CHAPTER 2

ANALYSIS OF HEAT TRANSFER OF INFANT WARMER

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ABSTRACT

An infant warmer is an overhead heating device used to help infants regulate their body heat to achieve their normal body temperature. However, problems may arise in obtaining the correct heat settings. The objective of this study is to determine the most appropriate operating conditions of such units. A combined analysis of heat transfer from the heat source and the influence of the surrounding environment temperature is performed to calculate the temperature distribution for the infant warmer. A simulation application is used to recreate the design and run the simulations according to the boundary conditions as a guideline. The results for a single heat source show a very non-uniform temperature distribution. On the other hand, the results for the double heat source show a very uniform heat temperature distribution. Based on the observations, it is recommended that a dual heat source be used for an infant warmer for more favourable results.

Keywords: Infant warmer, Heat transfer, CFD

2.1 INTRODUCTION

Regulating body temperature is important for newborn survival. Optimum regulation of body temperature is essential for their health and development. The survival of newborns depends on their ability to regulate their body temperature. In the whole term, the healthy infant may easily regulate body temperature. Preterm and sick babies often struggle to maintain optimum body temperature without external help [1]. This vulnerable infant is at high risk for hypothermia, which is a medical condition where an infant loses body heat faster than they can produce, leading to the core body temperature dropping below the normal range, 35°C [2].

To help the infant achieve their normal temperature and help them regulate their body temperature, the infant will be put under a warming unit. The warming unit is heated, and the surrounding temperature is monitored with the help of a sensor. The surrounding temperature is lower than the infant's body temperature, affecting the baby's ability to regulate temperature to a normal level. Continuous heat loss due to this can be serious, particularly for tiny, premature infants suffering from respiratory distress or cardiac failure. A combined analysis of the surrounding environment and heat transfer mechanisms, which involve conduction, convection, radiation, and evaporation. These combinations were conducted to calculate temperature distribution and heat transfer in an infant warmer [3].

Hypothermia occurs when body temperature drops below 37°C, leading to significant complications, including death (Mullany, 2010). Many infants, even full-term ones, are born with a near-hypothermic body temperature. Being born in a cold environment can cause a rapid drop in body temperature. At birth, an infant transitions from a warm, wet environment to a cool, dry one. Babies are typically delivered in labour rooms or operating theatres, which are maintained at cooler temperatures. This sudden change causes significant heat loss, forcing the infant's body to work harder to regulate temperature. To assist with this process, infants are often placed in infant warmers, which help stabilise body temperature between 36.5°C and 37.4°C. Severe temperature fluctuations can lead to neonate hypoxia, acidosis, hypoglycemia, and, in extreme cases, death, all of which are closely linked to temperature instability (Ionio et al., 2021).

Simple measures such as drying the infant to minimise evaporative heat loss, wrapping in blankets to reduce convective and conductive heat loss, and skin-to-skin contact with the mother to limit radiative and conductive heat loss can help regulate the infant's body temperature (Ionio et al., 2021).

Nursing care plays a crucial role in preventing excessive heat loss, as prolonged cold stress can overwork heat-producing mechanisms, reduce energy reserves, and result in hypoxia, acidosis, hypoglycemia, and, in severe cases, could lead to death. While simple interventions are sufficient for most full-term infants, premature and low birthweight infants often require additional thermal support due to their high surface area-to-mass ratio, immature regulatory systems, limited energy reserves, and insufficient insulating subcutaneous fat.

In infant care centres, one common type of heater is the radiant heater, which typically consists of one or more cylindrical heaters positioned above the infant. A cylindrical radiant heating element generally consists of a resistance wire coil insulated with compacted insulation within a metallic tubular sheath. Alternatively, the heating element may be designed with a resistance wire coil within a quartz tube for additional protection. These heating elements generally measure approximately 18 inches in length and ½ inch in diameter (Institute, 2020).

Since cylindrical heaters emit infrared radiation (IR) in all directions (360 degrees around their length and from their ends), a reflector is necessary to direct heat toward the infant. A standard design includes a metallic reflector enclosing the upper portion of the heating element, shaped in a parabolic cross-section to focus radiation downward efficiently. However, these reflectors tend to be bulky and require strong support to ensure stability above the infant. Additionally, when the heating element features a quartz tube enclosure, extra protection is needed to prevent breakage, as a shattered quartz envelope could pose a significant safety risk to both the infant and medical personnel (Silverman et al., 1958).

2.2 METHODOLOGY

This chapter outlines the methodology used to evaluate the influence of various factors on heat transfer from an infant warmer to neonates. The study involves developing a three-dimensional (3D) model of the infant warmer using SolidWorks, incorporating both single and dual power source configurations. Boundary conditions are defined at the inlet, and numerical simulations are conducted using ANSYS Fluent 15.0. The process begins with obtaining neonatal measurements, which are validated against medical literature to construct a parametric model of the infant. Workbench software is used to identify and label different model components, generate a mesh file, and prepare a journal file for numerical computations. Key input parameters, including material properties, boundary conditions, and initial settings, are incorporated into the simulation.

The FLUENT solver is executed with an initial thermal boundary condition set at a constant temperature. An iterative approach is employed to refine boundary conditions between models until the convergence criteria are met, thereby enhancing accuracy and optimising computational efficiency. This methodology ensures precise temperature boundary conditions for the internal model. Additionally, a management program is used to perform heat transfer calculations on the infant warmer before and after design modifications. As part of these enhancements, an overhead screen is incorporated to improve heat transfer efficiency.

2.2.1 Geometry and mesh generation

In this research, the dimensions of the infant warmer are maintained in a standardised manner throughout all of the simulations. This is done to guarantee that the results are consistent and comparable. Likewise, a mesh that is consistent throughout the entirety of the computational study is utilised. The three-dimensional (3D) modelling of the newborn warmer is carried out with the help of SOLIDWORKS, whereas ANSYS Fluent is utilised for all of the numerical simulations and computations.

The first step in the modelling process in SOLIDWORKS is the extrusion of an initial sketch. It is at this point that the design specifications that were utilised in the simulation are used to determine the thickness and height of the arch that is extruded. Consequently, this guarantees that the model accurately depicts the structure that is intended to be analysed for heat transfer.

The geometric representation of the baby warmer is shown in Fig. 2.1. These figures detail the single and double power settings, respectively.

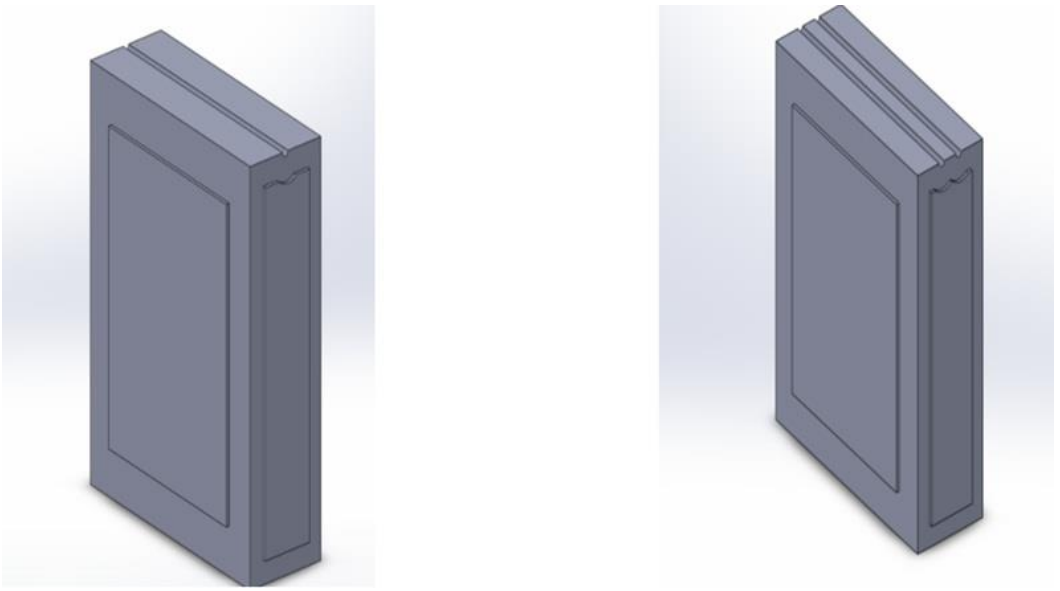

Fig. 2.1: Geometry of Infant Warmer (a) Single and (b) Double Power Source

2.2.2 Methodology Flow

Fig. 2.2 illustrates the systematic approach used in this study to analyse the heat transfer efficiency of an infant warmer. Once the boundary conditions are determined, appropriate software applications are selected for modelling and simulation. SOLIDWORKS is used to develop a detailed 3D model of the infant warmer, while ANSYS Fluent is employed for numerical analysis. The simulation process is then designed and developed, including the creation of a parametric infant warmer model, meshing, and defining solver settings for computational analysis. Following this, the ANSYS Fluent solver is executed to analyse heat transfer efficiency under different conditions, and results such as temperature distribution and heat flux are recorded.

After obtaining the simulation results, a detailed analysis is conducted to compare the findings with theoretical expectations, ensuring accuracy and reliability. The simulation process is further reviewed to validate the outcomes, and final results are documented for evaluation. Lastly, all findings, methodologies, and conclusions are compiled into a structured report, serving as a foundation for recommendations and future research. This structured methodology ensures that each stage is executed efficiently, contributing to a comprehensive and reliable study.

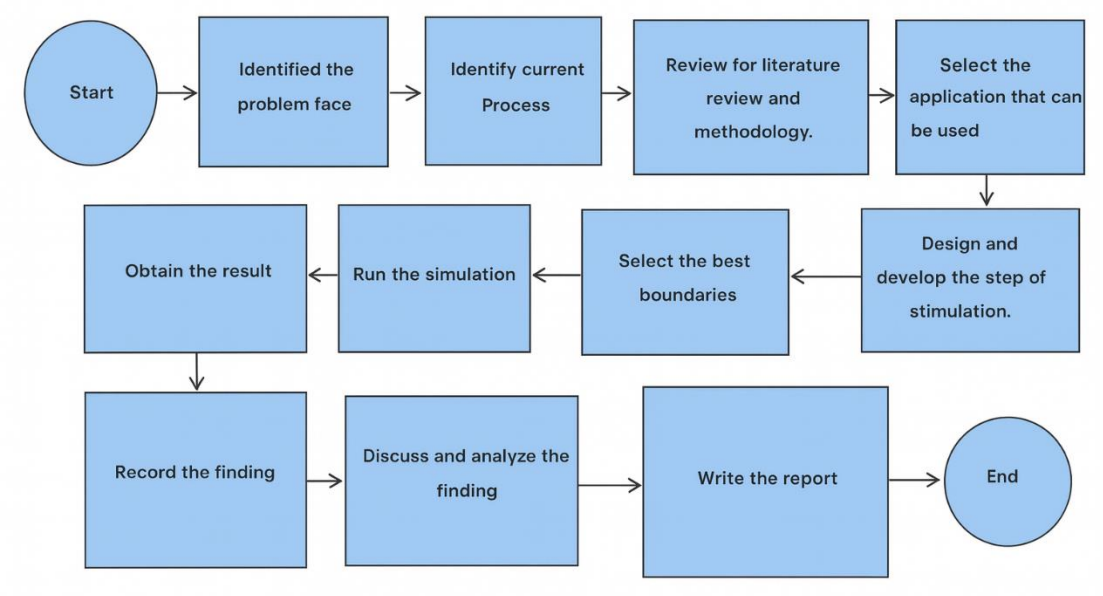

Fig. 2.2: Methodology Flow

2.2.3 Simulation

This study examines the heat transfer of the Infant Warmer and the impact of environmental conditions on infants. A specific boundary condition will be implemented to evaluate the effects of heat transfer and environmental settings with varying power sources on infants.

2.2.3.1 Simulation set up

The simulation procedure commences with the initiation of ANSYS Fluent and the establishment of a new project for the test configuration. The initial stage entails selecting the suitable simulation parameters, opting for fluid flow analysis with the Fluent solver to examine heat transport. After configuring the settings, the 3D model of the newborn warmer, previously created in SOLIDWORKS, is imported into ANSYS Fluent. This phase guarantees the precise representation of the warmer's geometry for computer study.

To improve numerical accuracy, meshing and geometry definition are carried out after the model import, as shown in Fig. 2.3. These figures illustrate the mesh structures for both single and dual power source configurations. Gravity is integrated as an essential component to simulate real-world settings. Furthermore, material attributes are allocated according to the particular thermal specifications of the investigation. Upon complete definition of the geometry, the boundary conditions are set to delineate the critical regions of the newborn warmer that will undergo analysis.

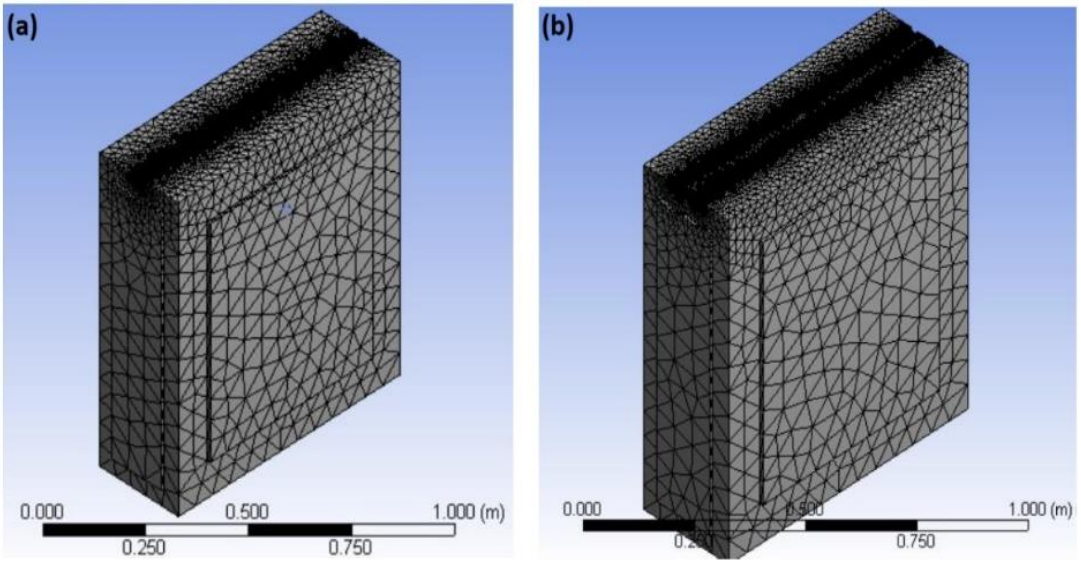

Fig. 2.3: Mesh of Infant Warmer (a) Single and (b) Double Power Source using ANSYS Fluent software

Upon configuring the requisite parameters, the simulation is initiated, and the solver operates iteratively until the convergence requirements are satisfied, hence guaranteeing the stability and dependability of the outcomes. The data obtained from the simulation is subsequently examined to assess the heat transfer efficiency of the newborn warmer across various power source configurations. The results elucidate the thermal efficiency of the system, accompanied by a summary of test conditions presented in Table 2.1.

Table 2.1: Test Parameter

Setting Warmer Temperature (°C)	Environment Temperature (°C) / Pressure Inlet and Pressure Outlet	Baby Temperature: 35
0	16	35.4°C
50	18	35.4°C
50	20	35.4°C
50	22	35.4°C
50	25	35.4°C
50	28	35.4°C
50	30	35.4°C
100	16	35.4°C

100	18	35.4°C
100	20	35.4°C
100	22	35.4°C
100	25	35.4°C
100	28	35.4°C
100	30	35.4°C

2.3 RESULTS AND DISCUSSION

For this study, the objective was to determine an ideal setting that ensures efficient heat transfer to benefit the infant. Various temperature values and power sources have been tested through simulations to evaluate their effectiveness in maintaining optimal infant body temperature. Several test runs were conducted using different combinations of surrounding temperature and power settings to analyse their impact on heat distribution. The results provide insights into the most efficient and safest settings that help infants regulate their body temperature while preventing the risk of hypothermia or overheating.

2.3.1 Result of the effect of the heat received by the babies

The results for the effect of power supply type on the temperature distribution in the range of 16 ºC to 30 ºC are shown in Fig. 2.4 to 2.10. Comparing the same temperature, a single power supply may be sufficient to provide thermal heat to the infant and provide a balanced temperature distribution. Meanwhile, a double power supply provided more heat and ensured rapid heat transfer, leading to quicker stabilisation of the infant's temperature. Adding additional temperature to the analysis is important to get the overall data about the warming unit. The data is included in Table 2.2.

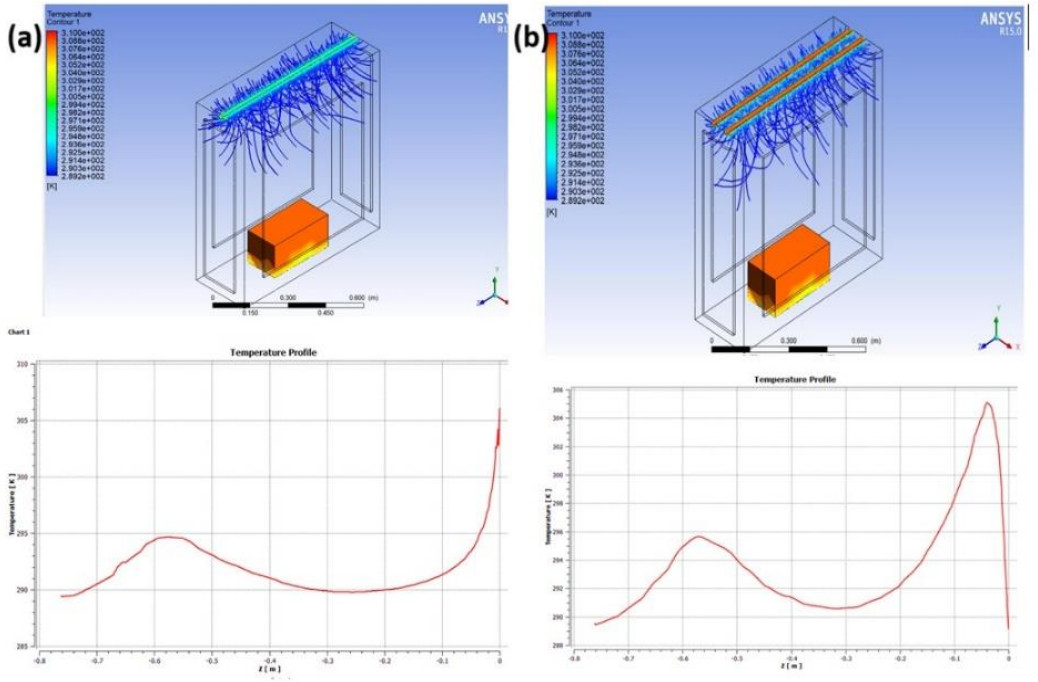

Fig. 2.4: temperature distribution on the infant when the surrounding temperature is 16 ºc with (a) a single power supply and (b) a double power supply

At higher temperatures of 25 to 30ºC, this heating temperature becomes necessary for the infant, especially in the long term, as it may lead to overheating, making the passive heating retention method more suitable.

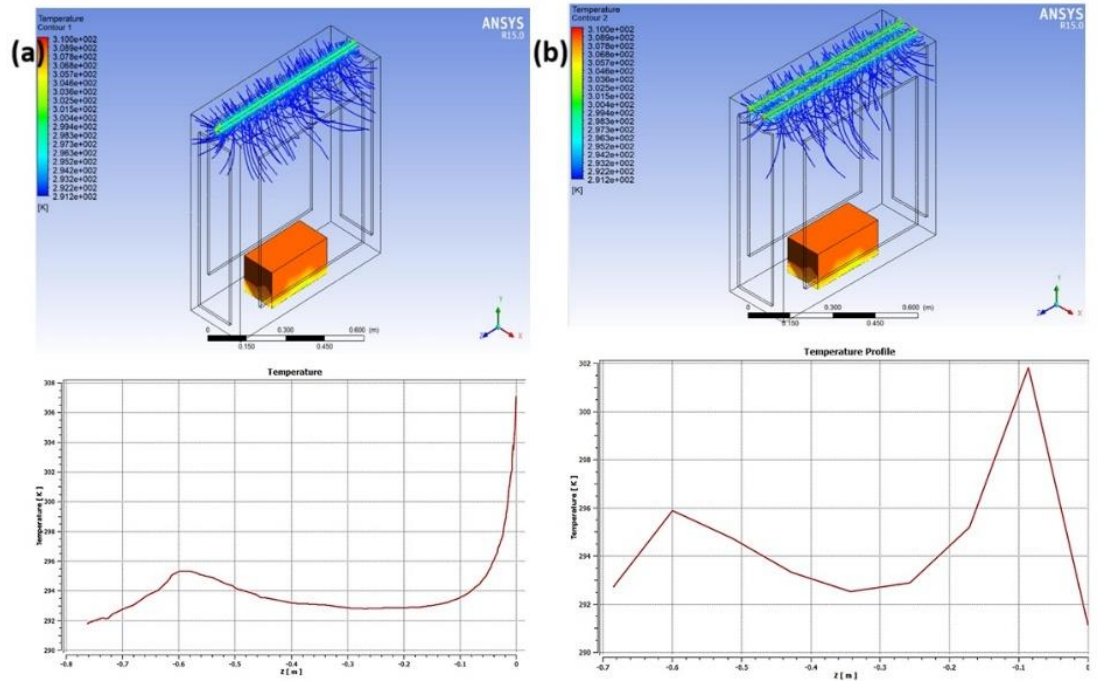

Fig. 2.5: temperature distribution on the infant when the surrounding

temperature is 18ºc with (a) A single power supply and (b) A double power supply

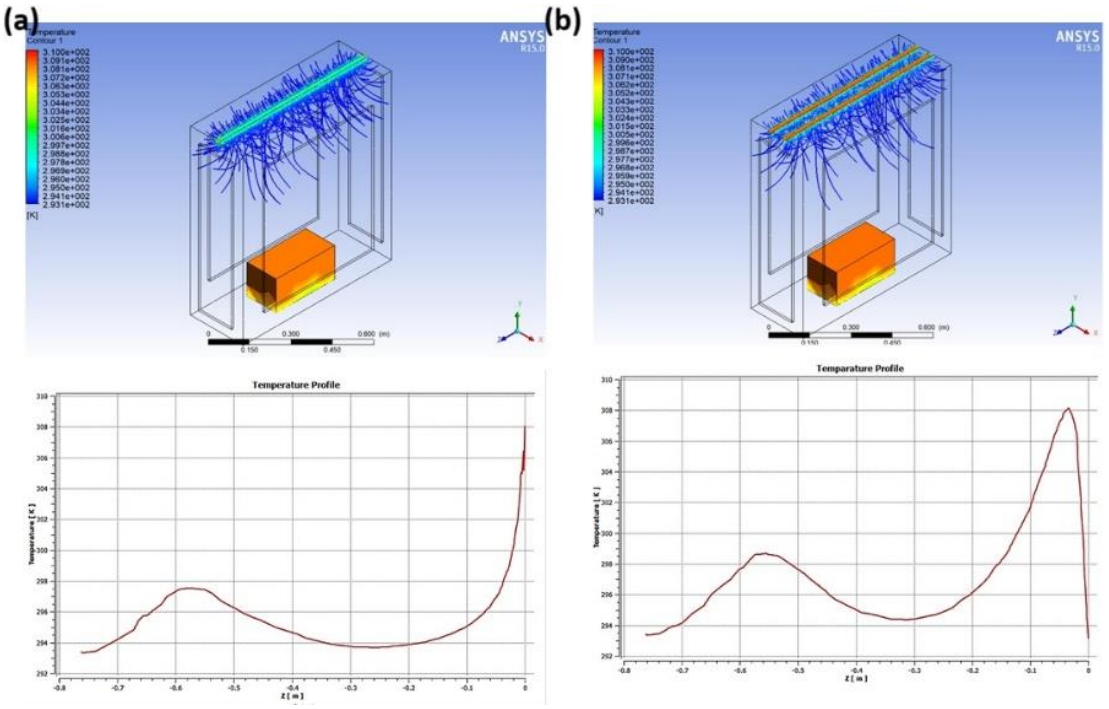

Fig. 2.6: temperature distribution on the infant when the surrounding temperature is 20ºc with (a) A single power supply and (b) A double power supply

Table 2.2: Summarised results on power supply and surrounding temperature

Surrounding Temperature	Single Power Supply	Double Power Supply
16ºC	Significant heat loss due to cold environment. Uneven temperature distribution. Higher risk of hypothermia.	• More heat is provided, compensating for loss. • More uniform temperature distribution.
18ºC	Reduced heat loss compared to 16ºC. More balanced	• Faster heat transfer. • Better temperature

	temperature distribution. Single power may be sufficient.	stability.
20ºC	Minimal heat loss. The temperature distribution is even. The least risk of hypothermia.	• Optimal heating, but excess heat may cause discomfort.

Generally, for temperatures below 18ºC, a double power supply was recommended based on the temperature distribution, as the double power supply was used to ensure sufficient warmth. Meanwhile, for the temperature between 20-22 ºC, a single power supply was ideal for maintaining an optimal infant body temperature. For the temperature above room temperature, precisely above 25 ºC, external heating should be minimised or avoided to prevent overheating.

Table 2.3 presents the simplified results extracted from the simulation figures. To ensure consistency, all simulations were conducted under the same initial conditions, with the starting infant temperature set at 35.4°C. Additionally, the size of the module remained constant across all simulations, ensuring that variations in results were solely due to changes in surrounding temperature and power source settings.

Table 2.3: Test Result

Setting Warmer: Temperature (ºC)	Environment Temperature(ºC)/ Pressure Inlet and Pressure Outlet	Baby Temperature: 35.4 o C	Heat transfer received by babies
50	16	35.4°C	36.85°C
50	18	35.4°C	36.65°C
50	20	35.4°C	36.25°C
50	22	35.4°C	35.85°C
50	25	35.4°C	35.55°C

50	28	35.4°C	35.45°C
50	30	35.4°C	35.42°C
100	16	35.4°C	36.85°C
100	18	35.4°C	36.65°C
100	20	35.4°C	36.25°C
100	22	35.4°C	35.85°C
100	25	35.4°C	35.55°C
100	28	35.4°C	35.45°C
100	30	35.4°C	35.42°C

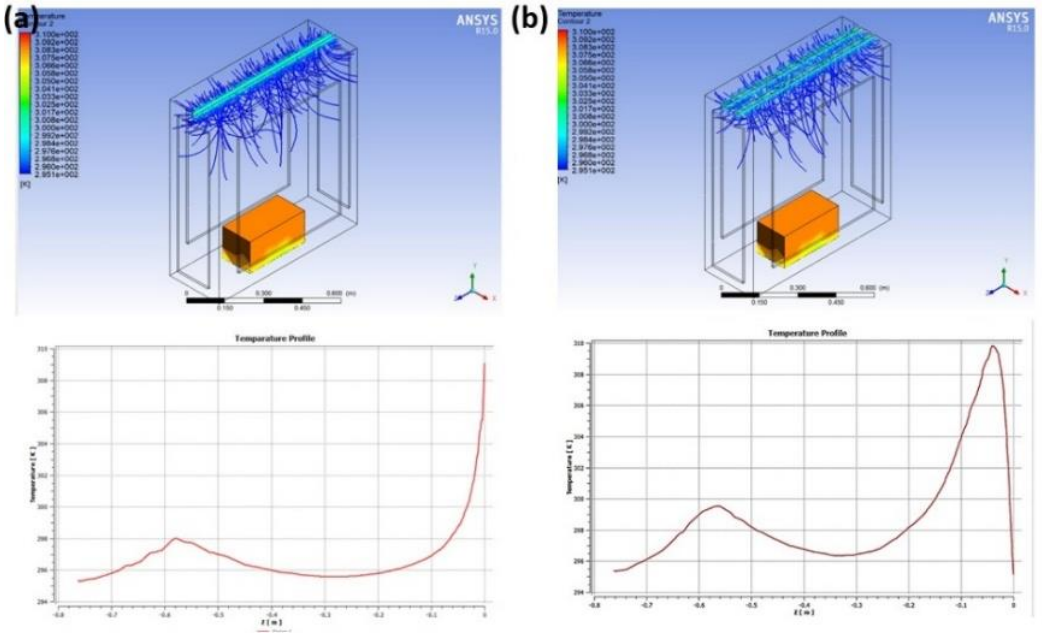

Fig. 2.7: temperature distribution on the infant when the surrounding temperature is 22ºc with (a) A single power supply and (b) A double power supply

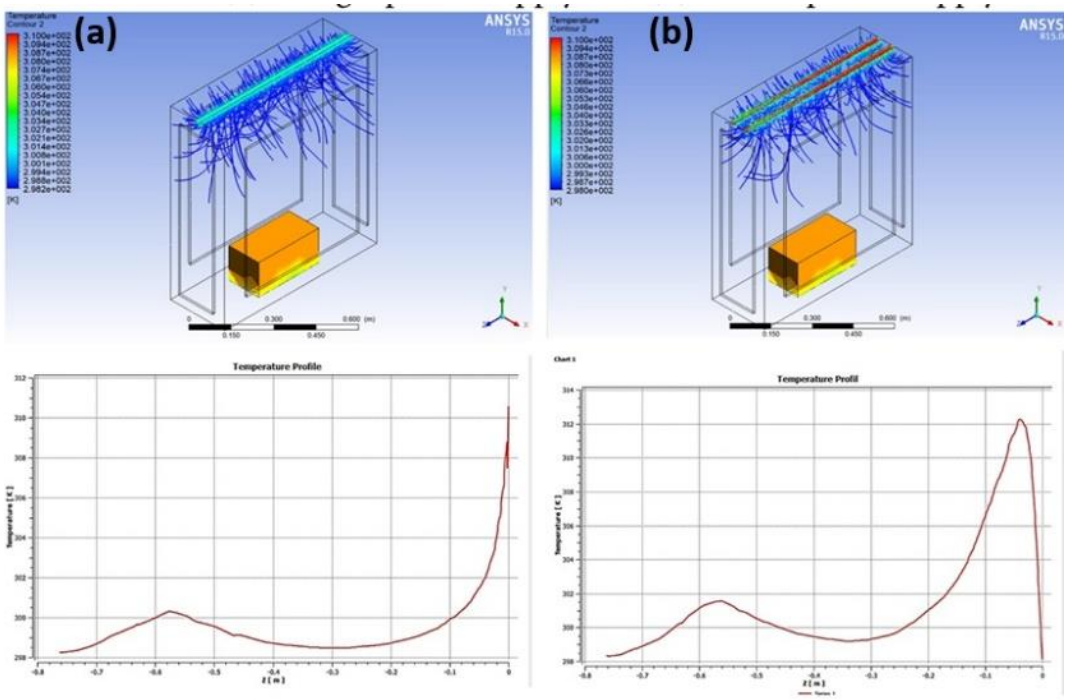

Fig. 2.8: temperature distribution on the infant when the surrounding temperature is 25ºc with (a) A single power supply and (b) A double power supply

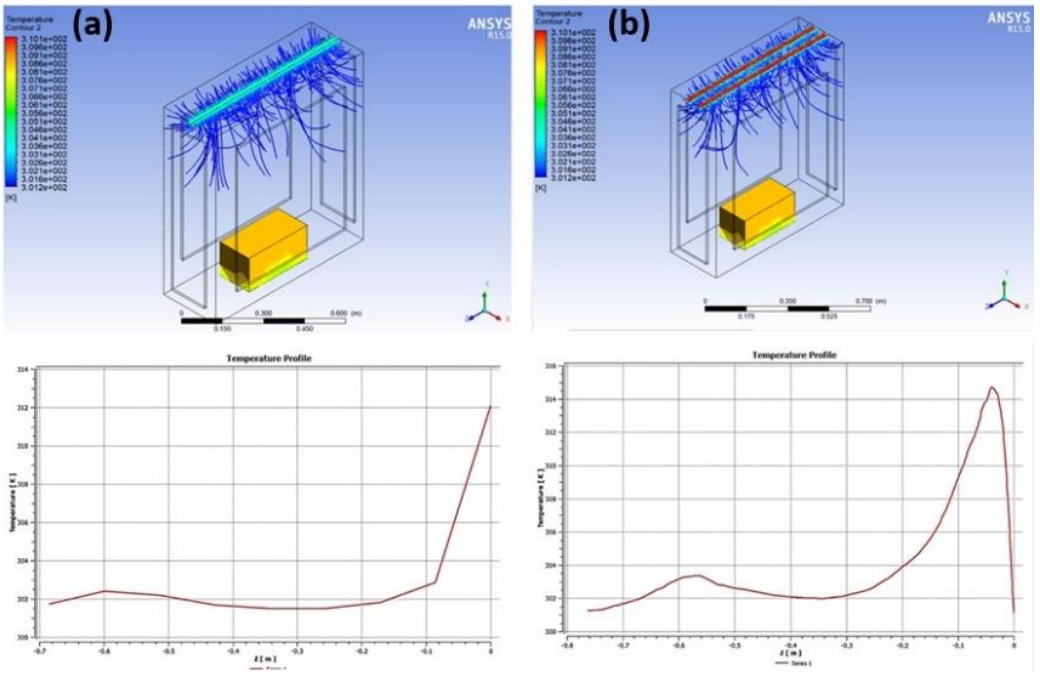

Fig. 2.9: temperature distribution on the infant when the surrounding temperature is 25ºc with (a) A single power supply and (b) A double power supply

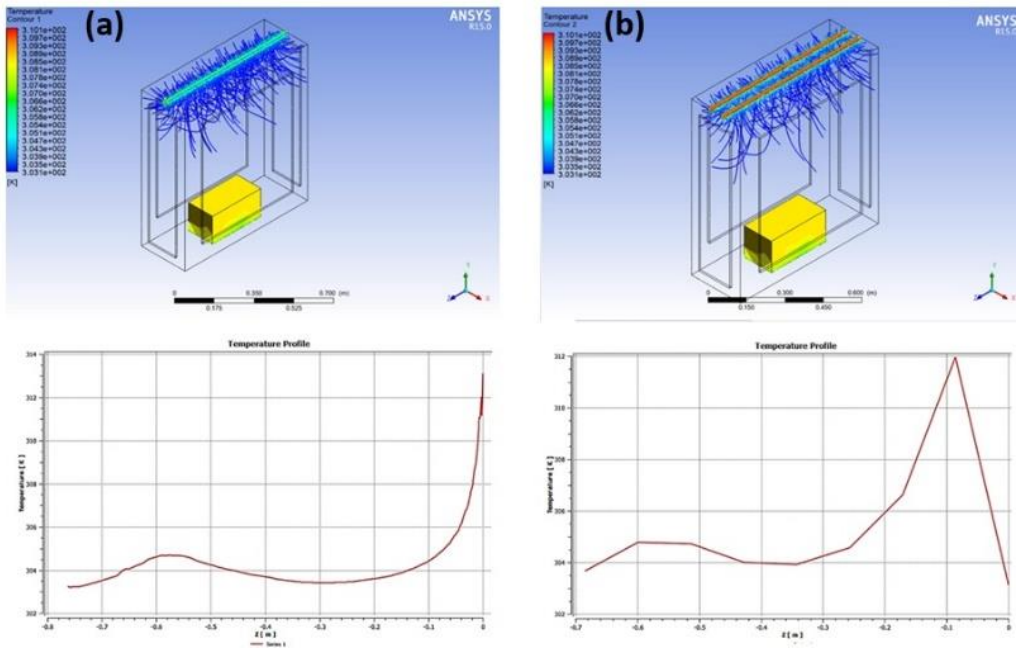

Fig. 2.10: Temperature Distribution on the infant when the surrounding temperature is 30ºC with (a) A single power supply and (b) A double power supply

Fig. 2.11 to 2.20 show the volume rendering results for the temperature range 16 ºC to 30ºC. Based on the simulation results, we analysed the heat transfer between the power source and the heat received by the infants. The surrounding temperature plays a significant role in determining the amount of heat the infant absorbs, as it directly affects heat distribution.

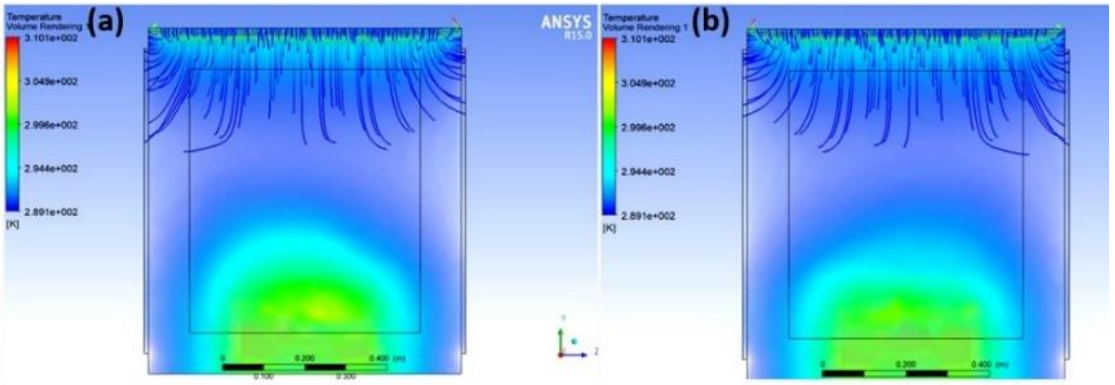

Fig. 2.11: Volume rendering of heat transfer when the surrounding temperature is 16 ºC with (a) A single power supply, (b) A double power supply

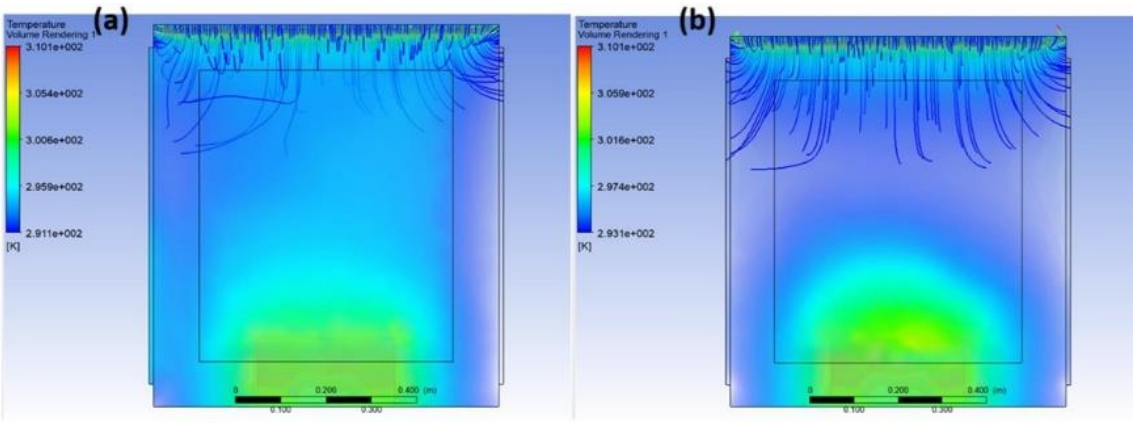

Fig. 2.12: Volume rendering of heat transfer when the surrounding temperature is 18 ºC with (a) A single power supply, (b) A double power supply

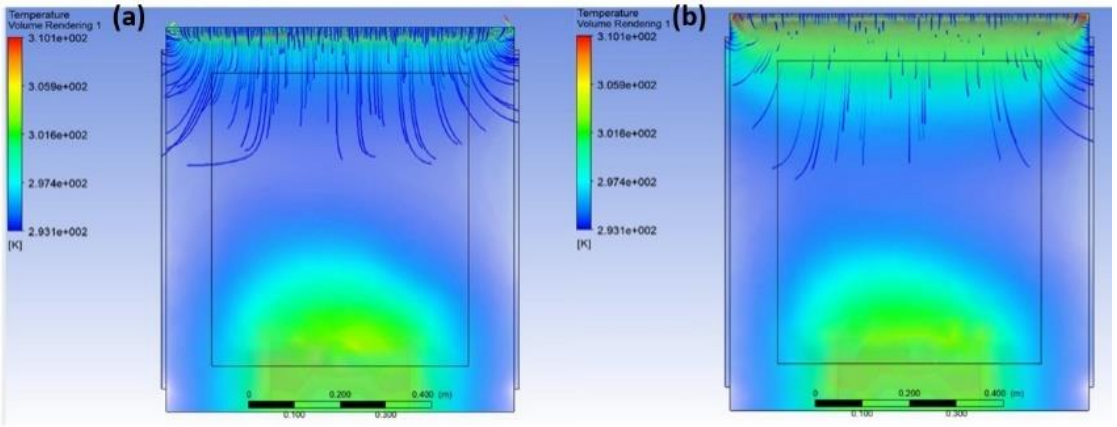

Fig. 2.13: Volume rendering of heat transfer when the surrounding temperature is 20 ºC with (a) A single power supply, (b) A double power supply

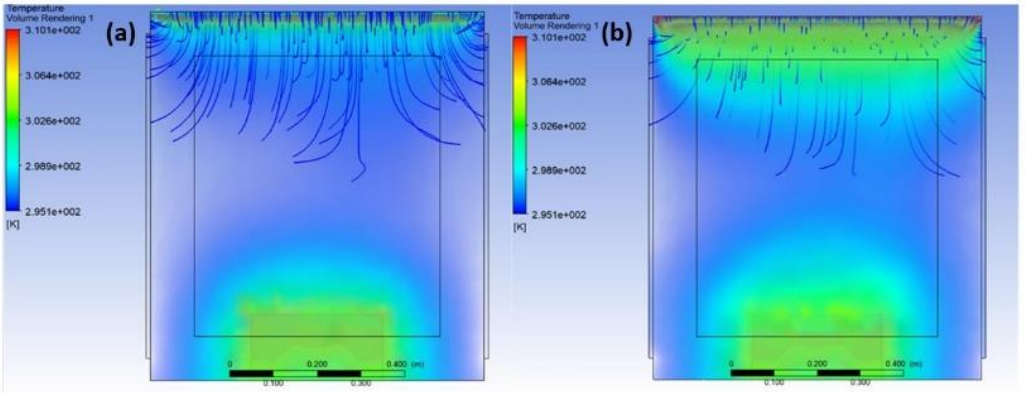

Fig. 2.14: Volume rendering of heat transfer when the surrounding temperature is 22 ºC with (a) A single power supply, (b) A double power supply

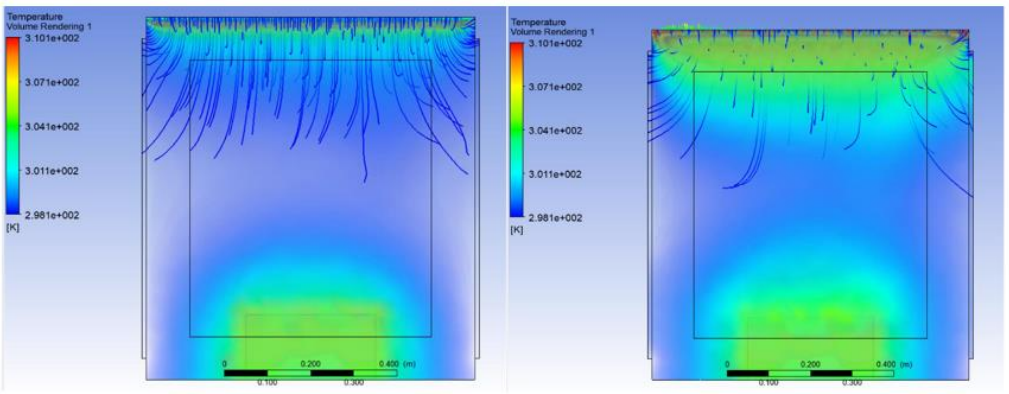

Fig. 2.15: Volume rendering of heat transfer when the surrounding temperature is 25ºC with (a)A single power supply and (b) A double power supply

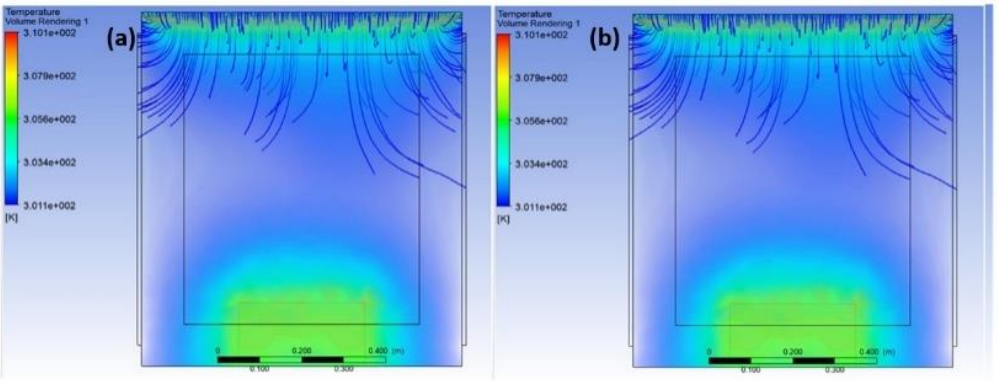

Fig. 2.16: Volume rendering of heat transfer when the surrounding temperature is 28ºC with (a) A single power supply and (b) A double power supply

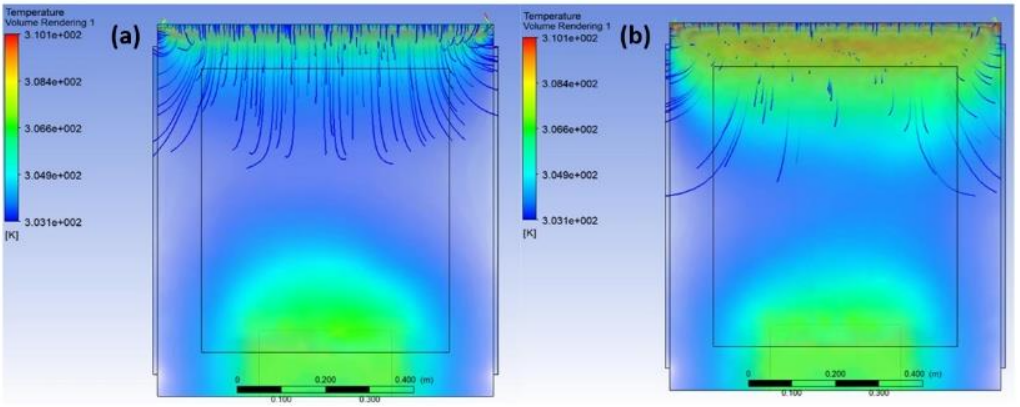

Fig. 2.17: Volume rendering of heat transfer when the surrounding temperature is 30ºC with (a) A single power supply, (b) A double power supply

Fig. 2.11 shows that the infant receives the highest amount of heat compared to other cases. This suggests that lower surrounding temperatures lead to

higher heat absorption by the infant, enhancing the effectiveness of the warming process. Conversely, Fig. 2.17 represents the least effective combination, where the infant receives the lowest heat from all simulations. These findings confirm that controlling the surrounding temperature is essential for optimising heat transfer and ensuring that infants receive adequate warmth for effective thermoregulation.

Based on the simulation results, a detailed comparison of the volume rendering of heat transfer and temperature distribution reveals differences in the heat received by the infant from both power supplies. The simulation demonstrates that, it is evident that a higher heat supply leads to a more even temperature distribution, enhancing the infant's ability to regulate body temperature effectively.

However, despite the observed benefits of increased temperature, it is crucial to balance heat exposure and safety. While a higher heat source ensures better heat distribution, excessive temperatures pose serious risks, including potential burns and permanent damage to the infant's skin. The key takeaway is that the infant's safety is the top priority, and the heat source must be carefully controlled to deliver only the necessary warmth without causing harm.

Overall, the study confirms that Infant Warmers function most efficiently in a controlled environment. The simulation findings suggest that these devices perform best in lower ambient temperatures with a higher but regulated heat source. Additionally, the size of the Infant Warmer used in testing plays a vital role in temperature distribution. The equipment should adhere to manufacturer recommendations and comply with the standards of the Malaysia Medical Device Authority (MDA). An inaccurate size can affect the simulation's accuracy, leading to incorrect plotting and unreliable results.

Another potential source of error in the simulation is the conversion between Kelvin and Celsius. Since real-life measurements are typically in Celsius, discrepancies can arise when converting values. Therefore, extra caution was taken in this study to ensure that all temperature values in Kelvin were accurately converted, minimising errors and ensuring the validity of the results.

2.4 CONCLUSION AND RECOMMENDATIONS

This study highlights the significant influence of surrounding temperature and heat sources on the heat transfer received by infants under an Infant Warmer. These factors play a crucial role in assisting infants in regulating their body temperature, preventing conditions such as hypothermia. By optimising environmental settings, Infant Warmers can effectively support thermoregulation, reducing the risk of temperature-related complications.

Engineering design software, such as SolidWorks, is an invaluable tool in producing and simulating infant warmer designs. It allows engineers to test various configurations and ensure the final product meets the required specifications. Additionally, ANSYS Fluent software facilitates real-life experimental simulations without harming the subjects. This software enables the prediction of possible hazards, allowing for safer and more efficient design iterations.

The main objective of this simulation is to ensure proper heat transfer to the infant, as newborns typically start with a body temperature of 35.4°C. To expedite thermoregulation and achieve a stable body temperature, infants are placed under an Infant Warmer. According to medical guidelines, the optimal temperature range for newborns is between 36.5°C and 37.5°C. A 1°C drop in admission temperature below this range increases mortality risk by 28%. The goal of this study is to determine the ideal settings for infant warmers to help reduce the mortality rate due to unstable body temperature.

This study also aims to identify critical parameters in the warming unit that affect temperature distribution. The surrounding temperature plays a significant role in ensuring infants receive adequate heat for effective thermoregulation. Meanwhile, the heat source contributes significantly to warming, but environmental constraints must be carefully managed to optimise its effects. The impact of different geometries on temperature distribution is another important consideration. A lower ecological temperature setting accelerates infant thermoregulation, while a higher heat source temperature improves heat transfer efficiency.

However, the heat source must not be excessively high for safety reasons, as infants are highly susceptible to burns. The optimal surrounding temperature for Infant Warmers is recommended to be below 25°C. While a higher heat source improves heat distribution, careful control is essential to prevent burns and ensure the infant's safety.

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