University of Southern Queensland

Faculty of Health, Engineering & Sciences

Infant Transport Incubator Cold Performance

A dissertation submitted by

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Abstract

The Mansell Infant Retrieval System is designed to be used by clinical personnel to transport under intensive-care conditions, premature or critically-ill infants to a medical centre by using either a road ambulance, fixed wing or rotary wing aircraft. The key component of the Mansell Infant Retrieval system is the Neocot which is a controlled environment capsule to accommodate the infant. This capsule needs to maintain a relatively constant internal temperature of 36 degrees Celsius.

This project tests a newly designed heating element to determine if under certain environmental conditions, the Neocot will operate in a manner complying with the current Australian standard IEC.60601-2-20. In order to pass the standard requirements, the new heater in the Neocot needs to be set at $36°C$ and be able to stay within a temperature range of $\pm3°C$ when the ambient external temperature was at -5°C for a total period of 15 minutes. Once 15 minutes have elapsed, the Neocot then needs to be placed in an external ambient temperature of between 20 to $25°C$ for a total period of 30 minutes. This means that in order for the Neocot to pass these requirements the internal temperature should not go above $39°C$ or below $33°C$.

The test, undertaken using the developed temperature logging equipments described in this project proved that the new heater design successfully passed the requirements of the IEC.60601-2-20 standard. The new heater was capable of maintaining the internal temperature of the Neocot within the required IEC.60601-2-20 Australian Standards in a cold temperature environment which exceeded the standards requirements. The following dissertation details the steps undertaken in designing a calibrated device to properly measure the temperature deviations of the Neocot as well as the results obtained from the cold test.

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ANTHONY VADALMA

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Date

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ANTHONY VADALMA

University of Southern Queensland
October 2014

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Chapter 1

Introduction

1.1 Background

This project dissertation will be based on a Mansell Infant Retrieval System Designed by Dr John Grant-Thomson. This system consists of three major components, these being the **Mansell Power Lifter**, **Neosled** and the **Neocot** each with a crucial role. The Mansell Power Lifter is designed to support the Neosled and Neocot as well as providing a means of loading and unloading the system from road ambulances, fixed wing aircraft and helicopters without the operator having to lift any of the components. The next component, the Neosled houses the Neocot as well as additional medical and electrical equipment and sits on top of the Mansell Power Lifter. Lastly is the Neocot, which is an environmentally controlled capsule for the infant. The Neocot regulates the internal ambient capsule temperature with fluctuations being no more than $\pm 1°$C. The Neocot is powered by a Power Supply Unit (PSU) and can be powered by both 12V or 24V DC as well as standard mains 240V. The below image shows a fully completed system with the necessary medical equipment attached (Grant-Thomson 1998).

Figure 1.1: Image of the Mansell Infant Retrieval System with fitted medical equipment.

The Neocot is heated by an electric element fibreglassed into the floor; this was effective however if a fault was to occur with the heating element, the floor of the Neocot would need to be cut out, re-fibreglassed and re-painted. This was time consuming and costly which placed a crucial medical device out of action. Therefore Dr John Grant-Thomson developed a removable heater floor that houses the heating element. This allowed for ease of access should it become faulty the floor could just be unbolted and removed. For this new design to be accepted by the Therapeutic Goods Administration, the heating element and overall Neocot thermal performance, must be tested according to the IEC.60601-2-20 Australian standard.

1.2   Outline of Dissertation

The dissertation consists of the following seven chapters: Chapter 1 provides an introduction to the Mansell Infant Retrieval System and how the project is related to this piece of equipment. Chapter 1 will also provide a detailed description of the relevant Australian standard extract IEC.60601-2-20. An introduction to the new heater is also provided in Chapter 1. Chapter 2 provides a literature review on all the aspects of the project. Since temperature logging hardware was required, the literature review contains sections on each of the different aspects required to produce an accurate device. Some of the aspects covered in the literature review are topics such as noise filtering, voltage amplifiers and temperature probes. Chapter 3 details the results from the first

cold test in 2007. This section provides results obtained as well as images indicating how the instruments were setup and used. Chapter 4 provides a description on the methodology implemented during the latest set of cold tests undertaken in 2013 and 2014. Chapter 4 also provides reasons as to why certain electrical devices were selected over others for the final build of the temperature measuring device. Chapter 5 details the latest cold test results based on the requirements outlined in the IEC.60601-2-20 Australian standard. Also images and descriptions on the method in which the cold test was undertaken is included in this chapter. A comparison is also undertaken with the original cold test to the new cold test to determine the difference in outcomes between the two different heater designs. Chapter 6 provides a warm up test analysis based on the IEC.60601-2-20 Australian standard. This was undertaken for both the original heater design and the new heater design to determine the differences in the amount of time that is required for the heater to raise the Neocot temperature by a certain amount. Chapter 7 provides an explanation of the development of an automatic temperature data retrieval program to simplify the temperature testing process of future Neocot's. The final chapter provides a comparison between the outcomes that have been achieved in the project with the outcomes that have been stated to be achieved in the project specification.

1.3 Objectives

The objectives of the dissertation is to outline the results obtained from conducting a cold test as specified in the IEC.60601-2-20 Australian Standard. The requirements being that the Neocot must be able to stay at the normal operating temperature of 36°C, while being placed in a cold room with an ambient temperature of -5°C. During this period the internal temperature of the Neocot is not allowed to deviate by more than 3°C. This must be maintained for a total period of 15 minutes after which the Neocot can be removed and placed into an environment with an ambient temperature of 25°C. During this period the Neocot is not allowed to overshoot the normal operating temperature of 36°C by more than 3 degrees celsius (IEC 2009).

In order for the above test to be carried out a set of objectives need to be developed. As per the project specification in appendix A the following will be the objectives of the dissertation:

- Research the requirements of the IEC.60601-2-20 Australian Standard.

- Research temperature sensing devices suitable for this application.

- Research how to properly design, construct and test an amplifier circuit.

- Design, construct and test an amplifier circuit for the required application.

- Research suitable A/D devices for the application.

- Design software to plot temperature measurement data.

- Determine the signal filter requirements for the measurements.

- Compare the results of the IEC.60601-2-20 Australian standard requirements.

As the dissertation progresses these above points will be met.

1.4   System Description

The Neocot is a temperature controlled chamber that regulates the internal chamber temperature to maintain a level suitable for an infant, with a temperature deviation of no more than $\pm 1^\circ$C. The average running temperature inside the Neocot is regulated at 36°C but can be adjusted from 28°C up to 39°C if the Neonatal nurse wishes. The Neocot operates by calculating the average air temperature between two sensors which are situated with one at the top of the Neocot and one at the bottom. This provides temperature control information to the main board which adjusts the power output of the heating element. The heating element consists of four separate sections each of which are monitored by a heater temperature sensor. The heat from the element is transported around the Neocot by means of a fan situated under the removable floor. The fan circulates the air around the internal chamber of the Neocot.

The heating element previously was fibreglassed into the floor of the Neocot. However the newly designed heating element is now removable and allows ease of access if the heating element became faulty in situations such as the element becoming overheated. Figures 1.2 and 1.3 illustrate the prototype of the new heater element design. The four larger holes in Figure 1.3 are the positioning of the four heater sensors which lie directly on top of each section of the heater PCB (Printed Circuit Board). Figure 1.4

illustrates two of the four PCB heating elements that are fibre glassed to a piece of foam and attached to an aluminium plate which is then bolted into the floor of the Neocot. The construction of the heating element is as follows. Two heater element PCB boards as shown in Figure 1.4 are connected together and wired, this is then placed with a piece of foam on the back side of the heater element and the whole assembly is then fibreglassed and bonded to a piece of aluminium sheet.
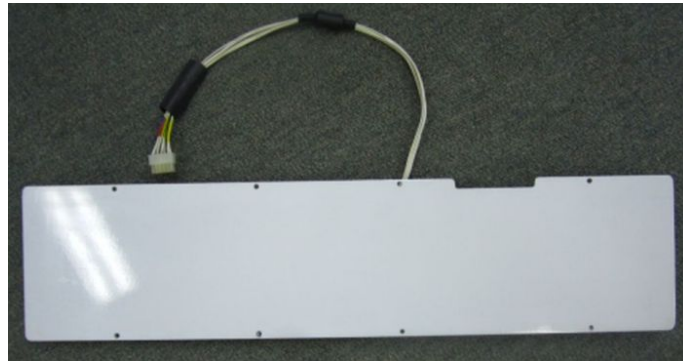
Figure 1.2: View from top of prototype Neocot removable heater.
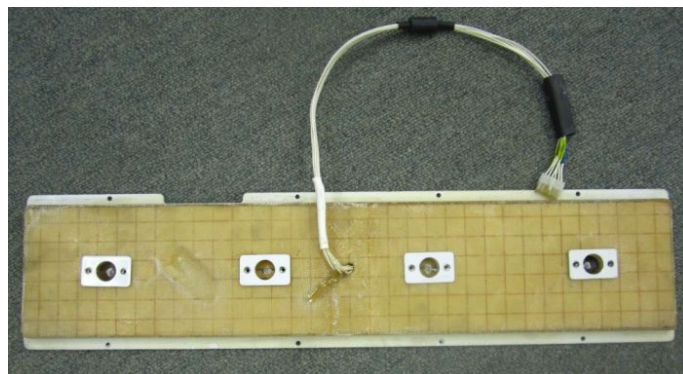
Figure 1.3: View from bottom of prototype Neocot removable heater.
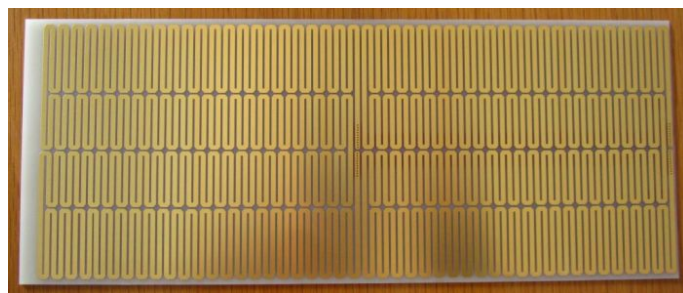
Figure 1.4: Two of the four heating elements that are fibre glassed to a piece of foam and attached to an aluminium backing plate.

1.5 Australian Standards and TGA Requirements

In this section the relevant Australian Standards and the requirements of the TGA (Therapeutic Goods Administration) will be analysed.

1.5.1 Regulating Bodies TGA and NATA

The TGA (Therapeutic Goods Administration) is the government body which certifies the use of medical equipment within Australia. In order for the new heating element to be approved, TGA needs to ensure that it is capable of complying with the relevant Australian standards. Other sections that need to be included are calibration certificates on all the devices that had been used.

NATA (National Association of Testing Authorities) is an independent organisation that provides assurance of technical competence on device's that require accuracy in testing, calibration and measurement (NATA 2014). An example of a NATA calibrated device is a mercury-in-glass thermometer with a calibration certificate indicating that the device has been properly calibrated according to the requirements of a standard (see appendix E).

1.5.2 Australian Standard Extract

The relevant Australian standard IEC.60601-2-20:2009 states:

> "The Infant Transport Incubator is operated as an air controlled transport incubator connected to an external power source. When the steady temperature condition is established at an ambient temperature within the range of 21°C to 25°C and at a control temperature of 36°C, it shall be set to operate in accordance with the accompanying documents without a supply mains and transferred into an environment where the ambient temperature is being kept at -5 ($\pm$2)°C and the wind velocity is not more than 1m/s. After 15 min it shall be returned into an environment where the ambient temperature lies within the range of 20°C to 25°C and reconnected to an

external supply and operated for a further 30 min. The transport incuba-
tor temperature shall be monitored throughout the whole test and at no
time shall it go outside the specific limits. If the accompanying documents
specify to meet this requirements at a lower ambient temperature then -5
(± 2)°C or for a longer period than 15 min the infant transport incubator
shall be additionally tested for compliance with those claims as indicated."

SOURCE: AUSTRALIAN STANDARDS IEC.60601-2-20:2009

1.5.3 Australian Standard Interpretation

The required standard IEC.60601-2-20:2009 indicates the requirements necessary to
conduct a cold test on an infant incubator such as the Neocot (IEC 2009). The require-
ments within the standard need to be met with evidence to support the conclusion and
be approved by the TGA before the design can be implemented in the device. The
following is an interpretation on the meaning of the standard and how the tests will be
implemented.

The requirements outlined within the IEC.60601-2-20:2009 Australian standard for a
cold test are as follows (IEC 2009): Firstly the Neocot needs to be operated off of
mains power until reaching its normal operating temperature of 36°C. Upon reaching
this temperature the power needs to be switched over to battery and the Neocot then
needs to be placed in an environment with an ambient temperature of -5°C. This en-
vironment ambient temperature is allowed to deviate by no more than ± 2°C. Another
requirement here is that the wind speed within the chamber is to be no more than
1m/s. The Neocot is to remain in this environment for a total period of 15 minutes.
During this period the internal ambient temperature of the Neocot is to at no point in
time reduce by more than 3°C. This meaning that while at -5°C the Neocot's internal
temperature should not drop below 33°C. Upon completion of the 15 minute period the
Neocot is to be removed and placed in an environment with an ambient temperature
of between 20 and 25°C and is to remain there for a further 30 minutes. During this
period the internal temperature of the Neocot is to at no point fluctuate by more than
3°C from the normal operating temperature of 36°C. This means once the Neocot has
been removed from the cold chamber it is to at no point have its internal temperature

increase above 39°C.

Therefore evidence needs to be produced indicating that if a device is used to measure the temperature deviations in both the cold chamber and Neocot, the device needs to prove that it has been properly calibrated. In order to satisfy this a detailed explanation on how the calibration of the devices were undertaken will be included within this dissertation. The TGA approves calibration being completed using a NATA approved device.

1.6   Risk Assessment

This chapter will outline a risk assessment on the project task. The risk assessment details any form of risk that could occur during the duration of the project. Also risks that can occur once the project has been completed have also been considered. The risk assessment was conducted according to the ISO 31000:2009 standard for risk management (ISO 2009). Within this standard certain key features that are necessary to correctly undertake a risk assessment are indicated. Section 5.4 through to section 5.6 are the most relevant sections for the project risk assessment. Within these chapters requirements of risk identification through to implementing risk treatments are analysed. During the undertaking of the risk assessment the risks are broken into separate categories being consequences of the risk, probability and Risk level. In order to determine what the risk level is, Figure 1.5 (USQ 2014) indicates how this is calculated.
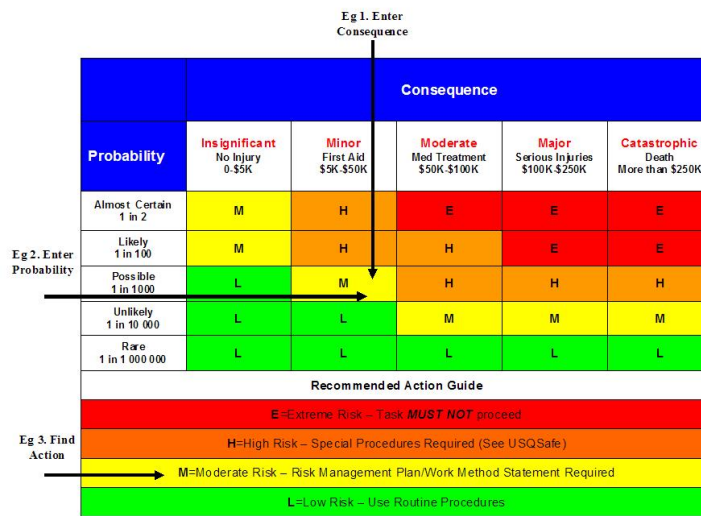
Figure 1.5: Risk level matrix.

Source: http://www.usq.edu.au/hr/healthsafe/safetyproc/usqsafe

The matrix is used be determining firstly what the consequences of the risk would be. Next the probability in which the risk could occur is analysed. Once these two are known the intersection point between the consequence and probability produce the risk level. Using the risk level matrix Figure 1.6 was produced indicating the completed risk assessment on the task.

Hazards	The Risk	Risk Assessment			Additional controls	Risk Assessment			Implementation
		Consequences	Probability	Risk Level		Consequences	Probability	Risk Level	
Sun Exposure	Possible Sun Burn	Minor	Unlikely	Low	Working as Much as possible in shade of cold	Minor	Rare	Low	Yes
Trip Hazard	Possible physical injury from tripping over electrical cable	Minor	Possible	Moderate	Cable moved close to edges of wall to reduce risk of tripping	Minor	Unlikely	Low	Yes
Temperature (Hot)	Possible Burning from use of soldering Iron	Moderate	Likely	High					
Temperature (Cold)	Exposure to temperatures at or below -5 degrees celsius	Insignificant	Almost certain	Moderate					
Vehicle Hazards	Possible collision with moving vehicles	Catastrophic	Unlikely	Moderate	All personel to remain in close proximity to testing	Cactastrophic	Unlikely	Moderate	Yes
Lifting Hazards	Lifting of Mansell Neosled with Neocot into cold vehicle/Possible	Moderate	Likely	High					
Electricity Hazard	Exposure to Electricity mains power	Catastrophic	Unlikely	Moderate					
Battery Shorting	Possible battery shorting	Moderate	Rare	Low	Masking tape placed over battery terminals to prevent	Minor	Rare	Low	Yes
Equipment Damage	Possible Damage to equipment such as tip over	Moderate	Unlikely	Moderate					

Figure 1.6: Risk assessment for research task.

As can be seen in Figure 1.6 for the practical aspects of the project the potential hazards were identified and listed. From the potential hazards the possible risk outcomes were then investigated. The outcomes were situations were the risk was present and the resultant physical effects that could occur should that hazard be confronted. From this

a risk assessment could then be undertaken using the hazard and potential risks. The risk assessment is based on the table indicated in Figure 1.5. This provides a means of determining the level of the risk involved. The table is based on two main factors, these being the probability that the risk would occur along with the consequences. The matrix splits the risk level up into 4 main components with these being: extreme risk, high risk, medium risk and low risk (USQ 2014). Joining the consequence level with the probability level provides the level of the risk. As an additional aspect to the risk assessment a control section was additionally analysed. This section was undertaken to try and reduce some of the risks that would be present in the project testing. As can be seen not all hazards can have additional controls as for some circumstances this is not practical. For situations such as burns from soldering irons a control cannot be placed on this.

Chapter 2

Project Devices Review

2.1 Chapter Overview

This chapter will undertake a literature review on the current technologies used in this project. The areas discussed are with relevance to temperature measurement with topics on different types of temperature measuring instruments such as thermistors and thermocouple's. Due to the voltage signal being generated by these devices being extremely minute, amplifier circuits will be discussed as well as noise filtering which in the case of this project is extremely important. A brief look at Labjacks and TeraTerm software will also be undertaken.

2.2 Temperature Sensor Design

As described in the Introduction a temperature sensing device was necessary to be developed. The device needed to operate in a manner that was suitable and met the temperature sensing requirements of the IEC.60601-2-20 Australian standard. The measuring point for the sensor is 10cm above the mattress in the Neocot in free space as shown in Figure 2.1:
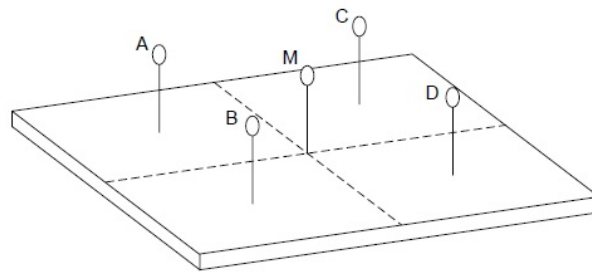
Figure 2.1: Points in space for measuring Neocot internal temperature

SOURCE: AUSTRALIAN STANDARDS IEC.60601-2-20:2009

The sensor point M is the crucial position for the temperature sensing as this is the point in space that is referred to in the IEC.60601-2-20 standard (IEC 2009). The other four points are air sensors which play a role in showing the distribution of temperature internally around the Neocot but are of no relevance to the section of standard focused on in this dissertation. In order for this to be achieved, the following devices were necessary to be researched: **temperature sensors**, **data loggers**, **noise filters** and **voltage amplifiers**.

The following sections provide a review on possible instruments that can be used to undertake the required temperature measurement task.

2.3 Temperature Sensing Devices

This section will discuss the different Temperature Sensing devices and determine which best suits the desired purpose in terms of accuracy and operating temperature ranges being the most crucial aspects.

2.3.1 Thermistor

The first temperature sensing device that will be analysed is the thermistor. Developed in 1930 by Samuel Ruben (Jones 2010) the thermistor is a device which is sensitive to the effects of changes in temperature by adjusting its internal resistance. The construction of a thermistor mainly contains the characteristics of solid semiconductor properties

(Ametherm 2013). Thermistors are manufactured in two different configurations. The first of which is being NTC (Negative Temperature Coefficient) and the second being PTC (Positive Temperature Coefficient). The temperature coefficient refers to the manner in which the thermistor reacts to temperature, with a negative temperature coefficient the internal resistance of the thermistor decreases as the temperature increases (Ametherm 2013) and opposite for a Positive Temperature coefficient. Thermistors are widely used in temperature measurement applications due to their compact size, cost and accuracy. A thermistor's accuracy is generally within the range of 0.01 to 1°C which is reasonable for most intended applications (Naik n.d.). Thermistors are also known for their extremely high sensitivity to changes in temperature (Sheingold 1980). This is very beneficial for the required application as even small changes in temperature need to be registered.

Thermistors are also non-linear in characteristics. Therefore if linearisation is required a linearising circuit needs to be used.

2.3.2 Thermocouple

The next temperature sensing device to be analysed is the Thermocouple. Thermocouples were invented in 1821 by the German physicist Thomas Johann Seebeck (Leigh 1988). A thermocouple is a temperature sensing device that consists of two leads consisting of different metals that meet at a junction end point (Leigh 1988). The junction is crucial in the correct operation of the thermocouple. There are multiple junction forms which are either crimped, twisted, spot welded, butt welded, brazed or soldered and Beaded gas welded (J.V.Nicholas & D.R.White 1994). When the wires of two different materials are placed together there forms a temperature measuring range. The types of thermocouples are categorised into letters that indicate the composition of the leads (percentage of material in each) and also the effective range of temperature measurement(info 2011). A thermocouple operates by using the Seebeck effect, this being that two different materials connected together when each individually is placed at different temperatures an emf Voltage is produced (Rowe 2006). Thermocouples also generally have a voltage sensitivity of between 6μV and 60μV per degree celsius. Although being the toughest of the temperature sensors, this low sensitivity is not very practical (Naik n.d.). However Thermocouples have the benefit of being able

to respond to temperature changes quickly (Sheingold 1980).

Thermocouples are very susceptible to what is termed 'parasitic junctions'. This is caused due to there being the two Thermocouple leads being of different materials then connected to a device to measure the voltage difference which consists of an again different material. This then causes another temperature difference which is added to the original signal coming from the Thermocouple. In order to remedy this another temperature sensing device needs to be placed at the source and an accurate reading needs to be taken. The difference then can be subtracted and used as a base measurement (Instruments 2012a).

2.3.3 Resistance Temperature Detectors (RTD's)

RTD's (Resistance Temperature Detectors) are another popular form of temperature sensing devices. RTD's operate in a very simple manner being that as the temperature increases the resistance inside the RTD increases as well. RTD's are constructed using two different configurations being: wire wound or thin film, each with their own set of advantages and disadvantages. The most popular configuration for the RTD is the thin film construction. This is due to this configuration being less expensive, stronger and having smaller dimensions as well as being more accurate than the wirewound configuration (Azom.com 2013).

RTD's are constructed in a similar manner to thermistors however RTD's are not as accurate when it comes to temperature measurement (Instruments 2012b). There is however one problem that cannot be overlooked, RTD's require a fairly large excitation current which is the amount of current that is necessary to magnetise a piece of metal. If this excitation current is too high the RTD can start to internally heat thus corrupting the temperature readings and rendering the data useless (Naik n.d.). RTD's are also non-linear in nature (Sheingold 1980) so if linearity is required on the output a linearisation circuit is necessary. The non-linearity however of the RTD is very different to the non-linearity of a Thermistor. RTD's are very close to being linear with just a slight form of non-linearity (Instruments 2013a).

2.3.4 LM35 Precision Centigrade Temperature Sensors

The last temperature sensor to be analysed is the LM35 precision centigrade temperature sensor. The LM35 produces an linear output voltage which is proportional to the temperature being measured in degrees celsius (Instruments 2013b). LM35's exhibit a very reasonable operating temperature range being between -55 to 150°C. This makes it very practical to use in many temperature sensing situations. The LM35 is capable of measuring the temperature with an ensured accuracy of 0.5°C (Instruments 2013b)which makes this temperature sensor one of the most accurate available. The main issue with an LM35 is that it contains a large amount of thermal mass similar to a thermocouple compared to for example a thermistor. This means that for an LM35 there is a longer amount of time required to reach the actual temperature. In most circumstances this lag in time is not of real concern as in this case.

One of the main benefits of using an LM35 is that the actual chip does not require calibration (Cuihong Liu n.d.). This makes it very user friendly.

2.4 Voltage Amplifiers

Most temperature sensing devices output a very low change in resistance, typically with an impact in the range of millivolts, this is quite difficult to work with and to adequately log from a data logger accurately. An amplifier circuit is then placed between the temperature sensing device and the data logger. This provides a significantly larger voltage scale to provide a more reasonable method of interpreting the data.
However there are multiple different configurations that can be used to design a voltage amplifier. While undertaking research on this topic a few configurations were detailed as being the best for the application. The following is a literature review on the configurations best suited to the application.

2.4.1 Differential Amplifier

The first configuration suitable for the application was a differential amplifier.
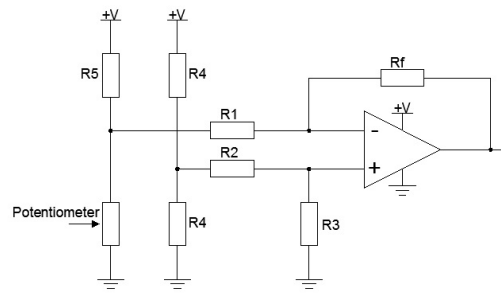
Figure 2.2: A typical Differential Amplifier used for amplification of voltage signals.

A differential amplifier is a simple yet effective device. A differential amplifier works by amplifying the voltage difference between the two input voltages. In the configuration indicated in Figure 2.2. The second leg acts as a preset voltage level that the first leg is then compared to, and the difference is amplified and this then becomes the output. Due to the voltage difference coming from the thermistor being extremely small compared to the preset voltage of the second leg the difference is minute. Therefore a gain is necessary to increase the voltage readings to a level so that the data logger is capable of reading and sensing the voltage.

$$K = \frac{R_f}{R_1} = \frac{R_3}{R_2} \tag{2.1}$$

Here K is the gain of the amplifier circuit. The gain is adjusted by adjusting the resistor values as specified in the equation (Circuits 2012a). The main disadvantage associated with a differential amplifier is being that in order to adjust the gain the resistors need to be continuously replaced (Circuits 2012a), for this application that is not an issue of real importance.

2.4.2 Instrumentation Amplifier

The next configuration suitable for the application was an Instrumentation Amplifier.
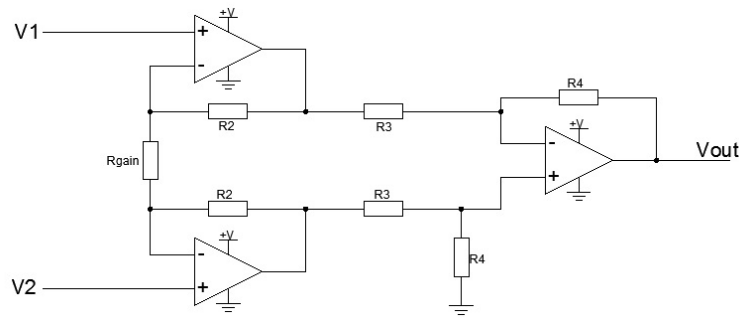
Figure 2.3: Representation of an Instrumentation Amplifier

Instrumentation Amplifiers are just a build on from the differential amplifier configuration. The main difference with an instrumentation Amplifier is the adjustment of the gain value. With the previous differential amplifier resistors needed to be replaced, in this case for the Instrumentation amplifier only one resistor R_{gain} needs to be changed to adjust the gain of the circuit. These amplifier circuits have high accuracy and precision regardless of the environment in which they are placed (Devices 2014).

When a temperature probe is connected to an amplifier circuit the output voltage that is produced needs to be calibrated to the temperature difference of the temperature probe.

2.5 Data Loggers

In order to successfully collate the measured data from the temperature sensing device a data logger is necessary. A data logger is an instrument that samples a channel every preset amount of time and collects the information (which is typically a voltage) on that channel and provides this information to another program which collates the data.

Labjack was chosen as the data logger of choice due to its accuracy and availability. The Labjack is a device that allows a connection between the computer and a device that is to be measured in terms of a digital or analogue measured signal (LabJack 2014). The LabJack product is available in many different variants, the most common of these being the U3 and U6 models. For the required application a data logger was required to have 2 analogue input channels and be able to handle $\pm 10V$ on each channel.

2.6   Noise Filtering

The use of an amplifier circuit to amplify the voltage signal from the temperature probe results in some inaccuracy. This being mainly from the fact that any noisy signal that is attached to the voltage signal coming from the temperature sensor, once it reaches the amplifier becomes amplified along with the required signal from the temperature probe. This is a problem due to the noisy signal corrupting the required signal and not producing accurate results. The noise experienced can be both generated internally in the op-amp as well as come from external sources. This is a very crucial element in the project as any noise may corrupt the signal and render the measured output data useless.

Breaking noise interference down, op-amps can experience noise interference externally from sources such as RF (radio frequency)signals and mains transmission line power. Op-amps can also generate noise internally such as Shot noise, Thermal noise, Flicker noise, Burst Noise and Avalanche noise (Instruments 2008). However these produced noises are insignificant and will not affect the output of the signal by a large amount.

There are multiple ways in which noise filtering can be achieved in this circumstance. The main types have been examined to determine which suits the requirements.
Firstly due to the temperature probe needing to extend beyond the compartment of the Neocot, this means that the cable will act as an antenna for any stray RF signals. A simple way to minimise these affects is to use twisted pair cabling. When two cables are twisted together (signal and ground) and receive the same noise on each the difference between the two cables will become zero thus cancelling this signal out (INC 2001). The original signal does not become affected due to one lead having the signal while the other is grounded.

Capacitors are another crucial electrical element which play an important role in noise filtering. Capacitors are placed in configurations such as high pass filters and low pass filters. A high pass filter meaning that only frequencies above a certain value are allowed to pass on through the filter. Whereas a low pass filter means only frequencies below a certain value are allowed to pass (L.Floyd 2008). Another form of filter design

that is simple and effective is an RC filter.

RC filters consist of a resistor and capacitor. The resistor is connected in series with the input or output of the device and the capacitor follows shortly after connected between the resistor and the device to ground. Based on calculations for the RC filter a time delay can be calculated and adjusted depending on the requirements. For the case of this project a reasonable time delay is allowed. This is due to the rate at which the temperature being able to change inside the Neocot as well as outside the Neocot not being fast enough to warrant inaccuracies.
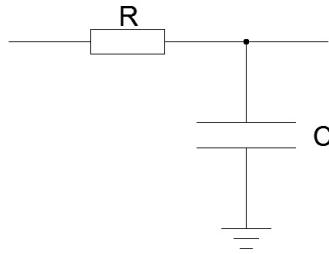
Figure 2.4: Representation of an RC Filter

The formula to calculate the time delay that will be experienced by this filter is:

$$T = RC \tag{2.2}$$

High and lowpass filters can be constructed in a similar manner to an RC filter just with the placement of both R and C changing between the configurations. In a low pass configuration the resistor is placed in series with the connection to the input or output of the device and the capacitor between them to ground. Whereas with the high pass configuration the capacitor is placed in series with the input or output of the device and the resistor is connected between them to ground. If the two configurations are placed together this forms a pass band filter (Rashed 2013).

Another type of noise filter is a notch filter. This filter removes noise at a certain frequency and allows all other frequencies to pass through. The application of a notch filter is not appropriate for this case as the frequency of concern are not known.

2.7   Testing Programs

2.7.1   TeraTerm Software

In order to log the data that was being generated by the Neocot, a logging software was used. Wenross Holdings Pty Ltd had previously manufactured a temperature logger based on the 5 sensor array indicated in the IEC.60601-2-20 Australian Standard Figure 2.1. The sensor array data was processed by a program called Tera Term. TeraTerm is free to download and is designed to be an emulator on the host computer (Informer 2014). Tera Term collects the data that is being transmitted and saves this data to a file format. In this circumstance the file format is a text file. The data that is outputted from the hardware not only indicates the temperature measurements but also other aspects such as power consumed by the heater and temperature measurements from the Neocot's internal temperature sensors.

2.7.2   Automating Temperature Data Retrieval Program

For the aid of future users a program will be developed to allow a quick and simple method of undertaking both warm and cold performance tests on Neocot's. This will also provide a means of calibrating the temperature probes on the device. Due to time constraints a stand alone program is not practical to be developed therefore an excel visual basics for applications (VBA) program will be developed.

VBA is a programming language hosted in a large program such as excel or word (Lomax 1998). VBA is designed to use the applications of its host as part of the programming structure. This means that if a button is pressed in excel it operates the written code and executes it using the host program and other external programs that are necessary and defined. VBA operates by using macros which are created in the host program (Excel or Word) and executes the task. VBA can be used to undertake simple and complex tasks and is particularly used in situations where a specific task needs to be done that cannot be undertaken by another means (Microsoft 2009). An example of this would be if a set of documents each needed a specific task done to them a VBA macro could be developed to undertake this task on each. For the required application VBA is perfect as it will communicate with a secondary program that is communicating

with the Labjack and undertake a specific task on the data that is retrieved.

The requirements of the program are to adequately log data being provided by the Labjack when the start button is pressed. Upon completion of testing (stop button pressed) a graph is generated to provide information on temperature versus time and a calibration button needs to be included, which when pressed should provide a detailed set of instructions on proper calibration of the temperature probes.

Chapter 3

Neocot Standard Conformance Check

This chapter will outline the previous cold tests that were undertaken on the Neocot with the original heater design. These will then be compared to the Australian standard IEC.60601-2-20 (IEC 2009) and also compared to the new heater design to see the improvements.

The first cold test to be undertaken on a Neocot was on the 2nd of February 2007. The test was undertaken on Home Ice-creams premises using a supplied cold chamber. The original Neocot cold test was conducted using the original heating element. This being that the heater element was fibreglassed into the floor of the Neocot unlike the new heater element which is bolted into the floor of the Neocot.

The cold test was conducted in the same manner as the new cold test according to the IEC.60601-2-20 Australian standard. This means that after reviewing the standard extract the Neocot needed to be maintained in an environment of -5°C with an allowable deviation of ±2°C for a period of 15 minutes. During this period the internal temperature of the Neocot was not allowed to drop by more than 3°C. This being that the test was undertaken according to the requirements outlined in the IEC.60601-2-20 Australian Standard (Refer to section 1.5.2 above for full Australian Standard extract). The temperature sensing device that was used was a 5 sensor array designed according to the IEC.60601-2-20 Australian standard for the temperature distribution within the

Neocot. This data was then logged using Tera Term on a laptop computer connected via an RS-232 connection. The images below illustrate the setup that was used for the original cold test:

Figure 3.1: Laptop configuration for gathering of temperature data.

Figure 3.2: Neocot setup within the cold room.

Due to the cold chamber in which the cold test was undertaken not being capable of regulating a steady temperature the graph indicates a large deviation in external temperature. The reason for this was due to the cold chamber in which the Neocot was placed in was continuously heated and cooled due to the doors opening and closing. This could not be helped as the test was undertaken during work hours. The graph of the result can be seen in Figure 3.3:
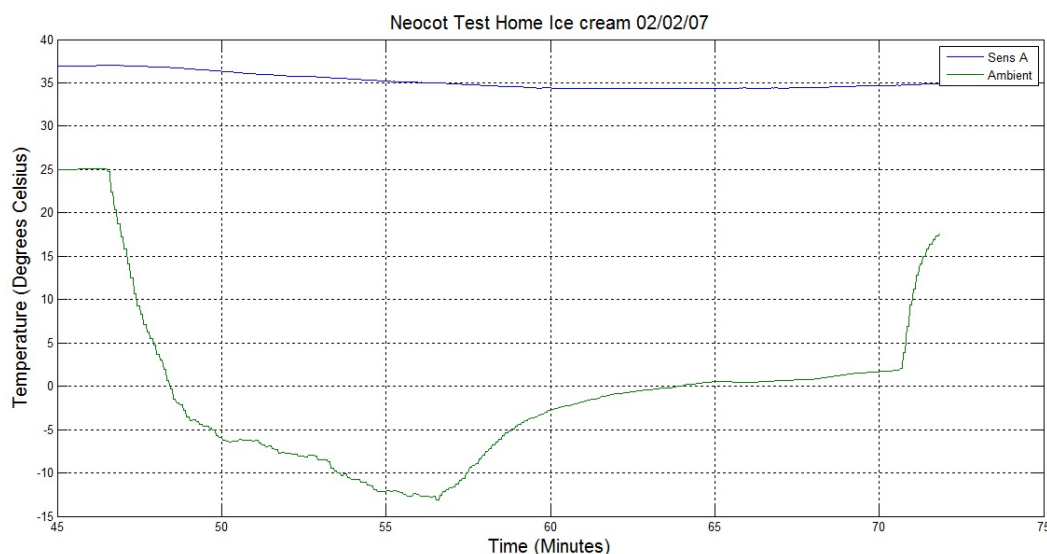
Figure 3.3: Results from the first cold test undertaken at Home Ice-cream.

The graph indicates the temperature experienced within the Neocot as well as the ambient environmental chamber experienced outside of the Neocot. Sensor A in the above graph is the middle sensor on the 5 sensor array board. This is outlined in the IEC.60601-2-20 Australian Standard as being the most important of the 5 sensors to remain at the required temperature levels within the standard. As can be seen, when the above graph is analysed the external temperature that was experienced by the Neocot does not stay steady at -5°C for the required period of 15 minutes. Therefore the period between the 0°C crossings were taken. The total time period between these crossings were calculated to be just over 15 minutes. If the average temperature was then taken over this period it was found to be approximately -5.84°C which indicates that the Neocot had complied with the requirements of the IEC.60601-2-20 Australian Standard.

Chapter 4

Design, Construction and Calibration Procedures

This section will detail the process undertaken to make decisions in order to complete the requirements of the project based on the IEC.60601-2-20 Australian standard. The device that already had been manufactured proved to not operate at the temperature range required. This being that the device was not capable of measuring temperatures below 0°C thus was not able to be used in the cold test. This is why a new temperature sensor was required to be constructed.

4.1 Selection of Components

4.1.1 Temperature Probe Selection

The main key component of the temperature sensor device is the actual temperature probe that will be used to measure the temperature both inside the Neocot chamber and outside in the external environment. The selection of the correct temperature sensing probe is crucial as the test must meet the IEC.60601-2-20 Australian standard. After undertaking a literature review on possible devices that could be used in this circumstance a Thermistor was chosen as being the most suitable due to its reliability, sensitivity and low cost. The Thermocouple was not chosen due to thermocouples being affected by issues such as parasitic junctions which would require additional calculations

and possibly hardware to overcome this effect thus taking more time to produce the final product (Instruments 2012a). RTD's were not chosen due to mainly their cost requirements for a suitable probe for the required application, as well as the effects of internal heating that RTD's are susceptible to (Naik n.d.). The next best temperature sensor was the LM35 precision centigrade sensors. These were also examined but were not selected due to their cost being fairly high as well. This is why the Thermistor was selected as being the most ideal temperature probe having an excellent sensitivity and range (Naik n.d.), for the given task.

The issue with all the temperature probes apart from the RTD is that they all require the use of additional hardware such as amplifier circuits. This adds in an extra level of complexity but however with the addition of an amplifier circuit the cost effectiveness will still be better off than using an RTD.

4.1.2 Voltage Amplifiers Selection

Due to thermistors being chosen as the suitable temperature probes, a voltage amplifier was necessary to be developed due to the voltage signal coming from thermistors being in the range of microvolts. Therefore after undertaking a literature review on suitable voltage amplifier circuits the differential amplifier was compared to its redefined version the instrumentation amplifier. After examining the circuits and undertaking construction tests on each, the differential amplifier was chosen over the Instrumentation Amplifier. This was mainly due to the fact that the Instrumentation Amplifiers gain was hard to control and regulate being only one potentiometer. In the case of the differential amplifier gain was controlled by two resistors which proved a little more stable. Upon further analysis to try and determine as to why the gain was hard to control on the instrumentation amplifier it was discovered that a potentiometer was not capable of being used in the gain adjustment position of an instrumentation amplifier. This was due to a potentiometer not being stable enough to control that gain level thus with changes in temperature the potentiometer would change resistance and so the gain also would change (D.Parsons & N.Hancock 2014).

4.1.3 Noise Filter Selection

All the noise filters researched worked for the required task. Each was constructed and tested to determine which provided the better noise filtering ability. The simple RC filter was selected in its low pass configuration. This provided the greatest amount of noise cancellation in the area in which the tests were being undertaken. This was also proven when the device was used for its intended application at the site of testing, in which the noise filter successfully eliminated all noise inputs. Also the use of large capacitors allowed for greater noise filtering capabilities due to noise being present of a high frequency.

4.2 Construction and Software

4.2.1 Temperature Measurement Device

After completion of research, a working prototype was built using a standard breadboard, to ensure that the selected devices operated as required. This proved successful so a final model was constructed to be used for testing the Neocot as shown in Figure 4.1.

Figure 4.1: Final temperature sensor prototype.

Figure 4.2 illustrates the completed circuit diagram that was used in the final temper-

ature sensing device.
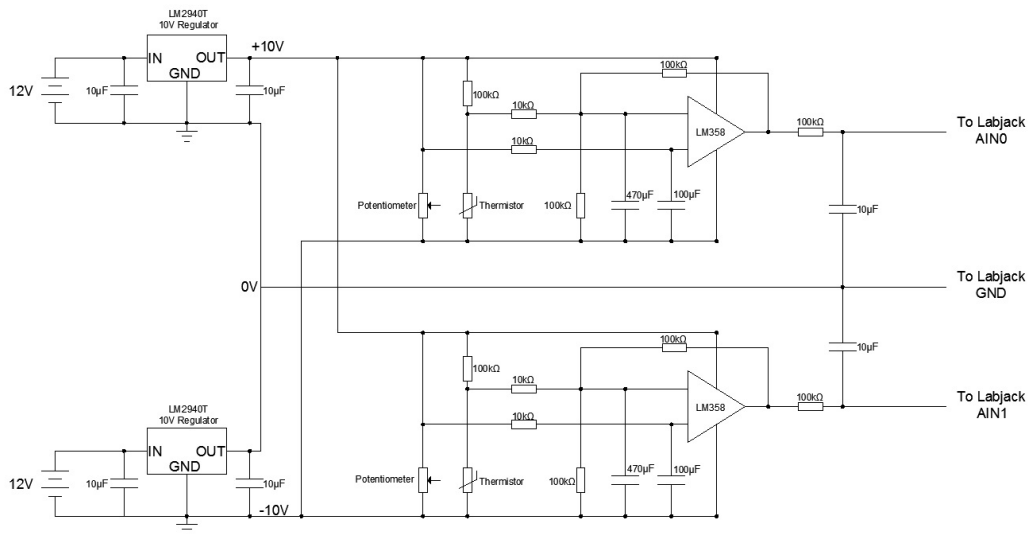
Figure 4.2: Circuit diagram of the completed temperature sensing device.

The black box situated on top of the LabJack houses the prototyping board that contains the amplifier circuit. The temperature sensing device works by when the temperature changes on the thermistor probe the difference in voltage signal becomes amplified in the amplifier circuit which passes that voltage signal through to the Labjack inputs. The Labjack then supplies this voltage level to a program generously supplied by Dr John Leis which logs the data and places it in an excel spread sheet.

The issue here was that the supplied program could only sample at its lowest rate of 500Hz. This was far in excess of what was required for a temperature sampling rate of around 2Hz. To remedy this, a MATLAB script was developed to average the number of samples that are being supplied (see appendix B). The code operates by taking the first 250 samples and takes the average of these values. This cuts the sample rate down to around 2Hz which is suitable. The reason is that the temperature inside the Neocot chamber and in the external environment is not going to change quickly and thus cuts the samples down from a couple of million to a couple of thousand for one test period of 45 minutes. The MATLAB code also generated the relevant required graphs indicating all the temperatures experienced both inside and outside the Neocot. The TeraTerm temperature sensing device was also placed in the Neocot with the newly designed temperature sensor to determine the accuracy and suitability of the design. Some MATLAB code was also generated to convert the data being provided by Ter-

aTerm to graphs although averaging of the data was not required due to TeraTerm already logging data at around 0.5Hz (see Appendix B).

4.2.2 Automating Temperature Data Retrieval Program Design

The process of setting up and calibrating the device was time consuming. It was proposed that these procedures could be simplified by creating a program that automatically logs the data and generates accurate plots. This would remove the need for extra steps such as running the results through a MATLAB averaging script. The automation program can sample data at a selected rate with an adequate rate for temperature measurement being around 0.5Hz per channel so as to minimise the amount of data being collected as temperature deviation is not that apparent.

The automation program was created from VBA programming language. This meant that as long as the computer has a Microsoft Office program (preferably Microsoft Excel) this automation program will operate.

The program was required to communicate directly to the LabJack and at certain time intervals collect the temperature voltage signals coming from each channel on the Lab-Jack. In order to successfully communicate with the LabJack some VBA library code was downloaded to provide a communication connection between the LabJack and Excel. This however did not work, the VBA communication code provided by LabJack did not support the UD library required therefore the LabJack could not communicate directly with Excel.

In order to fix this communication issue, a new method of communicating with the LabJack and Excel was developed. This involved the use of a command prompt program previously developed by Dr John Leis that allowed the communication of the LabJack with command prompt. This meant that instead of the VBA code trying to communicate directly with the LabJack and taking its data values, now the VBA code communicates with the command prompt. The program operates by: Upon pressing the start button the macro opens a command prompt window and changes its directory. Next the program designed by Dr John Leis is executed on one of the channels and reads the voltage. After a time delay of 1 second the program loops and does the same

for the second channel and reads the voltage. This provides a sample period of once every 2 seconds on each channel or 0.5Hz. The process is halted when the stop button is pressed.

In order to simplify the process of calibrating the temperature sensor, a calibrate button has also been included. Upon pressing this button, message boxes appear indicating steps and materials required to correctly calibrate the temperature sensing device.

4.3 Calibration

Before the temperature device can be used in testing the IEC.60601-2-20 Australian standard against the new Neocot heater the device needed to be properly calibrated using a NATA approved temperature sensor. A mercury in glass thermometer was used that had this proper calibration certificate (see appendix E). This calibration process was crucial as this provided the data that was used to generate the formulas for converting the voltage value to an equivalent temperature.

During the cold test it was decided that an additional meter should be used to provide a real time temperature read out, outside of the cold truck. Due to this device not having a NATA calibration certificate it was decided that it should be calibrated as well along with the temperature probes. In order to properly calibrate the devices at negative temperature salty ice water was used. The salt in the water reduced the freezing point of the water which meant that temperatures well below zero could be obtained. After some calculations a ratio of salt to water was calculated to provide a reasonable negative temperature.

In order to maintain a uniform temperature distribution across all of the probes they were all placed together within a small plastic sleeve as shown in Figure 4.3.
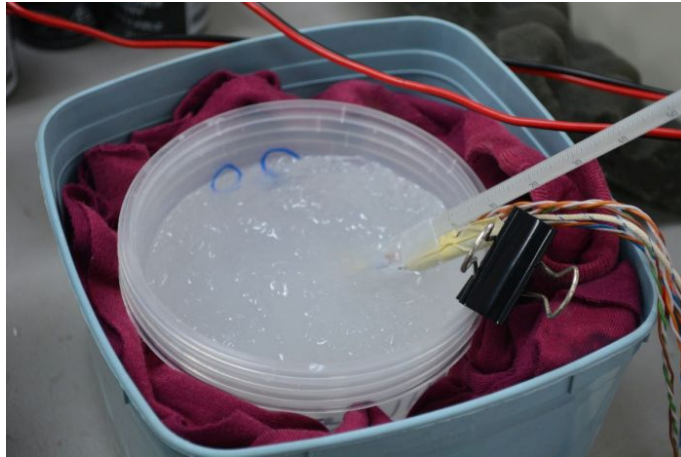
Figure 4.3: Probes placed together in plastic sleeve then submerged in salty ice water.

The minimum temperature that was capable of being obtained with the salty ice water was approximately -9°C. This was more than adequate for the calibration process as the Neocot would only be placed in an environment of approximately -5°C.

It was discovered that temperature fluctuations were crucially affecting the performance of the amplifier circuit. This was mainly noticeable with the thermistor probes. This meant that readings taken at different periods of the day as the ambient temperature changed would adjust the voltage signal value that was produced. In order to combat this the amplifier circuit and LabJack were placed inside the Neocot at 36°C and left over night so as all the components were at the same steady temperature. This provided a more accurate means of calibrating the devices. Figure 4.4 illustrates the setup for the new calibration process.

Figure 4.4: New calibration process, amplifier circuit and LabJack maintained in a temperature controlled environment.

A comparison was then undertaken with the LabJack and amplifier placed at different temperatures to see what the true effects were on the probes. Figure 4.5 illustrates the calibration curve produced when the LabJack was maintained in a steady stable temperature of 36°C which is experienced during the cold test.
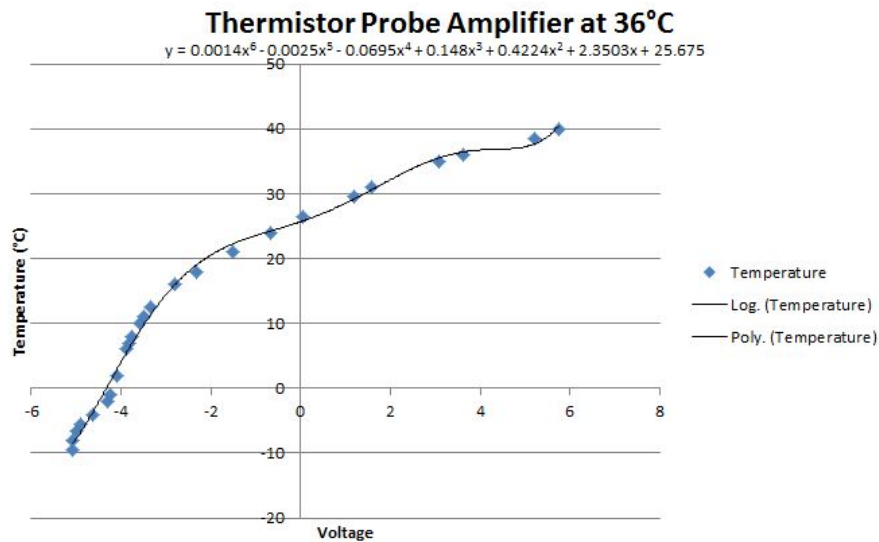
Figure 4.5: Calibration curve of thermistor probes while LabJack and amplifier circuit maintained at 36°C.

When the LabJack and instrumentation amplifier were placed in a much colder environment the results can be seen to drastically change. This is illustrated in Figure 4.6.
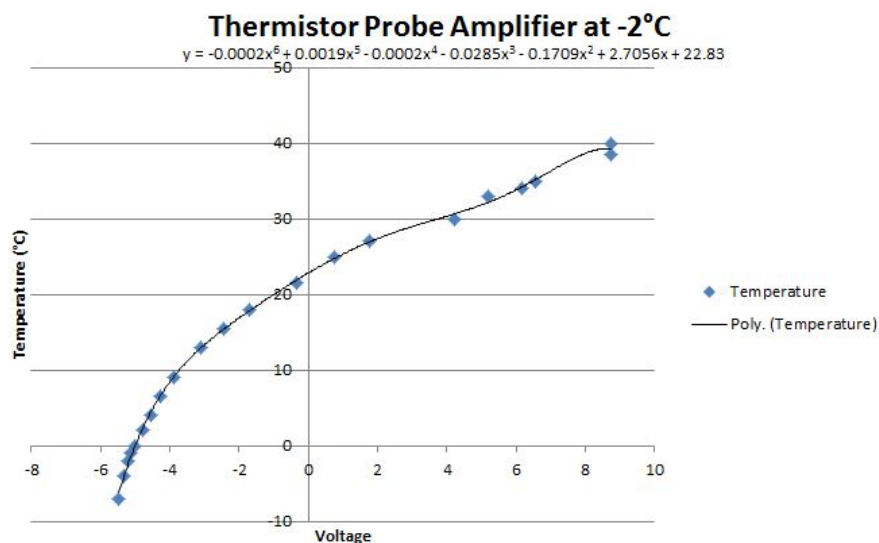
Figure 4.6: Calibration curve of thermistor probes while LabJack and amplifier circuit maintained at -2°C.

This meant that in order to have an accurate calibration the device needed to be maintained at the average operating temperature of 36°C. Figures 4.5 and 4.6 contain a calculated trendline that best matches the data distribution. As can be seen by the formulas the best fit is provided from a 6th order polynomial function. With this knowledge the calibration process could begin.

With the probes placed in the salty ice water readings were conducted on the voltage signals at increments of 1°C for the duration from approximately -6°C to the maximum temperature required of 40°C. The extra meter that was calibrated had its temperature readout compared to the temperature readout of the mercury thermometer which was placed in the plastic sleeve along with the probes. From this a table was produced containing offset values for certain temperatures to provide a means of quickly determining what the average temperature was within the environment (see appendix F).

With the new calibration process undertaken formulas could then be produced for both of the thermistor probes. Thermistor probes exhibit a non-linearity nature which meant that a much more complex formula was obtained around the sixth order. These formulas were used in MATLAB to generate the temperature graphs for each of the probes during the testing.

Figure 4.7 indicates the calibration graph for the thermistor probes. Due to the response of the thermistors being fairly similar and due to the thermistors not being the main testing probes just one formula was developed.
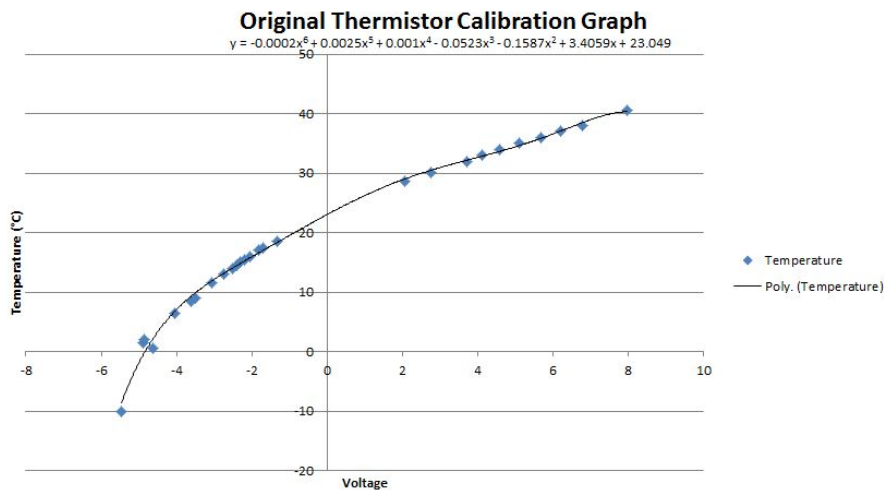
Figure 4.7: Original calibration curve of thermistor probes

The formula that is indicated in Figure 4.7 is the formula that was used during the first cold test. The formula mathematically represents the relationship between the voltage of the A/D (LabJack) and the temperature within the testing environment.

Chapter 5

Neocot Standard Conformance Recheck

This chapter will detail the method in which the cold tests were undertaken as well as the results obtained and the instruments used.

5.1 First Cold Test

Once the preferred instruments were selected the first cold test could be undertaken on the Neocot. The first priority was to find a temperature chamber large enough to house the Neosled with a Neocot and power supply unit housed in it. Bidvest Pty Ltd provided a cold truck that was able to be borrowed on their premises. The cold truck was capable of setting and regulating an approximate environmental temperature of -5°C with a measured wind speed of 0.4m/s. The Neocot was then transported to the premises using the power lifter and was lifted from the power lifter into the truck once all the equipment was prepared and logging.

Figure 5.1: The Neocot just before the start of the cold test.

Figure 5.2: The laptop used in logging of the data during the Cold Test duration.

Figure 5.1 illustrates the Neocot setup just prior to being placed in the cold truck with all the testing equipment placed inside the Neocot and the data beginning to log. The Neosled was then slid off of the power lifter and placed inside the cold truck while at a set ambient temperature of -5°C where it stayed for 15 minutes. Figure 5.2 illustrates the Laptop that was used in logging the data inputs from both TeraTerm and the newly developed temperature sensing device.

The temperature sensing device consisted of two thermistor probes. One was situated inside the Neocot placed in the central area of the mattress as shown in figure 2.1.

The other temperature probe was placed outside the Neocot and taped to a piece of conduit to indicate the ambient temperature inside the cold truck without temperature interference coming from the Neocot.

The cold test was executed according to the IEC.60601-2-20 Australian standard. This being that the Neocot remained in the cold truck at -5°C for the 15 minute duration. Upon completion of the 15 minutes the Neocot was removed from the cold truck and placed in an environment with a temperature of approximately 25°C. The Neocot had to remain in this environment for a further 30 minutes upon which the data logging was completed (IEC 2009). Figure 5.3 shows the produced graph of data once the collected data was run through the MATLAB average code and plotted.
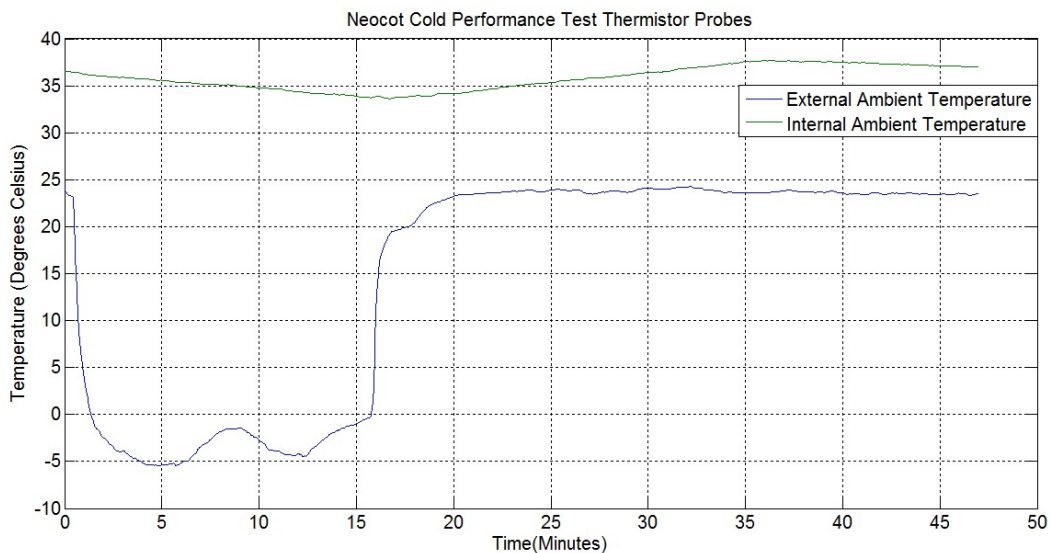
Figure 5.3: Graph indicating the results of the first cold test with the new temperature sensing device.

The results indicate the temperatures that were experienced both inside the Neocot during the cold test as well as the external environmental temperature. The temperature inside the cold truck stayed within the allowable temperature range being -5°C with a deviation of no more than ±2°C for a duration of 15 minutes. Therefore this cold test can be used to justify to the TGA that the Neocot heating element has passed the requirements.

It can be seen that after the 15 minutes elapsed the ambient temperature outside the Neocot was approximately 25°C. The reason that the Neocot had to remain in this

temperature for a further 30 minutes was to ensure that the temperature inside the Neocot did not overshoot the maximum allowable temperature of 39°C.

5.2   Additional Cold Tests

Additional cold tests were undertaken on the 23rd of July 2014 using a Bidvest provided cold truck. After analysing the results from the first cold test it was decided that a more linear temperature sensor should be used to reduce the calibration equations and simplify the task of converting the voltage to a temperature. Looking back at the literature review the next best linear temperature sensor was the LM35 precision centigrade sensor. To avoid having to remove the previous functioning thermistor probes an additional section of hardware was placed on the same board using the new LM35 chips. This now meant that during the cold test four probes could be used to help produce a better understanding of the temperature within and outside the Neocot, as well as providing some redundancy should a fault occur. The calibration was then redone in the exact same manner as that indicated in the previous chapter. The difference now is that the LM35 probes being linear produce a much smaller equation. Figure 5.4 illustrates the new hardware prototyping board used with the thermistors and LM35 chips attached.
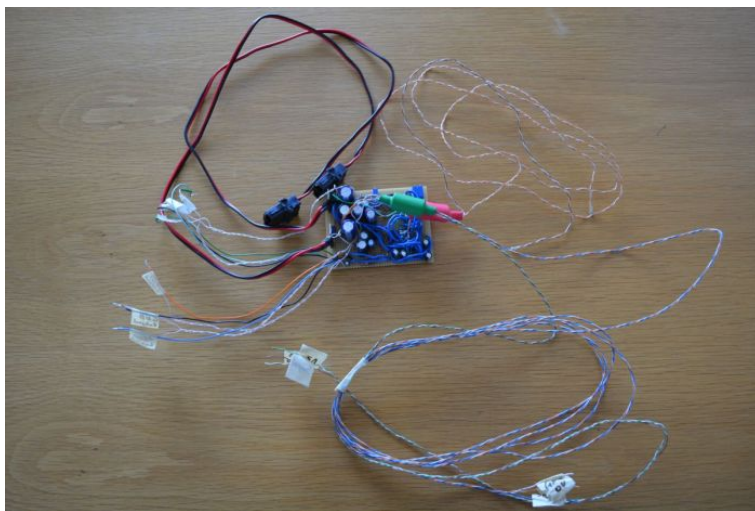
Figure 5.4: Temperature sensor hardware with LM35 chips and thermistors.

The final product with the thermistor and LM35 probes can be seen in Figure 5.5.
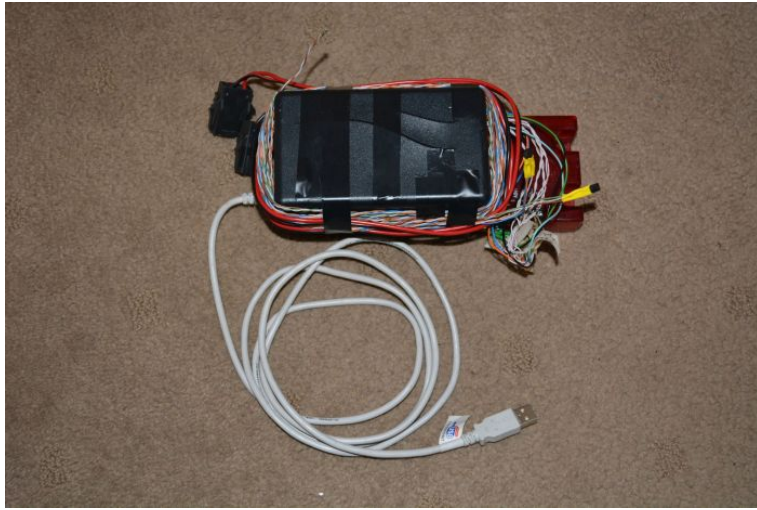
Figure 5.5: Final temperature sensor device with LM35 chips and thermistors.

Figures 5.6 and 5.7 indicate the calibration graphs for the LM35 probes. Due to each probe not being identically the same the response is marginally different. Therefore to ensure as much accuracy as possible as these probes will be the main probes during the test, a calibration graph and formula were developed for each probe. The formulas that were produced by these graphs are the exact formulas that are contained within the MATLAB code in appendix B.
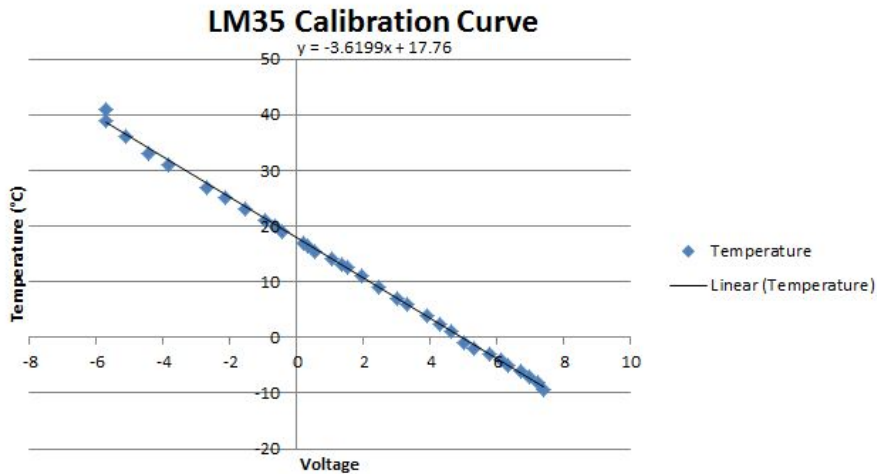
Figure 5.6: Calibration curve of first LM35 probe using the new calibration method.

As can be seen in Figure 5.6, the LM35 probes exhibit a very linear output voltage proportional to temperature. As can be seen by the formula in the graph, it is far simpler to calculate the temperature within the Neocot using the LM35's instead of the thermistors. Figure 5.7 exhibits a similar response.
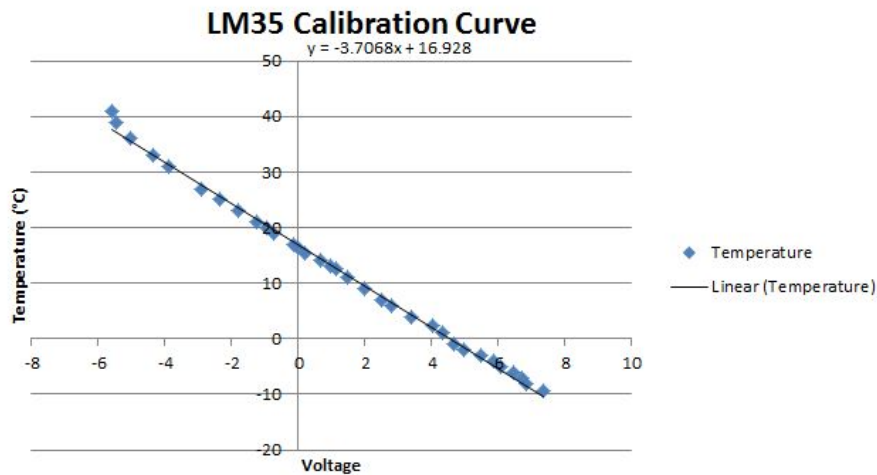
Figure 5.7: Calibration curve of second LM35 probe using the new calibration method.

Using these calibration graphs during the cold test also provided a means of visually comparing the voltage being displayed on the computer to a temperature on the graphs.

During planning for the second cold test it was discovered that the placement of the original external ambient temperature sensor was not adequately measuring the temperature within the cold truck. It was decided that a probe should be placed well away from the Neocot out in the open were it could measure an accurate ambient temperature without the effects of warm air coming from the Neocot. This meant that one of the LM35 probes were placed towards the back of the cold truck to produce a better reading of the environmental temperature. Figure 5.8 illustrates the new layout within the cold truck that would be used to produce better temperature readings.
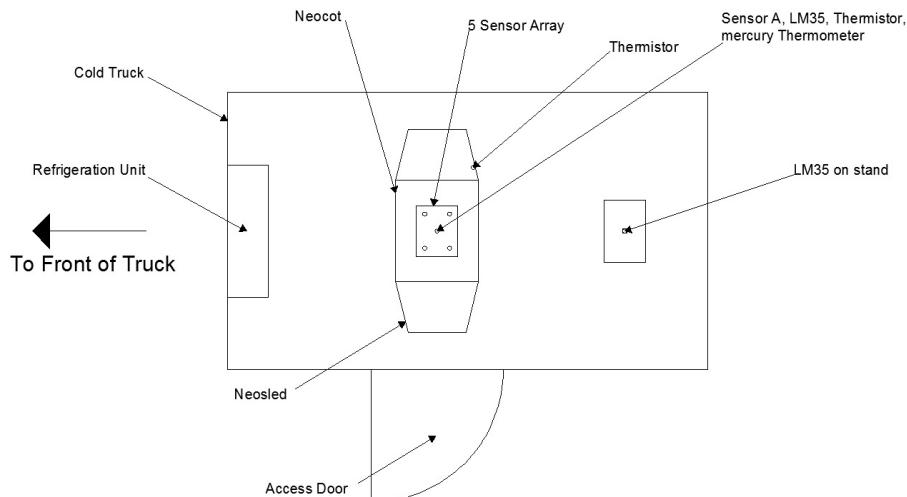
Figure 5.8: Temperature probe layouts within the cold truck.

In total seven probes were used during the cold test, two thermistor probes and two LM35 probes. Inside the Neocot one of each of the probes were placed along with additional sensors from equipment such as a Propaq monitor, mercury thermometer and a TeraTerm probe to produce a visible display upon removing the Neocot from inside the cold truck. Figure 5.9 illustrates the positioning of the probes within the Neocot.
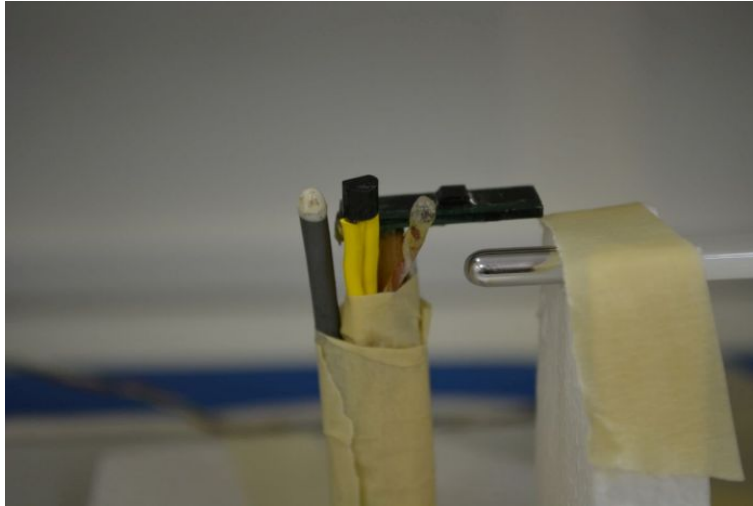
Figure 5.9: Temperature probes positioning within the Neocot.

The probes from left to right are Propaq thermocouple probe, LM35 probe, thermistor probe, TeraTerm probe and the mercury thermometer.

Similar to the original cold test the Neocot was transported to Bidvest using a power lifter. Before the Neocot could be placed into the cold truck a temperature value needed to be obtained indicating the ambient internal temperature of the cold truck. This was done using one of the LM35 probes placed on a wooden stand. This probe was placed at the back of the cold truck to produce a more accurate reading of the internal temperature within the truck. The decision to place the probe at the back of the truck was due to the location of the airconditioning unit being at the front and the air blows along the roof and circulates down around the back door and returns along the floor. Placing the probe at the back of the truck ensured that it was within an area that was going to always remain at the temperature of the airconditioning unit. So as the probe was not affected greatly by the wind flow a stand was used to increase the height of the probe from the floor of the truck. Figure 5.10 illustrates the stand and probe used to undertake this task.
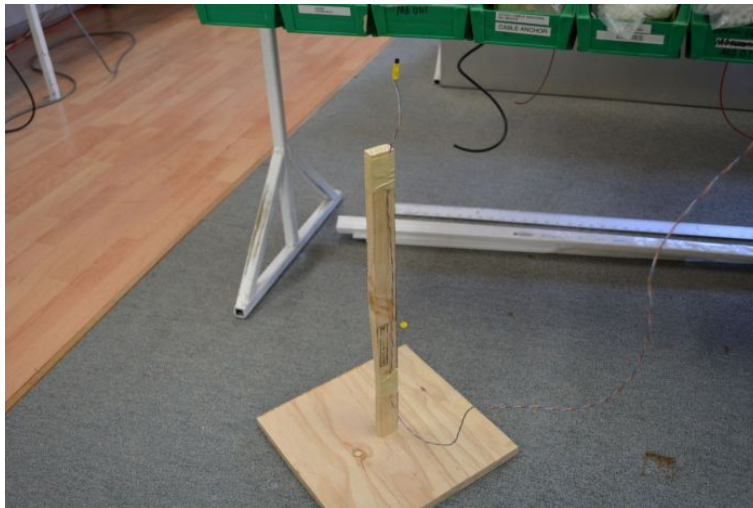
Figure 5.10: Stand used with the LM35 probe placed inside the cold truck.

This probe was placed first into the cold truck with the LabJack running. This provided a voltage that was capable of being converted to a temperature via a calculation. This provided a means of knowing what the ambient temperature was within the cold truck before placing the Neocot inside.

Figure 5.11: Neocot just prior to placing in cold truck with the LM35 external temperature probe placed inside.

Once the temperature was at an adequate level the Neocot was placed inside with TeraTerm and LabJack logging data. As per the IEC.60601-2-20 Australian Standard and similar to the previous cold test the Neocot was to be left in the environment for a period of 15 minutes. TeraTerm provided a digital readout of the internal temperature experienced within the Neocot. Over the 15 minute period this temperature was to not drop below 33°C. The test was maintained for the 15 minute period without the

internal temperature dropping below 33°C. Due to this the Neocot was left within the chamber for a further period of time to prove that the Neocot was capable of exceeding the requirements of the IEC.60601-2-20 Australian Standard. The results that were obtained are shown in figure 5.10.
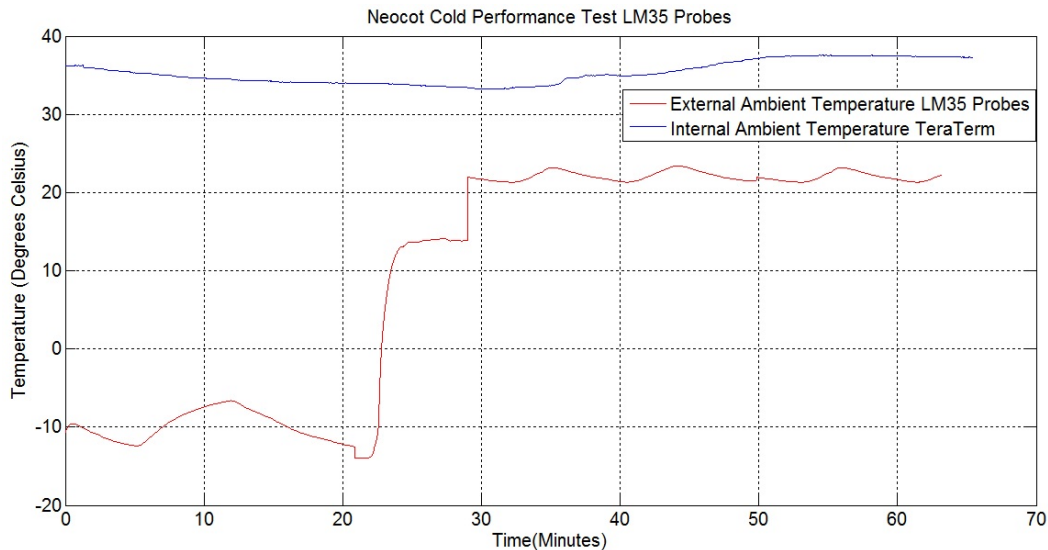
Figure 5.12: Neocot additional cold test results using the LM35 probes.

In total the Neocot remained in the cold truck for a period of approximately 22 minutes before being removed and placed in an ambient temperature being between 20 and 25°C. The levelling off of the temperature between the 24 to 28 minute mark is due to the external ambient temperature of that day being only around 14°C. This is below what is required in the IEC.60601-2-20 Australian standard and therefore the Neocot needed to be moved to a more suitable environment. The Neocot was taken back to Wenross Holdings and as can be seen upon entering the building the ambient temperature rose to a suitable level. The oscillation that is observed is as an effect of the air-conditioning unit.

The results from the second cold test illustrate how the new heating element within the Neocot has far exceeded the requirements of the IEC.60601-2-20 Australian Standard. The total period of time that the Neocot was required to be maintained in the cold chamber was 15 minutes at a temperature of -5°C (IEC 2009). The cold test has proven that the Neocot was capable of handling much colder conditions with an average ambient temperature experienced of around -10°C for a longer duration of just over 20 minutes. During this period the Neocot dropped to its minimum temperature of 33.2°C which proves its compliance with the standard. The IEC.60601-2-20 Australian

standard also specifies that the Neocot must be then left in an environment of between 20 and 25°C for a period of 30 minutes (IEC 2009). During this period the Neocot is to at no point exceed 3°C above the normal operating temperature. This means that the Neocot is not allowed to exceed 39°C. After analysing the results the maximum temperature that the Neocot warmed up to was 37.5°C. This means that the Neocot has successfully passed the second requirement of the IEC.60601-2-20 Australian standard.

During the cold test, thermistor probes were also included in the test to ensure that the results obtained by using the LM35 probes were correct. As shown in Figure 5.8 two thermistor probes were used. One of the probes were placed inside the Neocot while the other was situated on the Neosled just outside of the Neocot. The location of the external thermistor temperature probe was changed from the first cold test. Previously the probe was placed on a piece of conduit above the Neocot. It is believed that this was not providing an accurate measurement of the external temperature due to the heat from the Neocot rising. In this test the probe was placed at the same level as the Neocot and a small distance away as to prevent escaping heat from corrupting the reading as seen in Figure 5.13.
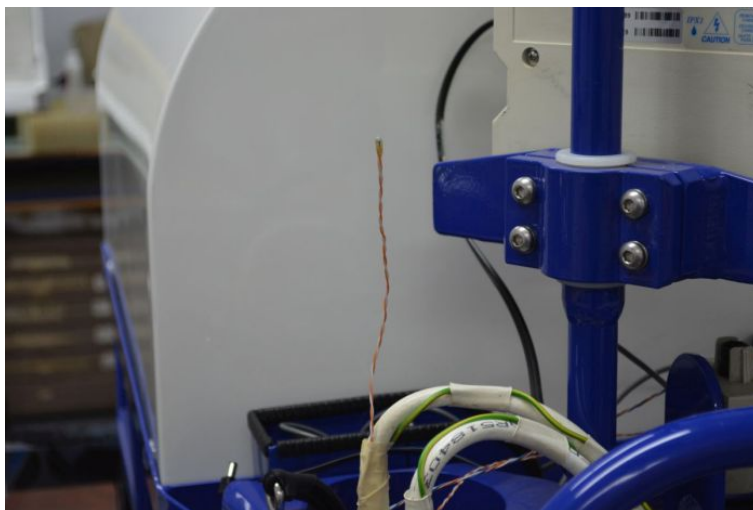
Figure 5.13: Location of the external ambient thermistor probe.

The results obtained from the thermistor probes are very similar to the results obtained from using the LM35 probes as shown in Figure 5.14. The slight deviation in some of the temperatures is due to calibration error of the thermistor probes. Due to a thermistor probe not producing a linear output an exact calibration of the output voltage with regards to temperature is difficult.
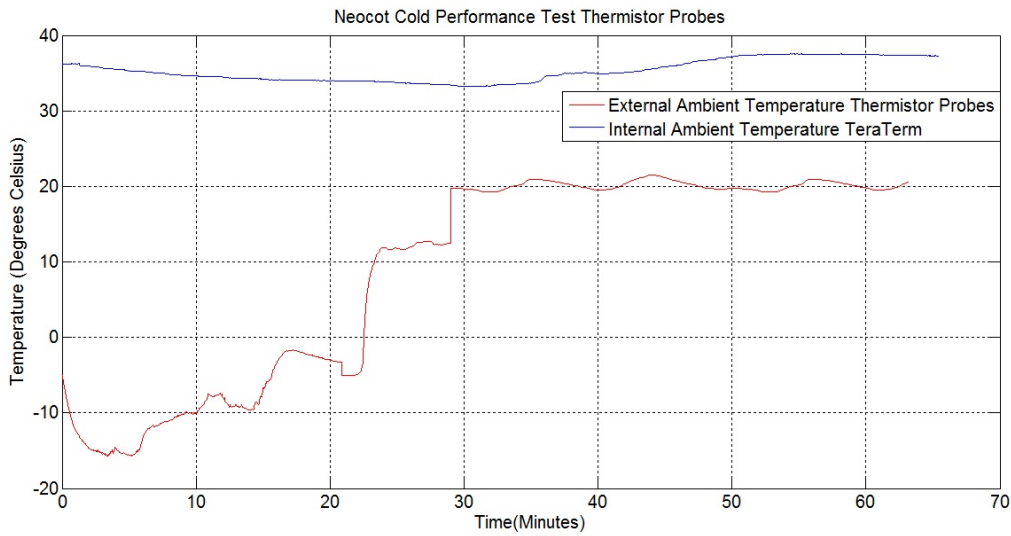
Figure 5.14: Neocot additional cold test results using the thermistor probes.

Analysing the results obtained using the two different probes it can be seen that the response time of the thermistor was far quicker than the response time of the LM35 probe. This is due to thermistors having less thermal mass than what the LM35 probe contains thus making the changes in temperature appear far more quickly for a thermistor than for an LM35. However due to the LM35 producing a linear output the calibration of this is far simpler and can be done with far more accuracy making the results obtained from the LM35 probes more reliable.

5.3 Comparison of results

This section will compare the results taken from the two cold tests undertaken with the new heater element with the previous cold test undertaken with the original heater.

The original cold test illustrated that the Neocot's original heater was capable of exceeding the requirements of the IEC.60601-2-20 Australian standard for a cold test. This was due to the Neocot being capable of maintaining its internal temperature within the required range according to the IEC.60601-2-20 Australian standard for a far longer period and at a much colder temperature. When this is compared to the results that were obtained during the recent cold test it can be seen that the new heater design has also exceeded the requirements of the IEC.60601-2-20 Australian Standard.

Chapter 6

Warm-up Time Results

This chapter will detail the results obtained while undertaking warm up tests on a set of Neocot's. The warm up test needs to comply with the IEC.60601-2-20 Australian Standard.

6.1 Australian Standard Extract

The relevant Australian standard IEC.60601-2-20:2009 states:

> "The warm-up time of the ME EQUIPMENT shall not differ by more than 20 from the warm-up time specified in the instructions for use (see 201.7.9.2.8). Compliance is checked by the following test: With the CONTROL TEMPERATURE set to 12°C above ambient temperature, the supply voltage being equal to the RATED voltage, and the ME EQUIPMENT operating as an AIR CONTROLLED TRANSPORT INCUBATOR, the INFANT TRANSPORT INCUBATOR is switched on, starting from COLD CONDITION. The time for the TRANSPORT INCUBATOR TEMPERATURE to rise by 11°C is measured. The humidity control, if fitted, shall be set to its maximum value. The water level of a humidifier water container shall be normal. The water in such a container shall be at ambient temperature."

6.2 Interpretation of Australian Standard Extract

The IEC.60601-2-20 Australian Standard extract on the warm up test requirements is shown in the previous section. This section will interpret that extract to determine how the test can be undertaken and the requirements involved.

The requirements of a warm up test is to ensure that the Neocot is capable of increasing in temperature by a certain amount over a period of time. This period being that the Neocot must be a able to increase by 11°C from a starting ambient condition (IEC 2009). This time period is then compared to the amount of time stated in the user manual for the Neocot to increase in temperature from its cold state to the operating temperature. The difference between the amounts should be no more that 20 percent (IEC 2009).
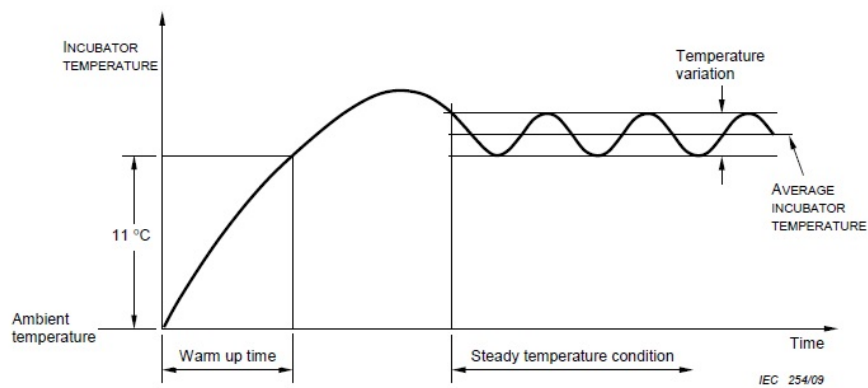
Figure 6.1: Variation of the internal temperature.

The above figure is taken from the IEC.60601-2-20 Australian Standard and illustrates the requirements of the warm up test results.

6.3   Methodology

Two Neocot's will be used to conduct this warm up test. One Neocot will contain the original heater and the second Neocot will contain the newly designed heating element. The results of the comparison will be compared to determine if there is an improvement with the new heater design compared to the original. Both Neocot's will be connected to mains power, with the PSU switched to AC during the duration of the test. Both Neocot's will also have there temperature settings placed on 36°C so as during the duration of the test the Neocot is continuously heating up. For this test TeraTerm will be used to log the temperature data within both of the Neocot's. The five sensor array configuration will be used as shown in Figure 6.2:

Figure 6.2: Five sensor array configuration within the Neocot.

6.3.1   New Heater Results

This section details the results obtained by undertaking a warm up test on a Neocot with the newly designed heating element in place compared to the requirements of the IEC.60601-2-20 Australian Standard for a warm up test.

The test was carried out according to the requirements of the IEC.60601-2-20 Australian Standard. Figure 6.3 illustrates the results after undertaking a warm-up test:
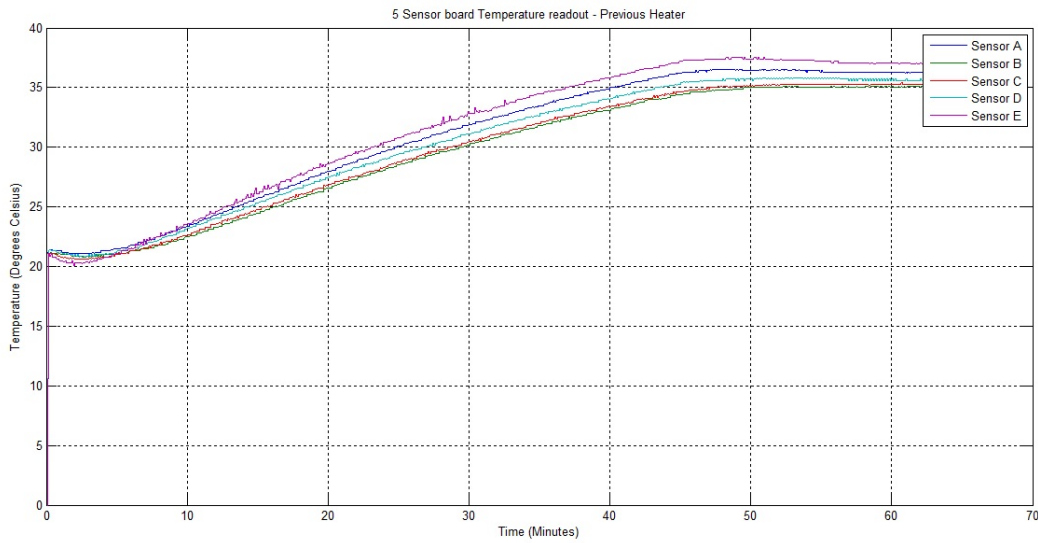
Figure 6.3: Warm-up test using the new heater.

The Neocot was started up from a cold condition as per the IEC.60601-2-20 Australian Standard requirement, it was then left to run for a period of just over one hour to ensure that the Neocot had reached its steady state temperature of 36°C. It can be seen that after analysing the data the amount of time that was required to increase the temperature inside the Neocot by 11°C was approximately 31 minutes. The point at which the internal temperature of the Neocot reached the 11°C point is shown in Figure 6.4:
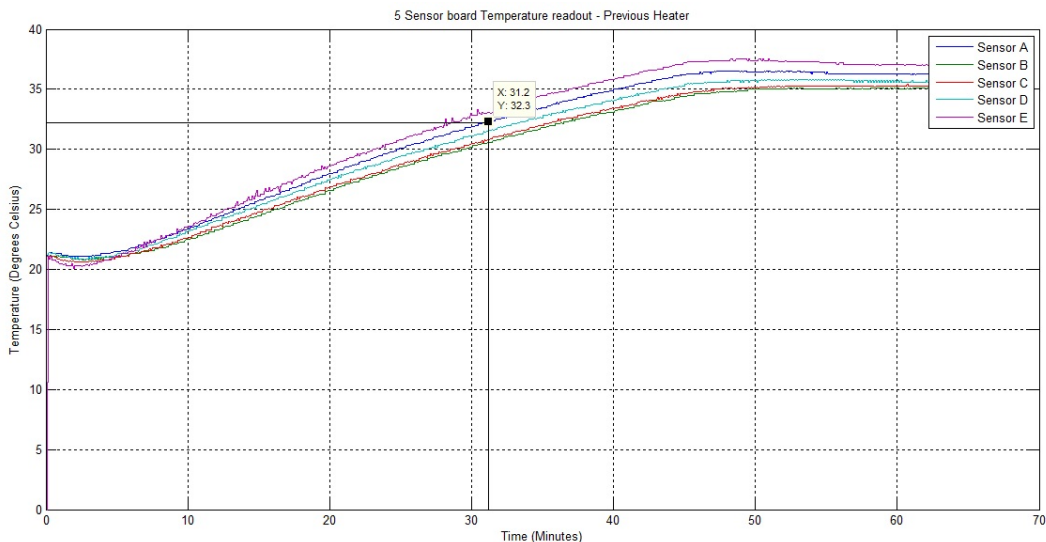
Figure 6.4: Warm-up test using the new heater time taken to increase by 11 degrees celsius.

6.3.2 Previous Heater Results

This section details the results obtained by undertaking a warm up test on a Neocot with the previous heating element in place compared to the requirements of the IEC.60601-2-20 Australian Standard for a warm up test.

The following test was carried out according to the requirements of the IEC.60601-2-20 Australian Standard. Figure 6.5 illustrates the results after undertaking a warm-up test.
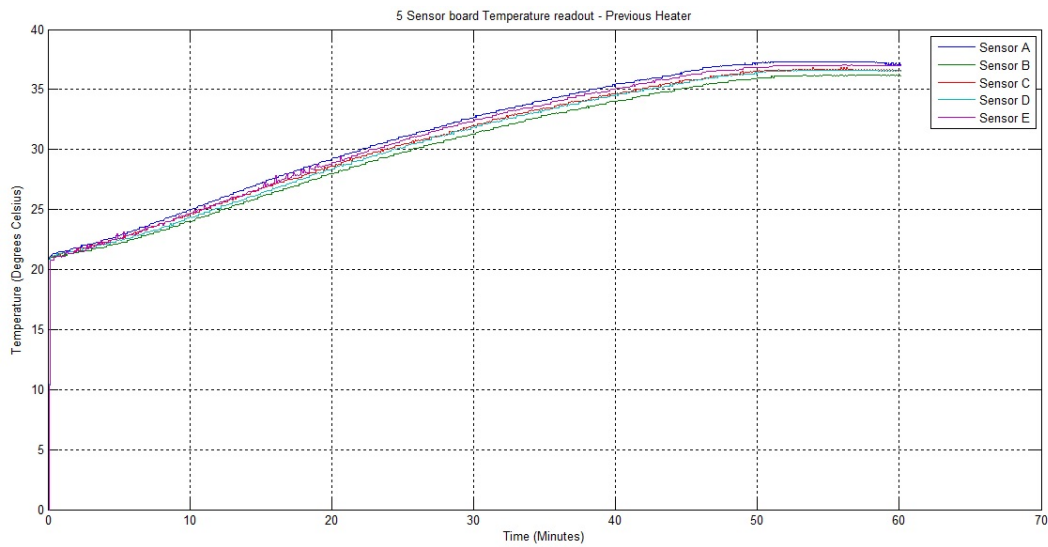
Figure 6.5: Warm-up test using the previous heater.
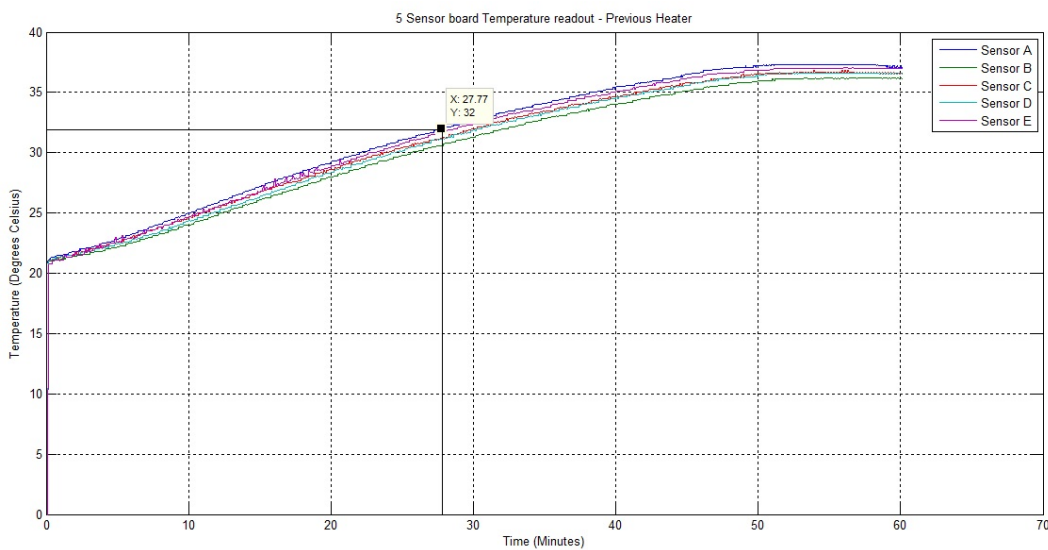
Figure 6.6: Warm-up test using the previous heater time taken to increase by 11 degrees celsius.

The test was carried out using the same procedure used for the new heater and compared to the requirements of the IEC.60601-2-20 Australian standard. This meant that the Neocot was started from a cold condition and had its internal temperature set to 36°C. The Neocot was then left to run for a period of time until the internal temperature of the Neocot had reached its steady state level of 36°C. From this the data could then be analysed and compared to the standard. Figure 6.5 indicates the results that were obtained during this warm up test. Since the standard specifies that the heat up time being the amount of time the Neocot requires to increase its internal temperature by 11°C. Figure 6.6 shows the result. The original heater was capable of increasing its internal temperature by 11°C in a period of 27.77 minutes.

### 6.3.3 Comparison Of Results

This section will compare the results between the two different heating elements and an analysis will be undertaken to determine if there is any improvements to the new heater design compared to the previous for the warm up test.

The user manual for the Mansell Infant Retrieval System states that the average time for the Neocot to increase in temperature from a cold condition by 11°C is around 45 minutes. The IEC.60601-2-20 Australian standard for a warm-up test specifies that the warm up time should not differ by more than 20 percent of the time specified in the user manual.

The results obtained from the heater elements were as follows: the new heater had a warm-up time of 31 minutes and the previous heater had a warm-up time of 27.77 minutes. The interesting thing to note is that the new heater was slower to warm up then the previous heater. One reason for why this is so could be due to a larger metal surface needing to be warmed up. In the previous heater a small metal shim was placed between the heater element and the fibreglassed floor. Whereas with the new design there is a far larger piece of aluminium placed on top of the heater element. The amount of time required to change the temperature of a large piece of metal to a small piece is greater and thus this could be a reason as to why the heater element is now a bit slower to warm the Neocot up. However as has been shown in the cold test having this extra heat retention capability the new heater is capable of keeping the internal temperature

of the Neocot at a steady temperature for a longer period than the previous heater. When the percentage difference is calculated for each of the heater elements compared to the time specified in the user manual the difference can be seen to be: 31% for the new heater and 38% for the previous heater. Looking at the IEC.60601-2-20 Australian standard for a warm-up test it can be seen that the percentage of time in which the new and previous heaters take to increase the internal temperature of the Neocot by 20 percent is outside of this range. However after analysing the IEC.60601-2-20 extract again it was decided that because the heaters are increasing the temperature faster than the time specified in the user manual this was to remain the same. This meant that what the users would read being that the Neocot will have a warm up time of 45 minutes will actually warm up in less time and thus be an improvement.

Chapter 7

Automating Temperature Data Retrieval Program

This chapter will outline the process undertaken to create a program that could automate the process of logging and plotting the temperature data being collected from the Neocot.

7.1   Background

The previous method for logging temperature performance data from a Neocot consisted of using a five sensor array connected through TeraTerm on a computer.

Figure 7.1: Five sensor array used for temperature logging of Neocot.

The issue with this method was in order to plot the collected data the file needed to be opened in excel, edited and then a plot could be generated. This extra process was the reason for trying to develop a program that any user could use without the knowledge or expertise on how the data logger operated. Figure 7.1 above is the current instrument used to log the temperature data from a Neocot. Before a Neocot can be given to a customer certain temperature tests need to be undertaken to ensure that the Neocot is capable of operating as required. Some of these tests include a warm up test to ensure that the time that the Neocot requires to reach its operating temperature is within a certain limit, also a calibration test to ensure that the temperature that is being displayed on the LED readout on the front of the Neocot does not differ greatly from the actual temperature being measured within the Neocot. This temperature difference can be no more than $\pm 1^\circ$C. The five sensor array illustrated in Figure 7.1 would be used for these tests. The data being collected by the five sensor array would feed its information in real time back to a computer running TeraTerm. Upon completion of the testing the TeraTerm data would automatically be stored as a text file on the host computer. This meant that in order to plot the data the text file would need to be opened in excel, formatted in a way so that the information stored within each column is known and then generate plots of the data. This is the reason behind wanting to generate a program that could automatically do all of the above processes without the user needing to do anything apart from starting the program. However the developed automation program would only be able to be used with the newly developed temperature sensor hardware.

7.2 Automating Temperature Data Retrieval Program Design

There are multiple methods in which a program can be generated. These include creating a designated stand alone program such as an .exe all the way through to creating a program that runs as a host to another program such as a VBA program. Due to the time constraints of the project creating a stand alone .exe program was going to be too time consuming as C language programming would need to be learnt. Therefore a VBA program was decided to be used to generate the automation program using excel as its host program. This meant that the data that was gathered by the

automation program could be directly stored into an excel page without the need of opening the created file separately after completion of the testing.

The program therefore required a start and stop button to begin the testing process and to end it. Another crucial aspect of a temperature logging device is the need for calibration. Therefore it was decided that an additional button should be placed in the program which would allow the use of calibration. Because calibration requires physically adjusting potentiometers inside the temperature testing device this could not be done automatically. The calibration process in the automation program therefore is a set of steps that the user would follow that indicates the process that needs to be undertaken to properly calibrate the device. The Figure 7.2 shows the user interface section of the VBA automation program hosted in excel:
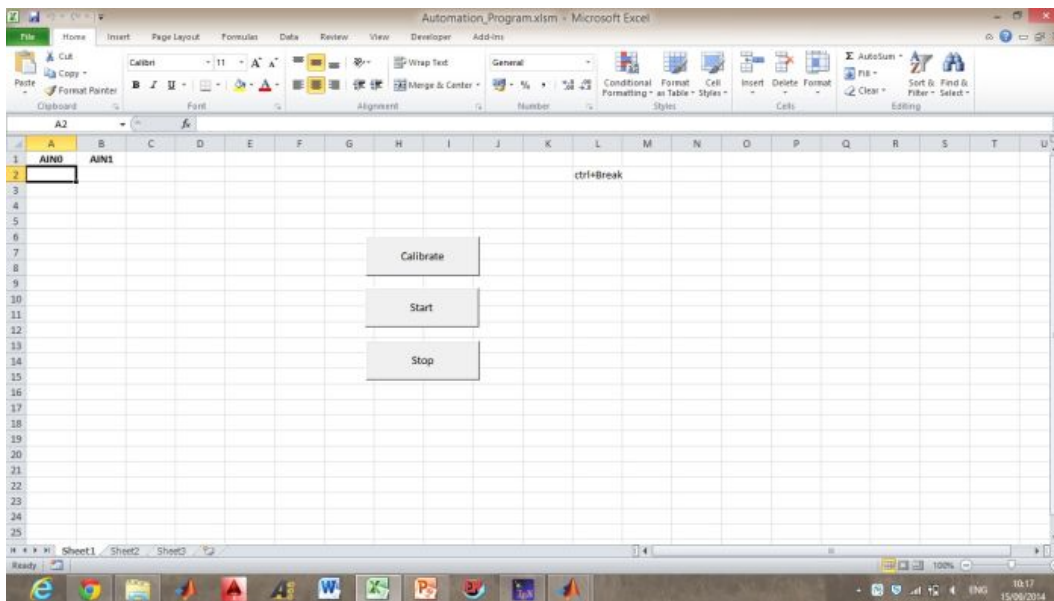
Figure 7.2: Automation program user interface display.

The user interface is very simple to operate. The user has a choice between three buttons: start, stop and calibrate depending on what the task is that needs to be undertaken. Once the LabJack is connected to the host computer, if the start button is pressed the automation program will begin communicating with command prompt, which in turn communicates to the LabJack and collects the required information. The stop button cancels this process and halts the execution of the VBA program. If a calibration is required the calibration button is pressed and a set of step by step

procedures for calibrating the device properly is displayed as shown in Figure 7.3:
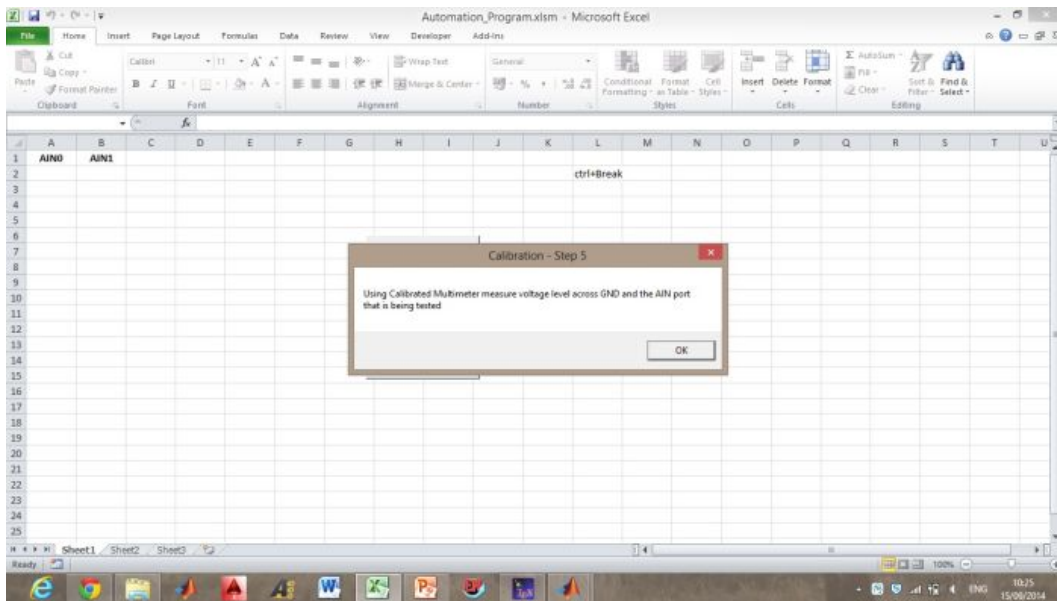
Figure 7.3: Automation program calibration process example of step by step procedure.

Appendix C contains the code that was used in order to generate the above results.

Chapter 8

Conclusions and Further Work

This chapter outlines the results obtained from the project and any further work that needs to be completed.

8.1 Achievement of Project Objectives

The following objectives have been addressed as set out in the project specification:

Research the requirements of the IEC.60601-2-20 Australian standard Chapter 1 provided a breakdown of what the IEC.60601-2-20 Australian standard was stating, also an interpretation of what the standard was asking is provided.

Research temperature sensing devices suitable for this application Chapter 2 provided a detailed analysis of the many forms of temperature sensing hardware and devices that are currently on the market for the required project specification. The main forms of temperature measurement devices that were analysed were Thermocouples, Thermistors, RTD's and LM35's. This chapter detailed the strengths and weaknesses of each of the different forms to make a choice for this application easier.

Research how to properly design, construct and test an amplifier circuit Chapter 2 provides a detailed literature review on the different forms of amplifier circuits that can be used for the purpose of this project. The two main types that were

analysed were differential and instrumentation amplifiers and the strengths and weaknesses of each were analysed.

Design, Construct and test an amplifier circuit for the required application
Chapter 4 provides a description on what instruments were chosen for the construction of the amplifier circuit. Reasons are also detailed as to why certain devices were chosen over others. The devices that were chosen to produce the final product are as follows: a differential amplifier was chosen along with thermistors and LM35 probes. The noise filtering used was constructed from a simple RC circuit composing of a resistor and a capacitor to filter out noise above a calculated frequency. Testing of the amplifier circuit was also detailed in chapter 4 with the process consisting of placing the probes within a salty ice water solution to ensure that the device was capable of measuring negative temperatures with a reasonable amount of accuracy. This setup was also used to calibrate the device before use.

Research a suitable A/D device for the application Chapter 2 provides a literature review on the type of A/D to be used for the project. Only one A/D was analysed due to the ease of access of this device. The chosen A/D for the application was a LabJack which would communicate with the amplifier circuit and provide a data output to the logging program.

Design Software to plot temperature measurement data Chapter 4 provides a description as to how the data was plotted from the LabJack. Due to the supplied logging program having a minimum logging frequency of 500Hz a program needed to be developed to reduce the amount of samples per second being taken. Therefore a MATLAB averaging program was developed to take the first 250 samples and average them so as the amount of data being stored did not exceed a realistic amount. Before the averaging code with 500Hz this would imply 500 data points per second. The test duration is typically between 45 and 60 minutes. Therefore there would be by the end over 1 million data points. Temperature cannot change that quickly therefore it was beneficial to average the number of samples collected before plotting.

Determine the signal filter requirements for the measurements Chapter 2 provides a breakdown on different types of signal filters that may be used in this circumstance. The main filters were RC and notch as well as high pass and low

pass. Each were examined and in chapter 4 the best filter for the application was chosen. This turned out to be the RC filter due to its ease of application. The other filters were considered but not implemented due to them requiring the interfering signal frequency to be known. In this circumstance the interference frequency was not known therefore an RC filter was used.

Compare results to the IEC.60601-2-20 Australian Standard requirements

Chapter 5 illustrates the results that were obtained from the two conducted cold tests on two separate Neocot's. The tests that were conducted were based on the IEC.60601-2-20 Australian standard for a cold test. This meant that the Neocot was placed in a environment of -5°C for a duration of 15 minutes before being removed and placed in an environment of between 20 and 25°C for a further 30 minutes (IEC 2009). The results that were obtained from the cold tests were then compared to the requirements of the IEC.60601-2-20 Australian standard to ensure that the cold test did pass. Chapter 5 also provides a comparison of the first original cold test results to the results obtained from the new heater cold tests.

In conclusion, the research project has been a success. It has proven the successful operation of the new heater design for the Mansell Infant Retrieval System. The design has far exceeded the requirements outlined in the IEC.60601-2-20 Australian standard in both the cold test results and the warm-up time results. The developed temperature logging device operated in a manner that was well in excess of what the previous expectations were for its operation. If more time was permitted removal of the LabJack would have been the next stage and replaced with a microcontroller.

8.2 Further Work

The majority of the project has been completed however the automation program still remains to be completed. At the current stage the automation program is capable of communicating with the LabJack and collecting data. However the gathered data is not correct. If more time was permitted this could be completed and in operation. Also removal of the LabJack and replacement with a microcontroller would also be beneficial in the future.

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Appendix A

Project Specification

Project Specification

For: **Anthony Vadalma**

Topic: Infant Transport Incubator Cold Performance

Supervisors: Dr John Leis

                Dr John Grant-Thomson

Sponsorship: Faculty of Health, Engineering & Sciences

                Wenross Holdings

Project Aim: The aim is to test the newly designed heating element for a Mansell
                Neocot. The test is to ensure that the internal environmental temper-
                ature meets the specifications outlined in the IEC.60601-2-20 standard.
                The requirements are that the internal temperature must not deviate by
                more than +/-3 degrees Celsius from the normal operating temperature
                of 36 degrees Celsius. This requirement must be met while the Neocot
                is placed in an environment with an external ambient temperature of -5
                degrees Celsius.

Program:

1. Research and understand the requirements of the IEC.60601-2-20 standard

2. Research temperature sensing devices suitable for this application.

3. Research information on how to properly design, construct and test a low noise
   Amplifier circuit.

4. Design, construct and test an amplifier circuit suitable for the use in temperature
   measurements.

5. Research a suitable A/D device for the application and capture data from Am-
   plifier circuit.

6. Design software to plot real-time temperature measurement data.

7. Determine the signal filtering requirements for the sensor measurements.

8. Compare the results obtained with the Australian standards temperature devia-
   tion requirements.

As time and resources permit:

1. Construct a complete system to automatically read and log temperatures and generate graphs.

<div align="center">Agreed:</div>

Student Name:	Anthony Vadalma
Supervisor 1 Name:	Dr John Leis
Supervisor 2 Name:	Dr John Grant-Thomson
Examiner:	Chris Snook
Date:	3rd March 2014

Appendix B

MATLAB Code

B.1   Averaging Code:

Listing B.1: LabJack averaging program using MATLAB.

```matlab
%
%Wenross Holdings, Neocot Research Project, Averaging code
%Anthony Vadalma, 0061019356, 6/12/2013
%

%
%Clearing all previous data values
clc
clear all
%

%
%Positioning of File location
File = 'Cold_Test_23_7_2014.csv';
File1 = 'Cold_test_23_7_2014.xlsx';
%

%
%Reading the csv file produced by the Labjack
Data = csvread(File);
%

%
%Averaging filter
A = Data(:,1);
B = Data(:,2);
C = Data(:,3);
D = Data(:,4);
counterA = 1;
counterB = 1;
output1 = zeros(floor(length(A)/250), 3);
output2 = zeros(floor(length(A)/250), 3);
while counterA <= length(A)-250
    SampleA = A((counterA:counterA + 250),:);
    SampleB = B((counterA:counterA + 250),:);
    SampleC = C((counterA:counterA + 250),:);
    SampleD = D((counterA:counterA + 250),:);
    averageA = mean(SampleA);
    averageB = mean(SampleB);
    averageC = mean(SampleC);
    averageD = mean(SampleD);
    output1(counterB,:) = [counterB averageA averageB];
    output2(counterB,:) = [counterB averageC averageD];
    counterA = counterA + 250;
    counterB = counterB + 1;
end
%
```

```matlab
%————————————————————————————————————————
%% Displaying Maximum and Minimum Temperature Values LM35 Probes
figure()
A = Data(:,1);                    %External Temperature Sensor
B = Data(:,2);                    %Internal Temperature Sensor
x1 = min(B);                      %Minimum Temperature Inside Neocot
x2 = min(A);                      %Minimum Temperature Outside Neocot
x3 = max(B);                      %Maximum Temperature Inside Neocot
x4 = max(A);                      %Maximum Temperature Outside Neocot
disp('The estimated error of the results is +-1 degree celsius')
disp('Maximum Temperature Outside the Neocot')
Y1 = -3.6199*x1+17.76;
disp(Y1)
disp('Maximum Temperature Inside the Neocot')
Y2 = -3.7068*x2+16.928;
disp(Y2)
disp('Minimum Temperature Outside the Neocot')
Y3 = -3.6199*x3+17.76;
disp(Y3)
disp('Minimum Temperature Inside the Neocot')
Y4 = -3.7068*x4+16.928;
disp(Y4)
YI = -3.6199*output1(:,3)+17.76;
YE = -3.7068*output1(:,2)+16.928;
plot((output1(:,1)/60),YI,'r')
xlabel('Time(Minutes)','FontSize',15)
ylabel('Temperature (Degrees Celsius)','FontSize',15)
title('Neocot Cold Performance Test LM35 Probes','FontSize',15)
set(gca,'fontsize',15)
hold on
Time = xlsread(File1,'A:A');      %Time interval in seconds
Sen5A = xlsread(File1,'R:R');     %5 sensor Board Point A value
DT = xlsread(File1,'G:G');        %Display Temperature value
plot(Time/60,Sen5A);
grid on
%————————————————————————————————————————

%————————————————————————————————————————
%% Displaying maximum and minimum temperature values Thermistor
figure()
C = Data(:,3);                    %External Temperature Sensor
D = Data(:,4);                    %Internal Temperature Sensor
x5 = min(D);                      %Minimum Temperature Inside Neocot
x6 = min(C);                      %Minimum Temperature Outside Neocot
x7 = max(D);                      %Maximum Temperature Inside Neocot
x8 = max(C);                      %Maximum Temperature Outside Neocot
disp('The estimated error of the results is +-1 degree celsius')
disp('Minimum Temperature Inside the Neocot')
Y5 = ((0.0004)*x5^5)-(0.0042*x5^4)+(0.0071*x5^3)-(0.1008*x5^2)...
    +(3.0172*x5)+22.64; %Minimum Temperature Value Inside Neocot
disp(Y5)
disp('Minimum Temperature Outside the Neocot')
```

```matlab
Y6 = ((0.0004)*x6^5)-(0.0042*x6^4)+(0.0071*x6^3)-(0.1008*x6^2)...
    +(3.0172*x6)+22.64; %Minimum Temperature Value Outside Neocot
disp(Y6)
disp('Maximum Temperature Inside the Neocot')
Y7 = ((0.0004)*x7^5)-(0.0042*x7^4)+(0.0071*x7^3)-(0.1008*x7^2)...
    +(3.0172*x7)+22.64; %Maximum Temperature Value Inside Neocot
disp(Y7)
disp('Maximum Temperature Outside the Neocot')
Y8 = ((0.0004)*x8^5)-(0.0042*x8^4)+(0.0071*x8^3)-(0.1008*x8^2)...
    +(3.0172*x8)+22.64; %Maximum Temperature Value Outside Neocot
disp(Y8)
disp('Average Temperature during the 15 minutes below zero')
YI2 = ((0.0004)*output2(:,3).^5)-(0.0042*output2(:,3).^4)+...
    (0.0071*output2(:,3).^3)-(0.1008*output2(:,3).^2)+...
    (3.0172*output2(:,3))+22.64; %Internal Temperature
YE2 = ((0.0004)*output2(:,2).^5)-(0.0042*output2(:,2).^4)+...
    (0.0071*output2(:,2).^3)-(0.1008*output2(:,2).^2)+...
    (3.0172*output2(:,2))+22.64; %External Temperature
plot((output2(:,1)/60), YE2,'r')
xlabel('Time(Minutes)','FontSize',15)
ylabel('Temperature (Degrees Celsius)','FontSize',15)
title('Neocot Cold Performance Test Thermistor Probes'...
    ,'FontSize',15)
set(gca,'fontsize',15)
hold on
Time = xlsread(File1,'A:A');      %Time interval in seconds
Sen5A = xlsread(File1,'R:R');     %5 sensor Board Point A value
DT = xlsread(File1,'G:G');        %Display Temperature value
plot(Time/60,Sen5A);
grid on
%————————————————————————————————————————————————
```

B.2 TeraTerm Plotting Code:

Listing B.2: MATLAB program to generates plots from TeraTerm.

```matlab
%————————————————————————————————————
%Wenross Holdings, Neocot Research Project, TeraTerm Results
%Anthony Vadalma, 0061019356, 18/11/2013
%————————————————————————————————————

%————————————————————————————————————
%Clearing all previous data values
clc
clear all
%————————————————————————————————————

%————————————————————————————————————
%Positioning of File location
File = 'Previous_Heater_3_7_14.xlsx';
%————————————————————————————————————

%————————————————————————————————————
%% Reading and Plotting of 5 sensor board Temperature values
Time = xlsread(File,'A:A');        %Time interval in seconds
Sen5A = xlsread(File,'R:R');       %5 sensor Board Point A value
Sen5B = xlsread(File,'S:S');       %5 sensor Board Point B value
Sen5C = xlsread(File,'T:T');       %5 sensor Board Point C value
Sen5D = xlsread(File,'U:U');       %5 sensor Board Point D value
Sen5E = xlsread(File,'V:V');       %5 sensor Board Point E value
plot(Time/60,Sen5A,Time/60,Sen5B,Time/60,Sen5C,Time/60,Sen5D,...
     Time/60,Sen5E)
xlabel('Time_(Minutes)')
ylabel('Temperature_(Degrees_Celsius)')
title('5_Sensor_board_Temperature_readout_-_Previous_Heater')
legend('Sensor_A','Sensor_B','Sensor_C','Sensor_D','Sensor_E')
grid on
% axis([0,60,30,40])
%————————————————————————————————————

%————————————————————————————————————
%% Reading and Plotting of 4 Heater Temperature Values
Time = xlsread(File,'A:A');         %Time interval in seconds
HT1 = xlsread(File,'L:L');          %Heater 1 Temperature value
HT2 = xlsread(File,'M:M');          %Heater 2 Temperature value
HT3 = xlsread(File,'N:N');          %Heater 3 Temperature value
HT4 = xlsread(File,'O:O');          %Heater 4 Temperature value
AMB = xlsread(File,'W:W');          %Ambient Temperature
plot(Time/60,AMB,Time/60,HT1,Time/60,HT2,Time/60,HT3,...
     Time/60,HT4)
xlabel('Time_(Minutes)')
ylabel('Temperature_(Degrees_Celsius)')
title('4_Heater_Temperature_readout')
legend('Sensor_A','Sensor_B','Sensor_C','Sensor_D','Sensor_E')
```

```matlab
grid on
%————————————————————————————————————————

%————————————————————————————————————————
%% Control Sensor readings
Time = xlsread(File,'A:A');          %Time interval in seconds
CT = xlsread(File,'D:D');            %Control Temperature value
TCS = xlsread(File,'E:E');           %Top Control Sensor value
BCS = xlsread(File,'F:F');           %Bottom Control Sensor value
plot(Time/60,CT,Time/60,TCS,Time/60,BCS)
xlabel('Time (Minutes)')
ylabel('Temperature (Degrees Celsius)')
title('Control Sensors readout')
legend('Control Temperature','Top Control Sensor',...
    'Bottom Control Sensor')
grid on
%————————————————————————————————————————

%————————————————————————————————————————
%% Display Sensor plotting
Time = xlsread(File,'A:A');          %Time interval in seconds
DT = xlsread(File,'G:G');            %Display Temperature value
TDS = xlsread(File,'H:H');           %Top Display Sensor value
BDS = xlsread(File,'I:I');           %Bottom Display Sensor value
plot(Time/60,DT,Time/60,TDS,Time/60,BDS)
xlabel('Time (Minutes)')
ylabel('Temperature (Degrees Celsius)')
title('Display Sensors Temperature readout')
legend('Display Sensor','Top display sensor',...
    'Bottom display sensor')
grid on
%————————————————————————————————————————

%————————————————————————————————————————
%% Single Sensor Plotting
figure()
Time = xlsread(File,'A:A');          %Time interval in seconds
Sen5A = xlsread(File,'R:R');         %5 sensor Board Point A value
DT = xlsread(File,'G:G');            %Display Temperature value
plot(Time/60,Sen5A);
xlabel('Time (Minutes)')
ylabel('Temperature (Degrees Celsius)')
title('Cold Temperature Test Internal Temperature')
grid on
%————————————————————————————————————————
```

Appendix C

Automating Temperature Data Retrieval Program

```
Private Sub Calibrate_Click()

    Dim Output As Integer

    Output = MsgBox("You are about to start Calibration" & _
        "Procedure", vbOKCancel, "Calibration")

    If Output = 1 Then
        MsgBox "Ensure Labjack USB Cable is connected to" & _
            "Computer and Temperature device" & _
                "powered", vbExclamation, Calibration - Step 1"
        If Output = 1 Then
        MsgBox "Place ice in container with water and place" & _
                "calibrated Mercury Thermometer" & _
                "inside", ,Calibration - Step 2"
        If Output = 1 Then
        MsgBox "Wrap Thermistor temperature probes in" & _
                "plastic and place in 0 degree celsius" & _
                "water with Mercury" & _
                "Thermometer", , "Calibration - Step 3"
```

```
    If  Output = 1  Then
    MsgBox ”Allow  a  minimum  of  10  minutes  to  allow” & _
           ”Thermistor  to  adjust  to  water” & _
           ”Temperature”, , ”Calibration − Step  4”
    If  Output = 1  Then
    MsgBox ”Using  Calibrated  Multimeter  measure” & _
           ”voltage  level  across  GND and  the  AIN” & _
           ”port  that  is” & _
           ”being  tested”, ,Calibration − Step  5”
    If  Output = 1  Then
    MsgBox ”Ensure  that  Voltage  measured  is  equal” & _
           ”to  the  Calibrated  0  degee  celsius  voltage” & _
           ”on  the  temperature  device. If not  adjust” & _
           ”potentiometer  until  voltage  is” & _
           ”same”, , ”Calibration − Step  6”
    If  Output = 1  Then
    MsgBox ”Repeat  Procedure  for  second  Thermistor” & _
           ”probe”, , ”Calibration − Step  7”
    Output = MsgBox(”Would  you  like  a  Test  the” & _
           ”Calibration?”, vbYesNo, ”Calibration”)
    End  If
    End  If
    End  If
    End  If
    End  If
    End  If
  End  If


End  Sub

Private  Sub  Start_Click()
Dim  s  As  String , a() As  String
```

```
Dim lRet As Long
Dim CmdLine As String
Dim bLoop As Boolean
Dim count As Integer
Dim IsAltKeyDown As Boolean


Call Shell("C:\Windows\System32\cmd.exe", vbNormalFocus)
'vbHide
'vbNormalFocus


newHour = Hour(Now())
newMinute = Minute(Now())
newSecond = Second(Now()) + 1
waitTime = TimeSerial(newHour, newMinute, newSecond)
Application.Wait waitTime



Application.SendKeys ("cd c:\Users\Anthony\Documents\USQ\ _
            Work Project\John Leis Programs") ', True
SendKeys "{Enter}"


bLoop = True


count = 2
'Command$
Do While count < 1048576
    If IsAltKeyDown = False Then
        newHour = Hour(Now())
        newMinute = Minute(Now())
        newSecond = Second(Now()) + 1
        waitTime = TimeSerial(newHour, newMinute, newSecond)
        Application.Wait waitTime

        Application.SendKeys ("ain U6 0 0") ', True
```

```vba
        SendKeys "{Enter}"
        'CmdLine = lRet
        Worksheets("Sheet1").Cells(count, 1).Value = CmdLine

        newHour = Hour(Now())
        newMinute = Minute(Now())
        newSecond = Second(Now()) + 1
        waitTime = TimeSerial(newHour, newMinute, newSecond)
        Application.Wait waitTime

        Application.SendKeys ("ain U6 0 1") ', True
        SendKeys "{Enter}"
        'CmdLine2 = lRet
        Worksheets("Sheet1").Cells(count, 2).Value = CmdLine2
        count = count + 1
    Else
        End
        'Call CommandButton2_Click
        'count = 1048576
    End If
Loop

End Sub


Private Sub CommandButton2_Click()

bLoop = False

End Sub
```

Appendix D

Original Cold Test Report

Neocot Cold Test performed on 2/2/2007:

Preamble:

A Neocot cold performance test was conducted by Mansell Neonatal Transport on 2nd February 2007. However no formal report was written explaining the protocol on the results at that time. I was present when the test was conducted thus qualifying me to compile a new report commenting on the 2007 Neocot cold test.

Introduction:

The Neocot is often required to operate with a stable internal temperature for an infant even though the ambient temperature may be below zero as often is the case in many countries. The Neocot is required to perform as an incubator compliant with the International Standard IEC 60601-2-20, Edition 2, 2009. Section 201.12.1.113 of this standard deals with "Change in ambient temperature". In particular, the standard requires:

"Following the changes in ambient temperature described in the following test, the TRANSPORT INCUBATOR TEMPERATURE shall not differ from the CONTROL TEMPERATURE by more than 3 Degrees Centigrade."

Compliance is checked by the following test:

"The INFANT TRANSPORT INCUBATOR is operated as an AIR CONTROLLED TRANSPORT INCUBATOR connected to an external power source. When the STEADY TEMPERATURE CONDITION is established at an ambient temperature within the range 20 to 25 Degrees C and at a CONTROL TEMPERATURE of 36 degrees C, it shall be set to operate in accordance with the ACCOMPANYING DOCUMENTS without a SUPPLY MAINS and transferred into an environment where the ambient temperature is being kept at -5 (+/-2) Degrees C and the wind velocity is not more than 1 m/s.

After 15 minutes it shall be returned to an environment where the ambient temperature lies within the range 20 to 25 Degrees C and reconnected to an external supply and operated for a further 30 minutes. The TRANSPORT INCUBATOR TEMPERATURE

shall be monitored throughout the whole test and at no time shall it go outside the specific limits."

Test Protocol:

The test required a cold chamber capable of maintaining a temperature of -5 degrees +/- 2 degrees when the Neocot was inserted in the chamber. The environment in the chamber was measured with a calibrated digital thermometer connected to a data logging computer. The interior of the Neocot was also monitored with a calibrated digital thermometer connected to the data logging computer. RS-232 cables connected the Neocot and the chamber thermometers to the computer which remained outside the chamber in the normal environment of the day approximating 25 degrees C. The test was conducted as described in the standard IEC 60601-2-20 given in italics above.

Results:

The software in the computer stored temperature measurements every 2 seconds during the entire test. The files so created were presented in graphical form and the graph is annotated "Neocot Test Home Ice cream 02/02/07". This graph was produced by generating a MATLAB script that completed the task of reading in the data, generating a graph as well as calculating the average temperature during the required 15 minute interval. The data collected is stored in: projects/Neocot/cold test/cot test home ice cream 02022007.txt.

The graph and MATLAB code is attached to this report.

The graph has three traces. These are:

1. Ambient temperature (light blue)
   This is the actual temperature of the cold chamber environment surrounding the Neocot.

2. Neocot internal temperature (Dark Blue)
   This is the measured internal temperature inside the Neocot capsule following its initial temperature setting of 37 degrees C.

3. Display mix temperature (Green)

   This is the Neocot temperature control signal which is a mix of the Neocot top and bottom digital sensors. This data is not required for this test but it collected to determine how the control system was operating.

Interpretation of Results:

Looking at the attached graph entitled "Neocot Test Home Ice cream 02/02/07" a validation of the results can be undertaken. The IEC 60601-2-20 standard emphasises that the Neocot needs to remain in a cold environment with an ambient temperature of -5°C ±2°C for a period of 15 minutes. Due to the environmental temperature during most of the conducted test being well below -5°C the zero crossings were chosen to be the upper and lower limits due to the period of time between them being approximately 15.41 minute. If the average of the temperature points between the zero crossings is taken the average ambient environmental temperature over 15.41 minutes within the cold room can be seen to be approximately -5.84°C which satisfies the requirements of the IEC.60601-2-20 standard.

Discussion:

Therefore it can be seen that the Neocot has passed all the requirements outlined in the IEC 60601-2-20 Standard for operating in a cold environment.

Acknowledgement:

I wish to record the contribution to the report from my colleagues Paul Priebbenow and Anthony Vadalma who were able to recover the original 2007 data.

I wish to also acknowledge the assistance given by the Home ice-cream Pty Ltd for allowing the use of their cold storage facility.

Dr John Grant-Thomson, RFD, DFM, JP
B Eng, MSc, PhD, FIE (Aust), CP Eng (Biomed).

Appendix E

NATA Mercury Thermometer Calibration Record

WIKA

NATA CERTIFICATE OF TEST

Pressure and
Temperature Measurement

Report on :   MERCURY IN GLASS THERMOMETER

ABN 49 004 465 936

Customer :   STOCK

WIKA Australia Pty Ltd
Unit N, 10 - 16 South Street
Rydalmere NSW 2116
Australia

CERTIFICATE No:	33/06	**DIVIDED TO**	0.5°C	
NAME OF THERMOMETER	AMA	**THERMOMETER No.**	0559336	
RANGE	-10.0° to 110.0°C	**ITEM No.**	526.10938	
WORKS ORDER No:	35112	**IMMERSION**	TOTAL	

RESULT OF TEST

THERMOMETER READING	CORRECTION TO READING	TEMPERATURE	UNCERTAINTY
°C	°C	°C	°C
0.00	+0.00	0.00	±0.08°C
25.00	+0.05	25.05	±0.10°C
50.00	+0.10	50.10	±0.10°C
75.00	+0.15	75.15	±0.10°C
100.00	+0.10	100.10	±0.12°C
0.00	+0.00	0.00	±0.08°C

DATE ISSUED: 27-Jan-06

DATE TESTED: 20-Jan-06

SHEET No: S20.06

REFERENCE EQUIPMENT: 9981802
9981809
9855810
9855811
9982193
ICE POINT STANDARD

Conditions of Test:

1. Device Under Test was tested in the Vertical Position.
2. The Temp. Device Under Test   **Does Comply**   with stated sections.
3. Coverage factor at confidence level 95%   **K=**   1.99
4. Uncertainty of reported corrections (rounded)   ±   0.1°C
5. Test was based on sections of   **AS 2831**   (Refer to note 4, page 2 of this report)
6. Comments: NIL.

CHECKED BY:

NATA SIGNATORY.
NEAL MURRELLS

N A T A

Accreditation Number 410, Heat & Temperature Laboratory

The tests, calibrations or measurements
covered by this document are traceable to
Australian National Standards of Measurement.

A Laboratory Report may Not be published except in full unless permission for the publication of
an approved abstract has been obtained from WIKA Australia Pty.Ltd. This laboratory is accredited
by the National Association of Testing Authorities, Australia.The Test(s) reported herein have
been performed in accordance with its terms of accreditation.

F/PA/027

WIKA Australia Pty Ltd   Tel: (02) 8845 5222   Fax: (02) 9684 4767
Email: sales@wika.com.au   www.wika.com.au

Sheet 1of 2

Appendix F

Additional Temperature Meter Calibration Table

NATA Thermometer Temperature (°C)	Meter Reading (°C)	Offset (°C)
-9.5	-4.5	-5
-7	-3.1	-3.9
-5	-1.5	-3.5
-3	0	-3
-1	2	-3
1	3.8	-2.8
2.5	5.1	-2.6
4	6.2	-2.2
6	8.1	-2.1
9	10.8	-1.8
11	12.4	-1.4
12.5	13.9	-1.4
13	14.5	-1.5
14	15.3	-1.3
15.5	17	-1.5
16.5	18	-1.5
17	18.1	-1.1
19	20.2	-1.2
20	20.9	-0.9
21	21.9	-0.9
23	24.1	-1.1
25	25.9	-0.9
27	27.7	-0.7
31	31.7	-0.7
33	33.7	-0.7
36	36.4	-0.4
39	39	0
41	40.6	0.4

Table F.1: Calibration table indicating results of additional digital temperature meter