# UNIVERSIDAD DE INVESTIGACIÓN DE TECNOLOGÍA EXPERIMENTAL YACHAY

**Escuela de Ciencias Biológicas e Ingeniería**


## TÍTULO:

Low cost neonatal thermic crib for home use (BioCrib).

Trabajo de Integración Curricular Presentado como Requisito para la Obtención del Título de Ingeniera Biomédica


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Urcuquí, septiembre 2020

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# Dedication

I dedicate this project to my family. Especially, to my parents Beatris and Luis who supported me in all possible aspects during these years of career. Also, I thank my parents for their advice that motivated me to accomplish an important achievement in my life. Also, I thank my sister Talia and brother Luis who supported and help me during these years.

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**RESUMEN**

El presente trabajo tiene como fin presentar un diseño teórico de cuna térmica de bajo costo el cual contará con las funciones básicas para mantener un ambiente termoneutral evitando que el infante pierda peso debido a la pérdida de calor. Este diseño está enfocado en brindar un servicio para infantes que han alcanzado un determinado peso y cumplen con las funciones necesarias de forma autónoma sin necesidad de una incubadora o calentador radiante de alta tecnología. De esta manera el infante podrá ser dado de alta con un peso de 2500g y con el uso de la cuna térmica se evitará perdidas de calor que incluso podría causar hipotermia en los infantes. También, el diseño busca ayudar a los hospitales a reducir costos en la adquisición de calentadores radiantes o incubadoras complejas de manera que el infante pueda dejar de usar uno de estos equipos reduciendo costos por estadías que afecta al estado y hospitales. Por otra parte, Ecuador es un país en desarrollo que carece de recursos suficientes para diseñar estructuras complejas para el cuidado de neonatos debido a este problema presente en todo el mundo muchos infantes mueren. Para ello, la cuna se podrá usar tanto en el hospital como en la casa, en el hospital los infantes menos graves podrán usar las cunas térmicas y las incubadoras complejas se usarán para los infantes que tienen una condición grave y que necesitan ser monitoreadas constantemente. En la casa, la cuna tendrá un sistema de uso básico el cual facilitará su uso.

**Palabras clave**:

Infante, cuna térmica, hospitales, ambiente termoneutral, calentador radiante

**ABSTRACT**

The purpose of this work is to present a theoretical design of a low-cost thermal crib that will have the basics functions to maintain a thermoneutral environment, preventing the infant from losing weight due to heat loss. This design is focused on providing a service for infants who have reached a certain weight and fulfill the necessary functions autonomously without the need for a high-tech incubator or radiant warmer. In this way, the infant can be discharged with a weight of 2500g, and with the use of the thermal crib, heat losses will be avoided, which in addition to causing weight loss can cause hypothermia in infants. Also, the design seeks to help hospitals reduce costs in the acquisition of radiant heaters or complex incubators so that the infant can stop using one of these equipment reducing costs for stays that affect the state and hospitals. On the other hand, Ecuador is a developing country that lacks sufficient resources to design complex structures for the care of newborns. Due to this problem, many infants die all over the world. For this, the crib can be used both in the hospital and at home. In the hospital, fewer graves infants will be able to use the thermic-crib, and the complex incubators will be used for infants who have a serious condition and who need to be constantly monitored. In the house, the crib will have a basic use system which will facilitate its use.

Keywords:

Infant, thermic-crib, hospitals, thermoneutral environment, radiant warmer

# CONTENT

# CHAPTER 1: INTRODUCTION-JUSTIFICATION

## 1.1. Premature infant births

Premature infant birth occurs before the average gestation period (37 to 42 weeks) (EFCNI, 2016). The World Health Organization (WHO) defines preterm births as those occurred before to complete the 37 gestational weeks (WHO, 1977). Besides, pre-term births are classified into three subgroups according to the gestational age: extremely preterm (<28 weeks), very preterm (28 weeks - <32 weeks); and moderate or late preterm (32 weeks - <37 weeks) (Blencowe et al., 2012). Premature infants are not able to control their body temperature, feeding, and breathing because the organs in charge of fulfilling these functions are immature (Balza & Fernández, 2010). Also, premature infants show several features as fragile aspects, thin skin, poor muscular tone, head disproportionate to the body, underdeveloped ears, and reproductive organs are poorly developed in both girls and boys. Therefore, they need special care to survive out of the uterus, which is given in the Neonatal Intensive Care Unit (NICU) (Balza & Fernández, 2010).

### 1.1.1. Preterm Births Causes

The preterm infant births have many causing factors. In general, the factors causing of preterm births are directly related to the mother and the environment in which they live (Petrou, 2003). The first one factor is the mother's age because there are evidence in which reveal that mother under 20 years have an immature uterus, so they are prone to develop or acquire infections that can trigger labor before time (Fraser et al., 1995; Slattery & Morrison, 2002). In other cases, the women over 35 years have more risks to deliver before time because of trouble related to the aging of the uterus (Macías et al., 2018; Mendoza Tascón et al., 2016). The second one factor is the social determinants which include the race discrimination, socioeconomic status that lead to inequity in the health system and social stress. (Goldenberg et al., 2008; Lewis, 2010; Purisch & Gyamfi-Bannerman, 2017). These are the most important factors that contribute to preterm births, and they lead to increase the infant death and morbidity rates in the world.

### 1.1.2. Preterm Births Consequences

Infant death and morbidity are the main consequences to have a preterm birth. The preterm infant death is usually generated by complications of prematurity that is also associated with gestational age and infant weight (Glass et al., 2015). Furthermore, preterm infants tend to develop disabilities of many types, including behavioral, motor, academic, and psychological impairment that occurred as a result of cerebral palsy, which in consequence contributes to increasing morbidities rates (Mendoza Tascón et al., 2016; Platt, 2014). As a result, most premature infants develop long-term problems which affect the family and society both economically as socially, and emotionally.

### 1.1.3. Survival rates according to the gestational age

Worldwide, nearly 14 million premature babies survive; however, each baby present different complications that vary according to the gestational age. It is worth mentioning that the survival rates vary according to the gestational age of the infant so that extremely preterm infants has less probability to survive, very preterm infants and late to moderate preterm infants have more probability to survive with the necessary attention (MSP-Ecuador, 2014). For instance, according to the WHO, nearly a 90% of the extremely premature infants survive in a developed country whereas in an underdeveloped country a 10% of the infants with the same gestational age survive (WHO, 2018). In short, the survival rates depend on the country in which they born.

### 1.1.4. Health problems and vital status

In the same way, the health problems depend on the infant gestational age because whereas gestational age is lower, the baby has less developed their organs (EFCNI, 2016). As a result, the baby presents several health problems which include infections, jaundice, retinopathy, anemia of prematurity, and necrotizing enterocolitis. Furthermore, extremely preterm infants and moderate preterm infants have a risk to develop respiratory pathologies as respiratory distress syndrome and bronchopulmonary dysplasia because their lungs are immature (Lawn et al., 2013; Rellan Rodríguez et al., 2008). The surviving preterm infants tend to develop: neurologic, cardiovascular, ophthalmic, gastrointestinal, metabolic, immunologic, hematologic, and endocrine pathologies (Rellan Rodríguez et al., 2008). In some cases, neurologic pathologies produce sequels that affect to long-term to the family and even the society because the premature infant can experience cerebral palsy. As a result, the brain is damaged leading to the motor or cognitive impairment. Besides, the literature agrees that an important rate tend to develop learning disabilities in the future (McCormick et al., 2011). Therefore, they need special care to reduce the sequels produced to avoid long-term problems.

### 1.1.5. Critical parameters to control in a premature infant

Premature infants need essential cares to survive and to improve their condition. Indeed, in the premature infants need to monitor body temperature, heart rate, vital signs, oxygen saturation, humidity, and jaundice (Mata-Méndez et al., 2009). Likewise, the main essential care is thermal care because they are not able to thermoregulate, so they need special equipment. Also, they need support to acquire nutrients to continue with the development of their organs and systems. Even, it is important to prevent the exposition to infections because they are vulnerable to develop sepsis (Lawn et al., 2013). Therefore, the most important parameters that are controlled in preterm infants are explained in more detail.

*1.1.5.1. Temperature control*

Newborns experience a drastic temperature change at birth, so they lose heat by convection and tend to develop hypothermia because they are unable to change their posture or make voluntary movements to produce heat by shivering thermogenesis in response to cold stress. Further, neonates thermoregulate their body temperature through the oxidation of brown adipose tissue and the increase of the norepinephrine and thyroid-stimulating hormone (Bissinger & Annibale, 2010; CMNRP, 2013). However, premature infants have less ability to correctly control body temperature. Mainly, preterm infants have immature organs and systems, and even their body size and skin thickness are thin, making them more vulnerable to cooling or overheating (Zamorano-Jiménez et al., 2012). Therefore, premature infants need a special biomedical device which helps to prevent heat loss and reduces oxygen consumption to ensure that the newborn can finish developing without complications (Zamorano-Jiménez et al., 2012). So, it is important to know the meaning of thermoregulation to understand the importance of this physiological parameter.

*1.1.5.1.1. Thermoregulation*

Thermoregulation in neonates is a physiological process to keep body temperature balanced, thus avoiding heat loss and keeping heat production equilibrated as necessary (CMNRP, 2013). Heat is produced as a result of metabolic rates generated by organs and tissues. Neonates tend to produce more heat through the brain compared to the liver and skeletal muscle. It is essential to mention that the body temperature in neonates ranges from 37 °C (Okken & Koch, 1995). Moreover, in newborns, heat is produced by non-shivering thermogenesis. This process allows to oxidize the brown adipose tissue to provide heat when the newborn is exposed to cold ambient temperatures (Asakura, 2004; Okken & Koch, 1995). Nevertheless, premature infants have an immature thermoregulatory system, which makes them prone to die of hypothermia (Okken & Koch, 1995; Roychoudhury & Yusuf, 2017). Also, preterm infants lack several characteristics necessary to produce heat, including less brown fat reserves, less glycogen reserves, and thin skin depending on gestational age (Roychoudhury & Yusuf, 2017). In short, premature infants cannot accomplish with their functions, so that they need a device to help to maintain the necessary temperature.

*1.1.5.1.2. Types of heat transfer by the baby*

Heat transfer permit to evaluate the principal factors to contributes heat loss. Heat transfer in newborns is carried out through 4 routes which are evaporation, radiation, convection, and conduction (Okken & Koch, 1995). The first one is evaporation, the newborn experiences this transfer seconds after birth because the liquid covering the baby begins to evaporate the moment it leaves the mother's uterus (Ringer, 2013). The second one, the heat transfer by radiation is the most important and dangerous because the heat is transferred by infrared energy from the newborn to objects near him (CMNRP, 2013; Ringer, 2013). The third one, the newborn is exposed to air flows that remove heat from the newborn's body surface and generate heat loss that can lead to hypothermia and even death in premature infants. Generally, this type of heat transfer is determined by factors such as surface area, airflow, and temperature gradient (CMNRP, 2013; Ringer, 2013; Soll, 2008). The last one, conductive heat transfer is generated when the newborn is in direct contact with a cold surface in which the newborn's heat is transferred to these objects losing heat and tending to develop hypothermia (CMNRP, 2013; Soll, 2008).

*1.1.5.2. Humidity control*

Humidity control is as essential as air temperature control. Premature infants tend to lose water and heat through the evaporation pathway, which mainly limits proper skin development, and even the newborn's skin tends to dry out. For this, it is essential to provide adequate levels of humidity to ensure the proper development of neonates (Okken & Koch, 1995). Humidity levels must be greater than 50% to reduce dehydration, electrolyte imbalance, skin trauma from drying, and even possible infections. The controlled humidity and temperature allow giving the infant the necessary conditions so that its development is adequate and difficulties are not generated during its maturation process of organs and systems. Moisture also reduces body weight loss (Zamorano-Jiménez et al., 2012).

*1.1.5.3.Oxygen control*

Premature newborns need to maintain necessary oxygen levels to avoid problems related to insufficient oxygen administration or excess oxygen. For this, the incubators have a controlled system that allows the nursing team to control the oxygen levels that the premature infant needs. (Okken & Koch, 1995). Furthermore, keeping oxygen administration levels under control is essential to avoid problems like retinopathy or hypoxia that can lead to death. Generally, preterm infants have oxygenation problems due to the immaturity of their breathing-related organs. For this, it is important to have a system that controls the levels of oxygen in the blood of neonates to administer the necessary levels of oxygen to maintain the proper development of the preterm infant in the incubator (Stenson et al., 2013).

*1.1.5.4. Jaundice*

Neonatal jaundice is called hyperbilirubinemia, which occurs more frequently in premature infants due to the immaturity of organs involved in the production and elimination of bilirubin (Rodríguez Miguélez & Figueras Aloy, 2008; Watchko & Maisels, 2003). Thus, neonatal jaundice produces a yellowish discoloration in the skin and mucosa of neonates at term and preterm due to an accumulation of bilirubin that can be physiological or pathological. In general, neonatal jaundice results from an elevation of the levels of bilirubin in the blood caused by the elevation of the hematocrit, and the increase of the entire hepatic cycle of bilirubin. The increase in bilirubin occurs because hepatocytes cannot capture bilirubin, and there is an inefficient conjugation of bilirubin in neonates naturally (Grosse & Simeoni, 2012; Watchko & Maisels, 2003). Generally, 60% of full-term newborns tend to develop jaundice in their first week of life, and 80% of preterm newborns develop jaundice. Definitely, it is important to maintain monitored the baby and provide the treatment because it can cause damage to the brain (Mitra & Rennie, 2017; Salum et al., 2015).

*1.1.5.4.1. Phototherapy of visible light*

Phototherapy is the most widely used treatment to reduce the levels of bilirubin in the blood of term and preterm infants. This type of treatment is relatively cheap and has minimal side effects, which is ideal for treating neonatal jaundice. Besides, phototherapy uses visible light in the 460 to 490 nm range of the blue region of the spectrum, which is considered the most suitable for treating jaundice (M. Jeffrey Maisles & McDonagh, 2008; Manotas, 2011). Phototherapy employs the light in the blue region of the spectrum range in 460 nm because bilirubin can absorb the light in this region. This range can more easily penetrate tissues, and as the wavelength of the spectrum increases, tissue penetration also increases. For this, it is essential to choose the appropriate wavelength range to obtain a therapeutic effect according to the needs of the newborn, either term or preterm (M. Jeffrey Maisles & McDonagh, 2008).

### 1.1.6. Criteria to discharge a premature baby from the NICU

It is essential to take into consideration several criteria before discharge preterm infants. For this, the physiological aspects of the preterm infant, such as thermoregulation, breathing control, respiratory stability, feeding ability, and weight gain should be evaluated to assure that the baby can accomplish with the basic functions. Generally, premature infants who reach a weight greater than 1800 grams are discharged from the NICU. Also, the infant must be able to control their body temperature and keep heat production and loss in balance, and they should reach temperatures of 36 to 37 ° C. Furthermore, the infant must have the ability to breathe in the position that avoids sudden death; this position is supine. And, infants should not have episodes of apnea with the cessation of breathing, a drop in heart rate, and oxygen desaturation. Besides, it is important to evaluate the weight gain patterns to guarantee stability in neonates, for which the standards should be 15 g / kg per day. Also, neonates should have a caloric intake preferably by the suction of 120 - 150 Cal/kg per day (Benavente-Fernández et al., 2017; Jefferies et al., 2014; MSP, 2015). Definitely, the premature infants should accomplish with the basic functions to avoid readmissions and death at home.

## 1.2. Incubators and Thermic-Crib

### 1.2.1. Incubators

The incubators started from the idea of the poultry incubator design. This type of incubators can generate heat and maintain a warm environment to enhance the development of chicks (Morilla, 2007). Neonatal incubators are developed based on this idea to reduce the mortality and morbidity rates of premature babies. Over the years, incubator designers have implemented new technologies to minimize the most common risks, such as burns. Although, the costs also increase daily because of the complex incubator system (Ferris & Shepley, 2013). Therefore, a neonatal incubator is considered a medical device that has a system with a suitable environment with characteristics similar to the maternal womb to provide the necessary conditions to help finish the development of the premature infant (Restrepo Pérez et al., 2007).

The basis of the incubator operation depends on its design and components. The incubator has a heating system that helps to thermoregulate the premature infant, and it can control the temperature to avoid heat loss and a humidifying system to prevent the baby's skin from getting dry and dehydrated. The device has sensor systems for detecting abnormalities and to maintain the baby in a safe environment. So, incubators are medical devices that are in direct contact with premature infants, so they must be safe and fault-free so that infants are not at risk of dying or burning (Ferris & Shepley, 2013; WHO, 2011).

Closed incubators are generally the first devices designed for the care of preterm infants and sick newborns. These devices have a thermoregulatory system that can be controlled by the user; that is, it is possible to regulate the temperature according to the need of the infant or it can be controlled by servo-motors. Besides, incubators have humidification and oxygen therapy (Hull & Wheldon, 1986; Wheldon & Rutter, 1982). On the other hand, radiant heaters were introduced long after the incubators were implemented and are known as open incubators. Radiant heaters have a radiation source which heats the infant and maintains it at normal temperatures to prevent heat loss. Generally, it is controlled by servo-temperature controllers (Hull & Wheldon, 1986; Wheldon & Rutter, 1982). Open and closed incubators are used depending on the infant's needs.

*1.2.1.1. Thermic-Crib (Open-Incubator)*

Radiant cribs are specifically designed to provide easier care for premature children who are too low in weight and have problems regulating their body temperature. Usually, this type of crib, as the name mentions, makes use of radiation to provide the necessary heat to low weight babies, although they can use convection and conduction systems. So, radiant cribs help the premature infant end its stage of development and mature its organs and systems. (Jácome et al., 2005; Oviedo & Valdivieso, 2016).

The operation basis of the radiant crib system is the heat transmission that normally occurs through a heater which in some cases is controlled by servomotors. The heat transmission occurs through the air in the form of electromagnetic waves which keep the newborn with the needed temperature to maintain an homeostasis in the thermoregulation (Jácome et al., 2005; Oviedo & Valdivieso, 2016). Then, radiant warmers must have the following characteristics to provide the necessary therapy to complete their development process (Soto & Jácome, 2005):

a) An electronic unit to control the infant's temperature
b) A screen that allows you to view variables such as the infant's temperature and the control temperature
c) Parameters such as the temperature that the baby must-have, also known as control temperature.
d) Auditory and visual alarms
e) Heating element
f) Support structure
g) In some cases, the radiant heaters have a phototherapy system.

Radiant warmers are developed based on rigorous standards proposed by control entities such as the FDA, which ensure the well-being of the premature infant. These characteristics allow to permanently and safely monitor the development of the infant and avoid damage to the patient due to operational problems of the medical equipment. Medical equipment intended to use for premature infants must have a microcontroller to facilitate temperature regulation to maintain a temperature between 35 °C to 37.5 °C. Besides, it must have a screen to show the patient's temperature, control temperature, and a timer. Also, the radiant crib must have an alarm system and sensors to monitor the newborn constantly. So, the most important element about the radiant crib is the heating element, which will allow maintaining the necessary environmental conditions so that the baby remains stable and safe (Soto & Jácome, 2005).

##### *1.2.1.1.1. Types of sensors*

Generally, a radiant warmer dispose of sensor to monitor different parameter to provide a special environment. Radiant heat cribs are designed using three types of sensors, which allow detecting the body temperature of the newborn, humidity, and environmental temperature. These sensors make it possible to detect the heat changes that the infant may experience and to modulate the temperature of the heating unit based on the data obtained from the newborn. On the other hand, it is necessary to use a sensor to detect the infant's temperature since it is important to determine the body temperature of the newborn and to prevent the infant from being burned or pathologically cold. Besides, the humidity sensors allow to detect the humidity levels of the environment and avoid that due to low humidity levels the infant loses heat through evaporation (Chicaiza & Chiliquinga, 2009; Pelaez, 2014). In short, the sensors permit to monitor constantly to the premature infant and detect abnormalities.

##### *1.2.1.1.2. Alarms*

Radiant heat cribs have an alarm system that allows detecting irregularities in the medical device or abnormalities with the newborn. Generally, servo-controlled radiant cribs unlike manual radiant cribs have an auditory and visual alarm system. So, radiant cribs have a general alarm, an alarm to detect high and low patient temperatures, high patient temperature, line disconnection, newborn check period indicator alarm, low battery, earth indicator, 100% heating system, its power for more than 12 minutes, and an alarm silencer (CENETEC, 2004; Soto & Jácome, 2005). The alarms let to maintain the needed environment to the premature baby.

##### *1.2.1.1.3. Others*

Radiant cribs have other components that help improve their quality and presentation. Although, some of these elements are necessary to facilitate the handling of the warmer bed. However, the implementation of other features such as resuscitators, X-ray chassis holders, counters, aspirates, resuscitation systems, oxygen tanks, examination lamp, vital signs monitor, heart rate monitor and phototherapy increases the costs in the design and acquisition of these medical devices (CENETEC, 2004; Soto & Jácome, 2005). As a result, premature infant can improve their health status because it is using a high technology.

### 1.2.2. State of the Art Incubators

Fong et al. provided a low cost incubator to the rural zones in which it is not available the electricity. They evaluated various factors that prevent to have incubators in areas that lack constant electrical power, making it impossible to maintain a device, which normally functions with electricity. For this, they developed a neonatal incubator that can be used with or without power. The project aims to provide incubators in these areas where there are higher death rates due to the lack of this type of device. They develop a neonatal incubator capable to work with minimal energy so that they implement solar panel to provide a minimum quantity of energy to function. They also used a thermal collector. Further, the neonatal incubator is designed to be manipulated by anything people because it of easy use. Furthermore, the neonatal incubator contains the necessary variables to provide a thermoneutral environment to the preterm infant. It also can help to the mother at home (Fong et al., 2013).

Soto and Jácome (2005) implemented a thermic-crib system. It consists of the implementation of a radiant crib system to help keep premature infants warm and provide them with optimal temperatures of between 36-37 ° C for their development. The thermic crib was designed using a microcontroller to facilitate regulation of the power supplied to the heating element based on the infant's need. Also, the radiant warmer has an LCD screen to display the temperature of the newborn and the temperature of the heating element. It also has a keyboard to adjust the temperature that the infant needs. The radiant crib also contains visual and audible alarms to detect abnormalities in both the device and the infant (Soto & Jácome, 2005).

The article of Quintanar & del Valle (2005) developed an optimal environment for premature infants. For this, they evaluated the basic needs of premature infants by collecting information directly with the neonatology staff. The project focused on designing a radiant crib with basics functions. Also, they focused on selecting the materials to be implemented in the thermoregulation system and for the treatment of jaundice. Also, the needs related to mechanical design were evaluated to obtain a design that operates efficiently. Then, the authors designed a radiant cradle with the basics functions and with a control system for variables such as heating, phototherapy, and subsystem movements such as height and inclination. Besides, the crib was designed with an interface with mobile devices capable of alerting of temperature variations in the premature infant (Quintanar & Del Valle, 2015).

Also, the work presented by Delgado (2017), it was implemented a radiant cradle of low cost. Delgado based their work to solve problems of health inequity in the marginalized areas of Mexico. Marginalized areas have shortages of medical equipment for newborns, for which parents of newborns have to go to more developed places to receive adequate care. In other cases, parents cannot move to the more developed areas for various reasons, which puts the life of the newborn who may die. This device has been developed with the lowest cost in terms of materials since it has managed to reduce 692% compared to radiant cribs that are on the market. This project has focused on implementing a neonatal thermal cradle model with the basics functions to be used in rural areas that lack devices to promote timely care of the newborn and prevent the increase in mortality and morbidity rates in the country (Delgado, 2017).

Based on the projects described, it is possible to argue that there is a need to implement radiant cribs that have the basics functions such as thermoregulation and phototherapy. Radiant cribs generally tend to be expensive due to the materials used to build these types of devices. However, the works related to these types of devices seek to reduce costs to solve problems due to the lack of these devices in marginalized areas around the world, including Ecuador.

### 1.3. Justification

Ecuador is an underdeveloped country in which the health system cannot afford the cost of purchasing high technology medical devices like neonatal incubators and radiant warmer. In the past years, some news circulated about the lack of neonatal incubators and thermal cribs, although in recent years, there is no clear evidence of this problem. The news is described as the main problem the lack of medical equipment, and the infrastructure of the neonatology areas in some hospitals in the country. On the other hand, investments in the health system were reduced due to the current situation whereby it arises the need to solve this problematic with the design of a low-cost thermic crib. So, it helps to diminish the long stay and the cost produced, in consequence this will help provide incubators for infants who need more care. It also can help in the rural areas in which the health sub centers lack of such equipment to provide the basic care in the first minutes to the babies. Generally, once premature newborns are discharged, they are readmitted again due to complications that occurred during their stay at home. In many situations, premature infants tend to develop problems such as jaundice, low weight gain, and dehydration (Hurtado Suazo et al., 2014). To solve these problems, it is proposed to design a thermic crib prototype with basic functions such as thermoregulation, phototherapy, and humidifier and alarms to maintain controlled the thermic-crib.

## CHAPTER 2: PROBLEM STATEMENT

Worldwide, around 15 million infants are born prematurely each year. It means that for 10 newborns, there is 1 baby born before 37 weeks of gestation. Also, according to the WHO, approximately 1 million premature infants die due to complications of prematurity. So, prematurity is considered the main cause of death for children under 5 years of age (March of Dimes et al., 2012). Likewise, the WHO data reveal that in 2017 die 6.3 per 1000 live birth neonates within the 27 days of birth. These data represent a significant number of infants who died shortly after birth due to problems related to prematurity. Also, we can observe a reduction of the death of premature infant between the year 2000 and 2017, although the number of deaths are still alarming (figure 1). Worldwide, deaths of premature infants are higher compared to Ecuador.

In Latin America, the leading cause of infant death is the prematurity followed by congenital malformations. In Ecuador, 35% of preterm infants in their first 6 days of life tend to die due to complications. Moreover, according to the Global Burden of Disease (GBD) sources, Ecuador is the second Latin American country in which infants die due to complications of prematurity (Proaño, 2019). On the other hand, the WHO data reported an important decreasing rates of deaths due to prematurity, paradoxically, these data are still alarming to an underdeveloped country as Ecuador because the mortality rate is 3,2 per 1000 livebirths in the 28 first day of life. Therefore, the causes of these deaths must be evaluated and solutions sought to help reduce the mortality rate in Ecuador.

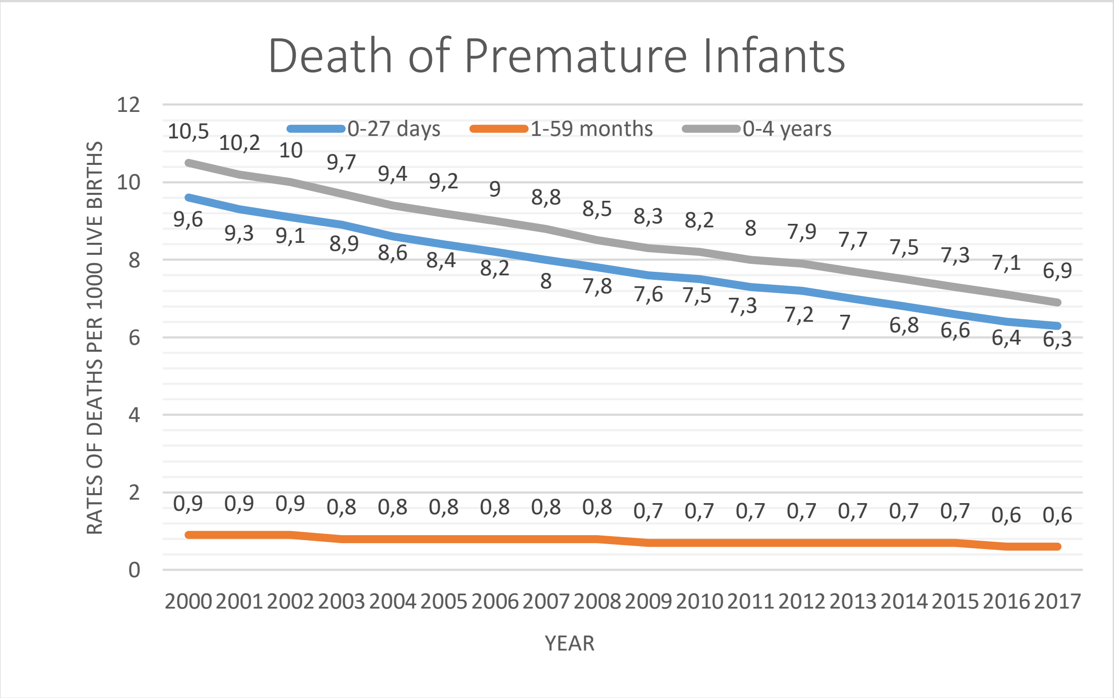

**Figure 1**. Global infant death due to prematurity according to the WHO data.

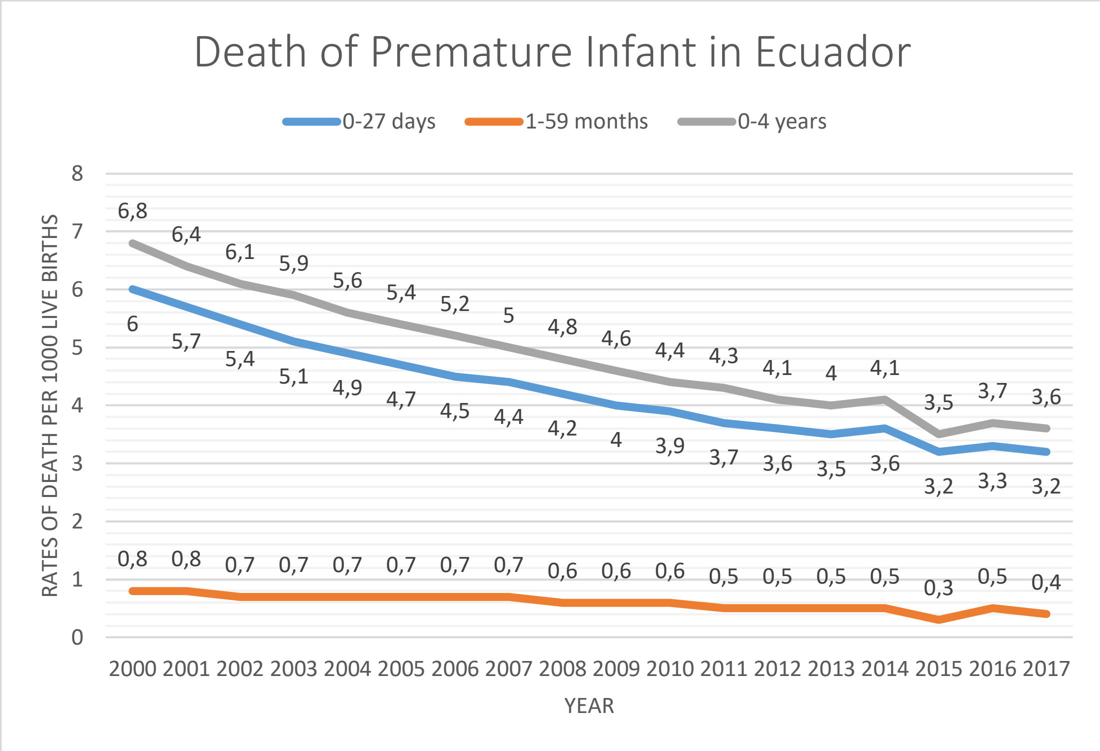


**Figure 2**. Infant death in Ecuador due to prematurity according to the WHO data.

On the other hand, one of the factors that affect newborns' health is related to the development level of each country in which they are born. In other words, if a premature infant is born in a developed country, it has a better chance of survival since all infants can acquire basic neonatal care. Developed countries have complex health systems structured to care for all infants, whether grave or not. However, in poor or developing countries where many infants do not have a severe illness or are mildly premature, they tend to be neglected due to a lack of medical devices and are prone to death (Guinsburg, 2019). Then, Ecuador is considered a developing country and lacks a health system structured to provide needed attention to all patients. So that, it is necessary to provide solutions to these types of problems that markedly affect the entire society. The intention is to seek materials to design low-cost devices that can be purchased both by the family and by hospitals. In this way, hospitals would have thermic cribs and incubators for preterm infants depending on their needs, for instance, a less grave infant could use a low cost thermic crib that provide the basic treatment, and incubators or radiant warmers would be used to save the lives of more grave infants.

In the past years, Ecuador show that the basic hospital lack of incubators or radiant warmers to treat premature infants. For instance, in Ambato, there was evidenced a demand for radiant warmer in a teaching hospital due to the lack of resources to acquire these medical devices. Also, some Ecuador's public hospitals are small and do not have the resources or enough space to acquire the necessary devices. However, people go to public hospitals because they do not have the resources to go to private hospitals where stays tend to be more expensive. Due to the lack of radiant warmers or incubators, hospitals can make transfers to level three hospitals. However, these hospitals reject the transference because these hospitals may also lack cribs to receive infants and the life of the infant, and the mother may be at risk (Pinto, 2013). Also, in Esmeraldas, there were 90 neonatal deaths per year due to the lack of equipment in the Neonatology Unit Care. In the Esmeraldas' hospitals, they had to place two infants per incubator because transfers to level three hospitals were rejected (La hora, 2009). However, there is no current information about this need. So, there are a great need to acquire new device to avoid such problems in public hospitals because most people used such hospitals.

On the other hand, there are problems related to the cost of prolonged stays, which generate costs for both the state and the family. Also, it has been identified that extended stays affect the quality of service in hospitals. In Ecuador, there are no studies on the costs of prolonged stays in ICU wards. However, in Colombia, this type of analysis is carried out to evaluate the impact of the cost of the stay of pre-term infants in hospitals. The costs vary according to several factors including jaundice, prematurity, pneumonia among others (Mendoza Tascón et al., 2014). Probably, this problem is present throughout the world and with greater prevalence in countries with fewer resources such as Ecuador. For this, a thermal cradle design is proposed that allows the discharge of infants with a weight greater than 2500 g, thus reduces long stays and therefore high costs.

Based on the data presented, Ecuador's hospitals do not have enough resources to acquire new medical equipment because of Ecuador is a country of low-income. Also, the stays of the infants generate costs for the family as well as for the hospitals and the state. For this, it is proposed to provide a basic radiant heater with phototherapy that allows solving the problems previously exposed. The proposed radiant warmer design will have the basic functions to help keep the infant warm and prevent weight loss. Also, this crib will be used with infants who have been discharged from the hospital with a certain weight. In the same way, it can be used in hospitals for infants who are not too ill, which will allow incubators and radiant heaters to be released to place infants who need it. It will provide more advanced incubators and radiant warmers for extremely premature infants.

# CHAPTER 3: OBJECTIVES

## 3.1.General objectives

- To design a low-cost and easy-to-use design of radiant heat crib that has the necessary characteristics to provide the basic functions that allow the newborn to be thermo-regulated, and also to provide a phototherapy system in case the infant has a mild jaundice.

## 3.2.Specific objectives

- To present design with a focus on preterm infants who fulfill the basic functions of breathing, feeding, and need only help to thermoregulate.
- To present the physical design of SolidWorks.
- To implement a control system.
- To propose a system to implement phototherapy for jaundice.

# CHAPTER 4: METODOLOGY

Firstly, a general search about the premature infant have been made to understand the main critical point to consider before to propose the design. For this, a search for scientific articles have been performed using database pages such as IEEE, Google Scholar and PubMed, so that, it has been used keywords such as preterm births, premature infant, survival rates, and health problems. The scientific articles were also considered the more recent articles to analyze the current situation, although, it was also selected articles of the 90's because of its information relevance to the work. Then, the scientific articles were classified based on the country in which they were performed and it was tried to obtain scientific investigation made in Latin America and Ecuador. In the same way, it searched data information in the WHO database in which there are information about the rates of death per 1000 live births due to complications of prematurity for the country and globally (WHO, 2016). This information provides a general vision about the infant death in the world.

Secondly, it was performed searching in the database about the incubators and radiant warmers. So, a bibliographic search was carried out using database pages such as IEEE, Google Scholar, and PubMed, for which it was used keywords as a neonatal thermic crib, low-cost incubators, and low-cost radiant warmers. Also, the thesis is searched in the repositories of the Ecuadorian universities. Therefore, this research was carried out to assess the relevance of this work in society and its importance in hospitals because several open and closed incubator designs have been created with different approaches to provide solutions to problems present in the world. So, in this work, an investigation was carried out on incubators and radiant warmers to gather information about the design approach.

Then, it was used SolidWorks software because the aim of this works is present a theoretical design of a thermic-crib for which. SolidWorks is a 3D CAD software design which allows to create, design, simulate, manufacture, and management data of the design of any idea. The software let to model any idea, starting with the design of the plans in 2D to later be designed in 3D (SolidBI, n.d.; SolidWorks, 2015). Besides, SolidWorks is an automation tool that allows us to produce models of ideas with the required dimensions and visualize them in real-time. Also, the software allows adding materials according to our requirements. The program allows to design circuits and do simulations of any type; you can even design each of the parts in 2D and facilitate the creation of the design in 3D (Dassault Sytemes, 2015). Therefore, the physical design of the thermal crib will be developed in SolidWorks software.

On the other hand, to design an incubator need to determine what is the design more pertinent to approach of this work. For this, it has been made a concurrent analysis considering three types of incubators designs as open and closed incubators.

## 4.1.Concurrent analysis to define the design

### 4.1.1. Design alternatives

Neonatal incubators must meet the safety requirements and could be accessible to parents, so an analysis of the existing neonatal incubator designs was carried out to evaluate their characteristics and determine the relevance of the design chosen with the proposed project. In recent years, neonatal incubator designs have been constantly evolving, meaning that each design that is on the market seeks to meet the needs of premature infants. However, these designs are usually expensive, and in developing countries, the acquisition of this equipment is scarce due to the lack of resources. For this, 3 alternatives are exposed to build the design of the thermal cradle.

1) Closed box incubators
2) Open-box incubators
3) Portable incubators

#### *4.1.1.1.Closed box incubators*

Closed box incubators, as their name says, are closed with a single purpose which is to provide a certain environment for neonates that need various parameters such as oxygenation, thermoregulation or humidity to survive (figure 3). These incubators are designed so that preterm infants are as little as possible exposed to microorganisms in the environment that can cause infections. In short, they are designed to care for extremely premature infants (Kumar, 2019). The closed incubators are designed with different materials which vary depending on the designers of such device. The more predominant materials are acrylic and polycarbonate. Also, the brackets are made of stainless steel material. In short, the model presented is the most common to find in a hospital.

**Figure 3**. Closed box Neonatal incubator. Source: http://www.neonatology.org/technology/equipment.html

***Advantage***

- Acrylic material maintains a thermoneutral environment
- The infant has the necessary conditions to survive
- More sophisticated

***Disadvantages***

- It is more expensive
- The infant is less accessible to be searched
- Infant undergoes drastic temperature change
- They produce noise

*4.1.1.2. Open-box incubator*

Open box incubator is a new design which is modified from the closed incubator. The open box incubators are also known as radiant warmers and are designed to facilitate the access of doctors and nurses to the infant and to give him the treatment he needs. This type of incubator has a warming system that is on top of the infant (figure 4). So, they are generally used to care infants who do not need oxygen to survive or for infants who only need to be thermoregulated (Kumar, 2019). Then, these devices are more expensive than closed incubators because the materials and components that make up these cribs are more expensive, which give a better aesthetic to the design (figure 4).


**Figure 4**. Open box neonatal incubator. Source: https://www.machinio.com/listings/38050615-open-incubator-drager-babytherm-8000-resuscitation-station-in-leszno-poland

***Advantage***

- The infant is more accessible to receive the necessary care
- The infant is not subjected to changes in temperature
- It is more aesthetic

***Disadvantages***

- Costs are relatively high
- Materials are expensive

*4.1.1.3. Transport Incubators*

Transport incubators have the same principle as the previous incubators. So, the difference is specially designed to transport infants from one place to another more easily. Therefore, these types of incubators are used when infants need to be transferred from one hospital to another. They can be less heavy (figure 5).

**Figure 5**. Transport neonatal incubator. Source: https://www.medicalexpo.es/prod/international-biomedical/product-68893-435287.html

***Advantage***

- Customizable
- The infant is not subjected to changes in temperature
- It is more aesthetic

*Disadvantages*

- Costs are relatively high
- Materials are expensive

### 4.1.2. Design alternative selection

The weighted criteria corrected ordinal method allows to decide between various solutions to implement a design. This method allows us to obtain significant results. It is based on tables where each criterion (or solution, for a certain criterion) is compared with the remaining criteria (or solutions) and the following values are assigned (Warren, 1988):

*1 If the criterion (or solution) of the rows is higher (or better;>) than that of the columns*

*0.5 If the criterion (or solution) of the rows is equivalent (=) to that of the columns*

*0 If the criteria (or solution) of the rows is lower (or worse; <) than that of the columns*

Then, for each criterion (or solution), the values assigned about the remaining criteria (or solutions) are added to which a unit is added (to avoid that the least favorable criterion or solution has a null evaluation); then in another column, the weighted values for each criterion (or solution) are calculated. Finally, the total evaluation for each solution results from the sum of products of the specific weights of each solution by the specific weight of the respective criterion (Warren, 1988).

#### *4.1.2.1. Technical characteristics*

The criteria for selecting the best design alternative were chosen based on the needs that arise in the problem.

**Moderate cost:** The design cost of the warmer should be less than imported cribs and incubators.

**Size -** Materials should allow to reduce design and implementation costs

**Low weight:** so it can be carried more easily by 1 person

**Aesthetics:** present design according to the needs and requirements of the client

Then, based on the defined criteria, the alternatives are evaluated next.

*Table I. Evaluation of the specific weight of each criterion*.

| |
|---|
| *Cost* > *size* = *weight* > *aesthetics* |

| Criterion | Cost | size | weight | aesthetics | ∑ +1 | weighted |
|---|---|---|---|---|---|---|
| Cost | | 1 | 1 | 1 | 4 | 0.4 |
| size | 0 | | 0.5 | 1 | 2.5 | 0.25 |
| weight | 0 | 0.5 | | 1 | 2.5 | 0.25 |
| aesthetics | 0 | 0 | 0 | | 1 | 0.1 |
| | | | | Sum | 10 | 1 |

*Table II. Evaluation of the specific weight of the cost criterion.*

| |
|---|
| Alternative 2 > alternative 1 > alternative 3 |

| Cost | Alternative 1 | Alternative 2 | Alternative 3 | ∑ +1 | Weighted |
|---|---|---|---|---|---|
| Alternative 1 | | 0 | 1 | 2 | 0.333 |
| Alternative 2 | 1 | | 2 | 3 | 0.5 |
| Alternative 3 | 0 | 0 | | 1 | 0.167 |
| | | | Sum | 6 | 1 |

*Table III. Evaluation of the specific weight of the size criterion*.

| |
|---|
| alternative 2 > Alternative 1 = alternative 3 |

| Size | Alternative 1 | Alternative 2 | Alternative 3 | ∑ +1 | Weighted |
|---|---|---|---|---|---|
| Alternative 1 | | 0 | 0.5 | 1.5 | 0.25 |
| Alternative 2 | 1 | | 1 | 3 | 0.5 |
| Alternative 3 | 0.5 | 0 | | 1.5 | 0.25 |
| | | | Sum | 6 | 1 |

*Table IV. Evaluation of the specific weight of the weight criterion.*

| |
|---|
| alternative 2 > alternative 3 > Alternative 1 |

| Weight | Alternative 1 | Alternative 2 | Alternative 3 | ∑ +1 | Weighted |
|---|---|---|---|---|---|
| Alternative 1 | | 0 | 0 | 1 | 0.167 |
| Alternative 2 | 1 | | 1 | 3 | 0.333 |
| Alternative 3 | 1 | 0 | | 2 | 0.5 |
| | | | Sum | 6 | 1 |

*Table V. Evaluation of the specific weight of the aesthetic criterion.*

| |
|---|
| Alternative 3 = alternative 2 > alternative 1 |

| Aesthetic | Alternative 1 | Alternative 2 | Alternative 3 | ∑ +1 | Weighted |
|---|---|---|---|---|---|
| Alternative 1 | | 0 | 0 | 1 | 0.167 |
| Alternative 2 | 1 | | 0.5 | 2.5 | 0.417 |
| Alternative 3 | 1 | 0.5 | | 2.5 | 0.417 |
| | | | Sum | 6 | 1 |

Next, the table with the calculations for the conclusions is presented.

*Table VI. Conclusions.*

| Alternative | Cost | Size | Weight | Aesthetics | ∑ +1 | Priority |
|---|---|---|---|---|---|---|
| 1 | 0.4*0.333 | 0.25*0.25 | 0.25*0.167 | 0.1*0.167 | 0.254 | 3 |
| 2 | 0.4*0.5 | 0.25*0.5 | 0.25*0.333 | 0.1*0.417 | 0.449 | 1 |
| 3 | 0.4*0.167 | 0.25*0.25 | 0.25*0.5 | 0.1*0.417 | 0.296 | 2 |

According to the results obtain of this concurrent analysis, the alternative 2 is the most relevant design to perform. Alternative 2 can be considered as the better option between alternatives 1 and 3. Alternative 2 is chosen as the design because it has better characteristics compared to the other alternative. Therefore, the design of the warmer crib will be similar to an open box incubator.

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### 4.2.<u>Materials for the Design</u>

In this work, it has been proposed a theoretical design of a low-cost thermic-crib, so that it has been selected different materials that help to reduce the development cost of the thermic-crib. The thermic crib has three main parts which are the support and the crib, warming system, phototherapy system and the control system. The materials were selected considering several aspects, in such way that the costs for the design are reduced and it is not dangerous for the infant.

### 4.2.1. Support and Crib

The support and the crib will be designed with wood as the main material of the thermic-crib. In fact, wood is a material that is used for different building projects because it is considered a great thermal insulator because it lacks free electrons, which are in charge to facilitate the transmission of heat from one element to another (Alvarez, 2016). Wood is an excellent thermal insulator because of its cellular structure since they have fibers that do not accumulate heat so the heat is maintained inside the building (Cuesta, 2018). Actually, the heat step speed from the human body to the wood is very small which means that the wood has a low thermal conductivity (Alvarez, 2016). At the same time, wood has hygroscopic properties which allows to self-regulate humidity and temperature to maintain a comfortable construction capable of moderating temperatures and avoiding sudden changes in temperature and humidity (Circe Materia, 2017). In this way, the thermic-crib can provide a normal environment in which the baby can be able to maintain the necessary temperature and conditions to gain weight.

Wood has able to reduce all types of noise which in many cases can affect the normal development of the premature infant. Actually, wood is capable of avoiding the entry and exit of noise which is due to a physical phenomenon that in turn depends on the density of the material(Circe Materia, 2017). Therefore, it is a material capable of dissipating the sound waves that try to enter through the material, consequently the echoes or sounds that can be unpleasant are reduced (Cuesta, 2018). In brief, wood is a better option to the design because it can help to maintain a comfortable environment to the baby.

On the other hand, there are investigations about the use of wood to build hospitals which contributes to the recovery patient. Actually, such investigations reveal that wood can help to reduce the stress of patient who are hospitalized for long periods of time providing an optimal environment with optimal temperature and humidity levels favoring allergy and asthmatic people(Blasco, 2019). Also, the investigations show positive results in the psychological and physiological aspects of people which assure the importance of used wood in hospitals (Blasco, 2019). Notably, in Europe has been increased the use of wood in the hospitals building because this material provides several benefits to the patients such as to promote patient recovery, reduce stress and enhance the patient’s mood (DFM Directorio Forestal Maderero, 2015).

Therefore, wood was chosen as a material that can contribute with several benefits for premature infants because they need a harmonious environment for their development to be adequate, and it could also contribute to reducing the consequences of being born prematurely.

### 4.2.2. Heater system

The heating system will supply the intensity of heat according to the infant's needs, for which it will be composed of a heating element and an aluminum sheet support. So, the heating element will be a tubular straight heater (Metallic Nickel Resistance) that has a length of 36,5 cm (figure 6). As a whole, radiant warmers used heating resistance of many types as quartz or ceramic tubes, infrared light, incandescent lamps and metallic resistance. So, metallic resistance was chosen because this element can be purchased in Ecuador and its price is not excessive, unlike diffusers, infrared light tubes and quartz. Also has it important properties that could provide excellent results in the thermic-crib to the infant. Thus, the heating element will be regulated depending on the ambient temperature, maintaining a thermo-neutral environment in the thermic-crib. Therefore, the heater will be placed inside the warmer bed and under the infant within an aluminum sheet in a parabolic shape to ensure that the heat emission is uniform and the infant is kept within the necessary conditions to avoid heat loss.

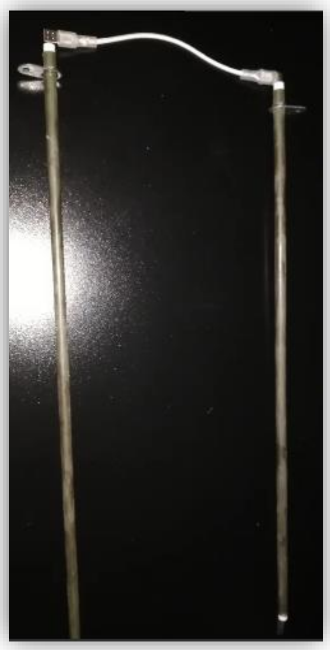


Figure 6: Tubular straight heater

On the other hand, the heating system will be controlled using a DTH11 sensor (figure 7). The DHT11 sensor has outstanding characteristics, which make it a component that can be used to control ambient temperature and humidity. In fact, it is a low cost and accessibility component with important features such as long-term stability, relative temperature, and humidity measurement, excellent quality, fast response, anti-interference ability, long-distance signal transmission, digital signal output, and accurate calibration (AOSONG, 2018). Then, the sensor will detect the values of the ambient temperature and humidity and send the signals to a controller which will activate the alarms if the temperature is below 34°C or above 36 ° C. So, in figure 8 can be seen a flow chart which describes how the temperature and humidity control system will work. Therefore, it will be used just an environment temperature and humidity sensor because the crib is designed to use as a support for children who only need to maintain their body temperature within the allowed ranges since they fulfill the main functions and only need to gain more weight to be able to thermoregulate by themselves.

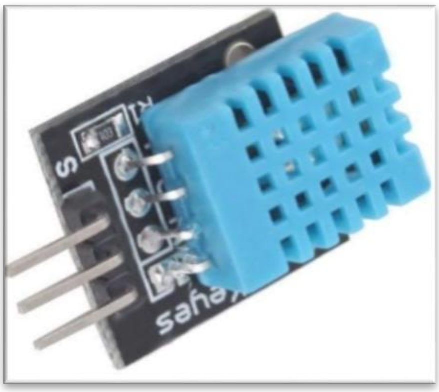


**Figure 7:** DHT11–Temperature and Humidity Sensor.

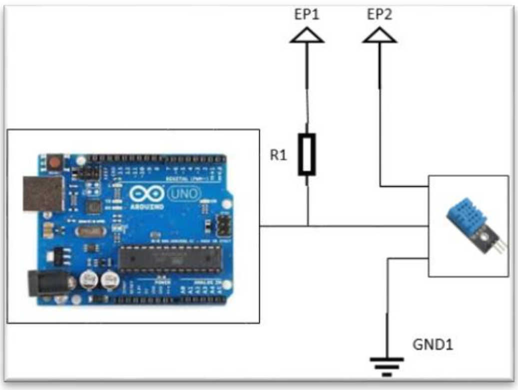



**Figure 8:** Circuit of the DHT11 sensor

### 4.2.3. Oxygen control system

The system will measure the infant's oxygen saturation to verify that the patient has normal levels of this parameter and to prevent deaths due to lack of oxygen or excess oxygen.

For this, a Spo2 oxygen sensor for neonates will be used: Bci Neonatal Oxygen Saturation Sensor. So, the sensor will detect the oxygen levels in the blood and will send this signal to a microcontroller which will sound the alarms in case the values are not normal (figure 9). The sensor has a design that will be comfortable for the infant and it can be acquired in Ecuador.

**Figure 9**: Bci Neonatal Oxygen Saturation Sensor. Spo2 sensor

### 4.2.4. Phototherapy system

*4.2.4.1.Selection of the number of LEDs*

Several authors define the intensity of jaundice phototherapy for intensive treatment (American Academy of Pediatrics Subcommittee on Hyperbilirubinemia, 2004; Maisels, 2015; M J Maisles, 1996) but the widely disseminated recommendation is that of the American Academy of Pediatrics Subcommittee on Hyperbilirubinemia (2004). According to this institution, the intensity for intensive phototherapy is 40 μW/( nm . $cm^2$).

To calculate the amount of LEDs used in a phototherapy for jaundice, the following equation will be used:

$$Number\ of\ LEDs = \frac{E_{max} \cdot A_c}{E_{LED} \cdot 1m^2}$$

The maximum luminous flux, $E_{max}$, is the maximum value of the luminous flux or illuminance. It is obtained from the radiometric light power using the equation:

$$E_{max} = max\left\{K_m \cdot \int_{\lambda_1}^{\lambda_2} V(\lambda) \cdot E_{e\lambda} \cdot d\lambda\right\}$$

where $Ee_\lambda$ is the irradiance in the spectrum range from $\lambda_1$ to $\lambda_2$. In this case, $Ee_\lambda$ = 0.254 W per module (=0.0847 W per LED) in the wavelength range of 460 nm to 480 nm.

Then,

$$E_v = K_m \cdot E_{e\lambda} \cdot (\lambda_2 - \lambda_1) \int_{\lambda_1}^{\lambda_2} V(\lambda) \cdot d\lambda$$

Also, eye sensitivity function, V( λ), in the case of a photopic vision can be seen in figure 6, whose maximum value is given at 555 nm. At this wavelength, maximum light efficiency ($K_m$) is of 683 lm/W. V(λ) is the relative luminous efficiency function that describes the eye human response at different wavelengths (Kalloniatis and Luu, 2005). The equation of V( λ) is:

$$V(\lambda) = e^{\left(\frac{-0.57\cdot(\lambda-555)^2}{1700}\right)}$$

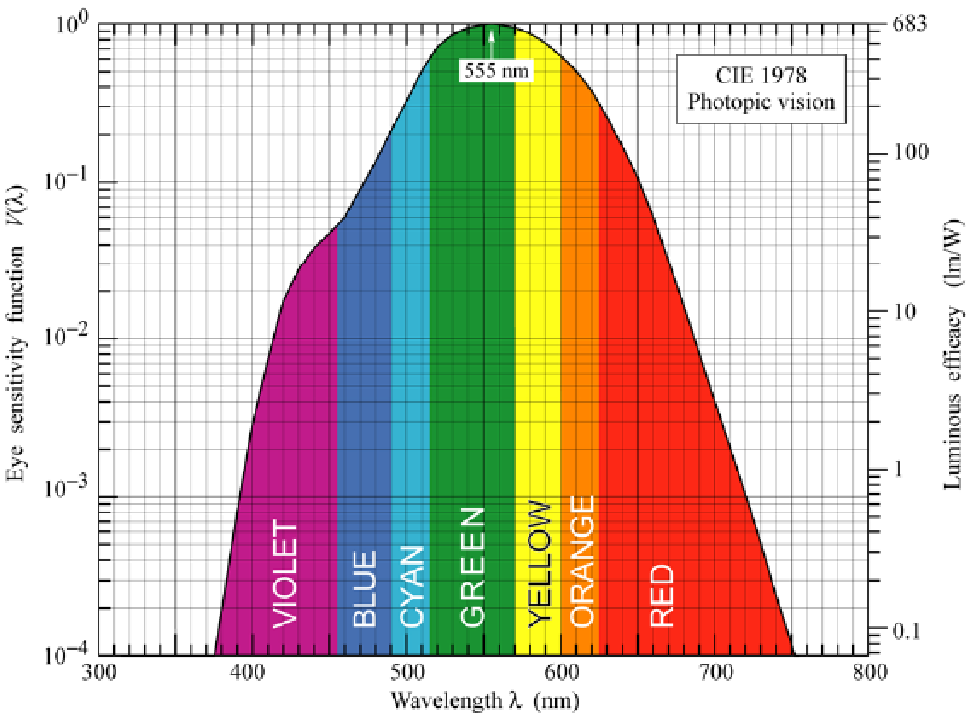



**Figure 10**. Eye sensitivity function (Kalloniatis & Luu, 1995).

In our case, the $E_{max}$ is:

$$E_{max} = max\left\{683\ \frac{lm}{W} \cdot 0.0847\ \mathrm{W} \cdot (480 - 460)\ nm \int_{460}^{480} e^{\left(\frac{-0.5\cdot(\lambda-555)^2}{1700}\right)} \cdot d\lambda\right\}$$

$$E_{max} = 14{,}000\ lx$$

$$E_{vtotal} = \sqrt{E_H^2 + E_v^2}$$

$$E_H = \frac{I_v * (cos\alpha)^3}{h^2}$$

$$E_v = \frac{I_v * (cos\alpha)^2 * sin\alpha}{h^2}$$

- A α = 0° se tiene que:

$$E_{vtotal} = \sqrt{E_H^2 + E_V^2} = \sqrt{\left(\frac{I_V}{h^2} \cdot (cos\alpha)^3\right)^2 + \left(\frac{I_V}{h^2} \cdot (cos\alpha)^2 \cdot sin\alpha\right)^2}$$

$$E_{vtotal} = \sqrt{\left(\frac{55\ cd}{(0.5\ m)^2} \cdot (cos0)^3\right)^2 + \left(\frac{I_V}{(0.5\ m)^2} \cdot (cos0)^2 \cdot sin0\right)^2}$$

$$E_{vtotal} = 220\ lx$$

$$Number\ of\ LEDs = \frac{E_{max} \cdot A_c}{E_{LED} \cdot 1m^2} = \frac{14{,}000\ lx\ \cdot 0.39\ m^2}{220\ lx \cdot 1m^2}$$

$$Number\ of\ LEDs = 24.8\ \sim 25\ \ LEDs$$

The number of LEDs that will be used to design the phototherapy system is 25, but each module has 3 LEDs. Therefore, 9 LED modules are needed to make the panel with the LED modules.

The distance to which the lamps must be positioned according to the irradiance that the infants need is detailed in the following table VII.

*Table VII. Irradiance per distance*

| ***Distance [cm]*** | ***Irradiance [µW/cm²/nm]*** *(460-490nm at 100% irradiance setting)* |
|---|---|
| *30* | >85,5 |
| *40* | >50,1 |
| *50* | >33,4 |

*4.2.4.2.Materials to design the phototherapy system*

The phototherapy system will be divided into three main parts, which will include a base for the LED modules and the housing that will cover the base with the LED modules. Each part will have a specific material which will be selected based on the needs of each part. First of all, the material that will form the base for the LED modules must have some essential characteristics because LEDs tend to be flammable. Additionally, LEDs can warp certain materials, which can lead to harm to premature infants. Taking into account that the thermo-crib will be used in infants, it is important to verify that the materials that will be used are correct to avoid problems with infants. For this, it was made an analysis of the physical, mechanical, chemical and thermal properties of high impact polystyrene (Cajas & Vargas, 2015) and silicon rubber (Table VIII).

Based on Table VIII, silicone rubber is one of the materials with better characteristics compared to high impact polystyrene. Although polystyrene has more important characteristics, silicone rubber is chosen because of the temperature of use as it is higher than the temperature of polystyrene. Silicone rubber can break more easily than polystyrene and can generally be attacked by alcohols, oils, and fats. However, silicone rubber will only be used as a base for the LED modules for which the mechanical and chemical properties can be obviated in this case.

*Table* VIII. *Materials for the design of the base for the LED modules.*

| | | **High impact polyestirene** | **Silicon Rubber** |
|---|---|---|---|
| **Mechanical properties** | Tensile strength (MPa) | 30-100 | 11 |
| **Physical properties** | Density (g / cm3) | 1.05 | 1.14 |
| | UV Resistance | Mala | Excellent |
| **Chemical properties** | Concentrated and diluted acids | Good-acceptable | Good |
| | Alcohols | Good-acceptable | Bad |
| | Fats and oils | Good-bad | Bad |
| **Thermal properties** | Operating temperature (° C) | 50-95 | -55-+225 |

M613BA is an LED module designed to produce high luminous efficacy, and installation is easy (figure 11). The cost of the LED module is low and it can be acquired in the country.

Figure 11: M613BA-UL, module LED

## 4.3. <u>Thermic-crib circuit design</u>

The circuit design was proposed to perform in Arduino which will be the main component that allows controlling the main functions of temperature, phototherapy, and alarms. So, it is proposed to design a control system for temperature, humidity, oxygen, and phototherapy. The design only presents a general vision of the components that will be use in the designing. Thereby, the principal components are a 20x4 LCD screen, DHT11 sensor, Arduino UNO, commercial humidifier, Bci Neonatal Oxygen Saturation Sensor, buzzers, push-button, and the basic components like resistors, and wires. It should be mentioned that, it is presenting a theoretical design of a thermic crib which aims to elucidate a general vision of the system to be developed. Therefore, it was performed a block diagram in which it is represented the functioning of each system.

# CHAPTER 5: RESULTS, INTERPRETATION AND DISCUSSION

## 5.1. Results

For the presentation of this theoretical design, a concurrent design analysis was performed to choose the most relevant design based on the approach that has been defined. For this, certain criteria were analyzed, including costs, size, and weight, since the most common incubators are designed with expensive materials and have several components which tend to increase the price of the incubators. So, the proposed design will be like a crib that will have a heating system in the lower part of the crib. The principal material to be used will be wood; this is a material that has many characteristics, the main ones being its cost and the accessibility of the material. Therefore, the crib should be inexpensive and accessible to both hospitals and people who need it since it can also be used at home.

Wood is the material that will be used in the design of the thermic-crib because of its excellent characteristics as a thermal and noise insulator. In fact, wood is a porous material, which makes it not able to conduct heat avoiding the heat transfer between any object and wood. Even, wood is considered as a material that keep the heat inside and this is able to modulate the temperature and humidity inside of a building. In other words, wood is considered a thermally insulating material that does not allow heat to be transmitted to the other sides and it also avoid that any noise pass thought the material (Suirezs & Berger, 2009). The property of thermal insulation allows that the heat does not dissipate, and the mattress heats up to keep the infant in the temperature conditions that it needs to avoid hypothermia. Therefore, wood is a good material to design a thermic-crib because it is looking for a material that allows keeping the heat inside a construction that would be the crib, and it is necessary to prevent the infant from transferring its heat to the wood. So, the wood meets these characteristics, which is why it is the best option. Also, it is a material that allows maintaining moderate temperature and humidity levels, so the infant would not experience hypothermia or hyperthermia.

On the other hand, there are evidence that wood can help to reduce stress, in the patient recovery and enhance mood. So, this material could help the premature infant to have a better development and reduce the sequels that are produced due to prematurity. Also, this material can help to the baby in the process to complete its development after the discharge of the hospital at home. Therefore, the material can help to improve the development in all aspect reducing the morbidity rates that affect the family and society. Additionally, the used of wood to design the thermic crib help to enhance the aesthetics. In particular, the aesthetics of the crib will be different from conventional incubators and will be comfortable and can be used easily. So, the thermic crib has a better aesthetics and could help to improve the life of a premature infant.

### 5.1.1. Humidity and temperature system control

In the block diagram, it can see the control system using the temperature and humidity sensor to control that the temperature and humidity conditions are those required to keep the newborn thermoregulated (figure 12,13). Once the system starts to function all the components of the system begin to accomplish its functions. The temperature and humidity sensor will sense the parameter which will sense to the microcontroller that send the signal to display the values on the screen and turn on the alarm in the event that the values are not within the normal ranges. So, the sensor will keep constantly monitoring the parameters. The process will be similar to the temperature and humidity. However, the values of the temperature will be used to control the heat intensity of the heating element to provide the required values to the premature infant. And, the humidity values let to control the humidifier in such way that the values of this parameter are in the range required. Therefore, each parameter accomplishes a special function.

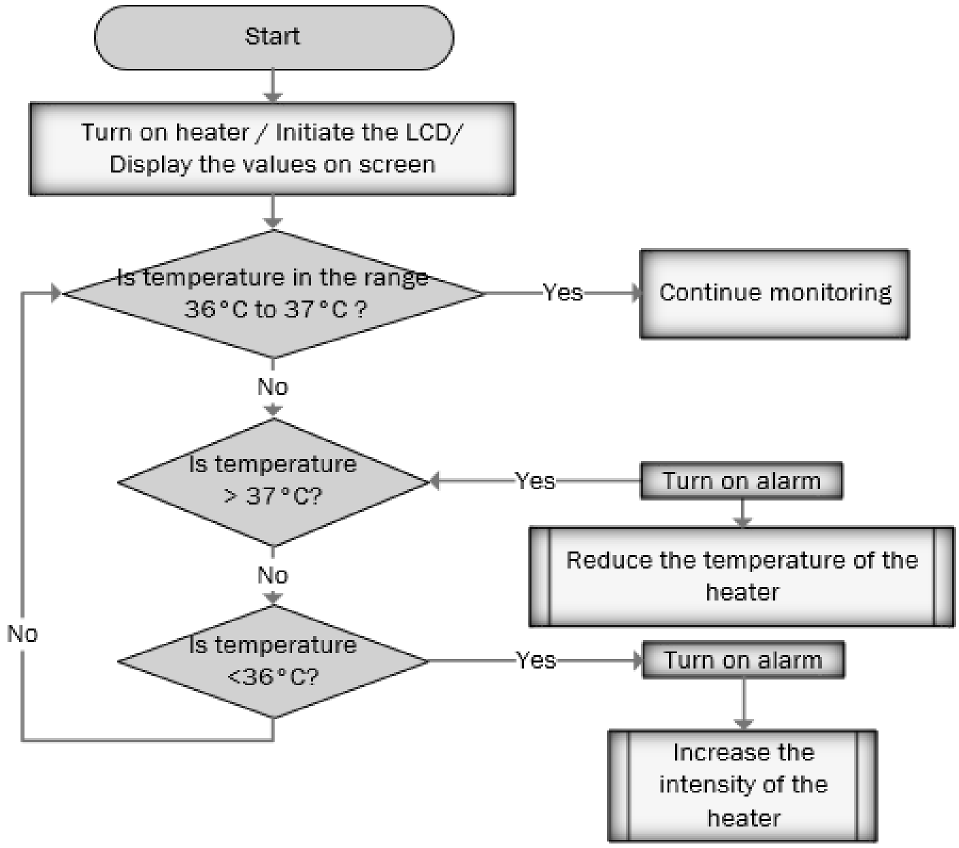



Figure 12: Blocks diagram of temperature control

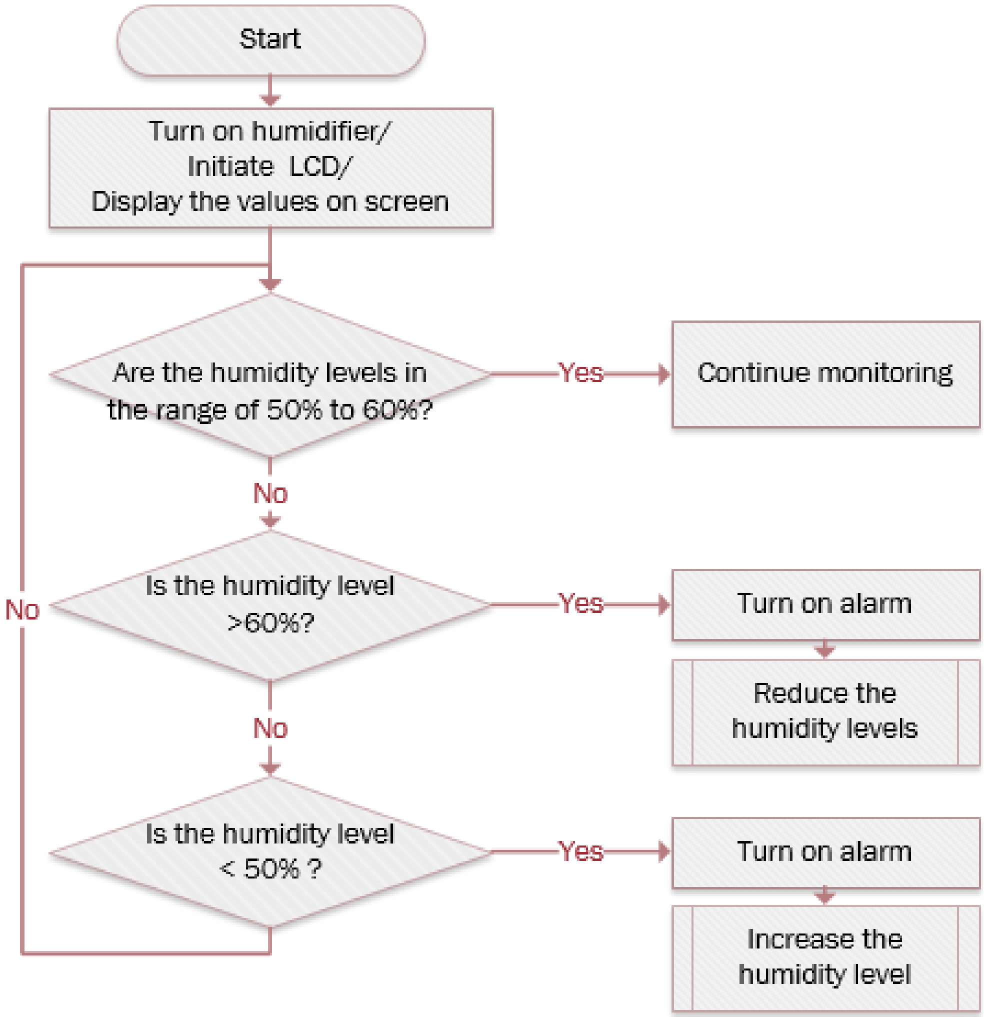



Figure 13: Blocks diagram of humidity control

### 5.1.2. Phototherapy system control

The phototherapy system will work manually which means a person will control the system. Si, the system will begin and the personnel must choose the type of phototherapy that will be applied to the premature infant according to their needs. The therapy will be applied to a moderate jaundice. Then, the system will monitor the time of therapy and turn on an alarm if the therapy is completed or continue with the therapy if the estimated time is not completed (figure14).

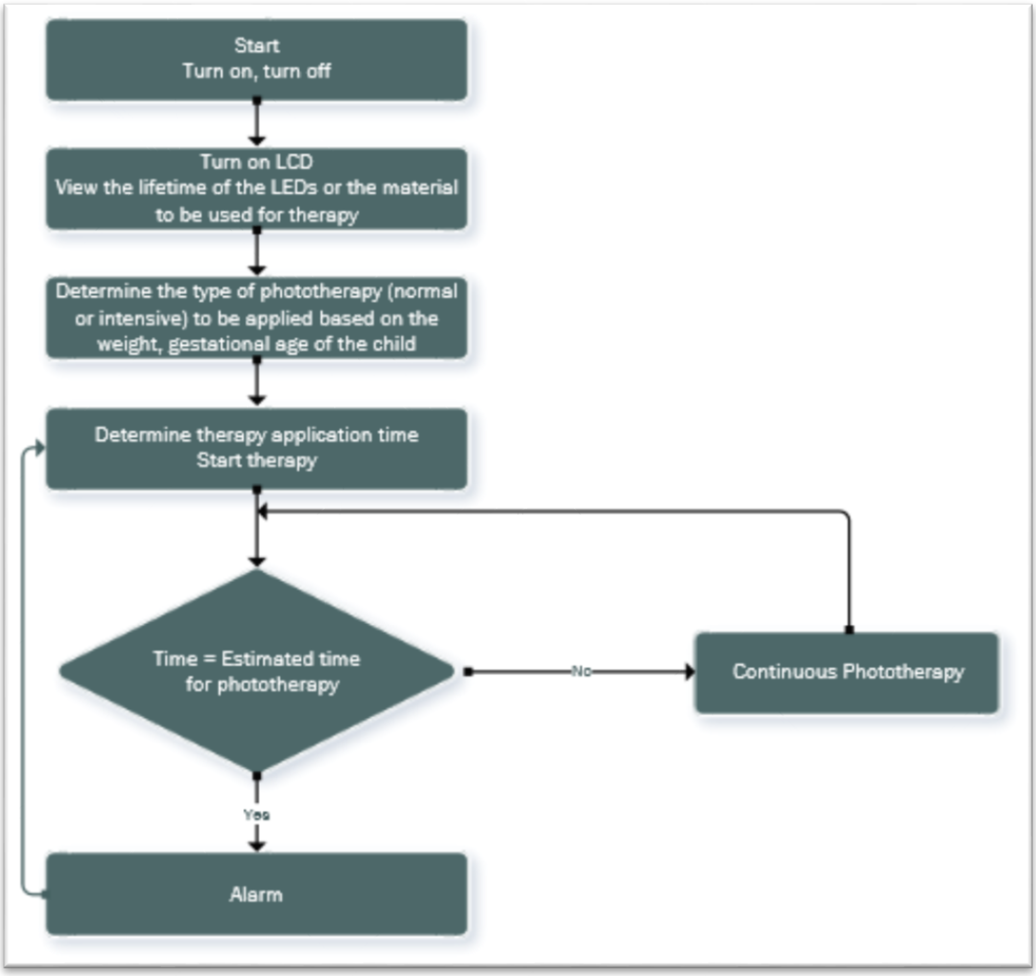



Figure 14: Blocks diagram to phototherapy system

### 5.1.3. Oxygen system control

In figure 15, it can see the block diagram to control the oxygen saturation of the infant. In this case, the oxygen saturation sensor will collect the infant's information and send it to a microprocessor, which will send the signal to the LCD screen where the data will be displayed. If the oxygen saturation levels are not normal, the alarm will sound. In this case, only the oxygen saturation is monitored and an alarm will be activated to warn the personnel.

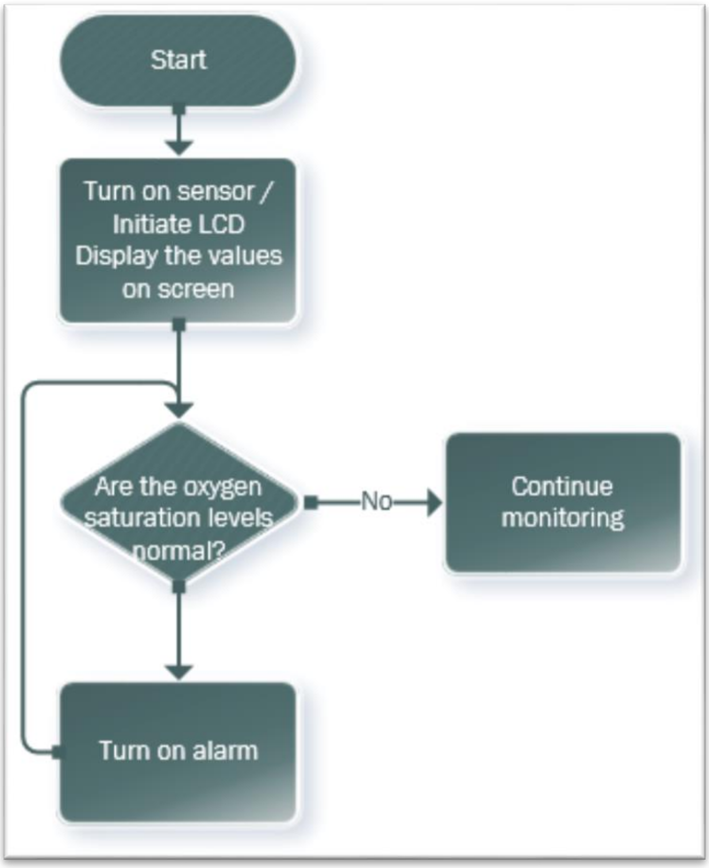



Figure 15: Blocks diagram to oxygen control

#### 5.1.4. Functioning of the general system

The circuit in general will work as follows (figure 16): the system will have a button to turn the warmer on and off and will have buttons to regulate the temperature and humidity levels. Also, it will have a button to turn on the phototherapy system and a button to turn off the alarms in case they turn on. The input signals will be the values acquired by the DHT11 sensors (temperature and humidity sensor), the oxygen saturation sensor. Buttons and sensor data will be considered as inputs which will be sent to a microcontroller. Afterward, these signals will be displayed on an LCD screen and the program will make the alarms sound when values higher and lower than the allowed ranges for the levels of humidity, temperature, and oxygen are detected. So, if the levels of these parameters are normal, the temperature must be maintained and must not be modified. Besides, relays will be used to control the heater and humidifier. Employing the humidity and temperature sensor, if a higher value is detected, the heater will automatically switch. In this case, if the temperature is lower, the heater will increase its intensity until it maintains the necessary levels. This process will be repeated with the humidifier. So, the thermic crib will provide a normal environment accomplishing with the required values.

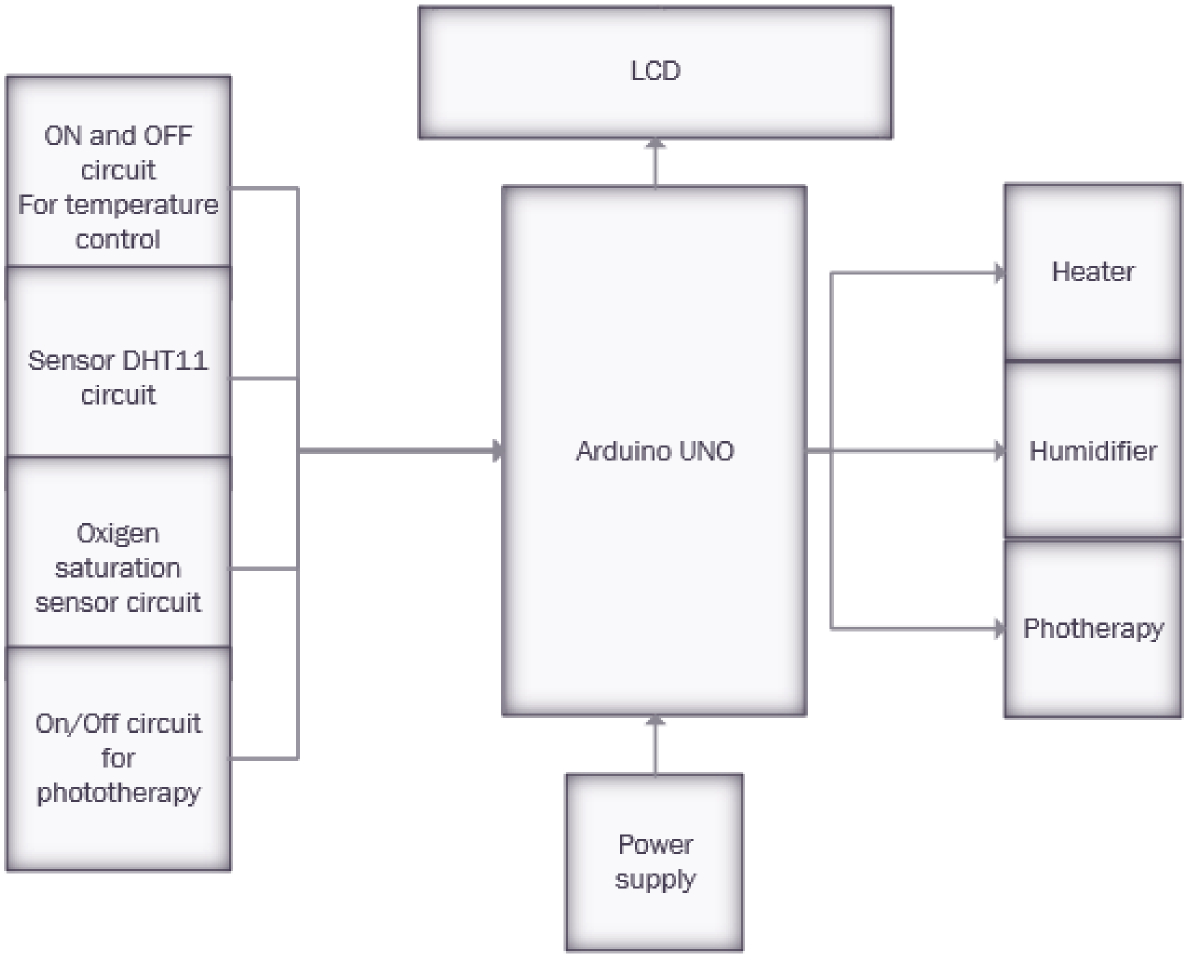
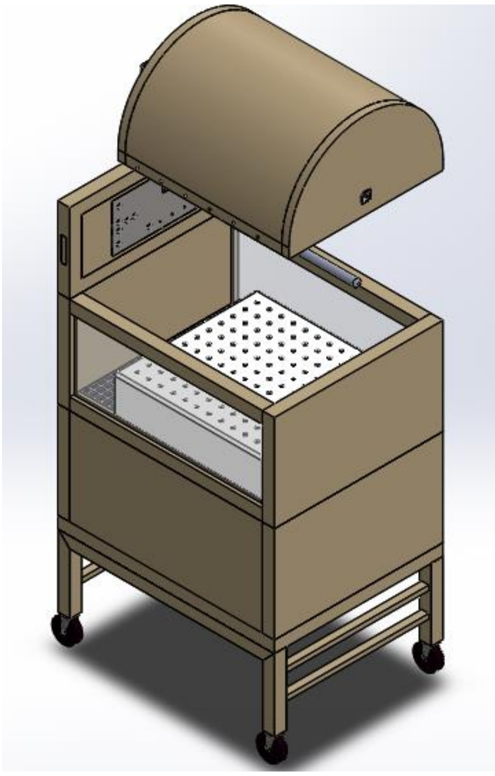



**Figure 16:** General blocks diagram

### 5.1.5. Physical design

The physical design of the thermic crib was made in SolidWorks which allows to make a design according to the dimensions that were determined based on the dimensions of a newborn (figure 17). The thermal crib consists of four main parts, which will be assembled using the box and Tenon technique; this assembly technique gives the piece's greater stability. These types of assemblies allow the parts to be more resistant to traction and compression; therefore, this technique will ensure that the warmer stays stable even when an infant is on the warmer bed.

The warmer cradle support is designed to make it easier to move the cradle from one location to another if necessary. This support will allow the crib to remain stable and can be easily moved inside the home and in the same way, it is designed of wood (figure 18).



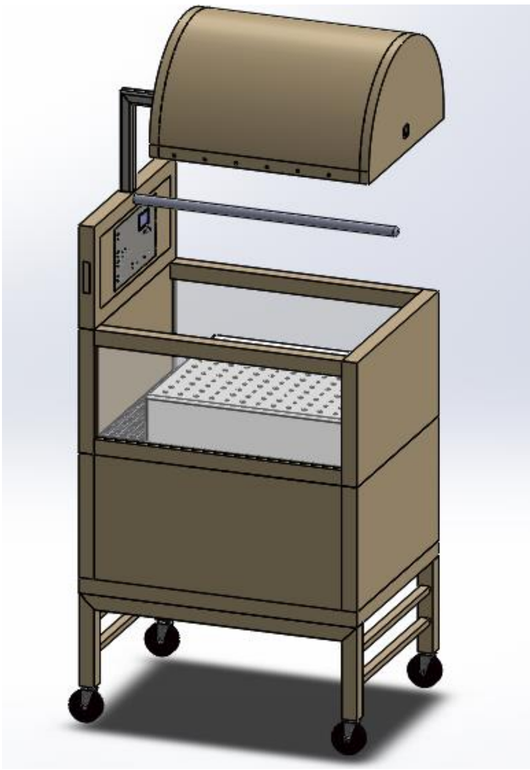


**Figure 17**: Final design of thermic-crib

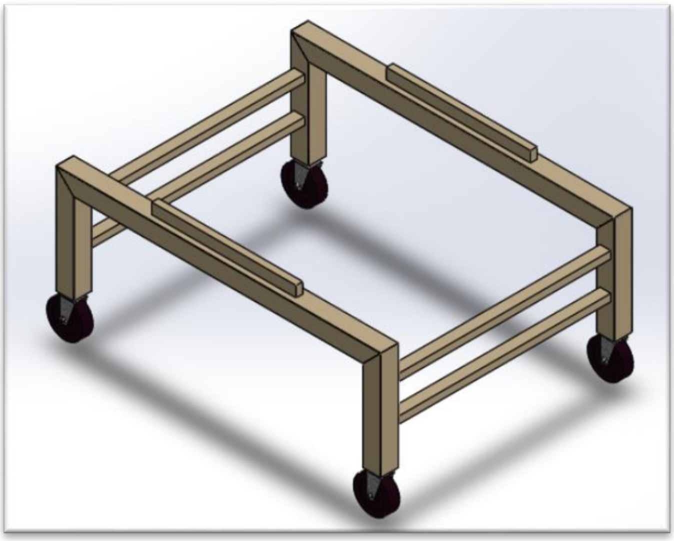


**Figure 18**: Crib support

The heating system will be placed in the lower part of the crib. The heater was placed on an aluminum foil in a parabolic shape (figure 19). Placing the heater with the foil in a parabolic shape allows the heat to be distributed evenly to the mattress and the infant to stay warm. In this way, this principle ensures that the distribution of heat within the crib is uniform or that no part of the infant's body is left unheated. Also, aluminum is a material that allows to keep that heat focused in the direction in which the neonate is to avoid hypothermia problems in the infant.

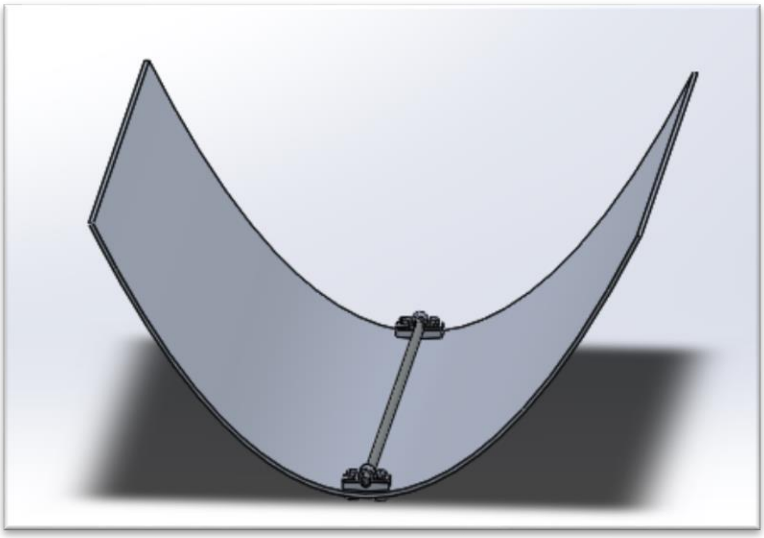


**Figure 19:** Heating system

The proposed design has a control system in which the circuit to control the system is located. The circuit is designed to fit inside a stainless steel metal box, which has properties that will allow it to keep the circuit safe from affecting the infant. Stainless steel can withstand extremely high temperatures, which means it is not damaged or warped. This material does not corrode due to its protective components. Also, it is a material that gives an improved aesthetic to designs. However, this material will only be used to serve as a housing for the circuit board. The design has a tube on top of the incubator, which will serve to place a blanket in case the ambient temperature drops drastically (figure 20).

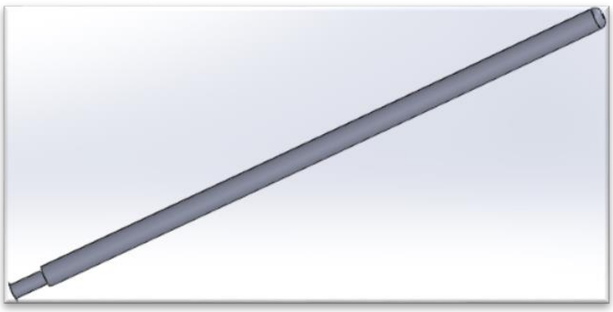


**Figure 20**: Tube for blanket

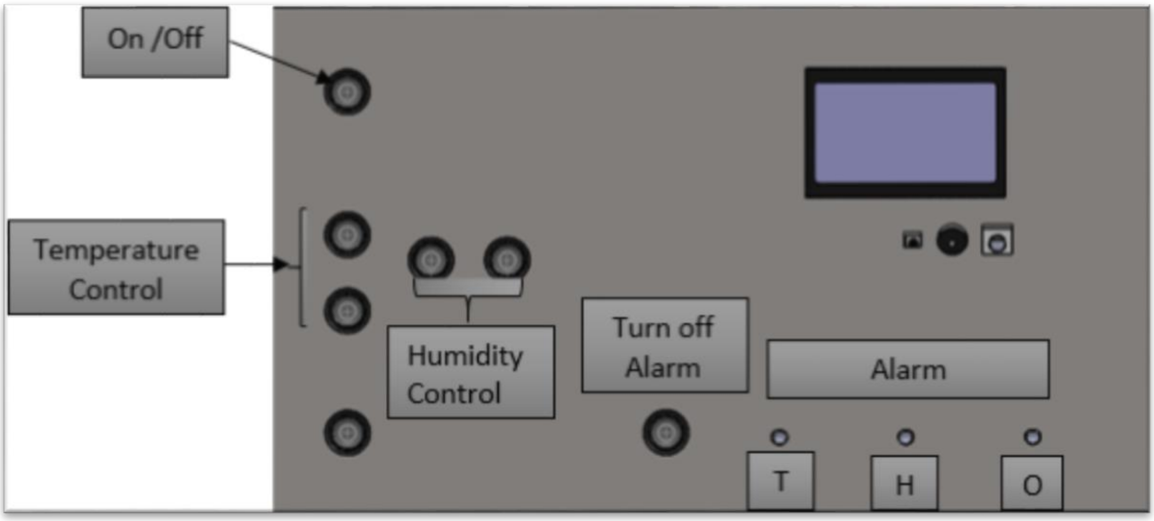



**Figure 21**: Panel control system

The design features a phototherapy unit to apply therapy to mild jaundince. This layout shows how the phototherapy unit will be positioned. Also, it is proposed that this unit can be easily removed so that it can only be used in case the infant needs this therapy. The part that will cover the LED modules will be made of wood with aluminum in order to reduce costs (figure 23). The base will be designed with silicone rubber because it is a material resistant to high temperatures. Furthermore, in figure 22 you can see how the LED modules will be placed. It is proposed to place them in this way so that the distribution of heat is uniform and can radiate to the entire surface of the mattress on which the infant will be placed.

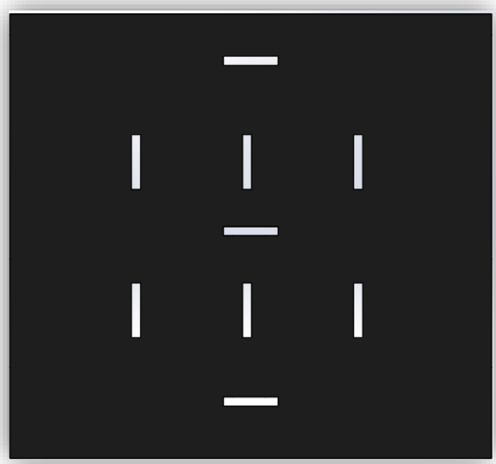


**Figure 22**: Distribution of the LED module

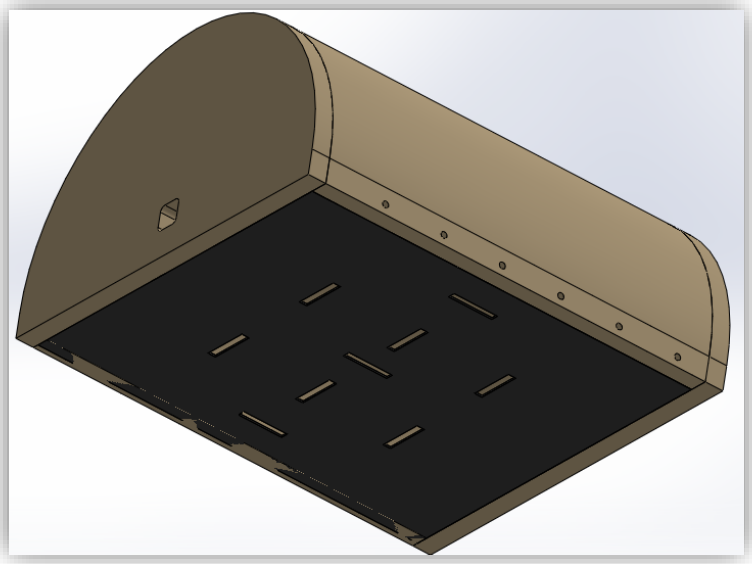


**Figure 23**: Phototherapy system

*5.1.5.1.Estimated cost*

The materials cost vary hence it was performed an estimation of the cost of each material and the cost of design. For this, it made a table in which are detailed each material with the approximated cost.

*Table IX. Estimated cost of material*

| **Material** | **Cost ($)** |
|---|---|
| Heater element | 10 |
| Aluminum sheet | 10 |
| Mesh | 5 |
| Bed | 5 |
| Humidifier | 9 |
| Oxygen Sensor | 48 |
| LED Module | 10 |
| DHT11 sensor | 2 |
| Silicon rubber | 23 |
| Total | 122 $ |

*Table X. Estimated cost of material for the circuit*

| **Material** | **Cost ($)** |
|---|---|
| Circuit design | 20 |
| Total | 20$ |

The wooden crib will be sent to be made in a carpentry with the design dimensions. It is estimated that the cost of the wooden crib would be around 150 dollars. Therefore, the total cost of the thermic-crib will be approximately 300 dollars.

*5.1.5.2.Simulation*

Consequently, a thermal analysis of the lower part of the warming bed was carried out to evaluate the thermal insulating property of the wood that is proposed to be used. For this, the temperature inside the crib and outside the crib were defined, allowing to evaluate if the heat flows towards the external face of the crib considering the thermal conductivity of the material. The temperature inside the crib was 37°C, and a temperature of 0°C was defined on the outside. The thermal conductivity of the material was 0.104; this conductivity belongs to the pine which is defined for the design of the thermal cradle. So, the simulation let to evaluate an important property which permit to evaluate the thermal insulating property and the thermal conductivity.

The figure 24 show interesting results in which it can be seen the thermal insulation. So, it can be seen that there is a uniform heat flow since it can be seen that the maximum temperature is concentrated inside the box and the minimum temperature is found on the external face of the box where the heater is placed. Therefore, it can be said that pine wood complies with the characteristics of thermal insulation, which allows heat to concentrate inside the crib. Although, the small temperature leaks can be observed located in the joint parts of the materials, which can be solved using wood sealants. Therefore, it is a material that has many advantages, among which is keeping the heat inside the crib.

On the other hand, the figure 25 show a resulting heat flow through the joints that were made in the design. That is to say, there may be small heat leaks in these areas which can be solved using wood sealants. Also, it can be seen that there is minimal heat flow inside the crib, which means that the heat flow is uniform, keeping the crib evenly warm. Therefore, wood has excellent properties and it can provide a better environment to the premature infant.

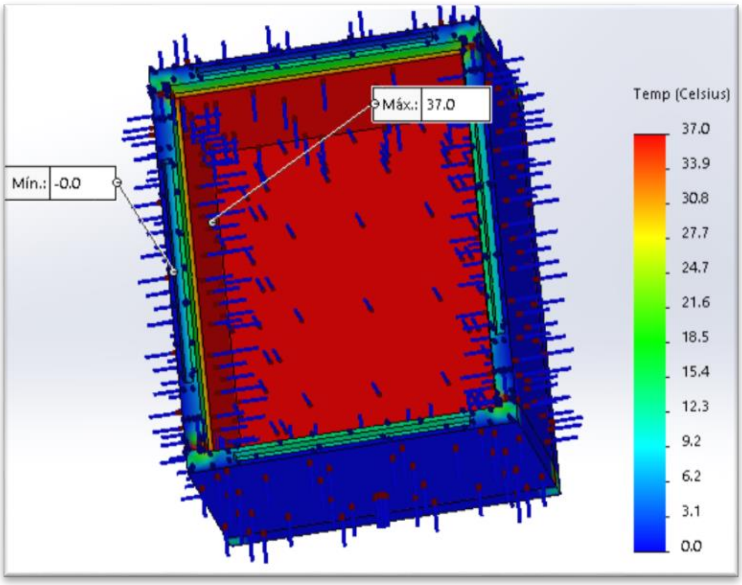



**Figure 24:** Thermic analysis

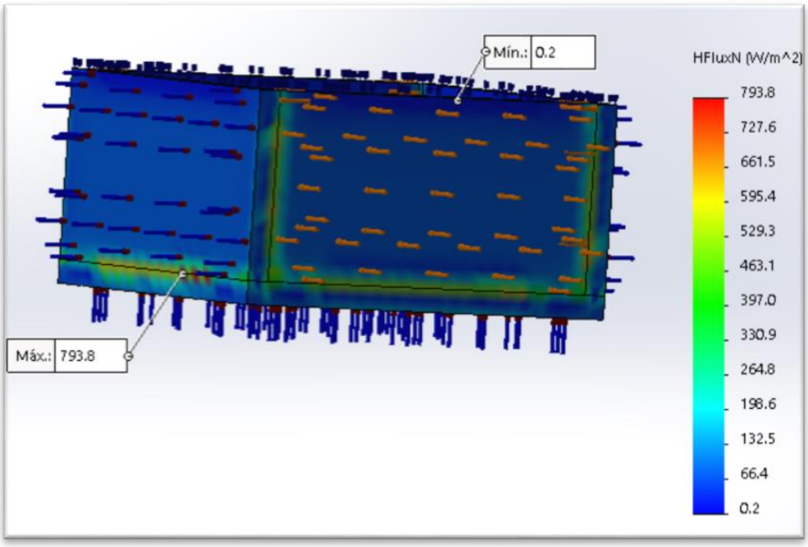



**Figure 25**: Resulting heat flow

### 5.2. Discussion

Wood is a material used to build houses, furniture, etc., and this material has been used to build low-cost incubators in underdeveloped countries in which there are inequity in the health systems. However, in Ecuador there is no project focus on to solve this problematic. One of the main reasons may be the rate of premature births and also the lack of resources and adequate infrastructure to acquire more equipment. Although, the rate of premature birth is still alarming because many children are born prematurely and need special care that many hospitals cannot afford. Therefore, it is necessary to solve these problems no matter how small they seem as a preventive measure because, at some point, they need for this equipment could increase.

In recent years, projects focused on designing incubators based on wood have been developed to reduce costs and focus on the main problems present in underdeveloped countries. For example, Incubaby is a project that has designed an incubator for hypothermic infants using materials such as wood to reduce design costs. This incubator has an innovative design and is very aesthetic with very simple materials (Boone et al., 2015). These types of incubators are more accessible for hospitals that lack the resources to purchase conventional incubators and warmed beds because they are so expensive. In Ecuador, the health sub-centers do not have incubators and there are even hospitals that lack sufficient equipment to care for premature infants, for which the proposed design can serve to meet the basic conditions to prevent premature infants from dying of hypothermia. In Ecuador, a problem arose due to the lack of equipment; to solve the lack of equipment, two children had to be placed per crib, which could be solved by designing low-cost cribs that can be purchased by hospitals.

The Omoverhi project developed a neonatal incubator with wood and stainless steel to reduce the design cost. The project focused on solving problems related to developing countries where there is less accessibility to health services, and they are one of the places with the highest rates of premature births. The design also focused on providing a solution for places where there is no electricity (Fong et al., 2013). So, it is essential to solving many problems that each country faces every day. Underdeveloped countries like Ecuador do not have the necessary resources to acquire enough medical equipment, and many premature infants tend to die due to the lack of the necessary care to survive.

Omoverhi and Incubaby projects design incubators using wood and there is no evidence of a thermic crib designed with wood. Such projects developed novel designs of incubators which provide the basics functions to help premature infants in the first days of life. In this work, the design has another focus and it is intended to use at home and hospitals, however, the design could be changed to be more ergonomic. Also, a disadvantages of the thermic-crib is related to the flammability of the material, which could be resolved through controls in the places where they are located and keeping it away from other elements that could cause fires. In terms of costs, the thermic-crib could be less expensive than the mentioned incubators, although, this can vary because the cost of the materials are not the real. By making a comparison with such incubators, it can be seen that the proposed crib would be less expensive compared to the crib of the Omoverhi project which has a design cost of more than 2000 dollars. On the other hand, the cost would be similar to the design cost of the Incubaby incubator because it cost approximately 300 or 400 dollars.

On the other hand, it is complex to ensure that the functionality of the thermic-crib designed is similar or better in terms of quality. First, only a design is presented in which several elements are proposed to be implemented. Therefore, it is necessary to implement it and carry out the respective analyzes to determine its functionality and make the necessary improvements to avoid putting the infant's life at risk.

Generally, in Ecuador hospitals such as the IES located in large cities have enough incubators and radiant heaters; however, the biggest problem that arises is the cost per stay of infants. In many cases, infants who were born more prematurely tend to stay for months in an incubator, generating costs that affect not only the hospital but also the state and society. For this, the proposed design is intended to help reduce these long-stay costs. So, if an infant has developed their organs and fulfills the basic functions such as breathing and has a weight greater than 2500g, they can be transferred to the crib. In this way, hospitals could have several thermic-cribs to transfer premature infants in which they can continue improving their ability to thermos-regulate on their own. Thus, there would be more incubators and free high-tech radiant cribs to be used with the gravest premature infants, and thermic-cribs would be used only for infants who fulfill certain functions but need help to thermos-regulate.

In developing countries like Ecuador, it is necessary to find solutions to the present problems due to the lack of resources to acquire so expensive equipment. These problems can be solved by looking for alternative materials to design devices, as is the case with this project, which focused on evaluating the importance of wood as one of the materials with excellent properties that benefit premature infants.

# CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

## 6.1. Conclusions

The present work presents the design of a thermal crib that, through a heating system located under the child, provides the necessary heat to maintain the infant thermo-regulated. The thermal cradle will allow the infant to be monitored in case of temperature rises or falls, for which the alarms must sound, and the temperature will be regulated based on the values acquired by the sensors. Besides, it will have a system that will maintain normal humidity levels so that the newborn does not become dehydrated. The design even has an oxygen sensor which will allow controlling that the oxygen levels are normal since this could cause the death of the neonate in case the values are not normal, in this way it would help to prevent deaths from suffocation. Also, the crib has a phototherapy system in case the infant shows signs of jaundice. On the other hand, thermic-crib has a control system in which the values of each parameter are observed. Therefore, the warmer bed will have the basic functions that an infant requires after leaving an incubator. It should be noted that the warming bed is intended to be used with infants who were born prematurely and have reached a weight of approximately 2500 g onwards and are capable of breathing without the need for help. Also, these children must have their organs in the majority well developed and functioning.

With this design, it is intended to help the mothers of premature infants who were discharged to remain calm and more comfortable in their homes with their children without the need to be in a hospital that in many cases can stress the mother so much as infants. Besides, the present design will allow hospitals to reduce costs for long stays of infants and even allow infants to release a more complex incubator so that another infant who is more seriously ill can be cared for.

Design cost are reduced by using different materials such as wood, which for some years has been used to design incubators in developing countries. This material is an excellent thermal insulator that helps allow the conditions within the warmer to concentrate inside so that the infant remains thermos-regulated. Although wood is susceptible to fire, these problems can be improved through proper treatments, and the crib can even be covered inside to prevent the wood from being damaged or deformed.

With this design, it is possible to reduce design costs as wood is a material that can be easily purchased anywhere. Also, this material makes it possible to design a crib with improved aesthetics that may even be more pleasant for the customer. Also, these designs could help reduce the stress infants are subjected to within hospitals since several studies have shown to help patients recover and reduce the stress of being within these nursing homes. Besides, the design proposes using a tubular heater to maintain a temperature within the ranges needed by neonates according to their weight reached. It is proposed to use a humidity and temperature sensor to measure the levels of these parameters, and based on these data regulate the intensity of the heater and a commercial humidifier.

### 6.2. Recommendations

It is important to carry out the implementation of the design to verify its operation and to carry out the respective tests because it is complicated use a software to test the functioning.

The bracket could be redesigned to make the wheels removable or fit inside the brackets so that the crib can be kept stable.

Improve the design to make it more aesthetic for customer and improve the size.

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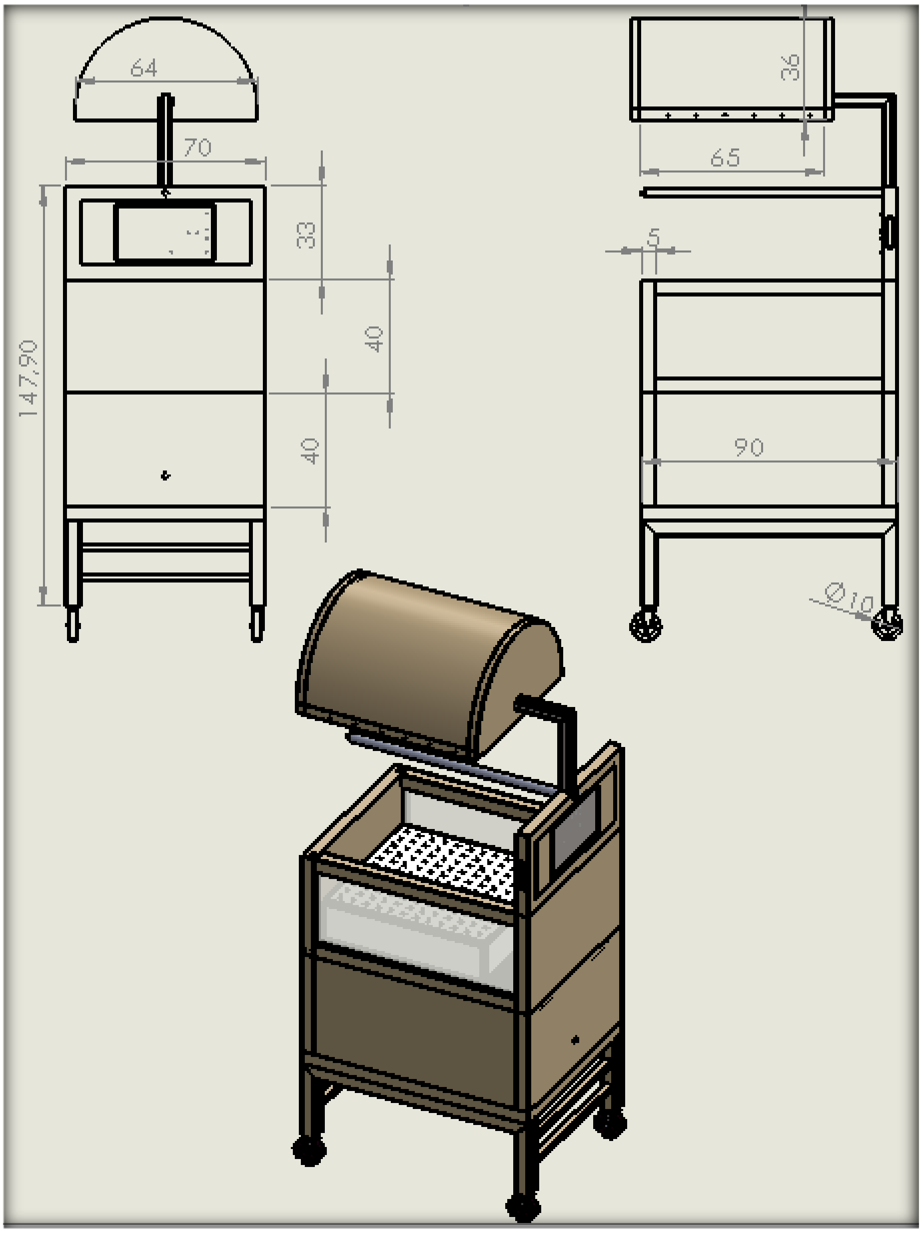
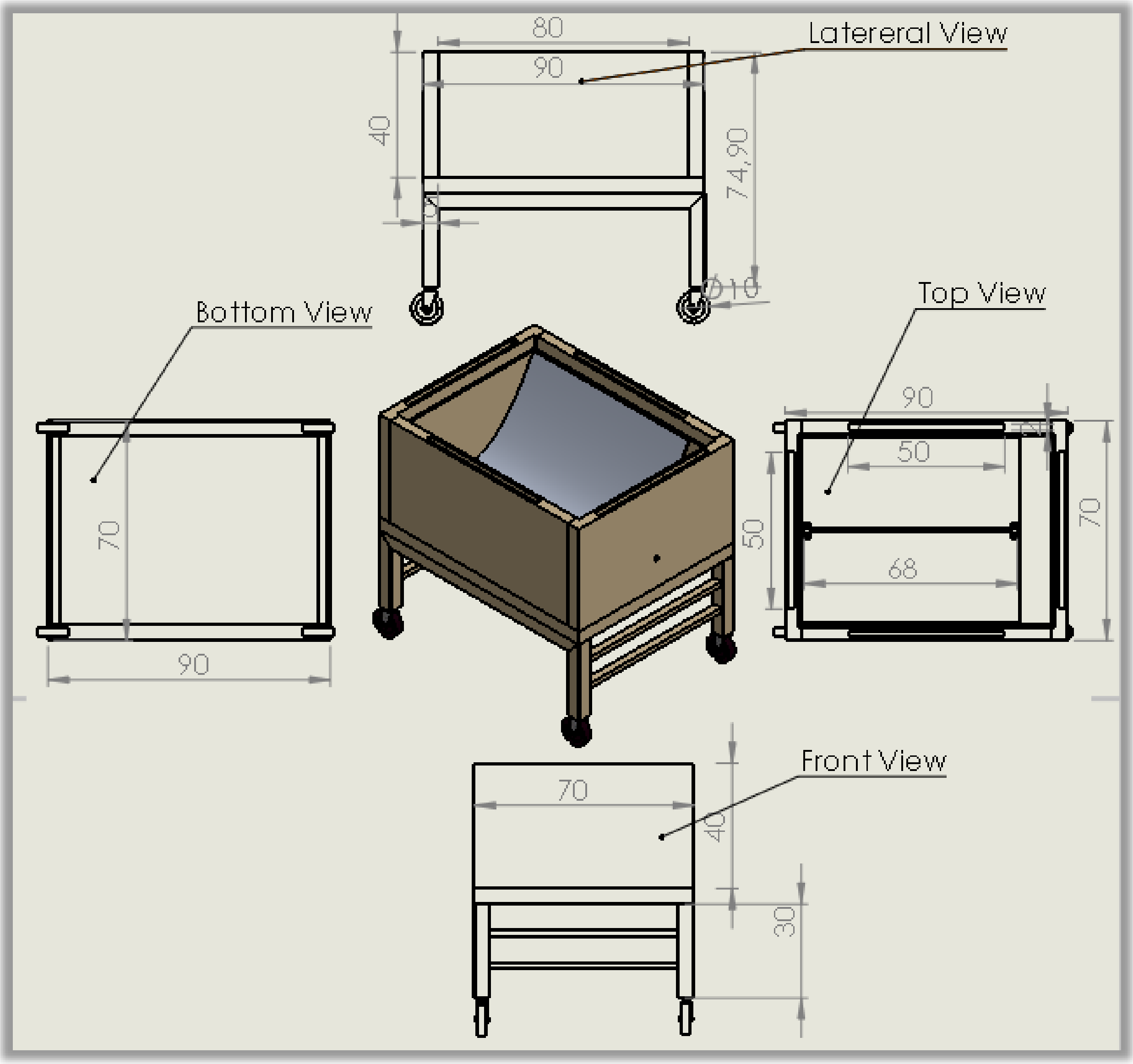
# 8. ANNEXES

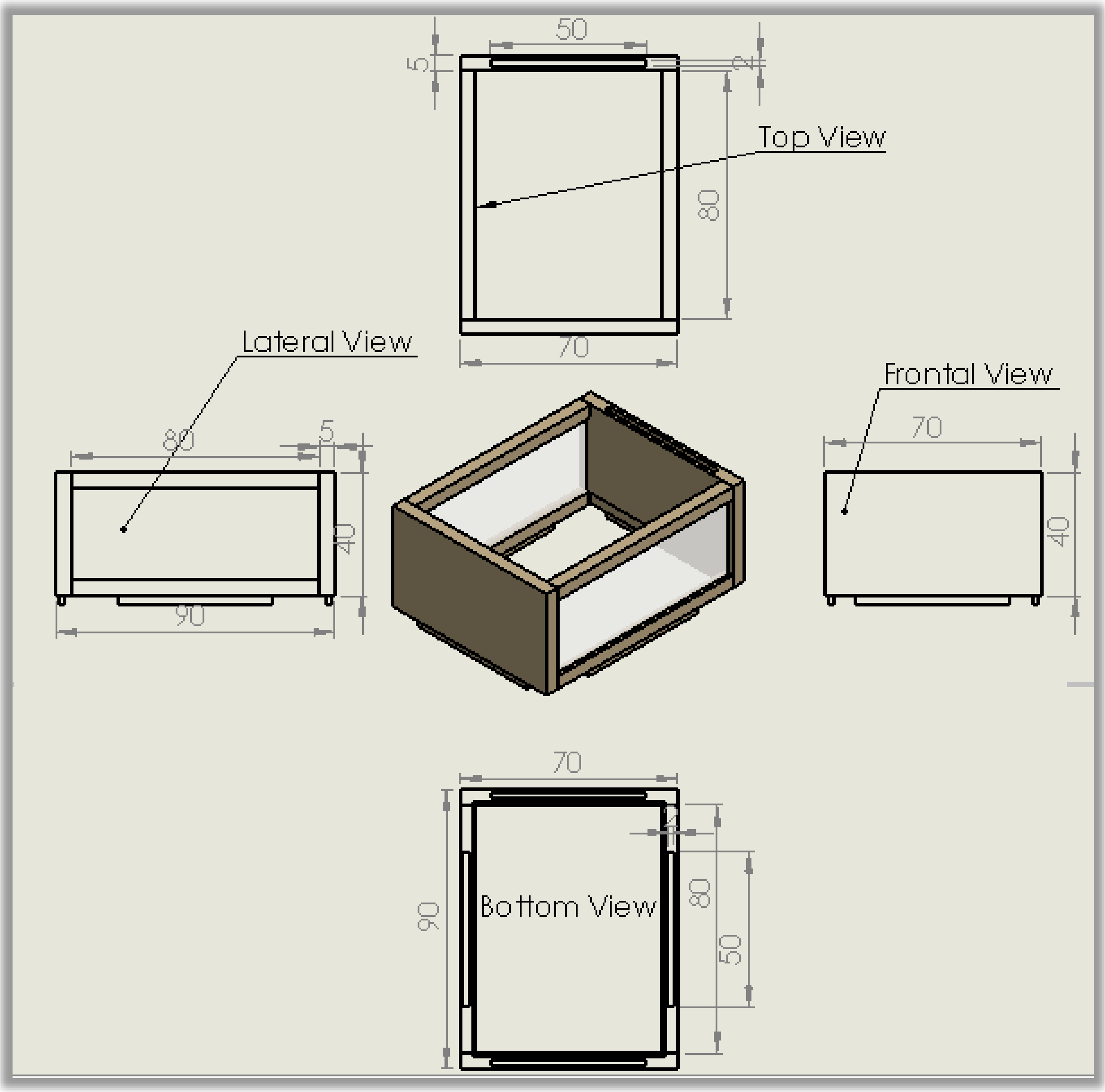
Appendix A: Thermic crib drawings



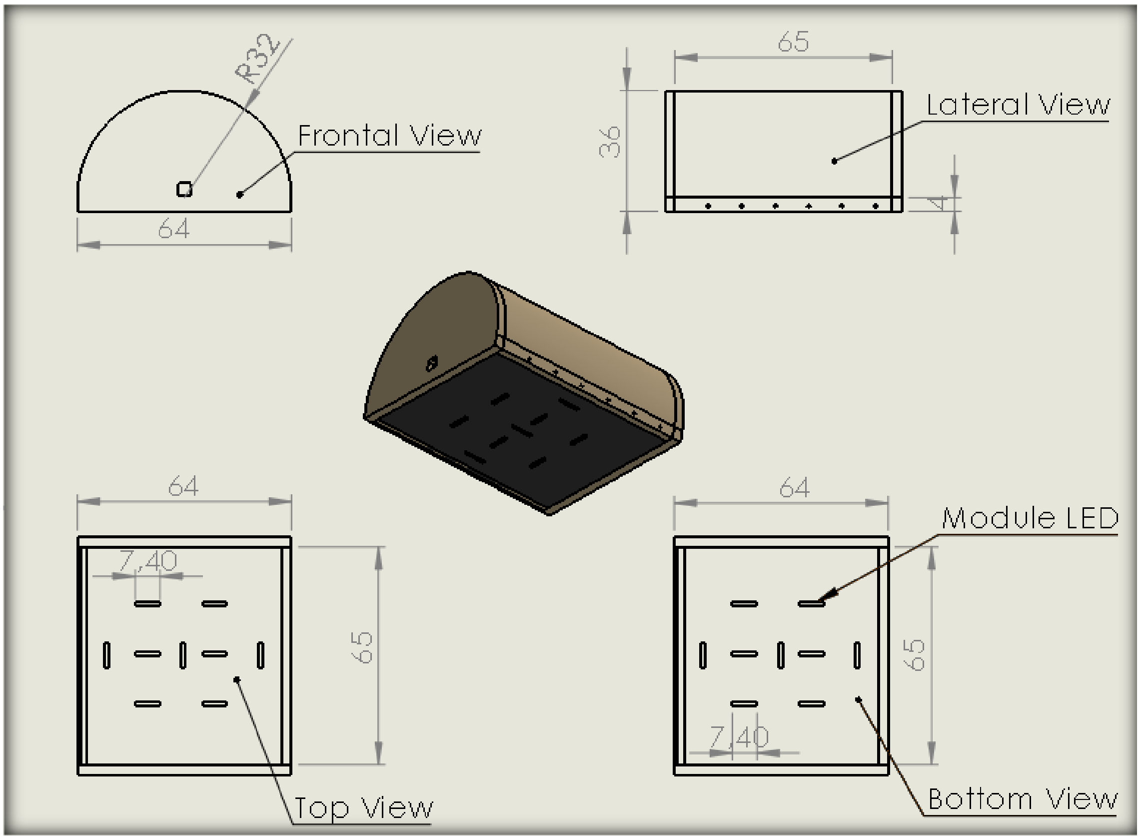
Appendix B: Lower part of the crib



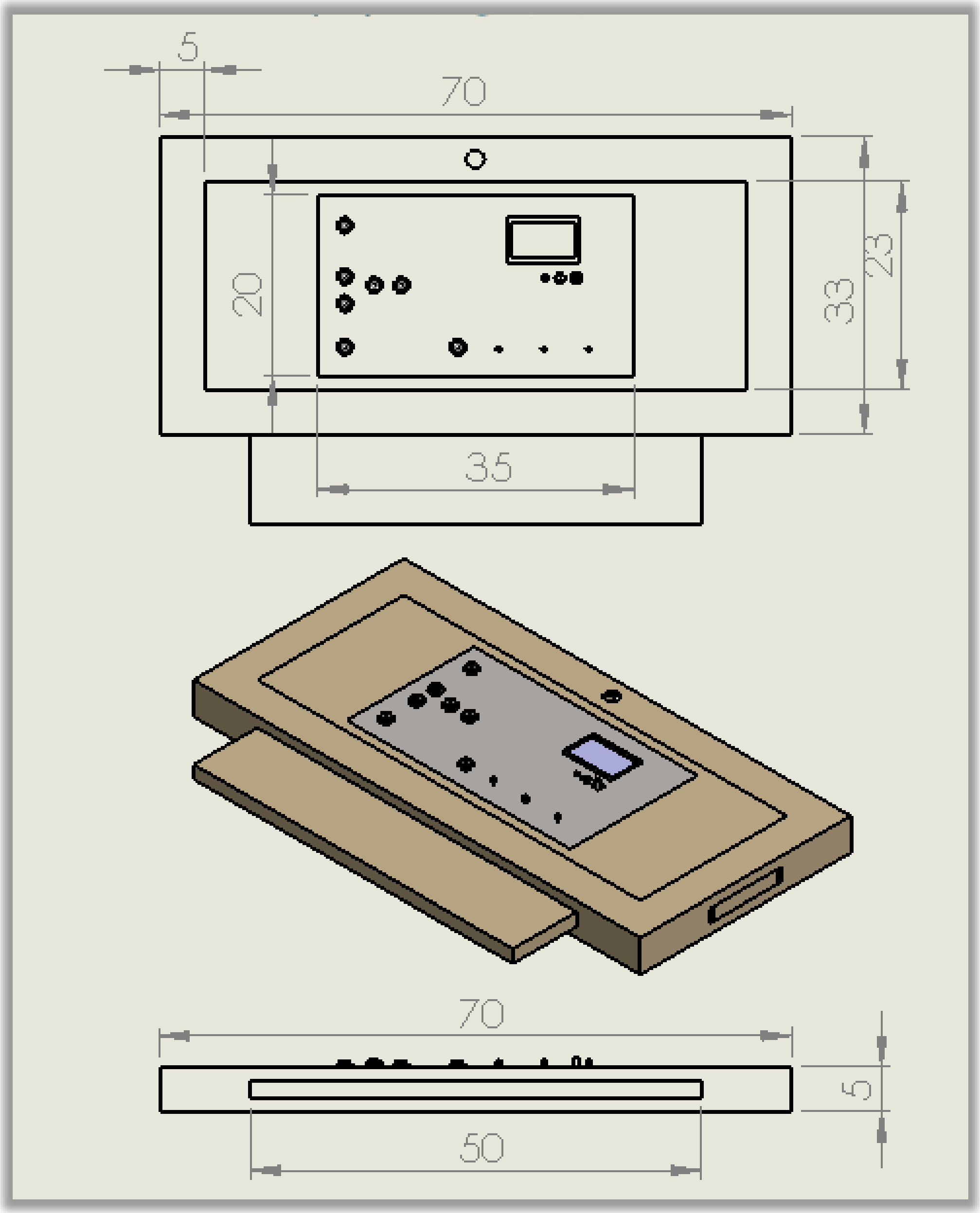
Appendix C: Second part of the crib with acrilic.



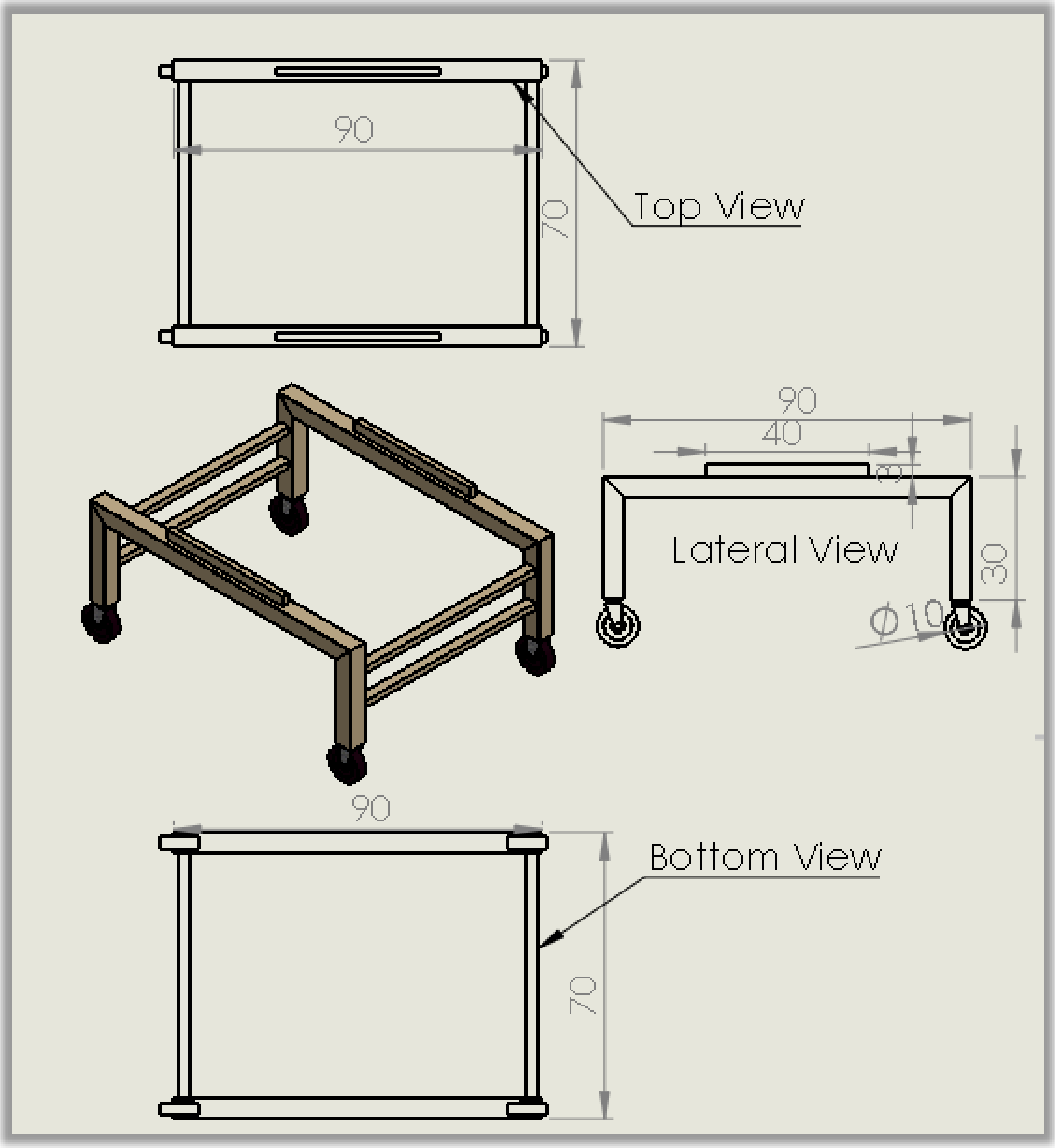
Appendix D: Drawings of phototherapy design



Appendix E: Drawings of the control panel



Appendix F: Support for the thermic-crib



Appendix G: Drawings of the heating system