Design and Construction of Temperature Control Device for Neonatal Movement

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Abstract

This research was intended to design and construct the temperature control device for neonatal movement from the delivery room to the recovery room, according to the need of the Queen Savang Vadhana Memorial Hospital, Thailand. The device design composed of an electronic system and a hood part. The electronic system consists of an electronically controlled system, microcontroller, temperature setting switch, temperature sensors, display, driver, heater, blower fan, over temperature protection circuit, battery, and C language program. The operation of this device could set the temperature at 36, 36.5, and 37°C respectively. The hood part was designed and constructed using 4-mm thick acrylic sheets. The results of functional testing on this device composed of 3 main parts: 1) temperature control and air velocity part which were verified by a standard calibrator Fluke INCU II Incubator Analyzer, and found that the percentage error was 0.63%, 0.66%, and 1.14%. Moreover, the air velocity part was 0.1 m/s which does not exceed the standard value of 0.3 m/s, 2) alarm part (safety system) which was compared with a standard calibrator Fluke17BDigital Multimeter, and found that the buzzer constantly beeps when the temperature inside the hood part exceeds 40°C, and 3) sound level inside the hood part which was verified by a Sound Level Meter model GM1356, and found that the maximum sound inside the hood was 50.1 dB, which was in the standard of not more than 60 dB.

Keywords: *Body temperature regulation, Hypothermia, Neonates*

1. Introduction

Neonatal low-temperature conditions were a common problem in the delivery room. The cause of the problem was that the baby's body temperature control system was not as effective as adults. In addition, the physiological characteristics of newborns have a wide body area compared to body weight and less fat content under the skin. As a result, keeping the heat inside the body was not good enough so it is easy to lose heat. The body temperature will change at any time according to the environment. Moreover, when the baby is born out of the mother's womb, it was wet and moist from the amniotic fluid and the temperature within the room. Giving birth at 25°C causes the newborn to lose the body's heat in a large quantity from evaporation, conduction, convection, and radiation, resulting in a rapid decrease in its body temperature (Patumat, Chalirat & Soontaree. (1999); Pimonrat, 2002; WHO, 2006; & Nittaya et al, 2009). Hypothermia was one of the important causes of neonatal death and morbidity in the developing countries (Birhanu, Balcha, Tesfaye & Feleke, 2018). The temperature criteria based on the World Health Organization's (WHO) classification of hypothermia indicate that the temperature at 36.0-36.4°C was defined as mild hypothermia, at 32.0-35.9°C as moderate hypothermia, and below 32.0°C as severe hypothermia (Mathur NB, Krishnamurthy S. & Mishra TK., 2005). Moving the neonates from the delivery room to the recovery room at a long distance of the Queen Savang Vadhana Memorial Hospital (Thailand) caused hypothermia in the neonates, and it was the main problem of doctors (Obstetrics and Gynecology). In the present, the nurses of this hospital have used the infant transport incubator which had a big size and was difficult to move. Furthermore, the neonates could be greatly affected by the transfer. Foreign countries have used a commercial transport infant incubator to move newborn babies from the delivery room to the recovery room. There are many pieces of research on nursing that concern heat loss prevention for preterm infants in the delivery room by using wrap or bags (RB Knobel, S Vohra, CU Lehmann,2005, S Vohra, et. al, 1999). In Thailand, there are also some studies that implemented thick fabrics and thin plastic to envelop the newborn baby during transportation (Runtawan, Yaowalak & Patama, 2015), including the use of the commercial infant transport incubator. However, the commercial infant transport incubator has a high cost.

Due to such problems, the doctors of this hospital wanted to use the small neonatal temperature control device which was similar to the infant transport incubator. Also, they needed the temperatures at 36°C, 36.5°C, and 37°C, respectively. We designed and constructed the temperature control device according to the doctor's needs by choosing materials and equipment that could procure locally. The device was small, easy to use and move, lightweight, transparent for observing the neonates, and low cost.

2. Objectives

The objectives of the study were to design and construct the temperature control device to move the neonates from the delivery room to the recovery room. The designed device has a low cost and the material can be found locally. The temperature could be controlled at 36, 36.5, and 37°C which is adjustable by using a microcontroller. There is a circulating ion of hot air inside the device with the blower.

3. Materials and Methods

3.1 Operating principle

Hypothermia occurs when the body temperature drops below 36.5°C where the lower limit of the normal range is around 36.5-37.5°C. Four ways a neonate may lose heat to the environment while moving are radiation, conduction, convection, and evaporation. The neonates with a body temperature of between 36.0° C - 36.4°C may be under cold stress which gives rise to concern. The neonates with a temperature of 32.0-35.9°C has moderate hypothermia, while a temperature below 32°C is considered being severe hypothermia (WHO).

The block diagram temperature control device for the neonatal movement was shown in Fig.1. The temp setting switch was used to set the level operating temperature of 36, 36.5, and 37°C. The microcontroller was the main component that controls all operations such as a heater, blower, drivers, display, and alarm. The temperature sensors in the hood part were used to measure hotness and were converted into an electrical signal, which supplied to the control unit for processing. The hood part was used to store the temperature.

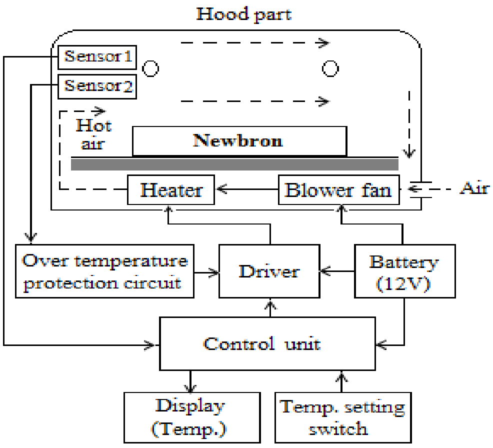

Figure 1 Block diagram of the temperature control device

3.2 Hardware Design

1) Temperature setting switch

A rotary selector switch was used to set the level working temperature of 36, 36.5 and 37°C which connected between the supply voltage (5V) and a microcontroller pin (D6, D7, D8). When the switch was closed, the microcontroller input was at a logical high level, but when the switch was opened, the pull-down resistor pulls the input voltage down to ground (logical zero value) which prevent the undefined state at the input of the microcontroller (Arduino Nano 3.0 ATmega328P). Note that R1, R2, and R3 were essential in order to prevent a short circuit while each switch (SW1 – SW3) was closed as shown in Fig.2.

2) Temperature sensor I

This sensor was used to measure temperature in a hood part and converted the temperature into an electrical signal which supplied to the control unit for processing. We interfaced the temperature sensor (DS18B20) and resistor (R4) with microcontroller according to Fig.2. The temperature sensor has a working range from -55 ° C to + 125 ° C and its accuracy in a range of -10 ° C to +85 ° C was ±0.5 ° C according to the manufacturer's data sheet.

3) Display

The results of both setting temperature and operating temperature were shown through the LCD screen for the user's observing. We interfaced the LCD display (OLED Display Module SSD1306) with the microcontroller according to Fig.2.

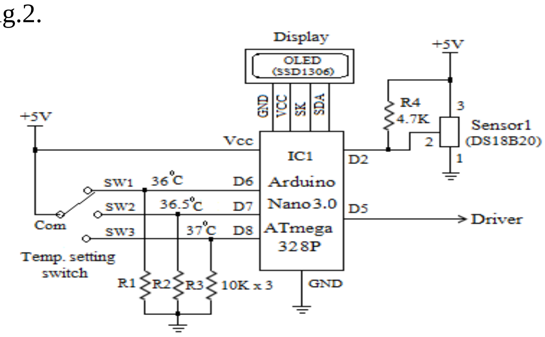

Figure 2 Interfacing of temperature setting switch, sensor1, and display with a microcontroller

4) Heater

The heater was used to generate heat in the hood part which changed the electrical energy into heat. This heater design constructed using the five ceramic resistors (10Ω, 20 watts) connected in parallel as shown in Fig.3.

5) Driver

The driver was used to control the voltage (+12V) from the battery into the ceramic resistor. It was designed and constructed using the R4, R5, R6, R7, LED1, IC2, and Q1 according to Fig.3. The output port (D5) of microcontroller produced the pulse width modulation signal (proportional control temperature) for controlling the driver to cut or connect the electricity from the battery into the ceramic heater. IC2 isolated the power supply of 5 volts and 12 volts.

6) Blower fan

The blower fan was used to generate airflow passed the heater, causing hot air to circulate inside the hood. Furthermore, it absorbed air from the environment into the hood. This fan was connected to the battery directly, not controlled by the microcontroller (Shown in Fig.3). The blower fan model BFB0712H was selected with 0.36 A and 12V power supply, and airflow 11.3CFM with 38dB noise.

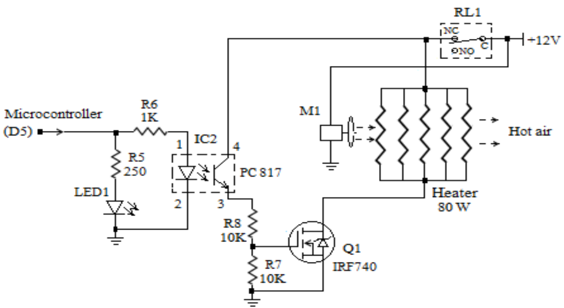

Figure 3 The driver, heater and fan blower connected together

7. Over temperature protection circuit

This design circuit was used to limit temperature at 40°C in the hood part as shown in Fig.4. It was a device's safety system. The LM35 (Sensor2) was used to measure the temperature inside the hood part that generated an output voltage of 10 mV/1$_{o}$C change in the measured temperature. The output of LM35 was applied to the non-inverting input (pin 3) of a comparator (IC3). A voltage divider network (R87, VR1) sets the threshold voltage at the inverting input (pin2) of the IC3. This threshold voltage (TP1) was set to 400mV which was equivalent to the temperature of 40°C. When the measured temperature exceeds the 40°C level, the IC3 pulls its output high (pin 1) to approximate 5V, causing transistor (Q2) to be forward biased instantly. Then, it conducts and pulls the relay (HRS-4H-S-DC-12V), the relay will cut off the power 12V of the battery from the heater immediately. At the same time, the buzzer received 12V of battery and will constantly beep.

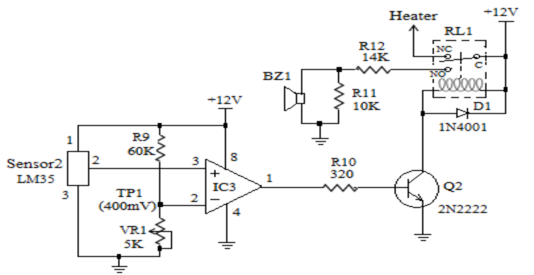

Figure 4 Over temperature protection circuit

8) Battery

The battery responded to the supply current and voltage to each circuit of the device. We chose a 12V, 12000mAh lithium-ion battery due to its advantages of small size, light weight, sufficient electricity to work, and having a charger. The characteristics of this battery are shown in Fig.5.

9) Hood part

The hood was used to keep and maintain a constant temperature of the neonates. We designed and constructed this part using the 4-mm thick acrylic sheets whose size is according to Figure 5. Furthermore, the user could see a baby in the hood. The hood has 4 ventilation holes, and the front has a lid that can be open and close to put the newborn in and out.

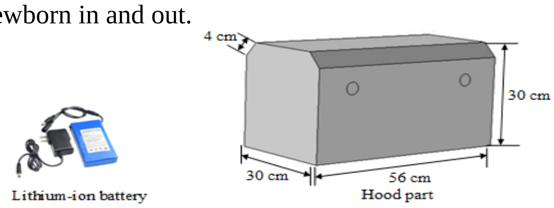

Figure 5 Characteristics of lithium-ion battery and hood part

3.3 Software design

The software for controlling the operation of the temperature control device was programmed with C-language according to the main flowchart shown in Fig.6.

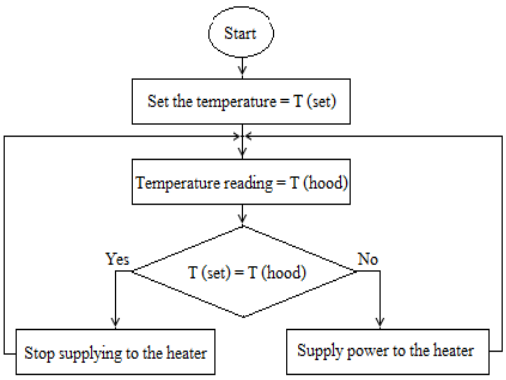

Figure 6 Main flow chart of the operating process

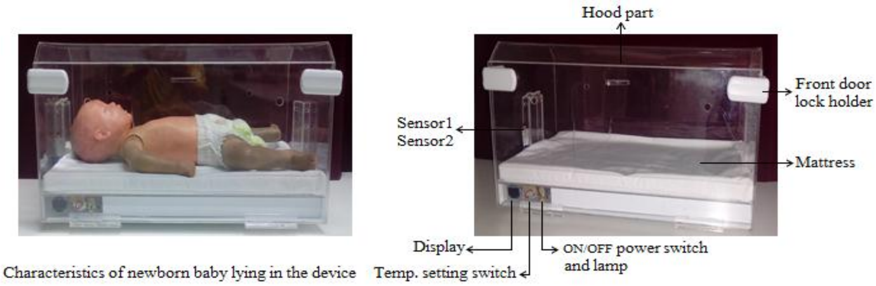

Figure 7 The completely designed temperature control device for neonatal movement

4. Results and Discussion

The results of the design and construction of the temperature control device for neonatal movement from the delivery room to the recovery room for medical equipment application are shown as follow:

1) The complete temperature control device is shown in Fig.7. It composes of 7 parts: 1) hood part, 2) sensor1 and sensor2, 3) display, 4) temperature setting switch, 5) NO/OFF power switch, 6) mattress, and 7) front door lock holder. This device weighs 5.5 kilograms.

2) The specification of the temperature control device was that it operates with a 12V, 12000mAh lithium-ion battery power supply. This device has 2 main operating parts. The first part was the temperature control unit that shows the adjust temperature and the measured temperature within the hood on the panel of the device. Furthermore, the device can be set at the temperatures of 36, 36.5, and 37°C by rotating the selector switch. The second part is the hood that keep and maintain a constants temperature. Inside the hood, there are the sensor1, sensor2, and mattress as described in Fig.1.

3) The functional testing results of the temperature were verified at 36, 36.5, and 37°C with an INCU II Incubator analyzer which measured the temperatures of 5 positions at the same time.

Table 1 Result of verified value at 36°C with an INCU II Incubator Analyzer

Time (minute)	T1 (˚C)	T2 (˚C)	T3 (˚C)	T4 (˚C)	T5 (˚C)	Average (˚C)	Standard deviation
15	36.11	35.29	35.57	34.51	34.09	35.11	0.81
30	37.17	36.48	36.81	35.60	35.95	36.40	0.63
45	36.92	36.25	36.58	35.37	36.08	36.24	0.58
60	36.42	35.74	36.10	34.92	35.91	35.82	0.56
75	37.14	36.33	36.76	35.43	36.21	36.37	0.64
90	36.72	36.01	36.39	35.20	36.10	36.08	0.57
105	36.96	36.29	36.58	35.32	36.41	36.31	0.61
120	36.98	36.25	36.60	35.38	36.35	36.31	0.59
135	37.06	36.25	36.63	35.43	36.26	36.33	0.60
150	37.00	36.32	36.69	35.42	36.48	36.38	0.59

From the results in Table 1 could to create graph the relationship between time and temperature as shown in Figure 8

Figure 8 Graph showed the relationship between temperature and time for the verified values at 36°C

Table 2 Result of verified value at 36.5°C with an INCU II Incubator Analyzer

Time (minute)	T1 (˚C)	T2 (˚C)	T3 (˚C)	T4 (˚C)	T5 (˚C)	Average (˚C)	Standard deviation
15	32.33	31.46	32.20	31.91	30.68	31.72	0.69
30	35.03	34.36	34.90	34.34	33.12	34.35	0.75
45	36.58	36.29	36.32	35.68	34.86	35.95	0.69
60	37.74	37.52	37.72	36.71	36.15	37.17	0.71
75	36.96	36.76	37.07	35.79	36.12	36.54	0.56
90	37.68	37.55	37.81	36.33	36.64	37.20	0.67
105	36.94	36.63	37.09	35.67	36.37	36.54	0.56
120	37.17	36.89	37.31	35.91	36.47	36.75	0.57
135	37.58	37.40	37.76	36.33	36.68	37.15	0.61
150	37.00	36.72	37.18	35.70	36.53	36.63	0.57

From the results in Table2 could create graph the relationship between time and temperature as shown in Fig. 9

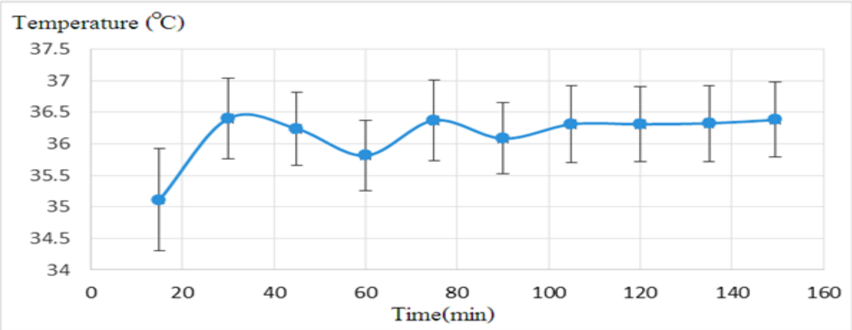

Figure 9 Graph showed the relationship between temperature and time for the verified values at 36.5°C.

Table 3 Result of verified value at 37°C with an INCU II Incubator Analyzer

Time (minutes)	T1 (˚C)	T2 (˚C)	T3 (˚C)	T4 (˚C)	T5 (˚C)	Average (˚C)	Standard deviation
15	33.61	32.45	32.69	32.26	31.75	32.55	0.69
30	37.26	35.75	36.21	35.56	34.99	35.95	0.85
45	36.94	35.94	36.71	35.68	35.91	36.24	0.55
60	37.48	36.30	37.26	36.08	36.30	36.68	0.64
75	36.83	35.87	36.66	35.63	36.23	36.24	0.51
90	37.51	36.28	37.30	36.03	36.57	36.74	0.64
105	37.34	36.05	37.08	35.81	36.50	36.56	0.65
120	37.12	36.04	36.91	35.78	36.56	36.48	0.57
135	37.60	36.38	37.39	36.10	36.80	36.85	0.64
150	37.66	36.26	37.40	35.98	36.78	36.82	0.72

From the results in Table3 could create graph the relationship between time and temperature as shown in Fig.10

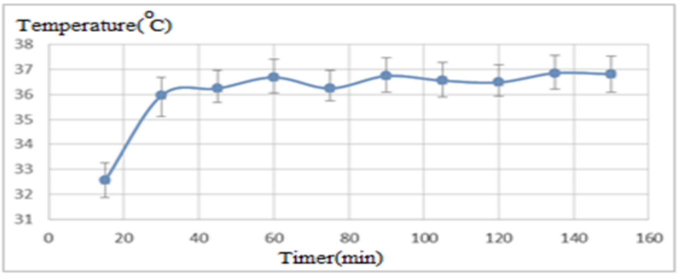

Figure 10 Graph showed the relationship between temperature and time for the verified values at 37°C

Table 1-3 shows the results of the value at 36, 36.5, and 37°C verified by an INCU II Incubator Analyzer which had the percentage errors of 0.63%, 0.66%, and 1.14% respectively. From the Graph in Figure 8-10, we presented the relationship between the time and temperature and found that there was a swing temperature inside the hood part. At a temperature of 37°C, the swinging of temperature was higher than those of 36 and 36.5°C. Our design used insufficient watt heater which included the design programmable system for controlling the temperature of the device that was not stable enough.

4) The functional testing result of the alarm when the temperature inside the hood exceeded 40°C was verified. We used a hairdryer to increase the temperature and used both the temperature control device and the Fluke 17B+ Digital Multimeter to measure the temperature inside the hood part. We found that the buzzer will constantly beep according to Table 4.

Table 4 Result of verified value at 40°C with a Fluke 17B+digital multimeter

Test sequence	Temperature control device (°C)	Fluke 17B+ Digital multimeter (°C)	Buzzer (Sound)
1	39.9	40.0	Beep
2	39.7	39.9	Beep
3	40.0	40.0	Beep
4	39.8	39.9	Beep
5	40.0	39.8	Beep

Table 4 shows the alarm sound (Beep) of the device when the temperature reaches 40°C according to the standard of Emergency Care Research Institute (ECRI) that has defined at not more than 40°C.

5. The functional testing result of sound level in the hood part was verified with the Sound Level Meter model GM1356, and found that it was 50.1 dB sound when the device was running, which was in the standard of ECRI (not more than 60 dB).

6. The functional testing result of the air velocity in hood part was verified by an INCU II Incubator analyzer, and found that it was 0.1 m/s, which does not exceed the standard value of ECRI (not more than 0.3 m/s.).

5. Conclusion

In this paper, we focused on the design and construction of the temperature control device for neonatal movement. This device composes of 7parts: 1) hood part, 2) sensor 1 and 2, 3) display, 4) temperature setting switch, 5) NO/OFF power switch, 6) mattress, and 7) front door lock holder. The operating of this device has 2 main functions as follow: 1) the temperature control part used for regulating the temperature within the hood part at constant values of 36, 36.5, and 37°C and 2) the alarm part that generating beep sound when the temperature inside the hood part exceeds 40°C. The function testing result of temperature control part was verified by the INCU II Incubator Analyzer, and found that the percentage error was 0.63%, 0.66%, and 1.14%, respectively. The function testing result of the alarm part found that the buzzer will constantly beep when the temperature inside the hood part exceeds 40°C. The functional testing result of sound level inside the hood part was verified by the Sound Level Meter model GM1356, and found that it has 50.1 dB which was in the standard (not more than 60 dB). The functional testing result of the air velocity part was verified by the INCU II Incubator analyzer, and found that it has 0.1 m/s which was in the standard (not more than 0.3 m/s). In addition, the device weighs 5.5 kilograms.

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