

DESIGNING A LOW COST AND LOW POWER-CONSUMING INCUBATOR FOR PRETERM INFANTS

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ABSTRACT

In the biomedical industry, incubators are crucial for the care of premature babies, as they struggle with temperature regulation, humidity control, and oxygen intake. High costs and limited power access in rural areas discomfit parents in developing countries from accessing incubators for their premature babies. To address these challenges, this article presents innovative design and development of an energy-efficient incubator, aiming to reduce premature infant mortality while offering a cost-effective solution for parents. The designed device is not only energy efficient and affordable but also a practical solution for saving the lives of premature babies in disadvantaged areas. By providing a feasible and practical solution, this innovation holds the potential to improve the survival rates of

premature infants in developing countries. Furthermore, the designed incubator is energy-efficient and easy to use and maintain, making it a promising advancement in sustainable innovation.

KEYWORDS: Premature baby, Incubator, NICU, Low cost, energy-efficient.

I. INTRODUCTION

The general definition of premature baby is if a baby's birth takes place more than three weeks before the baby's estimated due date that time the baby will be called as premature baby. World Health Organization (WHO) "Department of Maternal, Newborn, Child and Adolescent Health and Ageing (MCA)" states in "WHO recommendations for care of the preterm or low-birth-weight infants" that the premature babies have a gestational age below 37 weeks at birth.^[1] Whereas premature babies are born early these causes those several complications while adapting to a new environment. Doctors suggest the premature babies may have a few obvious symptoms such as low body temperature due to lack of stored body fat, respiratory distress, lack of reflexes for sucking and swallowing, leading to feeding difficulties.^[2] At this time, the preterm baby needs an environment which resembles the mother's womb and an incubator system was made to provide this service with controlled temperature, humidity and oxygen supply.

Incubator- a biomedical device which is designed like a box with a clear glass bassinet provides a corresponding environment like a mother's womb, keeping babies warm and protecting them from allergens or environmental pathogens. The incubator is equipped with devices that provide a baby with a controlled environment by regulating temperature, humidity, and oxygen. This box has ports and doors to do nursing and provide medical attention according to the baby's health.^[3] Incubators also reduced the excess noise which may cause sleep disruptions, redundant stress and the rise of baby's blood Pressure. As a result, all preterm babies who need special care and medical attention could be placed in incubators in a separate setup called the neonatal intensive care unit (NICU).

A. LITERATURE SURVEY

In a developing country such as Bangladesh where 17,100 newborns die every year and 72 per cent of them die within a day of being born due to air pollution and a lack of medical facilities.^[4] For premature babies, the environment plays a vital role because after the baby is born the body temperature starts to reduce drastically due to lack of body fat. Hence the preterm baby needs special attention so that the baby can take time to adapt to the new environment. An incubator is made to fulfil this purpose so that the baby can survive until he/she is familiar with the new polluted environment.

The invention history of incubators has few dissents, in The New York Times; it states that Dr. Charles C. Chapple, a retired pediatrician and professor in University of Nebraska

College of Medicine, invented the incubator in the mid-1930's.^[5] As opposed to, in 1880 at L'Hôpital Paris Maternité, a French obstetrician was Dr. Étienne StéphaneTarnier has observed the benefits of warming chambers for poultry at the Paris Zoo, and established similar chambers for premature under his care.^[6] His warm air incubators had solved the fatal problem of thermoregulation that many premature babies faced. Additionally, Dr. Martin Coney exhibited new incubators at the World Exposition in Berlin in 1896 and was known as the inventor of the incubator and eventually brought it to the United States to treat babies in New York, where Edith Eleanor McLean was the first baby placed inside an incubator in the United States.^[7] Consequently, The Library of Congress has a scan of a 1902 newspaper front page that published an article on infant incubators.^[8]

To reduce the infant death rate the team of doctors, nurses, neonatal facilities, biomedical engineers are trying to improve this device quality and accuracy of service. Consequently, there are diverse incubators developed based on variant features for example Giraffe Incubator, Car Part Incubator, Drager Air-Shields Isolate C450 QT.

B. PHYSIOLOGICAL CHARACTERISTICS OF PRETERM BABIES

Generally according to WHO preterm is defined as any birth before 37 completed weeks of gestation, or fewer than 259 days since the first day of the woman's last menstrual period (LMP). Hence preterm babies are classified into three subcategories according to their gestation period; extremely preterm (<28 weeks), very preterm (28–<32 weeks), and moderate or late preterm (32–<37 completed weeks of gestation).^[9] Extremely preterm and very preterm babies are very sensitive and after birth, the baby's skin starts to diminish water which causes heat loss leading to organ failure in the baby's body.^[10] Fig 2 illustration shows the different types of heat loss in newborn babies. In this illustration, there are four types of heat loss called Evaporation, Radiation, Convection and Conduction. As a result, to save a premature baby before the body temperature falls lower, it is essential to start the process of maintaining the body's internal core temperature which is known as thermoregulation in medical terms.

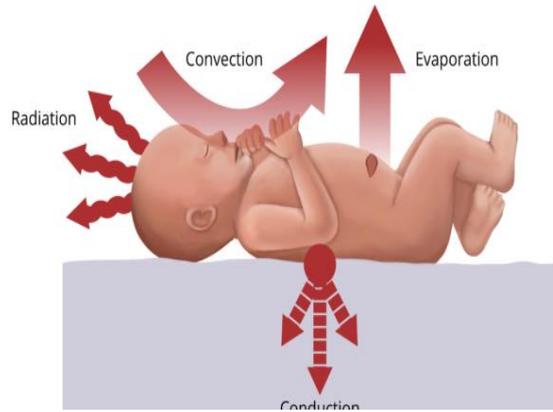


Figure 2: Mechanism of heat loss in infants.

A. Thermoregulation in a preterm baby

During gestation period the temperature in the mother's womb is much higher than the delivery room. It measured the mother's womb as having a temperature of 38°C or 100.4°F.^[11]

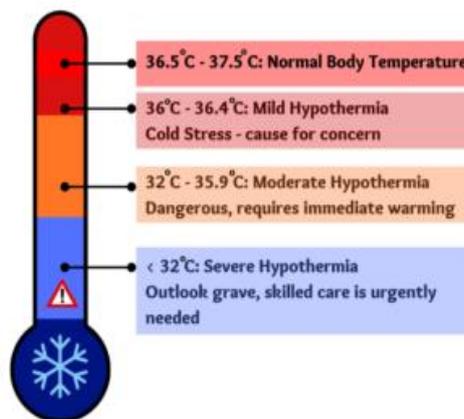


Figure 3: Sign of developing hypothermia.

At the time of birth, the baby stays wet and the temperature also stays higher than in the delivery room, due to this situation the baby loses temperature through the convection mechanism. If the heat loss is not prevented immediately, the baby can develop hypothermia and risk other health problems.^[12] As premature babies born with low weight, they are unable to regulate the temperature in their body like an adult. The lower the weight of the baby the greater the risk is. The incubator helps to regulate the temperature in the baby to stay warm and gain weight. Thermal stability ensures the baby's growth and reduces health problems.^[13]

C. MOTIVATION AND CONTRIBUTION

Bangladesh, a developing country, faces an imbalance in development with most progress concentrated around the capital. Limited incubator facilities for babies are available in major cities, posing a significant problem for premature infants who require urgent treatment. The setup of Neonatal Intensive Care Units (NICU) is required a high cost of incubators, though some medical centers have the necessary facilities like continuous electricity and water supply for maintaining humidity and temperature for premature babies. This scenario is the cause of many premature babies' mortality. Below the motivation and the contribution is described.

- ❖ Address challenges faced by parents in developing countries with limited access to affordable incubators for premature babies and aims to reduce mortality rates among premature infants in resource-limited settings.
- ❖ Introduce an innovative and energy-efficient incubator design.
- ❖ Offer a practical and cost-effective solution to overcome high costs and limited power access in rural areas.
- ❖ Empower local healthcare providers to offer specialized neonatal care, and the project's success may inspire further development of cost-effective medical devices and solutions with potential global impact.

V. DESIGN AND DEVELOPMENT

The design and implementation idea was developed in our university Lab. This incubator is designed to overcome previous and present incubators oversight. The implementation is divided into two parts- hardware and software is discussed in the following paragraphs.

A. CONCEPTUAL DESIGN

The basic concept of an incubator is to provide precise temperature and humidity to stop losing premature babies' body heat and water. Hence, it is crucial to design and monitor heat production and reduce water loss. On the other hand, only temperature control may not be enough for the baby, as the baby needs an environment similar to the mother's womb to survive and grow. As a result, the design is developed based on the four parameters to maintain premature baby's health is - temperature, humidity, light and oxygen. In implementation, these parameters are discussed in the following paragraphs.

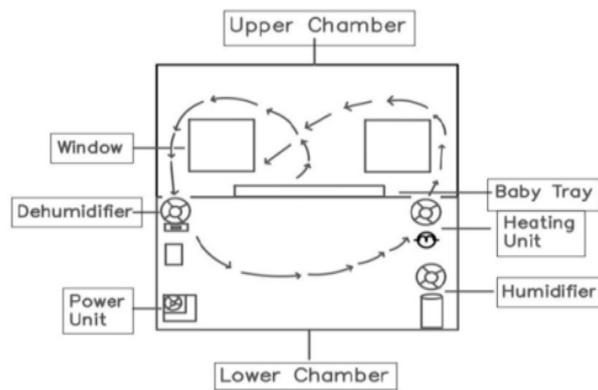


Figure 4: 2D model of the proposed incubator system.

B. TEMPERATURE CONTROL

Premature babies lose heat rapidly and the wet body of baby birth plays a vital role to lose heat. To stop thermoregulation in the baby's body the chambers of the incubator are made of Acrylic sheet as it is more advantageous over glass and plastic. The density of this sheet is 1100-1200 kg/m³. It is very much less than the density of glass which ranges from 2420 to 2790 kg/m³.^[14] This material maintains the temperature in the two upper and lower chambers and helps the baby to normal thermoregulation in the body. The natural environmental heat or temperature cannot enter through this material, aiding the chamber to reduce the temperature from inside slowly allowing the baby to adjust with weather.

C. HUMIDITY

Low humidity levels increase the temperature automatically and oxygen consumption accordingly will cause water loss for premature babies. Additionally, preterm babies with mediocre weight or illnesses are susceptible to hostile incidents such as Apneic spells. Some researchers have shown that premature infants bodyweight and insensible water loss is inversely proportional.^[15] Consequently, it is advantageous to monitor humidity to ensure the baby's normal growth in the incubator.

D. LIGHT

High light levels e.g., phototherapy is the lack of regular light/dark cycles may also immensely affect the premature infants. The level of ambient light should be yieldable during day-night cycling. The technique used to treat Jaundice in neonates also comprises light therapy. As premature infants stay sensitive after birth phototherapy is the best solution to

control the jaundice placed in baby incubators. Babies with jaundice receive the treatment of phototherapy for 4 to 7 days.^[16]

E. OXYGEN CONSUMPTION

When a baby's lungs are not fully developed and cannot provide enough oxygen, it causes breathing difficulties. It is known as Newborn respiratory distress syndrome (NRDS).^[17] Breathing problems and not consumption of oxygen lead to a premature baby's grave danger. In incubators, proper oxygen supply confirms that infants are protected from respiratory distress. In the conceptual design, these four parameters represent the vital features for developing incubators and leading the hardware design and controlling it through software design.

F. HARDWARE DESIGN AND ELEMENTS

The proposed system is shown in figure 5, in this system are shown hardware assembled and elements needed. The system has a controller unit controlling all commands to the electronic components. Microcontroller is used to provide all commands and it is cheap and affordable.

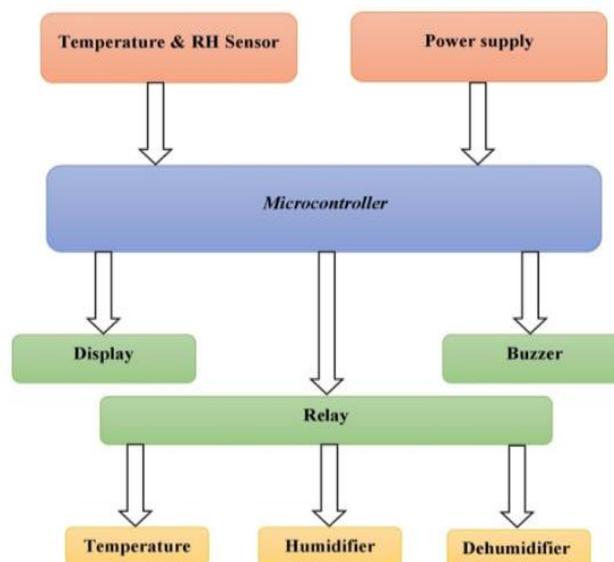


Figure 5: Hardware Schematic diagram of the proposed incubator.

In this proposed system Arduino Uno ATmega328 is used for control unit, there are other parts of vital elements used to build up this system are- temperature and humidity sensor DHT 22, relay for actuator unit, for heating unit an incandescent light bulb, cooling fan, peltier (TEC-12706), heat sink, LCD display, buzzer and power supply (12V).

VI. IMPLEMENTATION AND OPERATION

To implement the proposed system it is crucial and needed to be precise to control temperature, humidity level and oxygen in accurate amounts. An ambient temperature of 36°C-37°C, Humidity range 70%-75% RH and sterile air supply should be maintained in the whole system. As premature infants are very sensitive and can collapse at any time, hence the incubator system should run and execute properly is important. In figure-6 the circuit diagram has shown.

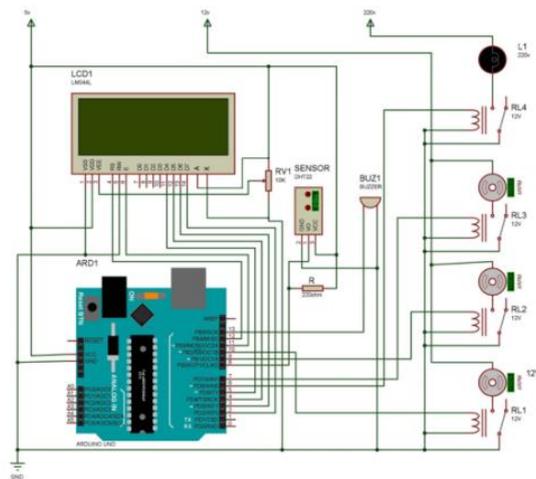


Figure 6: Circuit Sketch of the proposed incubator.

The proposed system is divided into three parts for implementation and operation, i) temperature control, humidity control and Oxygen supply. As the oxygen has specific amounts needed for the baby it has less attention in this section.

1. TEMPERATURE CONTROL

The temperature is anticipated using the sensor DHT22 and controlled via Arduino Uno in the circuit as the arrangement of the control system. The signal pin of the sensor is connected to the digital input pin 8 of the microcontroller. These are connected through relays (relay 1 & relay 2) with the digital output pin 6 and 7 of the Arduino board. Each Relays are of 5 volts and are connected with the Arduino Uno. The program is written to control the bulb and fan. When the temperature in the chamber falls below 36°C the bulb glows and the fan associated with the bulb is turned 'ON' as a result, the hot air is blown to the upper compartment through the pathway. Whenever the temperature in the chamber goes beyond 37°C the relay starts to operate and the bulb and fan automatically switches off. This process goes in a circle to maintain the temperature in chamber.

2. HUMIDITY CONTROL

The exhaustive humidity control system has two sections) Humidifier and ii) Dehumidifier. The lower chamber along with the heating unit is built to serve the purpose of controlling humidity. In this compartment, there is a fan connected with the digital output pin 10 and this is connected through relay 3. When the relative humidity falls below 70% the fan turns on to create water vapor. The fan is placed on the other side of the bulb to blow the vapors to the small upper chamber. To dehumidifier, a 12V 60-watt peltier module adjusted with heat sink in both hot & cold sides of the peltier and a 12 V dc fan adjusted with heat sink in the hot side bring out the hot air connected with the digital output pin 9. When humidity exceeds over 75% the relay 3 starts to operate and the dehumidifier goes ON and it automatically run until the desired relative humidity is achieved.

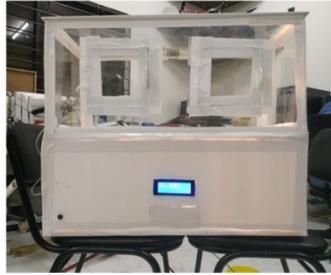
The operation of this implemented system is written by a software program developed in Arduino IDE. It includes a code editor with features such as syntax highlighting, brace matching, and automatic indentation and is also capable of compiling and uploading programs to the board with a single click. When the temperature of the system is less than 350C the relay 1 & 2 start to operate bulb and fan 1 goes ON and when the incubator reaches 370C the relay starts to operate and switch OFF the bulb and fan 1. When the temperature is between 350C to 370C it does nothing. At the same time, the relative humidity (RH) is greater than RH 75% the relay 3 starts to operate and the peltier and fan 2 goes ON.

VII. EXPERIMENTAL EVALUATION AND RESULT

The setup of the proposed incubator system was successfully made, although it is created in the university lab, real time results are not possible to attain. The program of the control system using blink code runs successfully. The temperature reading and the maintaining of humidity show significant results. The fig-7 shows the temperature and humidity reading on display and the final picture of the construction of the proposed system.



Figure 7(a): Accurate result of temperature and humidity control.



7(b)

Figure 7(b): Final view of the proposed incubator.

- **Temperature and Humidity**

As you the incubator stands three major points that's temperature control, Humidity regulation and maintains oxygen level. We measure our incubator data in the time frame of 10 minute.

Table 1: Experimental Data for Temperature and Humidity Control.

Time (minute)	Temperature (Measured)	Humidity (Measured)
0-10	350-360 C	72%
11-20	35.50-360 C	72% - 75%
20-30	350C	73.5% -75%
31-40	36.50 C	69% - 71%
41-50	370 C	74%
51-60	36.50-370 C	74%

We chose this time frame as we find that the premature infant body release 1 degree temperature in per minute and our device continuously maintain 35 to 37 degree temperature we measure our chamber drop temperature below 35 degree after 10 to 15 minute. So we consider taking data with the scale of 10 minute time frame. On the other hand we simultaneously we also measure the humidity control section data from our device. If you see the table 1, the data shows we achieve more than 95% accuracy what we want output from our device.

- **Oxygen**

In our project at the Oxygen Concentration section we always maintain 88% to 95% as it is the safe range for most preterm babies. In addition you know below 85% – Risk of low oxygen (hypoxia), which can damage organs and above 95% – Risk of too much oxygen (hyperoxia), which can cause retinopathy of prematurity (ROP) (a condition that can lead to

blindness). Considering all the circumstances we decide to supply oxygen if the preterm babies need by.

VIII. COMPARISON OF EXISTING AND DESIGNED INCUBATORS

The design incubator is a cost-effective and efficient solution for neonatal care, specifically designed to address the challenges faced by underprivileged communities and healthcare facilities in resource-limited settings. Unlike existing incubators, such as the Giraffe Incubator, Car Part Incubator, HEBI (Hemel Baby Incubator), Ohmeda Giraffe OmniBed, Dräger Air-Shields Isolette C450 QT, Dräger Isolette C2000, and Dräger Caleo, our incubator incorporates a practical control system that ensures accurate temperature regulation, Humidity control low power consumption, and ease of use. By maintaining an affordable price point, our design aims to improve healthcare access for a larger population, particularly in rural areas, refugee camps, and underdeveloped countries like Bangladesh.

The thermoregulation technology in our incubator is very much innovative; creating a stable and safe environment for premature babies. The humidity control technology is sustainable and effective also. Unlike some existing incubators, our design prioritizes simplicity and user-friendliness, making it easier for healthcare providers to operate and provide specialized neonatal care effectively. Energy efficiency is another area where our design stands out. With a focus on low-power consumption, our incubator aligns with sustainability goals, reducing energy usage and minimizing its accessible to all.

Our proposed incubator system is designed to be highly cost-effective by utilizing locally available resources and incorporating low-cost yet durable electronic components. It is estimated to be 7 to 8 times more budget-friendly compared to high-end incubators in the market. This affordability allows us to provide a similar level of functionality and performance at a much more accessible price, making neonatal care more attainable for healthcare facilities in resource-constrained areas and underprivileged communities.

As we already explain that we are trying to build a low cost Incubator for Preterm Infants for the rural people those who can't effort regular incubator. We are using the local product to make it cheaper and affordable for all level of people. The main difference of the existing incubator and our project is cost minimization. The cost details in table 2, shows it cost approximately 100 \$ altogether based on market value.

Table 2: Cost Analysis of System.

SN	Device	Unit	Price
1.	Arduino uno atmega328	1	10 \$
2.	Temperature and RH sensor	1	3 \$
3.	Power Supply	6	12 \$
4.	Display	4	8 \$
5.	Relay	4	2 \$
6.	Humidifier	1	3 \$
7.	Acrylic sheet	--	4 \$
8.	humidity sensor DHT 22	1	4 \$
9.	Cooling Fan	4	1.5 \$
10.	Peltier (TEC-12706)	1	3 \$
11.	Buzzer	2	1.5 \$
12.	Electrical Wire	--	2 \$
13.	Dehumidifier	1	3 \$
14.	Resistor	10	1 &
15.	Capacitor	10	1 \$
16.	Connecting Wire	--	2 \$
17.	Bulb	3	2 \$
18.	Others	--	5 \$
	Total		97 \$

IX. CONCLUSION

The birth of premature babies is the modern times' most concerning issue. And the death rate of premature babies is extravagant in underdeveloped and developing countries as most rural and in some cases urban areas are lacking NICU set up. The proposed system is a proto-type and it has been made to fulfill the purpose of lower power consumption in biomedical incubator devices and affordable for most medical centers, hospitals and clinics. Although it is not complete to set up in the medical environment now, it has many possibilities to develop this device at a cheap rate and research in the future such as the proposed model can be further improved by using a voice detection system using DSP to detect if the baby's crying and a battery can be used as an alternative power source which will be working in load shedding time.

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