to essential neonatal care, including adequate thermal protection, may be limited [4].To address this critical issue, incubators play a vital role in neonatal intensive care units (NICUs). The design of incubators focuses on temperature and humidity control, aiming to minimize heat loss and prevent the formation of eddies, thus ensuring optimal thermal conditions. However, in LMICs, the scarcity of reliable and well-maintained stationary neonatal incubators presents significant challenges [5].

After conducting interviews with St. David's Medical Center and International Biomedical. Ltd., it has been concluded that oftentimes, hospitals in these developing communities lack the resources to upkeep, repair, and maintain their incubators. In these LMICs, broken incubator parts lay waste because the maintenance of the machine is unknown to the hospital staff. To tackle these challenges, we focus on creating neonatal incubators from familiar electronic parts so that part specific expertise is not required to bring a broken incubator back into operation. Additionally, there is a need to develop cost-effective solutions that offer reliable thermoregulation and incorporate fail-safe mechanisms to ensure infant safety in resource-limited settings.

To achieve our goal, we propose the ThermoRevive Incubator—an innovative device that improves infant thermal care in LMICs by utilizing affordable materials and repurposed hardware components from everyday electronics. ThermoRevive seamlessly integrates cost-effective materials such as acrylic and wood for the standing structure, along with automotive and computer parts sourced from scrap yards to ensure effective powering and thermoregulation. The current prototype incorporates automotive headlights, CPU fans, polyvinyl chloride (PVC) pipes, and a DHT11 temperature sensor for convective and thermoregulated heating. For powering, the device uses a lightweight PC power supply unit (PSU) that provides stable energy and flexibility in delivering different voltages to accommodate various devices in the incubator. In future iterations, the model will incorporate solar panels and a Maximum Power Point Tracking (MPPT) charge controller to meet heating and lighting needs during off-grid scenarios, such as transport. A standard sealed lead-acid (SLA) car battery sourced from auto yards will also be integrated with the proposed solar panel. A manual providing detailed instructions on the working of the machine will also be publicly provided.

Furthermore, this project aims to develop an affordable and user-friendly incubator priced within $200, targeting hospitals and neonatal units in Mexico and India, where electricity shortages and a shortage of skilled healthcare workers hinder the required regular operation and maintenance of expensive and advanced neonatal technology.

2. Statement of Impact

Our technical solution, ThermoRevive, offers several benefits to neonatal departments around LMICs. Firstly, it tackles the issue of limited preventative maintenance by integrating familiar automotive and computer hardware components.This approach increases the number of personnel equipped with the necessary skills to effectively maintain the devices, mitigating the risks of equipment failure and suboptimal performance caused by limited resources and infrastructure.

Additionally, the current cost of stationary incubators further exacerbates the challenges faced by LMICs. Typical prices for incubators in the United States range from $1,500 to $35,000, making them unaffordable for many developing nations[5]. ThermoRevive's innovative use of repurposed parts significantly reduces costs while maintaining functionality and performance. By pricing our solution within a $200 budget, ThermoRevive provides a low-cost alternative that enables healthcare facilities to acquire an adequate number of incubators to meet the demand and provide quality care for premature infants.

While there are other economical alternatives to neonatal incubators, these come with their own shortcomings. For example, Kangaroo Mother Care, while effective, can be stigmatized due to cultural beliefs and misconceptions surrounding privacy and social norms in public hospital settings. It also immobilizes mothers who need to return to work after their pregnancy, preventing them from consistently choosing to adhere to this method. On the other hand, radiant warmers are less stigmatized but lack the same level of control as incubators, which leads to increased insensible water loss from the infant's body. ThermoRevive eliminates the stigmatization and cultural barriers associated with KMC and also provides more precise and adjustable thermoregulation than warmers. ThermoRevive offers improved care and reduces the risks associated with radiant warmers.

In areas with inconsistent power supply, ThermoRevive's integration of solar energy provides a reliable and sustainable power source. This eliminates the dependency on a consistent electrical grid, ensuring continuous operation and preventing disruptions in thermoregulation. The incorporation of fail-safe mechanisms further enhances the incubator's ability to maintain consistent and optimal thermal conditions, even during fluctuations in ambient temperature or power outages. This robustness significantly reduces the risks faced by premature infants and enhances their overall safety.

Furthermore, ThermoRevive presents a way that enables those dealing with premature hypothermic cases to achieve optimal thermoregulation at an affordable cost, without compromising the functionality and performance of the incubator. Altogether, our use of repurposed parts and solar power enables a low-cost and energy-efficient solution that improves health outcomes and enhances newborns' chances of survival. Our ultimate aim is to establish a standard of care for infants in developing countries, ensuring that every newborn has the resources to survive.

3. Performance Specifications

3.1. Structural Materials

3.1.1. As seen in Figure 1, the incubator is separated into two sections. The first section is known as the "overhead cabin," where the patient is housed and where temperature regulation is crucial. Directly underneath the overhead cabin is the "basement," which hosts the electronics and circuitry to ensure the temperature and humidity of the overhead cabin does not interfere with the performance of the electronics. Together, this structure should be within 20 lbs, making it ideal to carry and transport.

3.1.2. PVC (Polyvinyl Chloride) pipes should be used to help thermoregulate the incubator via guiding warmed air and redirecting cold air. The PVC pipes should direct the thermoregulated air to be in a more controlled and efficient manner as seen in Figures 2 and 4.

3.2. Hardware Specifications

3.2.1. Power Supply Unit (PSU)

3.2.1.1. The ATX PSU (Advanced Technology eXtended Power Supply Unit) serves as a standardized power supply for computer PCs, responsible for providing essential electrical power to various system components. The PSU should include pins for +12V, +5V, +3.3V, ground, and a power-on signal (Fig. 5, 6). The 20-pin Molex connector plays a crucial role in the power delivery from the PSU to peripherals, ensuring reliable and efficient power distribution within a system.

3.2.2. Headlights

3.2.2.1. The halogen headlights should have a diameter of at least 4 inches and have an output of at least 400 lumens to provide sufficient surface area for heat generation and distribution within the incubator.

3.2.2.2. The headlights should be compatible with a 12V power supply, aligning with the power requirements of the ThermoRevive system.

3.2.3. Central Processing Unit (CPU) Fans & Heat Sinks

3.2.3.1. The CPU fans should have a maximum revolutions per minute (RPM) of 4800, in the case that the incubator needs to significantly decrease in temperature. For standard usage of ThermoRevive, the CPU fans should vary from 3000 RPM to 3500 RPM, to move heated air and adequately ventilate ThermoRevive for the neonate

3.2.3.2. Heat sinks should dissipate excess heat generated from the system before it enters the incubator.

3.2.4. DHT11 Temperature Sensor

3.2.4.1. The DHT11 temperature sensor should read the temperature of the ThermoRevive environment with an accuracy of 1 degrees celsius (Fig. 2). The DHT11 should report the temperature reading of the ThermoRevive environment to be displayed on the LCD.

3.3. Software Specifications

3.3.1. Arduino Mega

3.3.1.1. The Arduino Mega should be powered by the 5V output from the PSU. Additionally, it should connect to the headlights, CPU fans, the temperature sensor, and the LCD as seen in Figure 6 and 7. Based on the reading of the temperature sensor, the headlights will remain on or off. Similarly, the speed of the CPU fans will be regulated if the temperature exceeds 37 °C in order to thermoregulate the incubator. Furthermore, the temperature and any alerts will be displayed on the LCD (Fig. 7).

4. Implementation of Prototype

4.1. Thermoregulation System

4.1.1. Within the NICU, there are two primary pathways of infant physiologic heat exchange—conduction and convection. When an infant's environment is disrupted, it stimulates their physiologic response, resulting in an observed increase in metabolic rate ($Q_{\text{Metabolic}}$ rate) similar to what is seen in Formula I. This compensatory mechanism aims to correct the body temperature but at the expense of energy. Even the tiniest premature infant demonstrates this tendency, which can contribute to both conductive and convective heat loss, resulting in hypothermia.

4.1.2. Conduction involves heat transfer between solid objects in contact, while convection, the dominant heat loss mechanism, occurs through natural (air pressure gradient) and forced (CPU fans) means, transferring heat to cooler air. ThermoRevive implements an Arduino-controlled feedback system to regulate the temperature range within the overhead cabin by accounting for both conductive and convective heating (Fig. 8). A cost-effective solution is implemented by utilizing headlights as a heat source with the CPU fans circulating the warm and cold air (Fig. 2, 3, 7, 8).

4.2. Conduction: Automotive Headlights, Foam & Blankets

4.2.1. In pursuit of cost-effective heating solutions, ThermoRevive incorporates automotive headlights sourced from local auto yards to Austin, such as Austin Wrench a Part and LKQ Pick Your Parts. It is important to note that these parts are standard and readily available in Austin and the targeted LMICs in Mexico and India. Moreover, this innovative approach effectively replaces conventional and costly resistive heating methods, providing a more efficient and economical solution for neonatal care settings (Fig. 1, 3).

4.2.2. To address the issue of heat loss through conduction and through the acrylic dome, ThermoRevive incorporates the use of insulating foam and blankets along with the headlight heating element as seen in Figure 2. These essential measures aim to minimize heat loss by ensuring dry layers of insulation are in direct contact with the baby's skin. This becomes particularly significant for preterm infants who have limited natural insulation. By creating a comfortable environment and facilitating the regulation of the baby's body temperature, these measures promote optimal thermal stability and reduce the transfer of heat through conduction.

4.3. Convection: Forced Air Circulation via Fans & Pipes

4.3.1. Convective heat transfer involves the movement of heat through a fluid medium, with natural convection driven by temperature differences and forced convection facilitated by active air movement. In neonates, natural convection can lead to heat loss as warm air surrounding the baby's skin rises, cools, and descends, creating a temperature gradient. Additionally, the average metabolic rate of the target patient set was considered to predict the temperate generation from the neonate and the temperature differences within the various heating and circulation systems in the overhead cabin. To mitigate convective heat loss, ThermoRevive utilizes a system of CPU fans and PVC pipes to force air into the system, promoting convective heat transfer.

4.3.2. As seen in Figure 2, this process circulates warmed air within the overhead cabin, efficiently distributing heat and minimizing convective heat loss. In the ThermoRevive system (Fig. 2), CPU fans, operating at 180 pulse width modulation (PWM), which is 70.6% duty cycle or 3394.88 RPM, are employed in conjunction with heat sinks to effectively dissipate heat generated within the system. These heat sinks are specifically designed to efficiently transfer heat away from the heat source, facilitating effective cooling. Moreover, the incubator base incorporates a slab of wood with four drilled holes, which accommodate PVC pipes (Fig. 3, 4). These pipes, referred to as "T-connectors," play a vital role in facilitating convective heat transfer. Essentially, the bottom of these pipes interface with the heating element headlight, while the top remains open beneath the heat sink/fan assembly to allow for optimal air circulation.

4.4. Thermal Neutral Sensing

4.4.1. The neonatal thermoneutral range refers to the temperature range in which a newborn maintains a normal body temperature while minimizing energy expenditure and oxygen consumption. It is crucial to provide a thermoneutral environment for neonates to ensure their well-being and long-term outcomes. The recommended thermoneutral range for preterm infants is typically within the same range as term infants. The World Health Organization recommends a body temperature range of 36.5–37.5°C.

4.4.2. When initially powered on, the headlight takes approximately 20-30 minutes to reach the desired temperature and fully initialize. As the sensors detect changes in the baby's temperature, the headlights are turned on and off in response to maintain a stable and comfortable environment.For instance, if the temperature falls below the thermoneutral range, the system can activate the headlights for about 10-15 minutes. This helps to provide additional heat and circulate warm air within the incubator, thereby raising the temperature and bringing it back within the desired range. On the other hand, if the temperature exceeds the thermoneutral range, the system can turn off the headlights until the incubator reaches ~36.6 °C to prevent overheating and maintain a suitable temperature for the preterm infant.

4.5. System Powering

4.5.1. A PC was obtained from InventionWorks Makerspace at the University of Texas at Austin. This PC was used to obtain the fan heat sinks and an ATX PSU (Fig. 3, 4). The ATX PSU was converted to a standard bench power supply[6]. In order to convert the ATX PSU to a bench power supply, the 20 pin Molex Connector was stripped for the ground, 5V, 12V, power on, and 0V (Fig. 5, 6). Specific connections from the PSU to the rest of ThermoRevive can be seen in Figure 6.

4.5.2. To enable convenient control over the power supply for the incubator, an ON/OFF switch was incorporated by connecting pins 14 and 15 on the Molex Connector (Fig. 6, 7). This switch allows the user to effortlessly activate or deactivate the power supply. Furthermore, to ensure optimal performance of the power supply, a 20W, 10-ohm power resistor was employed. This resistor manipulates the PSU into perceiving the presence of a motherboard, enabling the power supply to operate at its full capacity. By connecting the power resistor across the 5V and ground pins of the PSU's Molex Connector, the necessary load on the PSU's 5V rail is simulated, emulating the characteristics of an actual motherboard.

4.6. LCD: Monitoring and Alert System

4.6.1. Located on the front side of the incubator as seen in Figure 2 and in more detail in Figure 7, the LCD is connected to the Arduino Mega which is connected to the temperature sensor. The LCD then displays the current internal temperature of the incubator so that it can be easily monitored by any users. Should the incubator exceed 37.5°C, a warning should be displayed on the LCD display to alert the caretakers that the incubator is not a safe environment for the neonate.

5. Proof of Performance

5.1. Precept Thermoregulation Data

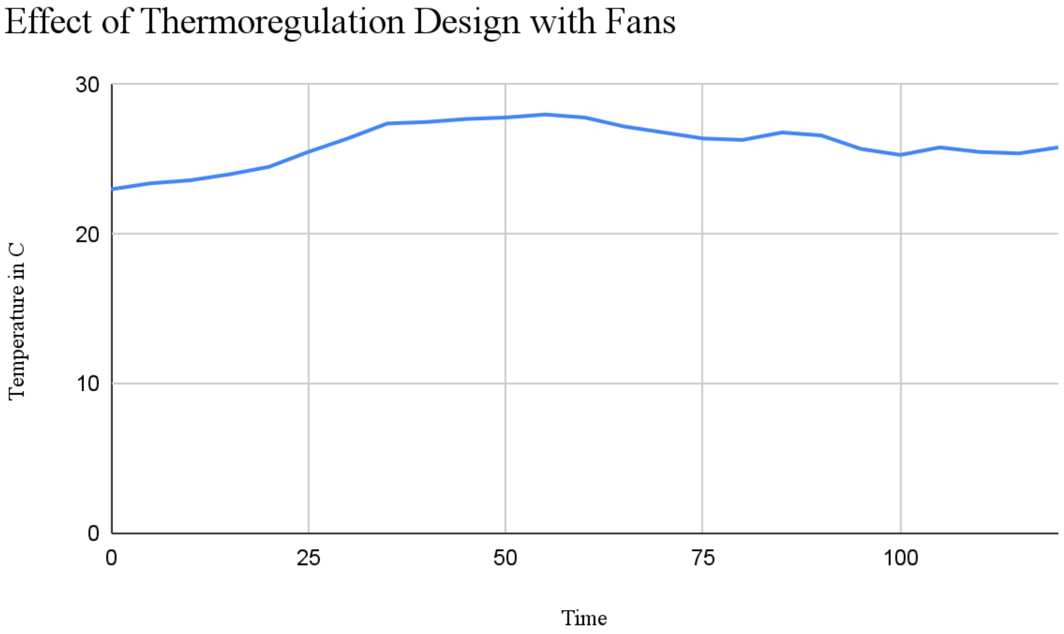
5.1.1. To determine if ThermoRevive's performance is cost efficient, several data sets were collected and compared to the performance specifications. The performance specifications were selected based on personal interviews with the Neonatal Transport Team at St. David's Hospital, Dr. Steven Abrahams at Dell Medical School's Pediatric Department, and International Biomedical's biomedical engineers in Austin. These specifications helped build certain usable characteristics into the device that would best benefit LMICs. There are two main data sets that show performance.

5.2. Measuring Air Flow Rate from CPU Fans

5.2.1. The first step in collecting preliminary data was to test the efficiency of the fans alone. By testing the efficiency of the fans alone, the efficiency of the fans' ability to disperse and circulate the warmed air throughout the overhead cabin can be measured. Therefore, the air flow rate of the CPU fans was measured using a tachometer. The average of all the fans is similar to the theoretical value with a 12% error yield and matches that of the current neonatal incubator. However, with this solution, the CPU fans used are much cheaper than the current models.

5.3. Measuring CPU Fan Feedback System

5.3.1. In addition to the air flow rate, the feedback system of the temperature sensor, which is connected to the Arduino, must also be tested. For this purpose, a hair drier, acting as an external heating mechanism, was introduced to the internal environment of the overhead cabin. When the external heat was introduced into the environment during the experiment, the temperature sensor notices the change in temperature, kickstarting a feedback mechanism that turns on the fans. When the fans turn on, they can help circulate the hot air and allow it to cool down. This can be seen in the graph shown below, which depicts how the CPU fan system was able to lower the internal temperature of the incubator when a heat source was added and effectively regulate temperature for a neonatal patient.



Graph. Depicts data collected from a controlled environment.

6. Business Plan

6.1. Customer Pricing

Part	Cost of ThermoRevive
Power Supply	\$0 – \$19.99[8]
Fans	\$0 – \$4.99[9]
Cooling System	CPU Fans: \$0 – \$4.99[9]
Heat Generator	Motor Vehicle Headlights: \$20[10]
User Interface	LCD: \$10[11]
Miscellaneous Material	\$50
Total Estimated Cost	\$80- \$104.98

6.1.1. ThermoRevive incorporates a thoughtfully designed structure utilizing affordable systems and materials, making it highly cost-effective for implementation in LMICs. In comparison to traditional incubators, which cost between \$1,500-\$35,000[5], this solution is remarkably more affordable, while still maintaining its essential functionality.

6.1.2. It is worth noting that the overall estimated cost of this incubator may vary due to the availability of materials sourced from nearby scrap yards. For instance, the acquisition of a power supply similar to the one proposed in this application may incur additional expenses. The main goal is to build the incubator using easily accessible materials, reducing the need for hard to get materials or technical knowledge and allowing for simple repairs and replacements.

6.1.3. Considering the moderate risk associated with patient well-being and the need for special controls, this neonatal incubator falls under the classification of a Class II medical device according to FDA guidelines. Additionally, it will require a 510k application for marketing within the United States. However, should the initial testing prove successful, we envision the utilization of this device in the specific LMICs targeted, namely Mexico and India.

6.2. Funding

6.2.1. Funding for the incubator can be acquired through the National Science Foundation which is capable of providing grants for various research projects, especially for undergraduates like us. In order to obtain such a grant, a proposal should be submitted and approved. The grant can provide funding for the technology of the incubator such as the heating and power sources. Furthermore, the grant will allow more flexibility in testing various power and heating sources as well as different types of materials for the incubator box.

6.2.2. Additionally, funding is available at *Austin Pets Alive!*, a pet shelter that pioneers lifesaving programs for animals in the Austin area. Because foster kittens are oftentimes orphaned and motherless, it is crucial for foster families to incubate the kittens. In the midst of the kitten neonatal incubator shortage in the Austin community, ThermoRevive is in the process of collaborating with the Neonatal Kitten center at *Austin Pets Alive!* To further develop the incubator to hold comfortable internal temperatures for the kittens.

6.2.3. Moreover, in our current partnership with Dell Medical School, this prototype can be improved and tested for use in Mexico. Future testing of the prototype will ensure that the incubator is safe for infant use and ensures that the incubator maintains the appropriate temperature.

6.3. Allocation of Funding for Specific Future Testing

6.3.1. The funds from applied grants and partnerships will be used with very specific motives. In future iterations of this prototype, the aim is to enhance the management of evaporative heat loss in neonatal incubators. Evaporative heat loss occurs when moisture evaporates from the skin surface of newborns inside the incubator, resulting in heat loss and potential cooling of the infants, which can affect their thermal stability. To address this issue, a plan to implement an improved humidification system within the incubator will be derived by adding a humidifier to the environment along with a humidity sensor.

6.3.2. Future designs will feature an upgraded humidification mechanism that maintains optimal humidity levels while minimizing the impact on the baby's temperature regulation. Humidification inside the overhead cabin will be accomplished through passive evaporation of water from a reservoir pan located in the air pathway underneath the incubator mattress. To facilitate this process, a sliding compartment within the basement will be built to house the pan securely. To ensure precise control and monitoring of humidity levels, the DHT11 sensor will be integrated, which includes humidity sensing capabilities. This sensor will enable us to accurately measure humidity levels inside the incubator and provide real-time output of humidity readings. This data will be vital for monitoring and adjusting the humidification process to maintain optimal conditions for the newborns. By implementing these future plans, the management of evaporative heat loss in neonatal incubators can be optimized, thereby enhancing the thermal stability and overall well-being of the infants at a cheaper price than currently available models.

6.3.3. LMICs often face challenges with unreliable power, particularly during natural disasters in remote areas where access to grid power is limited. This poses significant difficulties for various operations, including transport, which may require access to off-grid power sources. To address this, future prototypes of our device will be tailored towards off-grid purposes, using solar panels and a Maximum Power Point Tracking (MPPT) module, as outlined in Figure 9.

6.4. Manufacturing

6.4.1. Since several parts of the incubator are recyclable and repurposed hardware, they would be sourced locally from each individual country. The fan and heat sink can be sourced from an old CPU while the headlights can be sourced from any halogen headlight car, often found in car junkyards. The plastic crate to house the electronics, the wood to create the base structure and the PVC pipes to control air flow are also readily available in multiple countries. As the acrylic, temperature sensor, LCD display and switch can be harder to locate in low income communities, they will be manufactured in the US and shipped to these countries on a need basis.

6.4.2. To aid with manufacturing, ThermoRevive plans to assist hospitals to find and partner with local scrap yards and recycling company partners. When recycled materials enter the scrapyards, these companies will determine whether or not the material meets the standard, which were previously set in the performance specifications. Upon meeting the standard, the scrapyards will distribute the materials to the partnered hospitals who will complete the build of the incubator.

6.5. Distribution

6.5.1. As the incubator uses local parts, the incubators will be assembled onsite using a physical or online manual. The manual is open source and can be publicly found. As mentioned in Section 6.3.2, the materials will be shipped and distributed from local scrap yards that are partnered with various hospitals and neonatal clinics across Mexico and India where incubators are in heavy need.

6.5.2. Additionally, since ThermoRevive uses materials that are easily found in each respective country, a manual will be provided with some of the shipped parts. This manual will detail alternative material options that have similar properties and work in similar ways that are potentially easier to find in countries such as India and Mexico so that they do not have to import many international and niche parts. This will reduce the number of incubators that tend to go to landfills due to lack of knowledge on how to operate them while also continuing to provide a safe alternative to those high tech incubators.

6.5.3. By employing this device directly at hospitals where they will be built; doctors, nurses, volunteers, and other medical practitioners can easily be trained to feel comfortable with sanitizing and using the incubators on a daily basis. Training will be provided in an online course from ThermoRevive to ensure users are equipped to use the instrument. Training is also publicly available and open source.

6.5.4. If emergency situations arise where the device needs to be immediately fixed and the provided training is not enough for the medical staff to fix the incubator, the hospital can refer to local automobile mechanics or computer technicians to repair the incubator. This will be possible because the incubator will be made out of materials and parts that automobile mechanics and computer technicians, and they are already skilled to fix it.

6.6. Intellectual Property and Regulations

6.6.1. Because the purpose of this device and design is to tackle a global health issue, the design and hardware of this incubator will be publically available as open source.

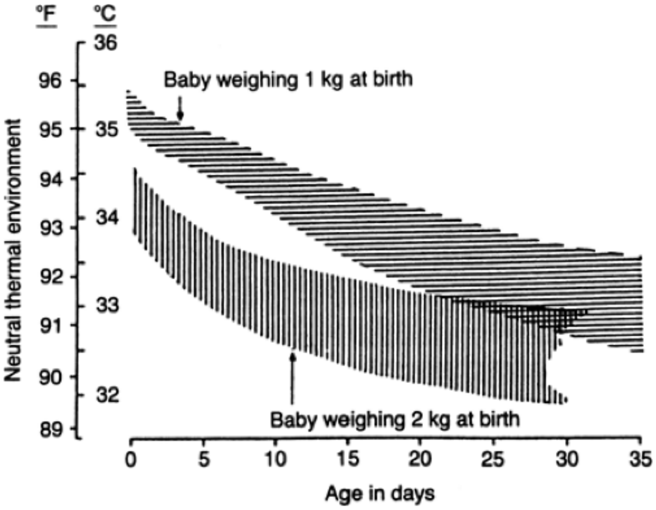
6.6.2. If implemented in Mexico with the provided funding, ThermoRevive, like all medical devices in Mexico, will need to be approved by the Federal Commission for the Protection against Sanitary Risk (COFEPRIS)[7].

7. Appendix

7.1. Formula I: Thermoregulation [12]

$$Q_{metabolic} + Q_{stored} = Q_{conduction} + Q_{convection}$$

7.2. Hey-Katz Diagram [13]



7.3. Figures

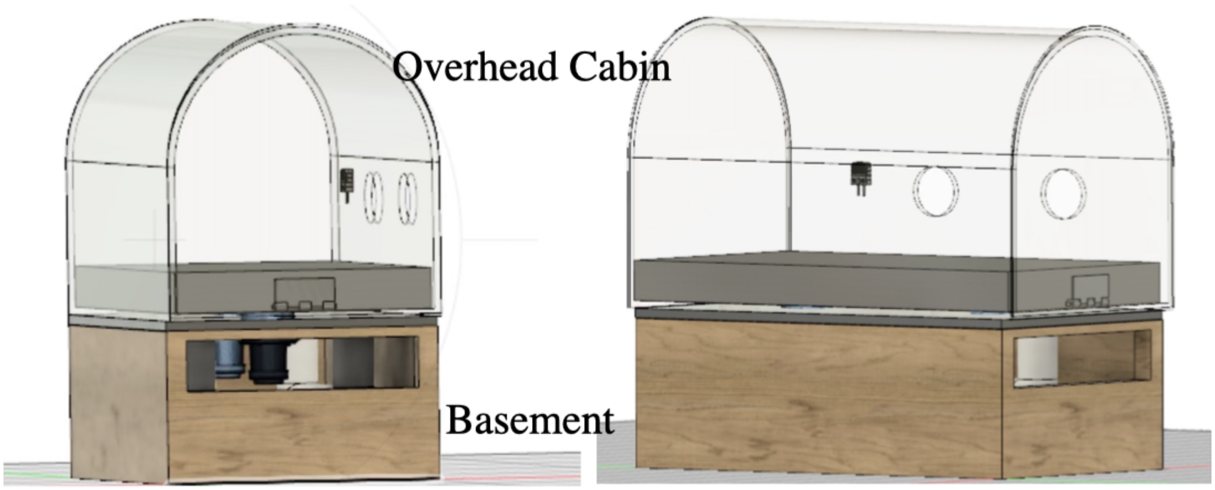


Figure 1. A CAD rendering of Thermorevive that explicitly displays the two main sections, the overhead cabin and the basement. The outside structure of the overhead cabin should be composed of wood and acrylic to house the infant. The top portion should allow visibility of the infant at any given time, whether that is through clear acrylic or wood with windows where medical professionals can view the patient. Plastic material that prioritizes visibility of the infant at any given time, a vital part of the incubator. Additionally, cheap foam padding should be placed on top of the wood within the overhead cabin to provide comfort for the patient.

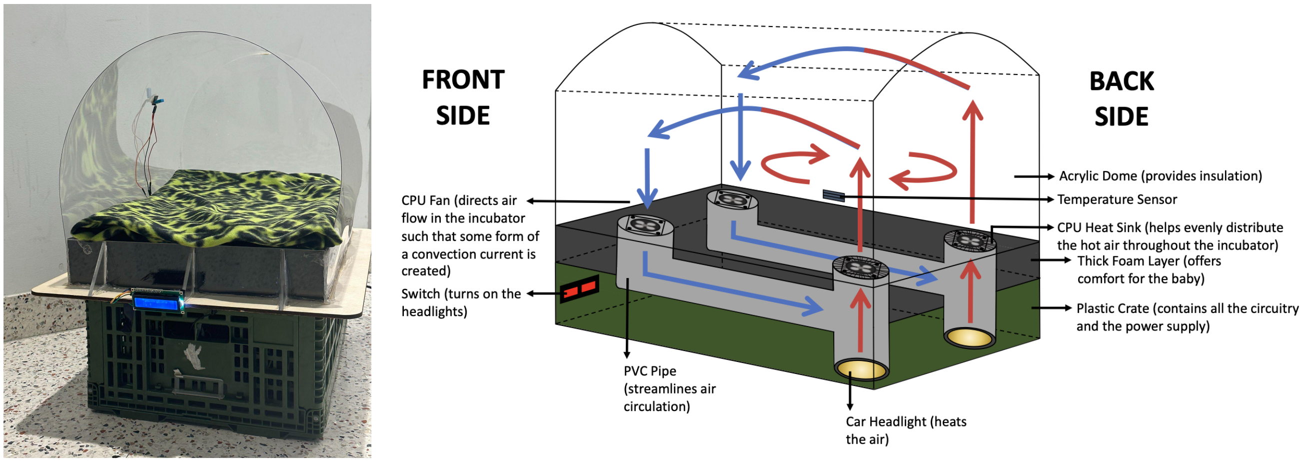


Figure 2. (1) Front view of ThermoRevive **(2)** Overall schematic of ThermoRevive with specifics on the hardware material and their purpose in ThermoRevive

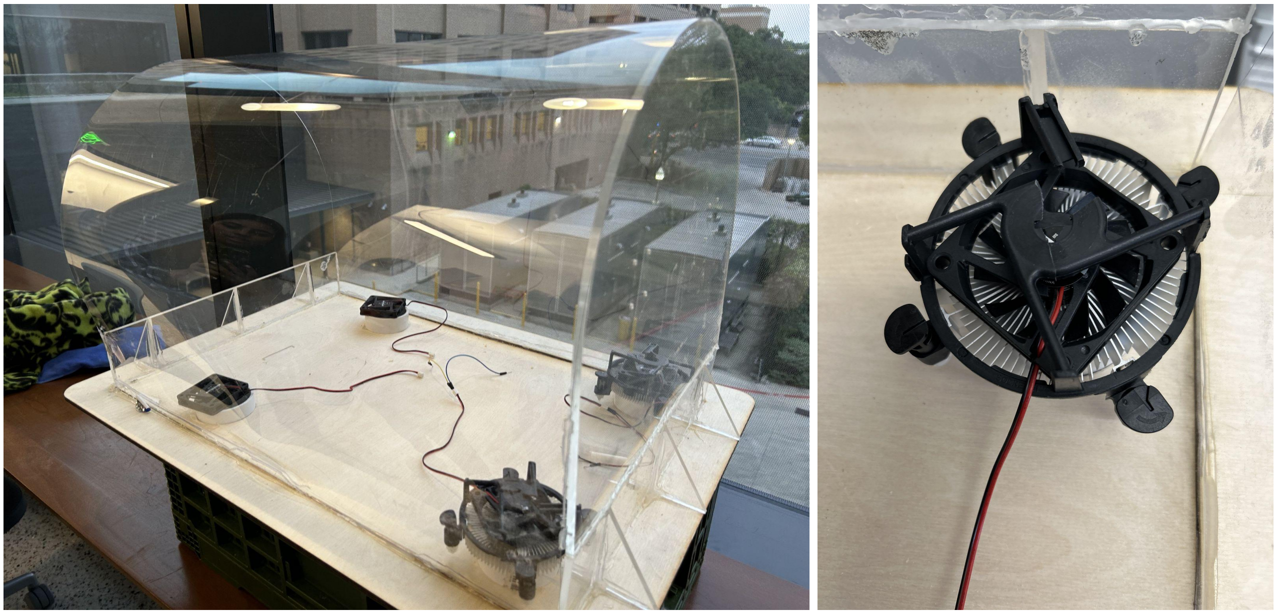


Figure 3. (1) CPUs fan (60mm x 60mm x 10mm) placed around the base of the overhead cabin. **(2)** Metallic Heat Sinks (80mm x 80mm x 20mm) placed under PC fan for heat dissipation.

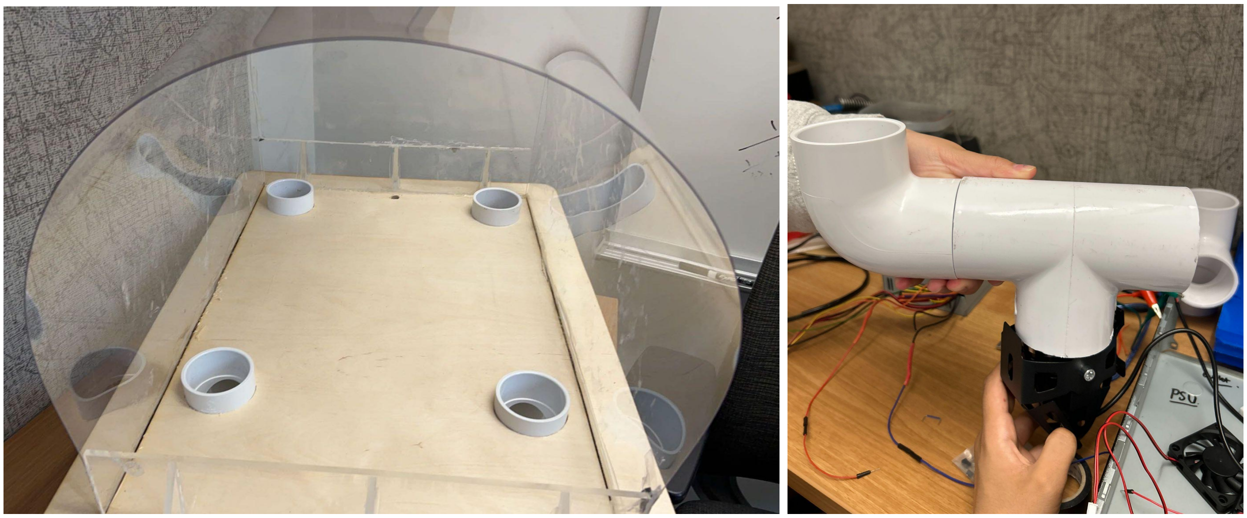


Figure 4. (1) PVC pipes penetrate through the wooden base. The PVC pipes should be 18 inches long and 2.1 inches in diameter. **(2)** T-connectors within the basement allow air flow from headlights. The PVC pipe in this connection should be 7 inches where it is connected to the CPU fans and the headlights. Where the PVC pipe is only connected to the headlight, it should be 5 inches.

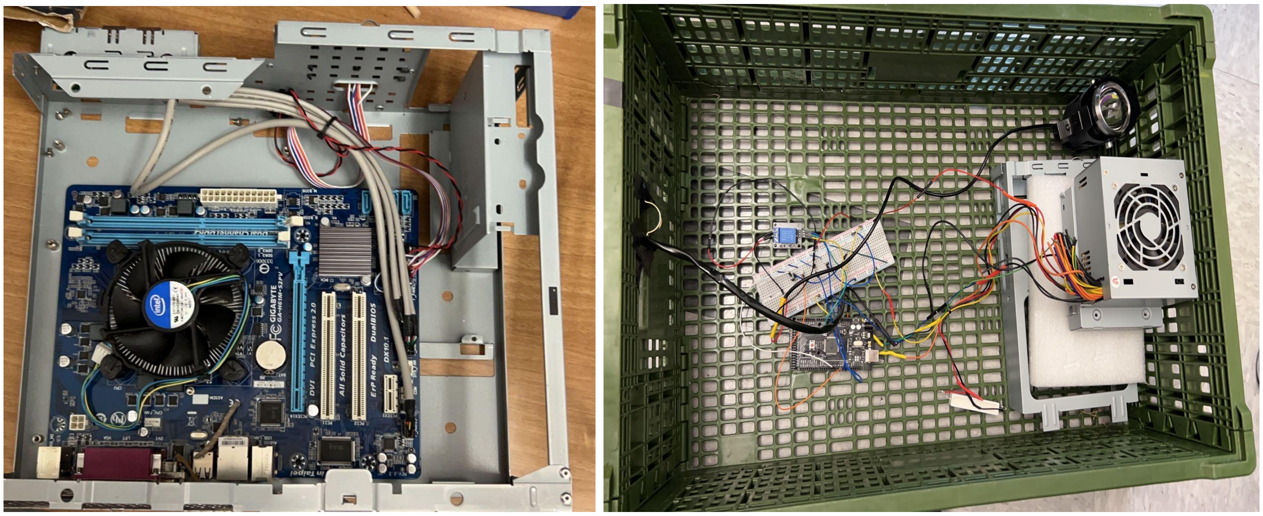


Figure 5. Spare PC dissembled to extract circuit and structural components (PSU, frames for support, heat sink fins). The ATX PSU should include a 20-pin Molex connector featuring 20 individual pins arranged in a specific configuration.

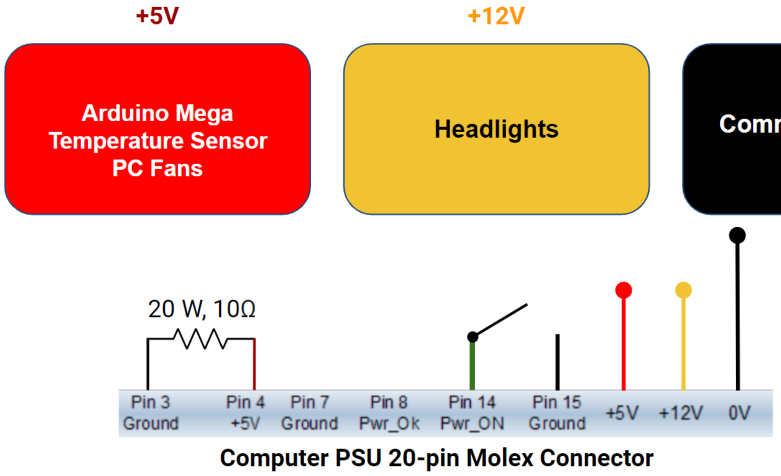


Figure 6. PSU voltage connections via Molex Connector with specifications to what each node specifically connects to.

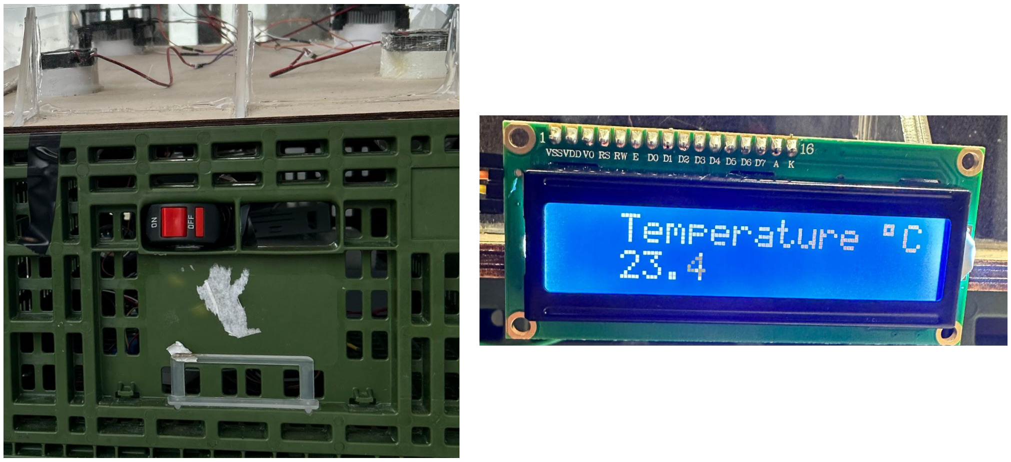


Figure 7. Close up of the (1) ON/OFF Switch for Power Supply and (2) the LCD on the frontside of ThermoRevive. The LCD should be 16x2 (16 characters wide, 2 rows) and able to communicate with an Arduino Mega. If necessary, the LCD should utilize an I2C (inter-integrated circuit) to ensure a better connection to the Arduino Mega. The brightness of the LCD should be determined by the potentiometer on the I2C connection and should never be set below 2.5V.

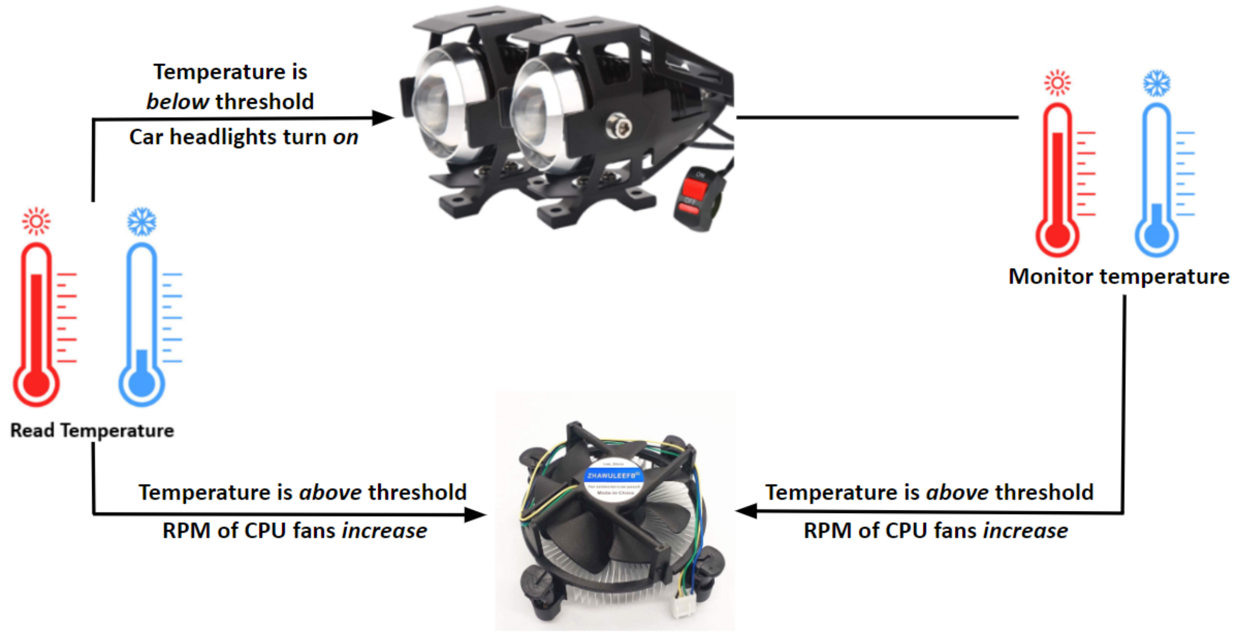


Figure 8. Thermoregulation flowchart for ThermoRevive. The headlights, temperature sensor, and the CPU fans are all controlled by the Arduino Mega which has the temperature monitoring and threshold embedded in its software.

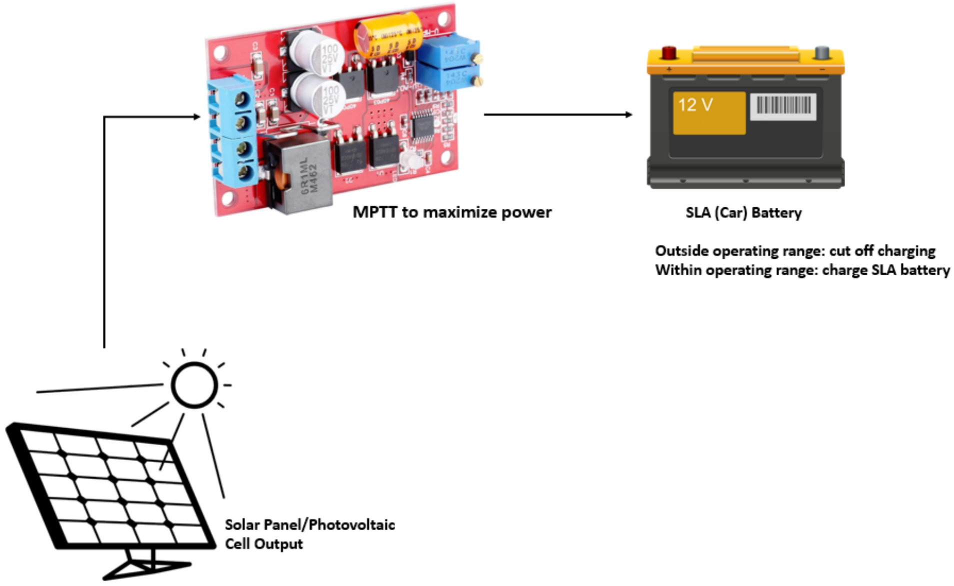


Figure 9. Solar energy flowchart detailing future plans for ThermoRevive. MPPT adjusts the operating voltage and current to maximize power. The panel will recharge an SLA car battery which will be used during transport operations.

8. References

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