University of Southern Queensland

Faculty of Health, Engineering and Sciences

The Effect of Materials and Conditions on Reflectorless Electronic Distance Measurements from a Total Station

A dissertation submitted by

Jeffrey James

In fulfilment of the requirements of

ENG4111 and 4112 Research Project

Towards the degree of

Bachelor of Spatial Science (Honours) (Surveying)

Submitted October, 2016

Abstract

Surveying has been a profession that has been around for many years now. Over the years with advancements in technology the equipment and techniques used to survey have changed. Currently there is a big use of reflectorless electromagnetic distance measurement (REDM) form a variety of platforms and in particular total stations. What is unknown is what effect that materials and conditions have on the REDM.

Twelve different materials were tested ranging from timber of varying types, concrete and metal of varying types. Six different conditions were tested including cold and wet targets. Ten different colours were also tested ranging from white to black in the colour spectrum. The incorporation of angles was also used as a factor of target influences. All the items tested changed the properties of the target in different ways.

Testing was carried out over a baseline under confined conditions to eliminated other sources of error associated with EDM and a procedure was developed to aid with the eliminated of other errors. As a result of the tight parameters set it allowed for any deviations in measurements to be associated with the target and interesting results were derived.

The results for the worst angle was 60^{o} and the worst colour was produced by black targets. The black targets had a mean of 3.7mm longer than the true distance and had a range of 15.16mm. The best performing condition was the targets influence by the cold and produced a range of 1.08mm and a mean of 0.0012mm less than the true distance. The metal targets performed the worst in relation to the range and the besser block had a mean of 1.65mm longer than the true distance as the worst material.

More testing can be done to provide more knowledge on how targets interact under different scenarios such as baseline distances, different lasers, different conditions and different materials. The combinations are almost endless.

Conclusions can be made that materials and conditions do have an effect of REDM and knowledge should be obtained to determine the likelihood of potential errors associated with REDM under different scenarios in order for the surveyor to obtain correct data.

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Limitations of Use

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111/ENG4112 Research Project

Certification of Dissertation

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Jeffrey James

0061017282

Acknowledgements

This research was carried out under the supervision of Ms Zahra Gharineiat, Lecturer, School of Civil Engineering and Surveying at the University of Southern Queensland. I would like to thank all staff at the University of Southern Queensland with particular mention to Ms Zahra Gharineiat for her help and guidance throughout the research.

I would also like to thank my employer Mr Michael Bereza of Bereza Surveying for his understanding and wiliness to provide assistance and equipment as required. I would also like to thank the clients of the surveying firm for their acceptance and help where required.

I would finally like to thank my partner Christine, my dog Coby and my family for their patience and understanding throughout the research project.

Contents

List of Figures

List of Tables

Acronyms

ATR	Automatic Target Recognition
EDM	Electromagnetic Distance Measurement
GNSS	Global Navigation Satellite System
IR	Infra-Red
Laser	Light Amplification by Stimulated Emission of Radiation
PPM	Parts Per Million
PS	Power Search
REDM	Reflectorless Electromagnetic Distance Measurement
TOF	Time of Flight
TS	Total Station

Units of Measurement

ºC	Degrees Celsius
km	Kilometre
m	Metres
mbar	Millibars
mm	Millimetres
Mrad	Milliradian
s	Seconds
μm	Micrometre
W	Watt

1 Introduction

Surveying has been a practice that has been around for hundreds of years and has evolved and developed over this time. With ever changing techniques and technology, the question of credibility and accuracy is always an important topic of discussion amongst developers, representatives and ultimately the user. This paper will look at the accuracies of Reflectorless Electromagnetic Distance Measurements (REDM) and in particular the impact that the target material and the conditions in which the target may lie to determine what effect they have on the measurement. The technology of REDM has been around for a while, however there is still a shortage of information relating to particular components of the measurement process. This paper will provide information and answers to common practices and ultimately increase the knowledge and understanding that surveyors have in relation to the use of this technology.

1.1 Project Development

The development of this project started back in 2014 from a construction site located on the South Coast of New South Wales. The job was an architecturally designed equestrian centre and as part of the surveyors' role on site was to ensure the correct positioning of the required elements through set out and checking procedures. This involved a lot of traditional surveying techniques along with the use of reflectorless measurements from a total station. The reflectorless measurements became more demanding as the project advanced due to the complexity and the requirement for a pristine finish. Some of the points that required survey were in difficult and hard to access locations. For example, the setting out of a ceiling pattern on the underside of a roof, 10 metres in the air. The material to be set out on was a combination of aluminium, steel and timber. Other situations encounter was setting out wall patterns on steel sheets what were double the ambient air temperature at the time. Above are only a couple of examples of the challenges faced throughout the construction of the facility.

With all the different elements and inconsistencies involved in the job the discussion of accuracy was becoming a topic of conversation. Whilst the data from the hand held recorders were displaying the correct information the question "is it actually correct" was still a topic of conversation.

There was evidence that external conditions and or materials were causing an alteration to a reading due to different measurements being obtained under different circumstances. Due to the uncertainty of certain measurements selected tasks had to be completed using traditional methods of a prism and an assistant.

1.2 Project Aim

To develop an understanding of what effect materials, have on a reflectorless electromagnetic distance measurement and to determine if certain conditions effect the reading as well.

To provide the surveyor with knowledge and confidence so that the task being performed is reliable and accurate.

1.3 Objectives

Although REDM measurements are considered accurate enough for most purposes it is unknown at what point these inaccuracies become too great. Based on the aim of this research project the following objectives have been derived.

- To gather an understanding of current knowledge in relation to error in REDM.
- To identify common materials and conditions that may affect the REDM.
- To determine the effect that different building materials have on a REDM from a total station.
- To determine the effect that different conditions have on a REDM from a total station.
- To create a table of materials that outlines the probable error against certain materials and conditions.

1.4 Project Implications

The project has the potential to discover information that could provide implications in the real world of surveying. If the information is found to have a major effect on REDM then the credibility of the technology will become invalid. This would be a huge problem as this technology is fundamental to new pieces of surveying equipment and would mean the technology would need to be refined in order to be usable by the surveyor. Whilst any indifferences found are not expected to be significant enough to cause credibility issues but more to gather an understanding of how much the conditions and materials could affect a measurement and using this information to determine if the measurement is accurate enough of the purpose of the measurement.

2 Literature Review

Electromagnetic distance measuring also known as EDM is a vital part of surveying technology. Traditionally the EDM would depart from the total station and travel through un obstructed space, it would then come into contact with a prism and would return the signal back to the total station giving a distance through calculation. Advancements in technology allows for this process to happen without the need for a reflecting prism to return the signal. This creates the term Reflectorless EDM. Its uses are constantly being adapted into new pieces of equipment and applications in the profession of surveying and mapping of the land and environment we inhabit.

Surveyors know and understand the accuracies, limitations and sources of error associated with traditional surveying (reflecting the EDM back from a prism). With reflectorless technology, there is no need for a prism as the EDM can reflect off any surface it comes into contact with. We know and understand the EDM component of the measurement, the sources of error associated and techniques on how to reduce the error. Creating what would be a true distance and a distance that can be replicated into the future under different circumstances and conditions. However, there is little understanding of what effect the reflecting surface has on the EDM and how conditions can affect the reflecting surface and potentially affect the EDM again.

Gathering an understanding of how different materials and under different conditions effect the reflectorless EDM, will provide the surveyor and the industry with the appropriate knowledge to determine if the current technique is appropriate for the required application and observation. This will be high value knowledge, as surveyors try to eliminate and or reduce the sources of error associated with their work. This will create data that is more accurate and reliable.

2.1 History of Surveying Measurements

The practice of surveying dates back to 2900BC in Egypt (Wolf, 2002), where land registers were used to redefine farm boundaries after flooding events on the river Nile. They would have used a standard unit of rope to create distance and this is evident in the building of the Great Pyramid of Giza being incredibly accurate for its time. From the 1st century, the Roman Empire defined surveying as a profession and surveyors used basic measurement techniques to divide the Roman Empire into lots for taxation purposes. They also developed new surveying instruments for the purpose of measuring horizontal and vertical angles as well as distances along lines. In Europe in the 18^{th} century, the position technique of triangulation was established and this technique is fundamental to the development of modern-day land positioning, measurement devices and techniques.

In the early days of British Colonisation in Australia, measurement methods that were used were as rough as pacing with footsteps. This process was very inaccurate and difficult to replicate. This was later changed to use a standardised unit of length known as a chain. The next advancement from the chain was the creation of steel bands and tapes, followed by EDMs and now Global Navigation Satellite System (GNSS) for distance measuring.

2.1.1 Theodolite

The theodolite was invented in 1570 by an English surveyor by the name of Thomas Diggs (Wolf, 2002). It was a device used for measuring angles in the horizontal and vertical plane. It was originally a circular plate with markings used to read direction and angle. In the mid 1800's the telescope was added to the theodolite significantly increasing the accuracies of the readings. Further advancements from this was to create digital readouts and automatic levelling. All these components are fundamental to what a theodolite is today.

2.1.2 Chain

The chain was developed by an Englishman by the name of Edmund Gunter in 1620. Its construction was made of heavy tempered wire and consisted of 100 individual links. Therefore 100 links created a chain. This was a very useful standard of measurement as it was converted quite easily into miles and even into area (Wolf, 2002). The usefulness of the chain is shown in the Figure 2.1 below.

MEASUREMENTS TO REMEMBER	
1 LINK	7.92 INCHES
25 LINKS	1 ROD/POLE/PERCH 16 1/2 FEET
100 LINKS	1 CHAIN OR 66 FEET
10 CHAINS	1FURLONG OR 220 YARDS
80 CHAINS	1 MILE OR 5280 FEET
10 SQUARE CHAINS	1 ACRE

Figure 2-1 Link and Chain Conversion

(Wright, n.d.)

With the chains advantages, came some disadvantages. Gunter’s Chain was very heavy, bulky and awkward to carry. Due to the many linked components the issue of wear and corrosion at the joints created an unstable length of measurement. The Chain was attached with markers at intervals of 10 links with a specific marker for each increment to 10 links which allowed for quicker readings in the field. Marking and the chain set up can be seen in Figure 2.2. Despite the issues with the chain, this method of distance measurement was the preferred way of measurement for hundreds of years.

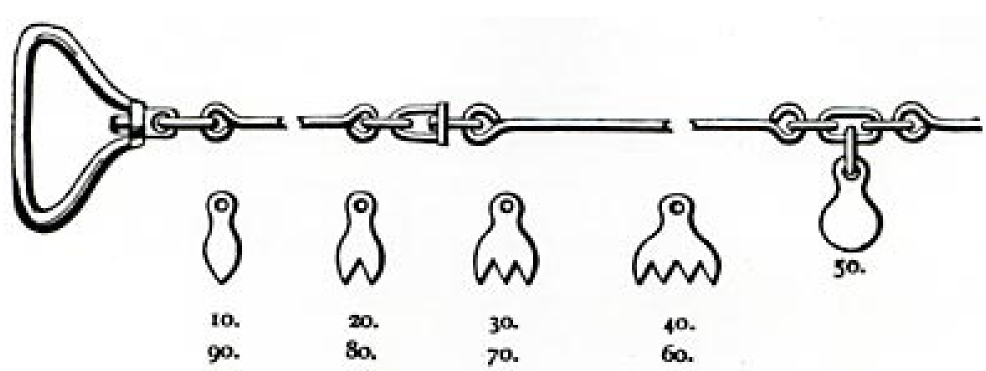


Figure 2-2 Gunter's Chain

(Queensland Government, 2016)

2.1.3 Tapes

Tapes began succeeding chains in the mid-1800s and were generally made of steel at a length of 100 feet long. These tapes were much more convenient than the chain as they were lighter, easily managed and eliminated the problem of wear and corrosion (Wolf, 2002). Tapes still came with issues such as a coefficient of expansion and contraction due to temperature. Sag was also a factor that had to be applied and taken into account to achieve the right distance. This was done by pulling the tape at a required tension to apply a sag correction. They could also be made of cloth which helped eliminate the expansion and contraction factor of steel. High precision tapes were also available at this time. They were made from nickel steel and were called invar tapes. These tapes were used in high precision works because of their very low thermal expansion coefficient but they were fragile and weren't allowed to touch the ground due to potential damage to occur. Extreme care was required when being used.

2.1.4 EDM

The EDM was first developed in 1948 by a Swedish physicist by the name or Erik Bergstrand (Wolf, 2002). This EDM instrument was called a geodimeter and was created as a result of research into measuring the velocity of light. The geodimeter would transmit visible light to a target where it would reflect and return to the emitting device, from which a distance could be calculated from the time of travel. This technology would dramatically change the surveying industry and is the first component of developing REDM technology. The first EDM's were very bulky and heavy. Over time their development meant they became lighter and more compact to the stage where they could be mounted to the top of a theodolite. Enabling a distance and an angle to be measured for the first time from one point with one setup. Figure 2.3 below shows what a normal setup would look like in this situation.

Figure 2-3 EDM Mounted on a Theodolite

(Wild Heerbrugg , n.d.)

2.1.5 Total Station

With the advancements of technology and computers, it has allowed a piece of equipment called a total station to be created. The total station is a vital piece of equipment in modern day surveying as is a machine that combines two very important pieces of equipment into one. This is the EDM component and the theodolite component all into one. These machines were first available in the 1980’s and have formed the backbone of what total stations can do today. Figure 2.4 illustrates what a modern day total station looks like.

Figure 2-4 Leica TS15 Total Station

(One Point Survey, 2016)

Modern day total stations are essentially a robot capable of performing many tasks at the touch of a button from the operator. Everything is electronic and seamlessly transitional from office to field making survey which was traditionally a two-person operation into a profession that can be easily performed by an individual.

2.2 Credibility of REDM

The credibility of reflectorless EDM is important to understand before in depth research can be performed on small amounts of deviation. If the credibility of the technology is proven to be insufficient it could have dramatic effects of where the technology is heading and who would be willing to use unreliable technology in a spatial environment where millimetres can be a major importance.

2.2.1 Previous Research

In 2010 research conducted by E. Lambrou and G. Pantazis has suggested that more investigation would be required before REDM could be considered a reliable measurement technique. They have identified ten points of interest in evaluating the credibility of REDM and the points are as follows:

1. The length of the distance measured;
2. The texture and the colour of the surface to which the measurement is made;
3. The reflectivity of the surface to which the measurement is made;
4. The illumination of the surface;
5. The incidence angle of the laser beam with respect to the surface;
6. The position of the measured point when measuring to inner or outer corners;
7. The size and shape of the footprint of the laser beam;
8. The area of the surface needed for reflection of the laser beam;
9. The laser class of the light beam used for measurement;
10. The type of electronic distance measurement technology used for the measurement.

(Lambrou & Pantazis, 2010)

Since the conclusion of their report in 2010 technology advancements have occurred and their reasoning behind their conclusion could quite well be different now in 2016 if they were to re conduct. Their 10 points of assessment are still valid as they are key points in what could alter a REDM. An understanding of the effects of each individual item, will provide a better understanding of what points affect the measurement and by how much rather than analysing all the effects in one go.

2.2.2 Safety

In the industry of surveying safety is always important and shouldn't be compromised in order to achieve a result. Through the advancements in technology, once deemed risky activities can now be performed with the reduction or even elimination of the risk. This is evident with the use of REDM technology. A major sector focusing on safety and technology is the mining industry. They are always looking for ways to improve safety through new technology. Original methods of surveying in the mines was for personal to walk around the mine floor amongst moving plant, near large holes and next to near vertical rock faces. With the introduction of REDM technology the surveyor would now be able to safely survey mine walls from a position that poses less risk (Talend, 2009). Along with the safety, the ability to actually locate points on a mine wall would only be possible with reflectorless technology. This demonstrates the credibility of the technology for its intended use.

With a lot of surveying technology and equipment, they are first tested in the mines and then adapted and further enhanced to make them usable in the urban environment. The tolerances associated in the mines are generally quite large and the technology works extremely well in this environment.

2.2.3 Advantages

The main advantage of REDM is the ability to survey what would be once inaccessible points. These inaccessible points could be anything from an object at a height such as the height of light poles or sags in powerlines to an object in a dangerous location such as a busy roadway or even an area of unstable ground (Reda & Bedada, 2012). The technology can allow for faster data collection and with increased accuracies compared to traditional surveying methods. The technology has opened up a new way of thinking about how data can be captured. It has also allowed for new information to be presented on survey plans which can be of high relevance for the purpose of the original survey.

2.3 Characteristics of REDM

It is essential to understand how an EDM works and the components that make up the device and how it operates to gather an understanding of the potential error and how to measure it. EDM is a laser which stands for Light Amplification by Stimulated Emission of Radiation (Key, 2005). Lasers have a very versatile range of applications and because of this they are divided into different classes. These classes limit the use of types of lasers to specific applications. Table 2.1 below outlines the class of lasers and which ones can be used in the building and construction sector.

Table 2.1 Laser Classifications

Laser Class	**Description**
Class 1	Safe for use under all conditions of exposure.
Class 2	Low-powered lasers that may require some administrative controls but present little hazard (for example, eye protection is usually provided by normal blink and aversion responses).
Class 3A	These lasers emit higher levels of light and their use requires more stringent engineering and administrative precautions in order to ensure they are not used with optical instruments (for example, a builder's level or theodolite) which would concentrate the beam so that it would all enter the eye.
Class 3B (Restricted)	These lasers operate at the same power levels as Class 3A but have higher levels of irradiance (power density). These lasers can be used for building or construction applications but should **not** be used in dimly lit building or construction applications (that is less than approximately 100 lux).

Class 3B	These lasers emit either invisible or visible radiation potentially hazardous to the eye and skin. These lasers must **not** be used for building or construction tasks.
Class 4	These lasers are high-power devices capable of producing diffuse reflections hazardous to the eye. Skin exposure to the direct beam of a Class 4 laser is also hazardous. These lasers must **not** be used for building or construction tasks.

(Safe Work Australia, 2012)

Total stations and specifically EDM's are usually classed as class 2 lasers. However selected models have lasers in the class 3B restricted class.

There are two main functions that the laser performs in the surveying industry. This is illustrated in Figure 2.5 and explained below.

- Visualising a point or straight line as implemented in levelling instruments such as rotating and line lasers
- Range measurement

  (Key, 2005)

Figure 2-5 Visualising Rotating Laser and Range Measurement Laser

(Stanley, 2012)

The visualising laser is a constant emission of a laser and is used for setting out square lines, horizontal level line and or vertical plumb lines. These can either be in the form of a continual rotating beam or a direct point.

Range measurement lasers are point focused beams and work on returning an emitted signal back to the device in order to calculate a distance. A modern total station has capabilities to perform both functions simultaneously.

2.3.1 Distance Measurement

For the purpose of EDM and REDM, they both use the range measurement function of a laser. Both EDM and REDM work exactly the same except for one difference. This being the amount of energy expressed when emitting the laser. EDM uses a very small amount of energy down to a few milliwats of power. Where the REDM uses quite considerably more power for the same signal. This power ranges anywhere from 1 to 20 watts (W) (Key, 2005). This high energy beam allows the signal to reflect off anything in its path creating the reflectorless component of the REDM. Because of this high energy and ability to reflect a signal back off anything it is important to make sure that there is no potential obstruction that could return an incorrect reading. There are two different ways that the beam can be emitted from the total station. Phase shift measurements and pulse distance measurements also known as time of flight (TOF). Each different type of emittance is better suited to different applications (Key, 2005)

2.3.1.1 Phase Shift

Phase shift is a measurement of a phase as it completes a cycle of 360 degrees. A cycle has a predetermined unit of length, this allows measurements to be derived by measuring the number of full cycles and part cycle in the returned wavelength. This part cycle is called the phase shift and is illustrated in Figure 2.6. If a returned signal is returned on a full cycle it is considered to have no phase shift (Reda & Bedada, 2012).

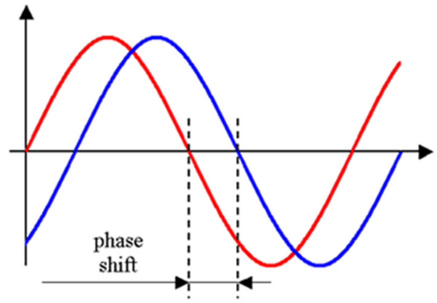


Figure 2-6 Phase Shift

(Australian Government - Bureau of Meteorology, 2016)

Phase shift measurements are considered to be the most accurate of the two methods as the beam is very narrow. However, it is limited in range because of error that can be accumulated in cycle phases. This is known a cyclic error. This potential error is reduced or eliminated from the reading by taking multiple readings to solve ambiguities before a result is displayed. This function is usually built into the EDM. Because of the multiple measurements that the total station will take, the time per point is slower than TOF measurements (Reda & Bedada, 2012).

The formula for calculating distance by this method is as follows and demonstrated in Figure 2.7;

$$D = 0.5(n\lambda + d) \tag{2.1}$$

Where:

D is the distance between the instrument and prism

λ is the wavelength of the modulated beam

n is the integral number of wavelengths in the double path of the light

d is the distance representing the phase difference

(Reda & Bedada, 2012)

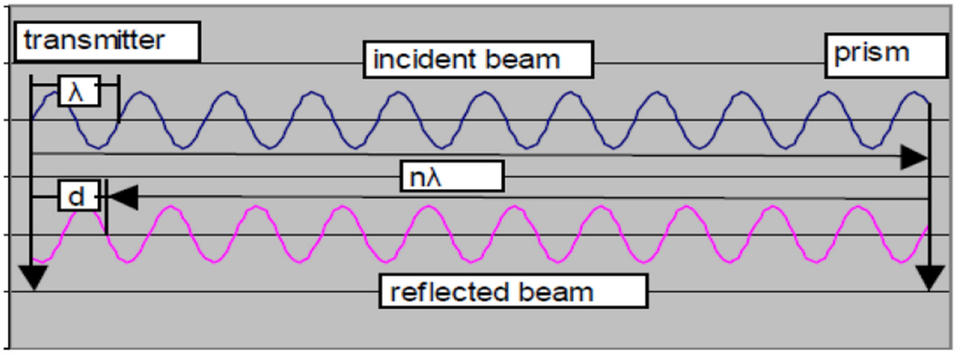


Figure 2-7 Calculation of Phase Shift EDM

(Reda & Bedada, 2012)

2.3.1.2 Pulse Method

Pulse method measurement also known as TOF transmits a signal from an emitter to a target and then immediately returns a signal along a parallel path to a receiver. Through time calculation a distance can be derived, giving the name time of flight. This is illustrated in Figure 2.8 below. The signal is emitted as a short pulse of intense radiation and can calculate the average of multiple signals in a short space of time (Reda & Bedada, 2012). This is where the name pulse method has been derived from.

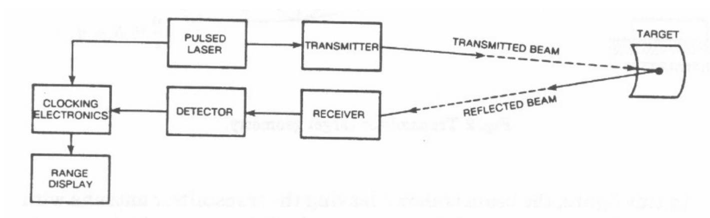


Figure 2-8 Pulse Method

(Anon., n.d.)

The pulse method is inaccurate over short distances but is a quick way of deriving a distance. Its main advantage is over long range distances due to the speed and relatively simple calculation. Upon the emitted signal coming into contact with a target the beam scatters and only one scattered signal returns to the receiver. The reason behind the returning signal travelling along a parallel path.

The formula for calculating distance by this method is as follows and demonstrated in Figure 2.9;

$$D = 0.5(c\Delta t) \tag{2.2}$$

Where:

D is the distance between the instrument and prism

c is the velocity of the signal

Δt is the difference in time from emitter to receiver

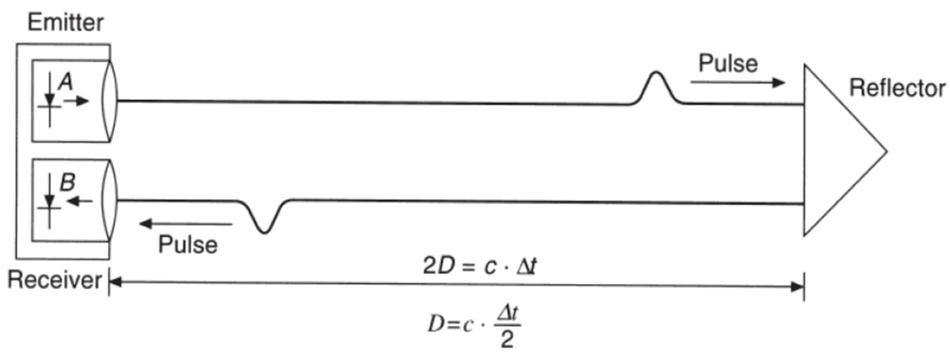


Figure 2-9 Calculation of Pulse distance EDM

(Reda & Bedada, 2012)

2.3.2 Beam Divergence

Beam divergence is directly related to REDM. Where traditional EDM with a prism can centre the signal, REDM cannot perform this centring process. The way beam divergence happens is when the signal leaves the total station it doesn't travel in a uniform shape or size. As a target becomes further away from the transmitter the laser beam gets bigger (Key, 2005). This is demonstrated in Figure 2.10. It is the same concept of how a flashlight works depending on the distance away from the target object.

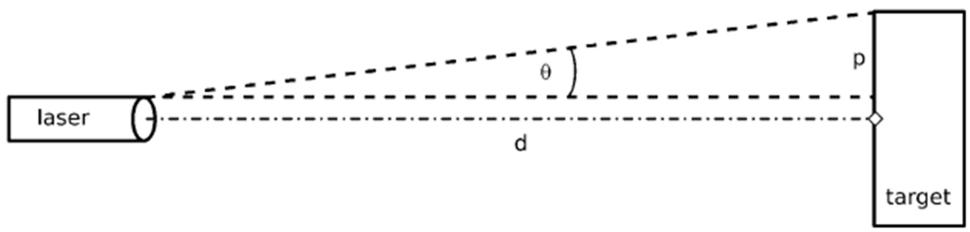


Figure 2-10 Beam Divergence

(Kowalczyk & Rapinski, 2014)

The further away the target is, the potential for a worse error to occur. As the beam gets bigger it can come into contact with more objects along the way. It also means that when the beam comes into contact with the target it is bigger than the point being surveyed. Different manufactures have different beam sizes and shapes varying from circles, ellipses and even trapeziums (Kowalczyk & Rapinski, 2014).

2.4 Systematic Errors in REDM

The main sources of error that have been identified to have an effect on reflectorless EDM measurements are; atmospheric corrections, EDM centring errors, instrumental errors, angle of incidence and target specific errors (Kowalczyk & Rapinski, 2014).

2.4.1 Atmospheric Corrections

Atmospheric corrections are required because any electromagnetic wave that passes through the atmosphere is affected due to the density of the air changing under different conditions. Because REDM uses a pulse or phase shift to determine the distance this correction is needed to be applied to ensure correct distance readings are obtained. This is usually applied in the emitting instrument so the adjustment can be calculated in real time. It is applied as a number in reference to parts per million (PPM). This is the error in millimetres (mm) for every kilometre (km). PPM is made up of temperature, pressure and relative humidity. Each individual element has a small effect on a distance which normally wouldn't be of much concern, however when combined together the effect is then magnified into an error of some significance.

2.4.1.1 Temperature

Temperature has the biggest impact on PPM. A change in temperature of 10 degrees Celsius (^{0}C) can change a measurement of 100m by 2mm. Most instruments are standardised around the 12^{0}C mark. If working in an area of over 30^{0}C, this can really start to have an effect on the distance if not applied correctly (Arseni, et al., 2015). It is important to note that an average temperature should be applied for long and or precise measurements as the temperature at the total station can be different to the temperature at the target.

2.4.1.2 Pressure

The air pressure has a relatively small effect on the total PPM. A change of 50 millibars (mbar) equates to approximate a change of 10 PPM. When converted to an effect over 100m it would mean a difference of 1mm. Pressure has less effect on PPM than temperature but more effect than relative humidity.

2.4.1.3 Relative Humidity

Relative humidity has a small effect on the distance especially over a short distance. Over a distance of 100m, relative humidity is said to have only 0.66mm to 1.3 mm difference as changes in relative humidity vary from 0% to 100% (Arseni, et al., 2015). It is still a condition that needs to be taken into account as slight changes can still change a distance result.

2.4.2 EDM Centring

Centring errors are normally human error and is a random error as a result of poor positioning of the target on the desired location and or poor calibration of equipment. This is easily overcome with the aid of a brace and correctly calibrated measuring and targeting instruments. Centring errors are not normally a source of error in reflectorless EDM because the target is a fixed object at a fixed location (Kowalczyk & Rapinski, 2014).

2.4.3 Instrument Errors

Instrument errors can be anything from statistical, drift, cyclic, alignment or slope (Kowalczyk & Rapinski, 2014). With an instrument in good calibration and regularly serviced these potential errors are considered to be very small and insignificant. These errors generally have very little to no effect over a short distance.

2.4.4 Angle of Incidence

Angle of incidence is another error that can occur. This occurs from the target not being perpendicular to the total station. This is an error very well associated with beam divergence. In the Figure 2.11 it can be seen how distort the beam can become in comparison to the true position.

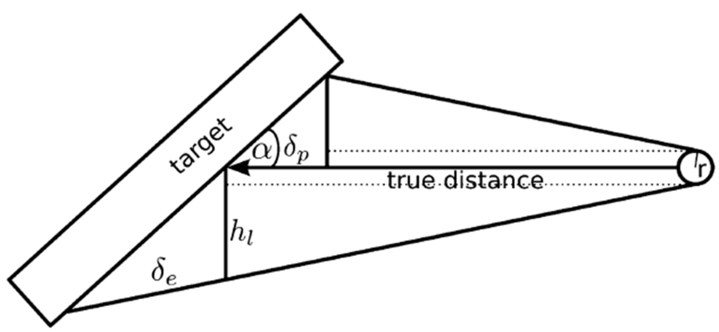


Figure 2-11 Angle of Incidence

(Kowalczyk & Rapinski, 2014)

This causes a depth distortion issue as a reading can be reflected from any point where the beam comes into contact with the target. Giving either a shorter distance, longer distance or the true distance. There is no guarantee that the error will be the same for each measurement.

2.4.5 Target

Target errors can be anything from the properties that make up the material to the environment where the target is located. This area of error is very vague and unknown. There are many different sources of error and many different combinations that can be derived from the different elements of a material and the different external conditions that could affect it.

2.5 Material Influence in REDM

As it has been stated before the target object can be a source of error for REDM. E. Lambrou and G. Pantazis have explored this concept and the results achieved were very concerning and ultimately leading to their conclusion of further development needs to done (Lambrou & Pantazis, 2010). As mentioned before this paper was from 2010 and technology has changed and newer instruments are now available. Their research investigated a variety of colours, textures and materials to gain an understanding of the effect that the material has on REDM. Some conclusions that have been drawn from this research has been that most measurement seemed to be of shorter distance and that certain materials provided either no result or a result of extreme variance. Some of their material of choice seemed to be for the effect of the research and not for practical use in the everyday practice of surveying.

2.5.1 Colour

As part of E. Lambrou and G. Pantazis research, they have made some conclusions on the effect of colour in relation to REDM. They have mentioned that darker colours and shades generally measure longer than the true distance. Where lighter colours and shades do the opposite and measure generally shorter distances (Lambrou & Pantazis, 2010). If you read the works conducted by K. Kowalczyk and J. Rapinski, they state that colour seems to have no effect on the distance measurement as any deviations of results could have been obtained from other sources of error and the deviations were generally within the tolerances for these errors and the machine (Kowalczyk & Rapinski, 2014). The type of lasers used for each test and results seems to play a part in the accuracy and precision of the data collected. It is unclear which set of results are definitive as there is very little comparable data published.

2.5.2 Texture

Differences in the texture can be anything from a rough surface like a brick or roof tile to a smooth surface like a metal roof gutter. The finish can be of gloss from a polished marble tile to a matt finish of a painted wall. From results published by E. Lambrou and G. Pantazis it can be seen that different textures can provide different results. Difference between a set of results against grey paper and grey cement was 25mm (Lambrou & Pantazis, 2010). If results such as this are true, then the accuracy of REDM would be proven to be very poor.

As time goes on new materials and composites are being used in the construction of buildings and infrastructure and creating new surfaces to in which REDM can be used. From previous research it is unclear to what degree a material of certain texture and colour has on a REDM.

2.6 Condition Influence in REDM

Very little is known about how conditions can affect a REDM. It is important to gather an understanding of what effect a condition can have on a measurement. As it will allow a surveyor to make better judgement if a REDM is going to be reliable or not. Common conditions can be the angle of incidence, illumination, target temperature and moisture. With each condition it is unknown what effect it has on a REDM and to what extents these conditions can be pushed in order to still achieve desired results.

2.6.1 Angle of Incidence

From previous research and an understanding of how angle of incidence works and happens, we understand that it has a direct effect on REDM. What we don't know is at what angle do measurements become unreliable. If work is to be performed to a certain tolerance, how far can this angle of incidence be pushed and still achieve required results. A better understanding of this condition will allow a surveyor to have more knowledge that a measurement they are obtaining is accurate and could potentially increase the amount of data that can be obtained from a particular setup.

2.6.2 Illumination

Illumination is said to be a factor in REDM that will affect the credibility of the technology (Lambrou & Pantazis, 2010), which is confirmed by the manual for the Leica TS15 stating the range in which REDM can be used under certain conditions. A maximum distance of 200 meters (m) in direct sunlight and a range of 400m plus in dark conditions (Leica Geosystems, 2011). This confirms that illumination has an effect on the measurement but does it have an effect on the accuracy of the REDM and if it does how much effect can it have.

2.6.3 Target Temperature

There isn't much knowledge about if the temperature of a target has an effect on a REDM and if the thermal properties of a target absorb energy from the REDM, causing distortion in the measurement. This would be very useful to know as in surveying there is a lot of focus on keeping the instrument in the shade and at air temperature, as direct sunlight can cause an imbalance of heat in the total station which can cause the bubbles and axis's to become off centred and out of level, ultimately effecting observations.

2.6.4 Moisture

Moisture on a surface is a situation that most surveyors would incur on cold frosty mornings as they produce a wet due on all surfaces. A document released by Trimble in 2005 has stated that a TOF laser is better suited to measuring to wet surfaces. Which until this type of laser became available was harder to achieve accurate results for a wet surface (Hoglund & Large, 2005). This is because of the increased energy emitted from this type of laser helps penetrate in ambiguities of a wet surface. However there hasn't been any direct testing to see what the actual accuracies are and what the results would be when measuring to a wet surface.

3 Methodology

In order to be able to achieve results that will satisfy the aim of this project, a well thought-out and structured methodology will need to be developed in order to achieve credible results and conclusions. All the sources of error will need to be identified and either eliminated or reduced so reliable data can be recorded and useful results captured.

From here an in-depth material and condition identification analysis will be carried out in order to identify useful materials and conditions. Once these have been identified the next step of determining testing equipment can be carried out and calibration of the equipment can start. Finally, the development of a sound testing procedure will need to be completed in order to achieve desirable results.

3.1 Material identification

It is important for the research that the materials that are chosen are going to be of value. They need to be materials that will commonly be used in REDM. If materials are chosen that do not satisfy this criterion, then the research, whilst might be sound, will be of little value to the surveying profession and will be a waste of time, effort and energy.

In order to determine common materials a series of site visits were performed in various locations in order to identify materials that may be encountered when performing particular surveying jobs and tasks.

The first site visit was conducted around a new housing development site. This site was chosen because of the need for surveyors to perform identification surveys on new houses. A lot of the time corners of the buildings and related structures that require surveying, REDM is a very good way to locate these points without the need of a traditional two-man survey crew and applying offsets in relation to prisms. From this site visit the following materials have been identified;

- Bricks Shown in figure 3.1
- Softwood Shown in figure 3.2
- Plastic Shown in figure 3.3

Figure 3-1 Bricks

Figure 3-2 Softwood

Figure 3-3 Plastic

The second site visit was carried out in an existing residential suburb. This location was chosen because of the need for surveyors to perform and complete detail surveys. Whilst some identified points are common with the first site visit, there are different materials and construction methods in the older suburbs. The following materials have been identified from this site visit;

- Hardwood Shown in figure 3.4

Figure 3-4 Hardwood

The third site visit was carried out on a construction site. This site is the same site where the project development was derived from. Surveyors in the engineering and construction sector use REDM a lot because of the forever changing environment and the ability to locate points at height or in difficult and unsafe locations to access, particularly in residential high-rise development where the best line of sight is up. From this site visit the following common building materials have been identified;

- Concrete Shown in figure 3.5
- Besser blocks Shown in figure 3.6
- Aluminium Shown in figure 3.7
- Galvanised Steel Shown in figure 3.8

Figure 3-5 Concrete Structure

Figure 3-6 Besser Blocks

Figure 3-7 Aluminium Edging

Figure 3-8 Galvanised Steel Support Structure

The final site visit that was carried out was at the local shopping centre. This location was chosen because on the need for surveyors to carryout lease surveys. This involves measuring the position of internal walls. REDM is really useful in these types of surveys as it allows a lot of data to be captured efficiently, accurately and easily. This site visit identified the following common building materials;

- Ceramic tile Shown in figure 3.9
- Plasterboard Shown in figure 3.10

Figure 3-9 Ceramic Tile

Figure 3-10 Plaster Board

In order to gather an understanding if materials have an effect on REDM, the REDM should be compared against a control measurement. There will be two types of control targets for this research and they are identified as follows;

- Prism Shown in figure 3.11
- Reflective tape Shown in figure 3.12

Figure 3-11 Prism

Figure 3-12 Reflective Tape

Whilst conducting the four site visits to identify materials, it was very apparent that the same material was being used except it might have been a different colour. As identified previously there is still some ambiguity on whether or not colour alters a REDM. Because of this 10 colours have been identified to be tested as part of the research. The identified colours are as follows and shown in figure 3.13;

- Blue
- Red
- Yellow
- Green
- Orange
- Pink
- Purple
- Grey
- Black
- White

Figure 3-13 Colours

3.2 Condition identification

Once again it is important that common conditions are identified so the research will be useful to the surveying community. Surveyors are expected to work in a variety of conditions and environments. This can be anything from the scorching temperatures of the west to the freezing temperatures of the snowy mountains in the east. Each environment will provide different circumstances in which surveyors must operate.

This research will focus on Canberra and the surrounding regions. Canberra is a good place to identify conditions as it generally experiences a very wide range of conditions over the seasons with hot and warm summers and cold and cool winters (Commonwealth of Australia , Bureau of Meteorology, 2016).

During the summer months in Canberra the average daytime temperature is 27.7^{0}C, with extremes beyond a temperature of 35^{0}C. During this time of year there is an average of 9 hours of daylight every day (Commonwealth of Australia , Bureau of Meteorology, 2016). Because of these conditions stationary objects can be warmer than the ambient air temperature as they absorb more of the sun's rays and heat. The air is generally dry with little humidity and depending on the time of day, an objects illumination can be intensified. From these general environmental conditions during summer the following conditions have been identified as condition that could have an effect on a REDM and produce an error;

- Dry object
- Hot object
- Illuminated object

During winter Canberra can get quite cold with an average daily minimum of -0.2^{0}C. Temperatures have been known to get as low as -5^{0}C and extremes can be even lower. During these months, daylight hours drop down to about 5 to 6 hours per day (Commonwealth of Australia , Bureau of Meteorology, 2016). Because of these environmental conditions a lot can happen to objects that may affect a REDM. Canberra is known to get frosts during the mornings. A frost is the crystallisation of water molecules on objects. Because objects can hold their thermal mass, air temperature is quite often warmer than the potential target object. Along with this as the frost thaws out an object will be left with a dew on its surface. Because of the reduced daylight hours often surveyors will have to perform some duties in the dark. From the winter environment the following conditions have been identified as a source of potential error;

- Wet object
- Cold object
- Unilluminated object

Finally, the last set of conditions that will be looked at are angles of incidence. As stated before these angles will have an effect on a REDM. To what extent is the unknown part of this research. The angles that have been chosen for this research are as follows;

- 0^{0} (Perpendicular)
- 22.5^{0}
- 45^{0}
- 60^{0}

3.3 Equipment

For this research only 1 laser will be used. This is because the research is to gather information on if materials and conditions have an effect on a REDM. Using multiple lasers to test for the same data would be testing the function and capabilities of a laser rather than trying to determine what can influence it. Further through this chapter an understanding of the equipment that will be used will be detailed in order to develop a testing procedure that will produce reliable results.

3.3.1 Total station

The total station that will be used will be a Leica TS15P 1” R400 shown in figure 3.14. This model is the second most advanced model in its group. The terminology of the model stands for the following;

- TS Total Station
- 15 Release group
- P Power search model
- 1” 1 second angular instrument
- R400 Pin Point reflectorless mode at a range of 400m

Figure 3-14 TS15P 1" R400

(Zenith, 2016)

Other models available in the Leica TS15 range come with different functions. They are available with different accuracies in the angular readings of the instrument and these will either be 1”, 2”, 3” or 5” second instrument. All models have a Pin Point Reflectorless mode with a range of either 30m, 400m or 1000m. R1000 models aren’t generally used in the construction sector as they have restrictions and limitations on how they can be used (Leica Geosystems, 2011).

The laser that is emitted from this particular total station is a visible red laser beam for visualisation or line of sight. The EDM component measures with a phase shift and not TOF. It has reflectorless capabilities of up to 400m in the correct conditions. The maximum distance possible under certain conditions is outline in Table 3.1 below when using standard Kodak cards.

Table 3.1 R400 Maximum Range

Type	Kodak Card	Range A (m)	Range B (m)	Range C (m)
R400	White 90% Reflective	200	300	>400
R400	Grey 18% Reflective	150	200	>200

Range	A	Object in strong sunlight, severe heat shimmer
	B	Object in shade, sky overcast
	C	Underground, night and twilight

(Leica Geosystems, 2011)

The Leica TS15 has 3 different lasers built into the machine. A Class 1 laser is used for standard EDM, Power search (PS) and Automatic Target Recognition (ATR). A class 2 laser is used for laser plummeting functions. Finally, a Class 3R laser is used for REDM. It is important to understand that this class of laser is the highest class of laser allowed to be used in the construction sector and care must be taken as its high power can cause damage if used incorrectly or inappropriately. The REDM laser when used emits 5W of power.

The beam divergence for the Leica TS15 has been expressed at 0.2 milliradians (mrad) x 0.3 mrad. This equates to a divergence of 20mm x 30mm at a distance of 100m, this can be seen in figure 3.15. The equation to determine the beam divergence at any distance with a Leica TS15 is as follows;

$$\mathrm{D} = d \times \lambda \tag{3.1}$$

Where

D is the beam divergence in one direction expressed in mm

d is the distance being measured in m

λ is the amount of deviation expressed in mrad from the manufacture

Figure 3-15 Beam Divergence from a Leica TS15

The distance accuracy of the Leica TS15 varies depending on which mode is used to measure. Some of the differences are outlines in Table 3.2 below;

Table 3.2 EDM Accuracies

EDM Mode	Target	Accuracy	Time
Standard EDM	GPR1	1mm + 1.5PPM	2.4s
Standard EDM	Tape	5mm + 2PPM	2.4s
REDM	Anything	2mm + 2PPM	3 – 6s

It is important to know and understand these numbers as it will determine the accuracy of the machine before any other errors can be considered to be affecting. It is also important to note that these accuracies are generally of a worst case scenario under general conditions. The accuracies can in general be either greater or smaller under certain conditions and situations. The formula to determine the accuracy of the measurement of a certain distance is as follows;

$$\mathrm{E} = c + \frac{d \times \partial}{1000} \tag{3.2}$$

Where:

E is the machine error expressed in mm

c is the constant error expressed in mm

d is the distance being measured in meters

∂ is the amount of PPM required to be applied

Anything outside the tolerance of the machine at a particular distance would be said to have external factors effecting the distance measurement.

The operating temperature of the Leica TS15 is from -20^{0}C to 50^{0}C. The machine is required to adjust from storage temperature to air temperature by leaving the machine exposed to the air temp for 15 minutes. This machine has PPM standardised to zero with the following values;

- 12^{0}C
- 1013.25 mbar
- 60% relative humidity

3.3.2 Tablet

A tablet controller has been chosen to perform the testing. This has been done to reduce the amount to input required directly into the machine. Where most of it can be done from a controller it will help eliminate the chance of bumping the machine during testing and potentially pushing the machine off level. The controller that has been chosen for this research is the Trimble YUMA 2 shown in figure 3.16. This controller was chosen because of the 12d software which is loaded onto it to control the total station. A big advantage with using the 12d software is that it can display results to sub millimetre precision, which will be helpful when trying to determine small amounts of deviations. If other equipment were to be used that display results to millimetre accuracy, then a deviation as small as 0.1mm could be displayed as a difference of 1mm. This is because whilst the calculation is performed to sub millimetre accuracy the machine with either round up or down to the nearest millimetre when displaying the result. Another advantage is the ability to be able to record the data at a safe distance and or location. This will be explained why in more detail later in this chapter.

Figure 3-16 YUMA 2 Tablet

(Trimble, 2016))

3.3.3 Atmospheric Equipment

Atmospheric measuring equipment is important to eliminate any potential PPM error involved in EDM measurements. The values of temperature, pressure and relative humidity will be entered into the total station prior to each measurement or when an atmospheric reading changes. The total station will then calculate the required PPM and apply it to the measurement. The device that will be used to measure the atmospherics during testing will be a Kestrel 5000 Environmental Meter shown in figure 3.17. This device has the following atmospheric accuracies;

Table 3.3 Kestrel 5000 Data Specification

Sensor	Accuracy	Display	Range
Temperature	0.5^0C	0.1^0C	-29^0C - 70^0C
Pressure	+/- 1.5mbar	0.1mbar	700mbar – 1100mbar
Relative Humidity	+/- 2%	0.1%	10% - 90%

Figure 3-17 Kestrel 5000

(Kestrel Meters, 2016)

Another device that will be used will be a Digitech ultra compact Infra-Red (IR) thermometer, shown in figure 3.18, to measure the temperature of targets for selected conditions. This will be discussed later in the chapter. The IR thermometer has the following accuracies;

Table 3.4 IR Thermometer Data Specification

Sensor	Accuracy	Display	Range
Temperature	+/- 2.5^{0}C	0.1^{0}C	-33^{0}C - 110^{0}C

Figure 3-18 IR Thermometer

(Jaycar Electronics, 2016))

3.3.4 Bracket

For this testing a specialised bracket will need to be made to fit onto a Leica SNLL 121 carrier. The design will be of similar construction to the bracket used by E. Lambrou and G. Pantazis in their testing. It will however be adapted to suit the needs of the equipment that is available for this testing. The bracket will be designed so it can house any of the materials selected and be rotated to the precise angle without changing the centre rotation point. This is a very important point as when rotation is performed, the target point cannot be in a different position otherwise it will produce a different result. This will eliminate any centring errors that could be associated with a measurement. A set of full drawings for the bracket can be found in Appendix B. The bracket will be made of timber and bolts with markings to allow for correct and consistent alignment. The bracket is shown in figure 3.19 below.

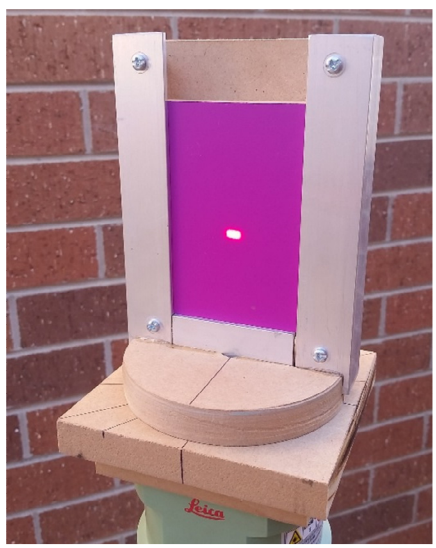


Figure 3-19 Bracket in Operation

3.4 Calibration

The calibration of the equipment will be of importance as good calibrated equipment will help minimise and even eliminated some sources of error. The equipment that will be calibrated for this testing will include the Total Station and the atmospheric equipment.

3.4.1 Total station

The total station is of most importance for calibration. A properly calibrate total station corrects for index, scale and cyclic error. To Calibrate a total station, the total station needs to measure distances over a prescribed baseline. The baseline used to calibrate the EDM of the total station that will be used in testing was the Watson EDM baseline. This baseline consists of 11 pillars ranging from 2.5m to a pillar over 1100m away. The sequencing of the measurements required for the Leica TS15 is prescribe in the EDM calibration handbook, prescribed by the Surveyor General of the Australian Capital Territory. After calibration of the Leica TS15 that will be used, the following errors were found;

- Index error = 0.99mm
- Scale Error = 2.16PPM
- Cyclic Error = Insignificant

From this the following formula has been derived so a EDM can be adjusted to true value, which should be applied to all measurements. Important to know that the index error can only be applied when using a prism and not REDM, due to it being a prism constant error and not a EDM error.

$$\mathrm{IC} = 0.99 - 0.00216 \times \mathrm{L} \tag{3.3}$$

Where:

IC is the instrument correction in mm

L is the distance measured in m

The full calibration recordings and Certificate of compliance can be found in Appendix C.

3.4.2 Kestrel 5000 Environmental Meter

The Kestrel 5000 Environmental Meter has been calibrated by comparing the results obtained from the instrument against permanent weather station instruments at time of purchase. The temperature was calibrated against an Ameteck DTI-050 Digital Temperature Indicator and STS Reference Sensor, the relative Humidity was calibrated against an Edgetech HT120 Humidity Transmitter and the pressure was calibrated against a Vaisala PTB210A Digital Barometer. All components passed and a full report can be found in Appendix D.

3.5 Condition Creation

To be able to replicate and create the conditions that will be tested to allow for consistent testing, methodology and equipment will need to be established for each condition. With all conditions it will be important to measure as quickly as possible to try and eliminate the amount change in the condition, to try and achieve data under the same conditions.

3.5.1 Wet

To create a wet target condition, the object will need to be covered in water. This can be easily done with the use of a spray bottle filled with water. It will be important to spray the target before testing the same amount of times to achieve consistent results and data, even though each target may absorb moisture at different rates. Three sprays at a distance of 150mm away and at an angle perpendicular to the target and will be performed prior to the first set of measurements.

3.5.2 Dry

A dry target will be quite easy to achieve as it will require no manipulation in order the achieve the condition. A dry target will also be used for baseline data as it is a condition that will be most commonly encounter by surveyors when using REDM. The main importance for a dry target will be to standardise the target temperature so it is the same as the surrounding ambient air temperature. This is done by leaving the target in the open air for 15mins.

3.5.3 Illuminated

Illumination will be relatively easy to replicate and will be done with the aid of a flood light for maximum illumination of the target. The light will be set up at a distance created by a 1m x 1m offset away from the target, creating an angle of 45^0 to the target and at a height of 1m. above the target. This is illustrated below in figure 3.20. The light will then be pointed at the target. This set up will be done like this to eliminate any potential reflectance of light from the target back to the total station. If light gets reflected back to the total station it will not allow for an EDM signal to return. This will not be an ideal situation if no data can be recorded because of light interference to the total station.

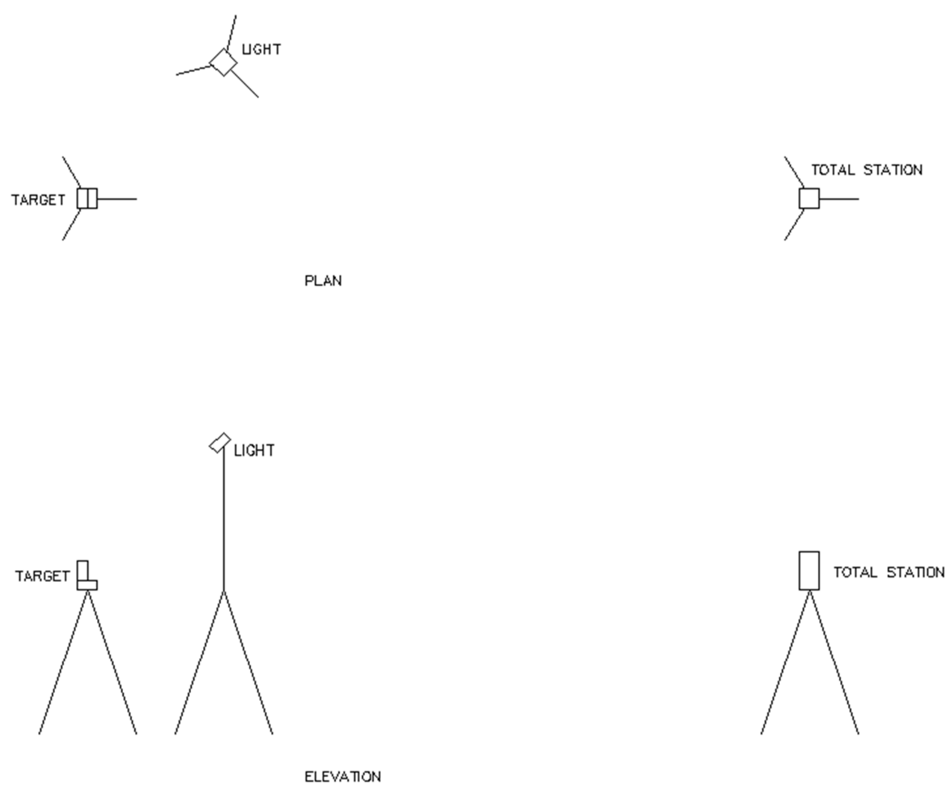


Figure 3-20 Illumination Diagram

3.5.4 Unilluminated

An unilluminated target will be easy to create. However, there are a couple of important points to consider before testing this condition. Worksafe Australia has stated that lasers of class 3B restricted should not be used in dark areas of less than 100lux. 100lux is approximately equal to the light level on a really dark day. However certain surveying tasks are required to be performed at night where light levels would be considered to be under 100lux. According to the Leica manual, a laser of this class can be used in dimly lit areas and generally works better under dark condition. They do state that additional care needs to be taken when operating these lasers in a dark environment. With all this taken into account to create an unilluminated object, the measurement will be taken in complete darkness. No one will be allowed inside the testing facility when these measurements will be taken. This will eliminate the risk of any part of the laser beam or scattered rays coming into contact with the eyes. Due to the use of the controller the recordings can be taken from a safe and remote location without any risk of exposure.

3.5.5 Hot

To create a hot target this will require the heating of the target before measuring can occur. This will be done by placing the targets in an oven before measuring. The reason an oven has been chosen is the ability to control and maintain the temperature of the target before testing. The temperature of the target will be initially set at 80^{0}C and a temperature reading will be performed prior with an IR thermometer prior to measurements. Care will need to be taken to make sure that heating the targets to 80^{0}C will not damage or alter the target in any way. The measuring range will be set between 75^{0}C and 65^{0}C. This will allow for initial cooling whist setting up the target and cooling during the measurement process. Depending on how quick the target cools the target may have to be placed back into the oven to reheat before more measurements at different angles can be taken.

3.5.6 Cold

To create a cold target this will require the cooling of the target before measuring can occur. This will be done by placing the targets in a fridge before measuring. The reason a fridge has been chosen over a freezer is for the ability to control and maintain the temperature of the target before testing and if a freezer was chosen then the ice that forms on the outer edge of the target can melt and create a wet target. The temperature of the target will be initially set at 0.0^{0}C and a temperature reading with an IR thermometer will be performed prior to measurements. Once again care must be taken in ensure that no damage is done to the target by cooling the target to near freezing temperature. The measuring range for this condition will be from 0^{0}C to 5^{0}C. This allows for warming of the target during setup and during the measurement process. Depending on how quick the target warms, the target may have to be placed back into the fridge to cool before more measurements at different angles can be taken.

3.6 Testing Range

The range in which testing will be performed will be a distance approximate to 7.1m from the total station to the target shown in figure 3.21 below. A short distance has been chosen for this testing to help eliminate other potential sources of error. As most errors are scaled in relation to distance a short distance will help reduce other errors which could compromise the results. Another reason for this adoption of a short distance is that the Leica TS15 measures with phase shift which is better suited to shorter distances for high accuracy work. Another advantage for choosing a short test range is to reduce the amount of beam divergence on the target, as beam divergence is once again a function of distance.

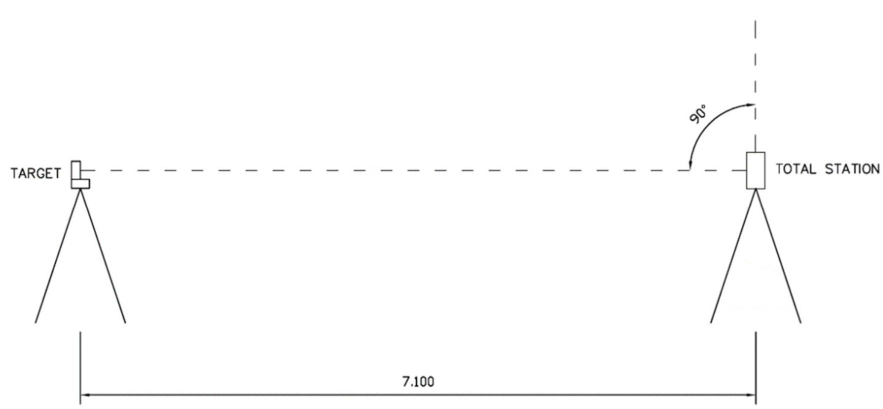


Figure 3-21 Testing Range Setup

3.7 Procedure

The development of the procedure has been developed based on all the information above and eliminating the potential for error.

Firstly, the total station and target will be set up at a distance on 7.1m apart. This will be done by placing two marks on the ground 7.1 meters apart by the form of a tape measure and then centring both total station and the target over the placed marks at a height above the ground which is equal to one another. This is done this way to eliminate the need for calculation of the horizontal distance from the slope distance obtained. By setting up the TS at a vertical angle of 90^0, this will ensure that all measurements are in a horizontal plane and that the target is also perpendicular to the TS in the vertical axis eliminating angle of incidence in the vertical angle.

Prior to each measurement being taken the temperature, pressure and relative humidity will be measured and recorded and be imputed in the TS and the relevant condition and angle of incidence will be applied. A series of five measurements will be taken to each material and condition setup and the average distance will then be taken as the result. From this average result the instrument correction will then be applied to obtain a true distance, this corrected distance will be the distance used in all analysis.

The order in which materials are measured is not of any importance, however the order in which the conditions are applied will have an effect on time, because of this the following order of condition measurement has been derived. The first condition to be tested will be materials under the influence of a cold temperature. This is because the cooling of the targets will take time and can be done prior to testing. Once the first material has been tested under this condition it will then be left to warm up to room temperature and the next material will be tested under the cold condition. Once all materials have been tested under the cold condition, the first material which will now have warmed up to room temperature will be tested under the condition of dry, then light, then, dark, then wet. Wet has been chosen last in this sequence because once this sequence is done the material can be place in the oven to dry from being wet and also warm up for the hot condition to be applied. This is done this way because the hot condition takes time to warm up and targets can warm up whilst other materials are being tested.

3.8 Testing Facility

Based on everything above the testing facility will need to have a number of components in order to test successfully. The facility will need the availability of power through multiple outlets. Without power the ability to create some of the conditions will prove very difficult. Power will be needed to power a fridge to make the targets cold to a set temperature. Power will also be needed to power an oven to once again make the targets hot to a set temperature. Power will also be needed to power a flood light to provide illumination of the target under this condition. Power will also be needed to power a laptop in order to book all the results of the data obtained.

The facility will need to be indoors for multiple reasons. Firstly, being weather conditions and atmospheric changes. Being indoors will provide a facility out of the potential rain, which would slow down testing and take up more time and the facility may not be available for additional testing dates at short notice. Another advantage of being indoors is that the atmospheric conditions don't change as quickly or dramatically indoors opposed to an outdoor environment. This will allow for testing to be performed under more standard conditions and environments rather than a forever changing one. This will help eliminate sources of error in fluctuating atmospheric conditions. Finally, an indoor facility will allow for the condition of a target under no illumination to be created. Being outdoors this target testing would then have to be performed at night.

Lastly the facility needs to be long enough to achieve a measuring distance that has been determined under the procedure.

The facility that has been chosen for this is a garage. As it complies with all the needs of power and has the added advantage of a fridge and an oven located very close by. Eliminating the need for portable appliances. The garage has no windows and when the doors are closed the inside will be in complete darkens. This facility will also allow for safe measurements to be taken under the dark condition as the Bluetooth communication from the tablet to the total station can work through the metal material of the garage doors. Finally, the garage is big enough to satisfy the range needed for testing.

4 Results

The results for each target type, condition and angle are outlined throughout this chapter. Each target will be tabulated and analysed individually to determine common trends. These common trends will be used to determine if materials and or conditions have an effect on a REDM. A full set of testing data and results can be found in Appendix E.

The prism data will be used as a baseline for all analysis as it is to be the most accurate form of measurement from a total station. Common trends, a baseline mean and range will be determined from this data and be used to compare the other data sets. A look at the angle and condition with the highest and lowest mean and range will be analysed and be used as useful information to determine outcomes.

Table 4.1 below will set the parameters to determine to what degree the data is precise and accurate.

Table 4.1 Accuracy and Precision Ranges

	Accurate Precise	Somewhat Accurate Somewhat Precise	Not Accurate Not Precise
Range	0-1mm	1.1-2.0mm	> 2.1mm
Mean	+/- 1mm	+/- 1.1 – 2.0mm	> -/+ 2.1mm

4.1 Prism

The results for the prism test are displayed in Figure 4.1 below. As shown in the graph the deviation between all measurements at different angles and under different conditions has a range of 1.0mm and the mean of the data is 7.1008m. Due to the base line setup and the prism being used no data was able to be captured under any condition at an angle of 60^0. The trend dictated from these measurements indicates that as the angle increases, the measurement distance increases. This data also shows that different conditions do not seem to have any significant effect on the EDM when using a prism. The angle of 0^0 had the smallest range and mean and the angle of 45^0 had the largest of both statistics. The dry condition had the smallest range and the unilluminated condition had the largest. The illuminated condition had the smallest mean and the wet condition had the largest.

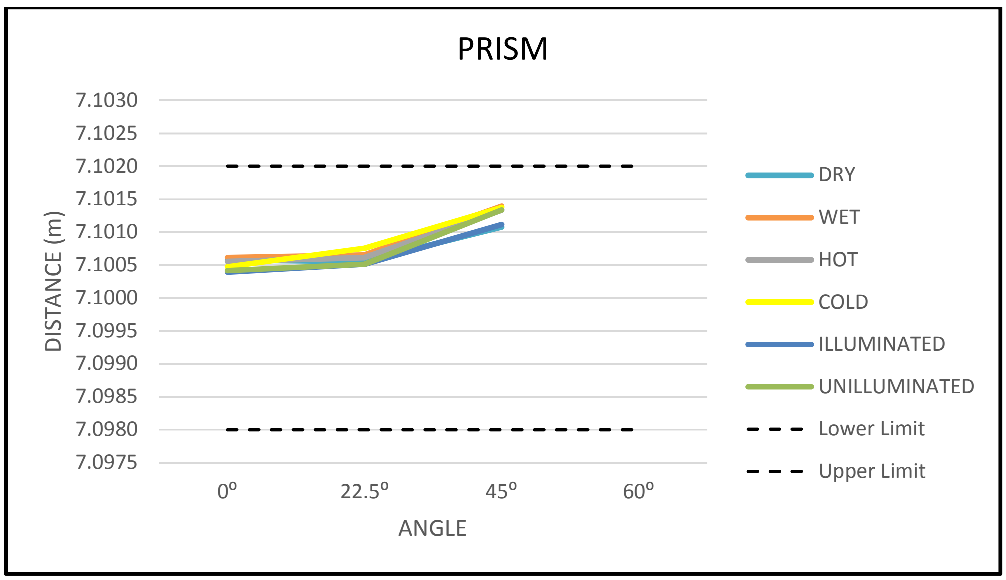


Figure 4-1 Graphed Prism Results

The baseline setup distance was measured at 7.100m. This is the true distance that all measurements should read and any measurements outside +/- 2mm from this figure will be determined to have direct target and or condition influence imposed. From the figure above it can be seen that all measurements were within the instruments tolerance and all distances measured longer than the true distance. The results for this set of data is accurate and precise.

4.2 Reflective Tape

The reflective tape results displayed in Figure 4.2 below shows a very sporadic set of results with no real common trend. The results have a mean of 7.1010m and a range of 1.6mm. the cold and unilluminated conditions seem to follow the same trend of decreasing in distance at the angles of 22.5^0 and 45^0 before increasing back to almost the same measurement at the 0^0 and the 60^0 mark. The wet and illuminated conditions have a similar trend where the distance increases before it then decreases as the angle becomes greater. The hot and dry conditions followed the trend of decreasing in distance as the angle increased. This is opposite to the trend set with the prism. All the measurements have measured within the manufactures specifications. The angle of 60^0 and the condition of hot have the smallest mean and the largest range of the angles and conditions. The angle of 0^0 and the condition of cold have the largest mean and the smallest range of the angles and conditions.

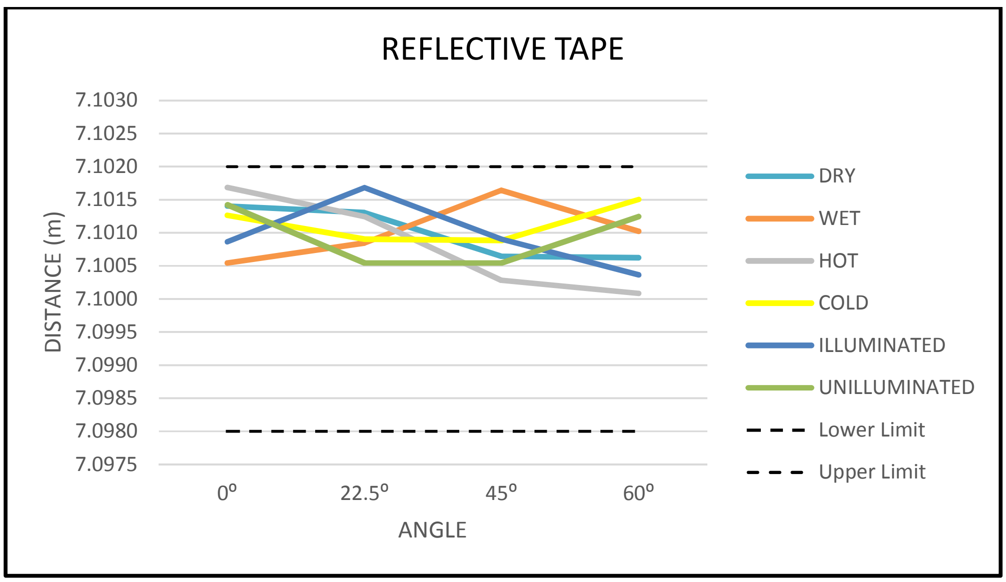


Figure 4-2 Graphed Reflective Tape Results

The measurements were generally longer than the true distance and also the mean was longer than the distance obtained from the prism baseline data. The overall range was larger than the prism data. The general trend set by the prism is not followed in this data set. From the results obtained the data can be considered accurate and somewhat precise.

4.3 Softwood

The softwood results are displayed in Figure 4.3 below. This set of data has a mean of 7.1010m and a range of 1.5mm. This range would be less than 1mm if the result of the hot condition at the angle of 60^0 wasn't taken into account. The general trend of the data is relatively flat with minimal downward fall over the larger angles. The hot condition and the angle of 60^0 both have the smallest mean and the largest range. The angle of 22.5^0 has the largest mean and the smallest range of the four different angles. The wet condition has the largest range and the illuminated condition has the smallest range of the six conditions. All the measurements are within the specifications set by the manufacture for REDM.

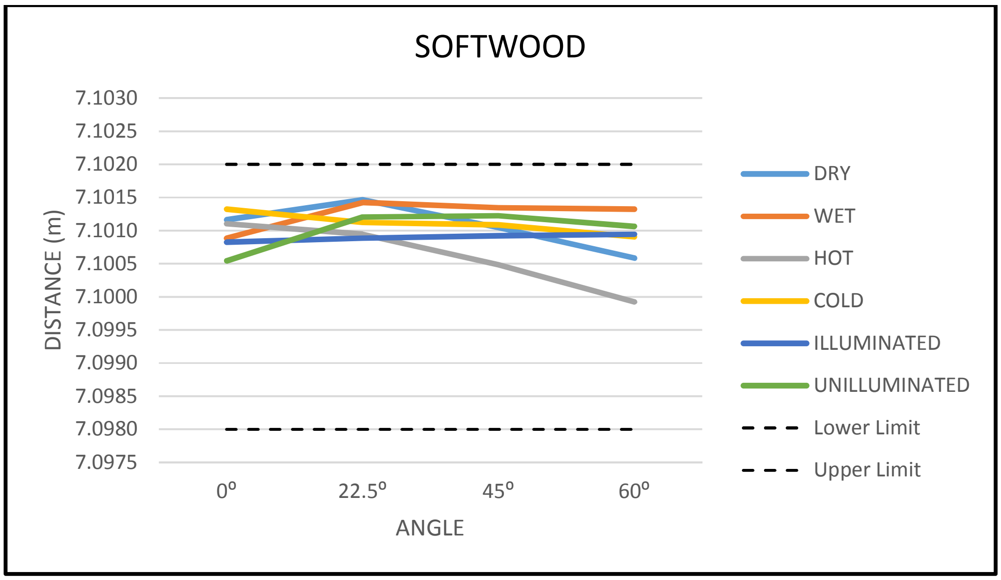


Figure 4-3 Graphed Softwood Results

The average distance was longer than the true distance by 1.0mm and also longer than the mean of the prism data set. The range is also larger than the baseline data. the general trend is different with more of a downward trend than an upward trend which was set by the prism. From the mean and range statistic it can be said that this data set is accurate and somewhat precise. The data would have been precise if the one outlining measurement was removed from the results.

4.4 Hardwood

The hardwood results displayed in Figure 4.4 below show quite a bit of deviation between the different conditions and angles. The data set has a mean of 7.1006m and a range of 2.2mm. The general trend of the wet and cold conditions is to increase in distance as the angle increases. The illuminated condition had an increase in distance trend after an initial decrease at the angle of 22.5^0, where the unilluminated condition had a trend opposite to the illuminated target. The hot target generally decreased in distance as the angle increased. The dry conditions produced data with the smallest range and the unilluminated condition had the smallest mean. The cold condition had both the highest range and mean of any condition. The angle of 60^0 also had the highest mean and range of any angle. The smallest mean of any angle came from the angle of 0^0 and the smallest range came from the angle of 22.5^0. All the measurements except for the cold condition at the angle of 60^0 were within the manufactures specification of +/- 2mm for REDM.

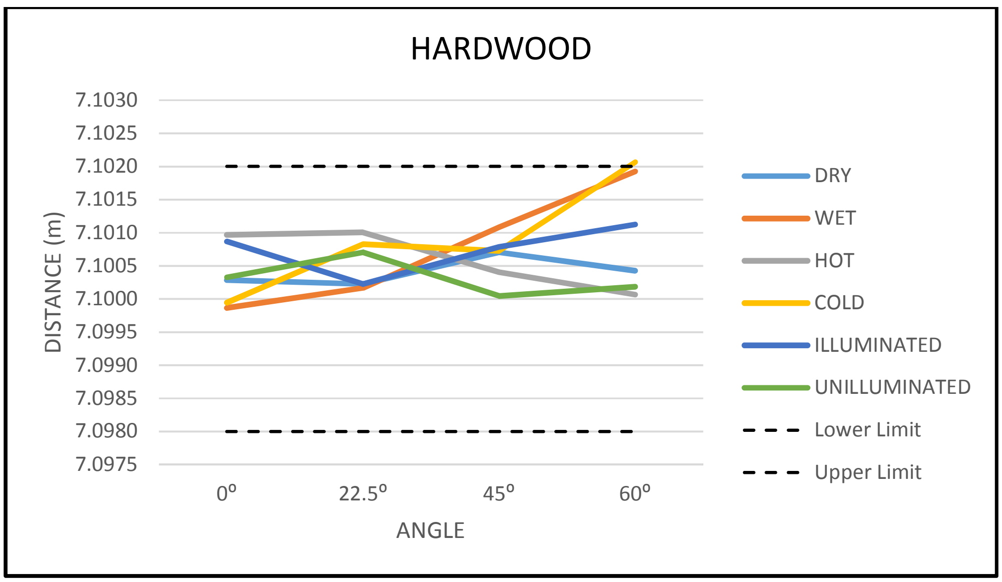


Figure 4-4 Graphed Hardwood Results

The average distance is smaller than the baseline data from the prism but the results are still quite varying between the different conditions and angles and this is shown with a range more than 2 times the range set in the baseline. Some conditions seem to follow the general trend of increase in distance as the angle increases. The results for the hardwood are said to be accurate but not precise.

4.5 Plasterboard

The plasterboard results are displayed in Figure 4.5 below. The results tend to be spread apart at the angle of 0^0, coming closer together at 22.5^0, becoming very consistent at 45^0 before spreading out again at the angle of 60^0. The general trend appears to be a decrease in distance as the angle become greater. The plasterboard has an average of 7.1006m and a range of 1.1mm. The dry condition and the angle of 45^0 have the smallest mean and range in comparison to their comparing conditions and angles. The hot condition has the largest mean and the cold condition has the largest range. The angle of 22.5^0 has the largest mean and the angle of 0^0 has the largest mean of the four angles. All the measurements are within the instruments tolerance.

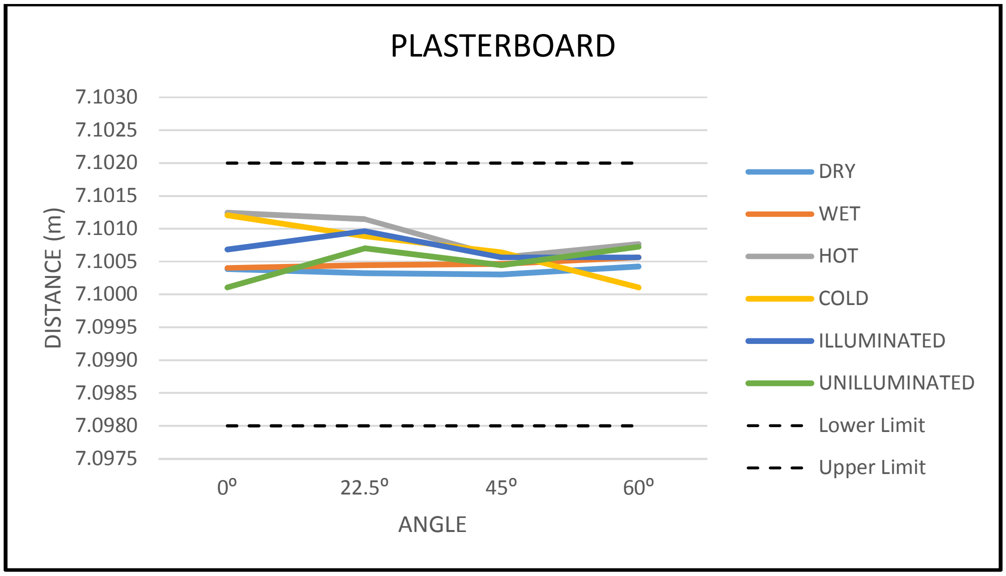


Figure 4-5 Graphed Plasterboard Results

The average is smaller than the average set by the baseline and the range is very similar, being only 0.1mm different. The mean is still longer than the true distance of 7.1000m by 0.0006m. The general trend is once again different when compared to the trend set during the prism data. This data set could be considered accurate and somewhat precise. With the range being 1.1mm the data was very close to being called precise.

4.6 Plastic

The results for the plastic material are shown in Figure 4.6 below. The results have a very big range over all the conditions. The range for this set of data is 10.0mm and the data has a mean of 7.1024m. It is important to note that the plastic material was black in colour and this will be demonstrated later in this chapter. The general trend of the data is to increase in distance as the angle become greater. All the measurements at the angle of 60^0 were outside the instruments tolerance of +/- 2mm. The illuminated condition provided an additional measurement outside the tolerance at the angle of 22.5^0. All other measurements were inside the tolerance. The unilluminated condition had the smallest range and mean out of the six tested conditions and the wet conditions had the highest for both mean and range. All the other conditions had a range of 4.2mm – 5.4mm. The angle of 0^0 had the smallest mean and range and the angle of 60^0 had the largest mean and range of the four angles.

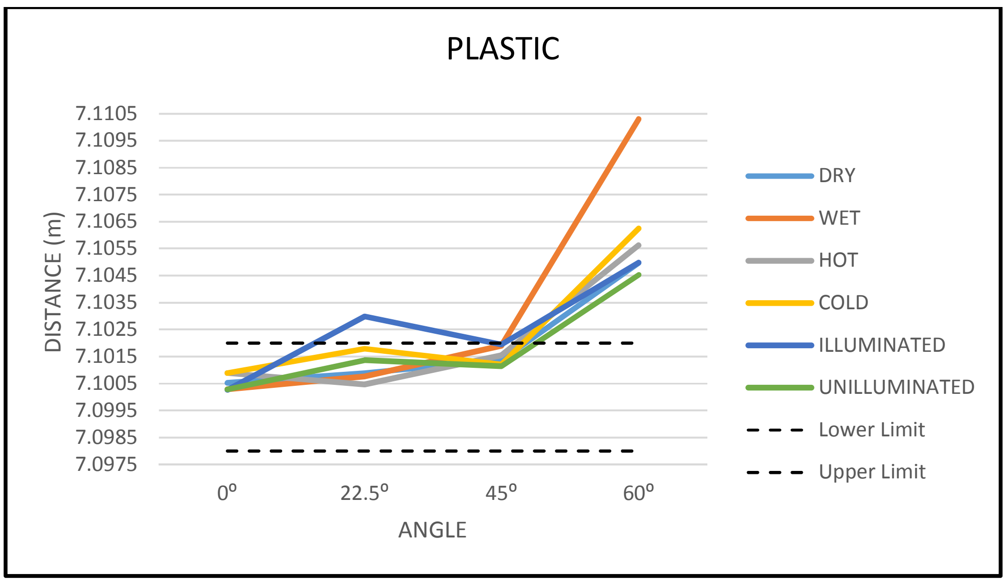


Figure 4-6 Graphed Plastic Results

The mean distance tended to be longer than the baseline prism data and also longer than the true distance. The range is much higher than compared to the prism data set. The general trend is in an upwards direction as the angle increase, this is the same trend obtained from the prism data. The data is considered not accurate and not precise. This data set could become better if the data for the angle of 60^0 was removed from the results.

4.7 Ceramic Tile

The ceramic tile results are displayed in Figure 4.7 below. The average for this set of data is 7.1016m. The ceramic tile had a range of 2mm and the trend of the data shows a sharp increase in distance from the angle of 0^0 to the angle of 22.5^0 before generally trending downwards or flat over the remaining angles. The data set had one measurement outside the instruments tolerance which was under the cold condition at the angle of 22.5^0. The angle of 0^0 has the smallest mean and also the largest range. The angle of 22.5^0 has the largest mean and the smallest range. The dry condition also has the smallest mean of the six conditions tested and the cold condition has the largest. The condition with the smallest range is the wet condition and the unilluminated condition has the largest.

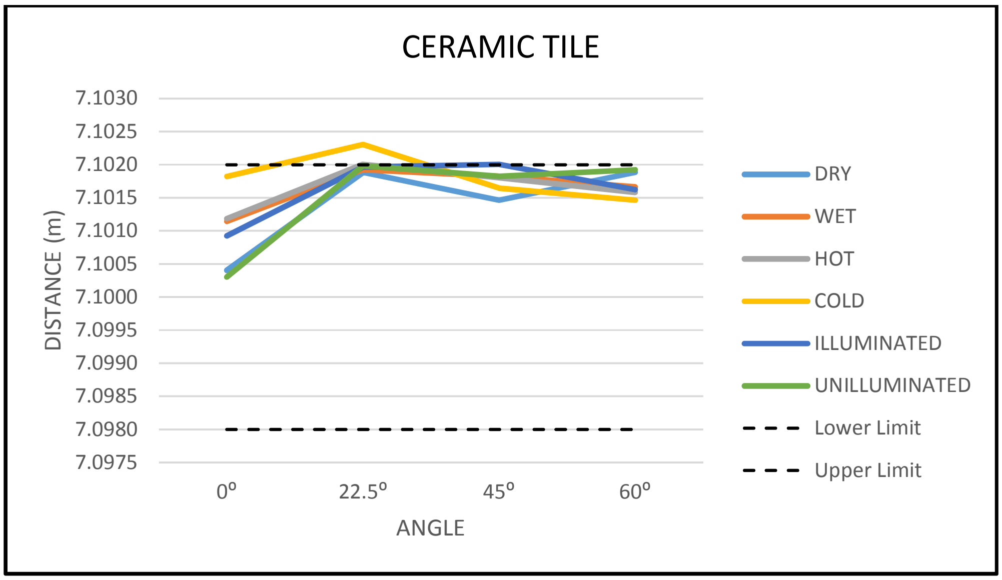


Figure 4-7 Graphed Ceramic Tile Results

The distances measured are longer than the true distance and generally longer than the distance obtained from the prism baseline. The range is double the baseline data. The general trend is different to the trend set in the baseline. From the data obtained the data set is somewhat accurate and somewhat precise. If the data for the angle of 0^0 was excluded the data set would become precise.

4.8 Concrete

The concrete results are displayed in Figure 4.8 below. The concrete data has a mean of 7.1005m and a range of 1.3mm. The general trend of the data is to decrease in distance over the angles of 0^0 to 22.5^0 before either increasing in distance or staying relatively flat. The angle of 45^0 had the smallest mean and also the smallest range out of the four angles. The angle of 0^0 had both the largest mean and the largest range of the angles. The condition with the smallest mean was the hot condition and the cold condition had the largest. The wet condition had the smallest range and the unilluminated condition had the largest range. All the measurements that were taken in this data set were within the manufactures specification of +/- 2mm.

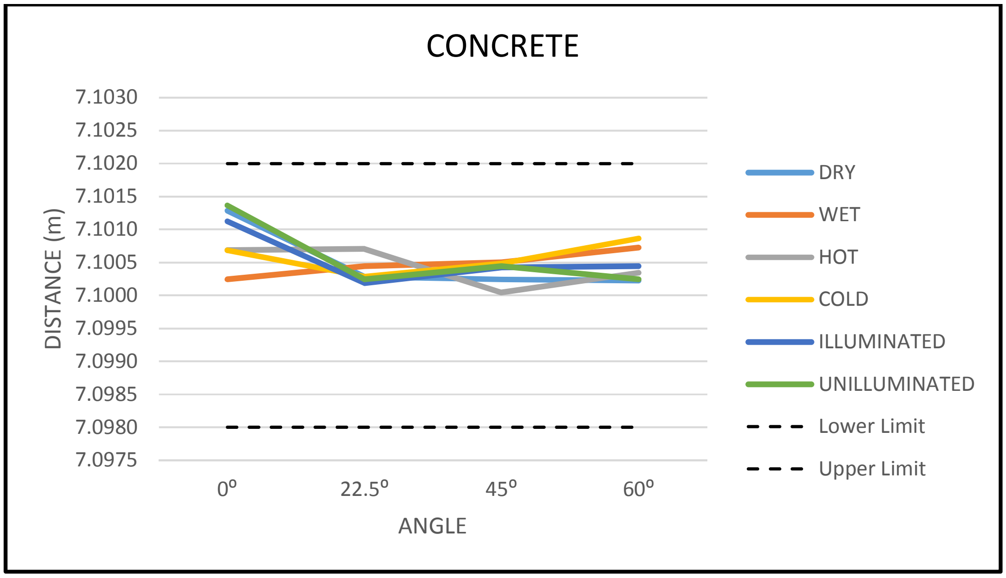


Figure 4-8 Graphed Concrete Results

The data in this set is accurate and somewhat precise. The mean was smaller than the baseline data and but still longer than the true distance of what the measurement should be. The range was larger than the baseline and if the results from the angle of 0^0 were omitted from the results the data set would be precise as well. The trend is also different to the prism data set.

4.9 Besser Block

The besser block results are shown in Figure 4.9 below. The trend of the besser block data shows a decrease in distance from the angle of 0^0 to 22.5^0 before increasing in distance again as the angle become greater. The only condition not to follow this trend was the wet condition with had an increase in every distance over the different angles. The mean distance for this data is 7.1017 and a range of 1.2mm. There were four measurements outside the instruments tolerance and these were under the hot condition at an angle of 0^0 and 60^0, the illuminated and unilluminated conditions at angle of 60^0. The angle of 60^0 had the highest mean and the lowest range of the four angles. The angle of 0^0 had the highest range and the angle of 22.5^0 had the lowest mean. The condition with the lowest mean was the cold condition and the hot condition had the highest. The lowest range was produced by the wet condition and the dry condition produced the highest range.

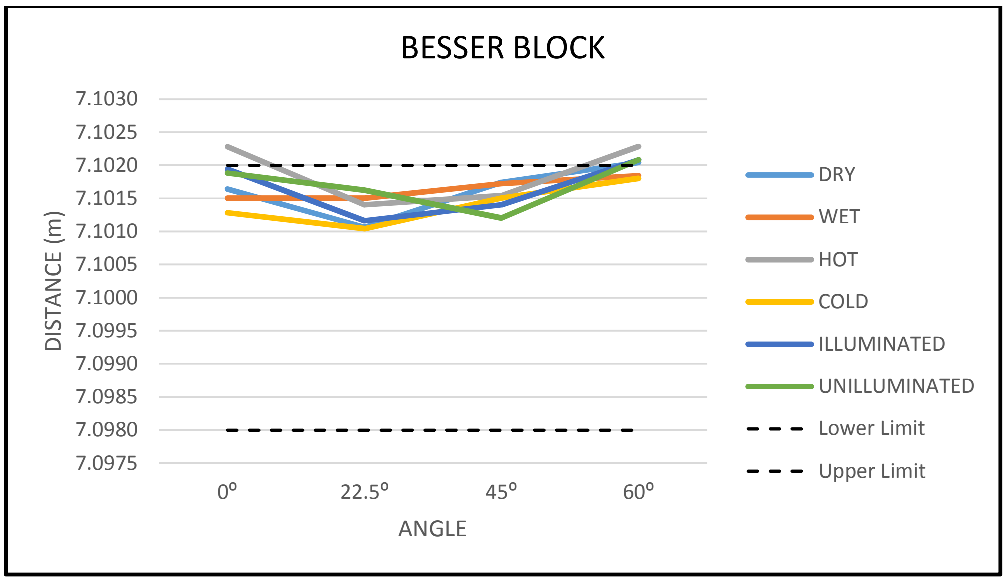


Figure 4-9 Graphed Besser Block Results

All measurements were at least 1mm beyond the true distance and with a mean distance nearly outside the instruments tolerance it was over double the baseline data. The range was only 0.2mm more than the baseline data. The data is somewhat accurate and somewhat precise. The trend seems to differ slightly from the prism trend.

4.10 Brick

The results for the brick material are displayed in Figure 4.10 below. The average distance reading for this material is 7.0999m and has a range of 1.9mm. The general trend of the data is to decrease in distance as the angle increases. All measurements were inside the manufactures specifications for tolerance. The angle with the smallest mean was 60^0 and the angle of 0^0 had the largest mean. The angle of 45^0 had the smallest range was and the angle of 22.5^0 had the largest range. The condition with the smallest mean was the unilluminated condition and the hot condition had the largest mean and also the largest range out of the six conditions. The wet condition produced the smallest range of the conditions.

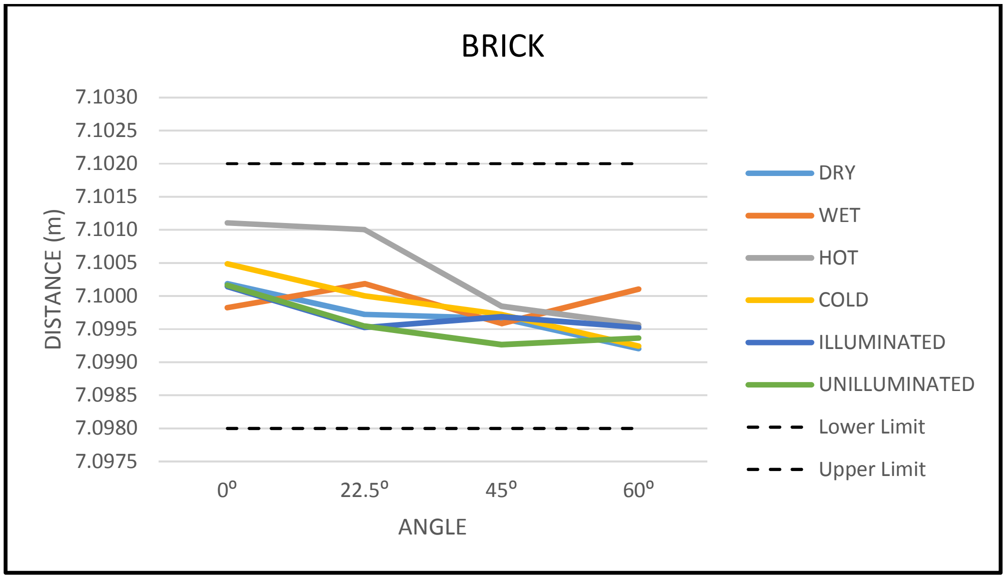


Figure 4-10 Graphed Brick Results

The mean for the brick material is shorter than the mean of the prism. It is however very close to the true distance of the base line being 7.1000m and only 0.1mm off. The range is larger than the baseline data. Again the general trend is opposite to the trend set by the prism. The data is said to be accurate and somewhat precise.

4.11 Aluminium

The data for the aluminium testing is displayed in Figure 4.11 below. This data has a mean of 7.1005m and a range of 3.9mm. The general trend for the data is to decrease in distance over the angles of 0^0 to 45^0. Then spike upwards at the angle of 60^0. The data captured at the angle of 0^0 had the smallest range and the angle of 60^0 had the largest range. this angle also had the largest mean and the angle of 45^0 had the smallest mean. The hot condition had the largest range and also the largest mean out of the six different conditions. The wet condition had the smallest mean and the cold condition had the smallest range. Despite the look of the graph there was only one measurement that fell outside the manufactures specification which was the hot condition at the angle of 60^0.

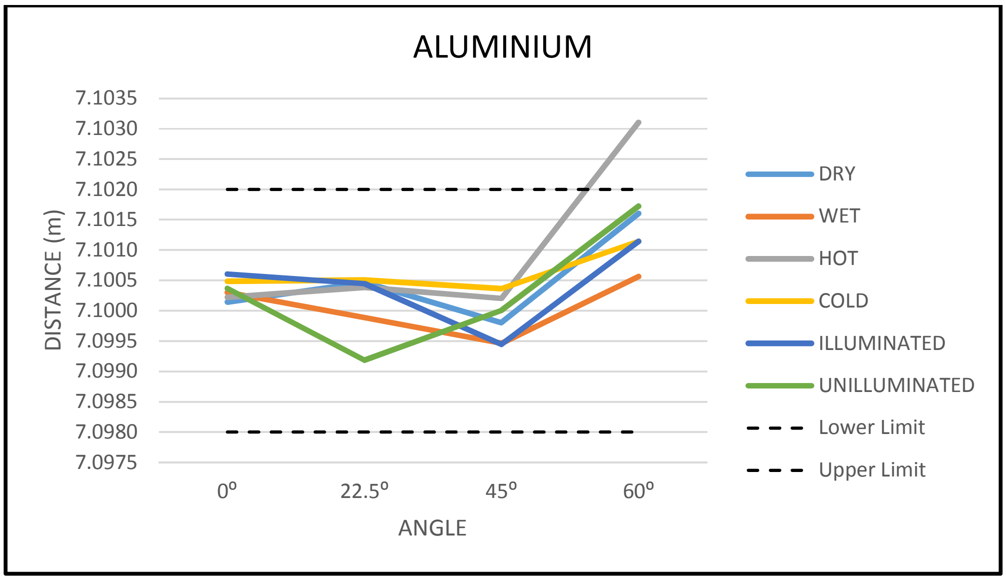


Figure 4-11 Graphed Aluminium Results

The mean for this data is smaller when compared to the prism baseline data. With the range being 3.9mm there was a spread of data below the and above the true distance. The general trend of the data is different to the baseline in comparison. This data can be said to be accurate and somewhat precise.

4.12 Galvanised Steel

The data for galvanised steel is displayed in Figure 4.12 below. The mean for this data set is 7.1012m and the data has a range of 4.7mm. The general trend of the data is to decrease or stay relatively flat over the angles of 0^0 to 45^0 before spiking at the angle of 60^0. All the measurements at the angle of 60^0 are outside the manufactures specification of +/- 2mm and all measured longer in distance. The unilluminated condition had the largest range and the cold condition had the smallest. The wet condition had the smallest mean and the hot condition had the largest mean out of the six different conditions. The angle of 60^0 had the largest range and also the largest mean. The angle of 22.5^0 had the smallest mean the angle with the smallest range was 0^0. If only the first three angles were observed the above trends would be different.

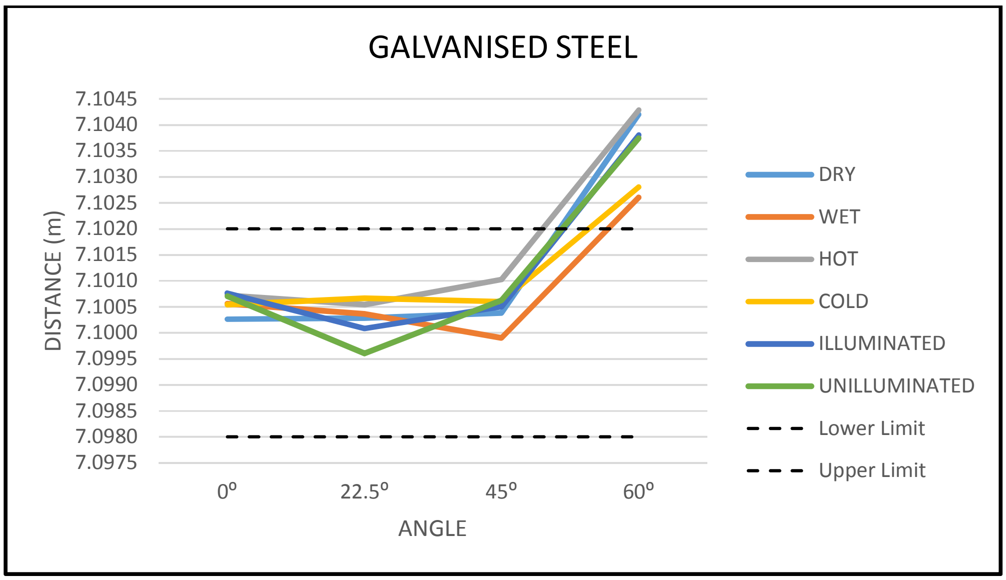


Figure 4-12 Graphed Galvanised Steel Results

The mean for the data is greater than the mean from the baseline measurement and is more than 1.2mm longer than the true distance. The general trend is also different when compared to the prism data. Overall the data somewhat accurate and not precise, however if the data from the angle of 60^0 was removed then the results would be vastly different.

4.13 Blue

The results obtained from observing the blue target are displayed in Figure 4.13 below. The colour has a range of 8mm and a mean of 7.1022m. This mean is outside the manufactures specification for tolerance. The general trend for this data set is to be generally flat between the angles of 0^0 and 45^0, then at the angle of 60^0 a sharp increase in distance was observed. All the observations at the angle of 60^0 were outside the instruments specification for tolerance. The illuminated condition and the angle of 60^0 had the largest range and the largest mean. The cold condition had the smallest range and the smallest mean out of the six conditions observed. The angle of 22.5^0 had the smallest mean and the angle of 0^0 had the smallest range.

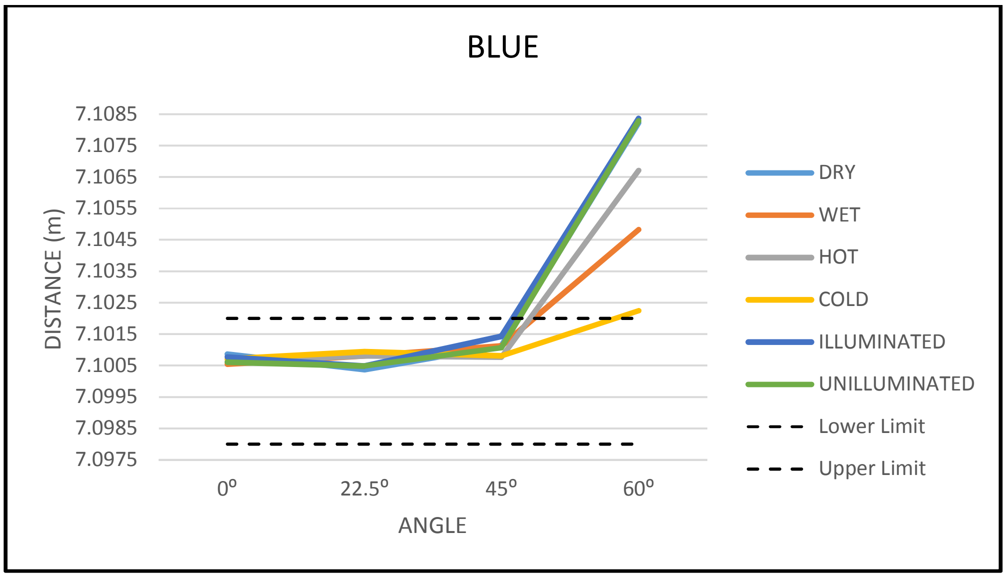


Figure 4-13 Graphed Blue Results

The mean compared to the mean from the prism baseline is quite different. However, if the angle of 60^0 is removed from the calculation then the mean would be much closer. Because of results from the angle of 60^0 the range is also very large in comparison. The general trend is similar to the data obtained from the prism baseline. When all measurements are utilised then the data set is not precise and not accurate. With the removal of certain measurements then the precision and accuracy can improve.

4.14 Red

The results for the red target are displayed in Figure 4.14 below. The red target has a mean value of 7.1008m and has produced a range of 0.7mm. The general trend of this data set is relatively flat or has a slight decrease in distance as the angle become greater. The angle of 0^0 has created the smallest range and the highest mean out of the four angles. The angle of 60^0 has produced the smallest mean and the highest range. The wet condition has the largest mean and the smallest range of the six different conditions tested. The dry condition has the smallest mean and the hot condition has the largest range. All measurements are inside the tolerance of +/-2mm set by the manufacture.

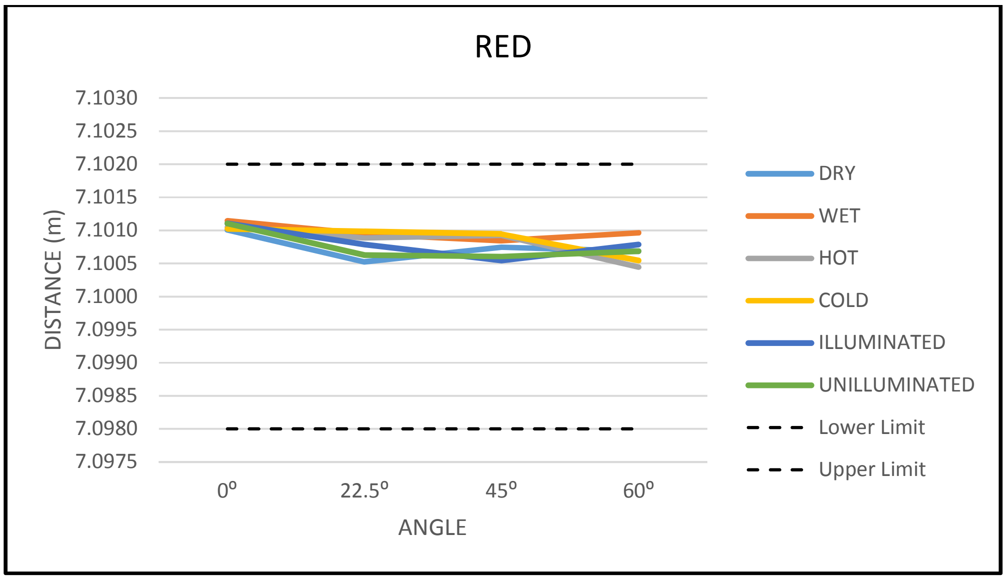


Figure 4-14 Graphed Red Results

The data obtained for this data set is precise and accurate. The range is smaller than the data obtained from the baseline and the mean result is 0.8mm longer than the true distance and shorter than the baseline measurement. The general trend is opposite to the trend set from the data obtained from the prism test.

4.15 Yellow

The data obtained from the yellow results are displayed n Figure 4.15 below. The data has a range of 1.4mm and a mean of 7.1005m. There is no real general trend that is obvious from the results. The dry and unilluminated conditions had a trend of decreasing in distance from the angle of 0^0 to 22.5^0 before increasing in angle over the remaining angles. The hot and cold conditions had the same trend of increasing then decreasing, then increasing in distance again as the angles become greater. The angle of 60^0 had the greatest range with 1.1mm and also had the greatest mean. The angle of 45^0 had the smallest range and the angle of 22.5^0 has the smallest mean with 7.1004m. The condition that had the greatest range and mean is was the unilluminated condition. The cold condition had the smallest range and the condition with the smallest mean was the wet condition. All measurements were inside the manufactures specifications for tolerance.

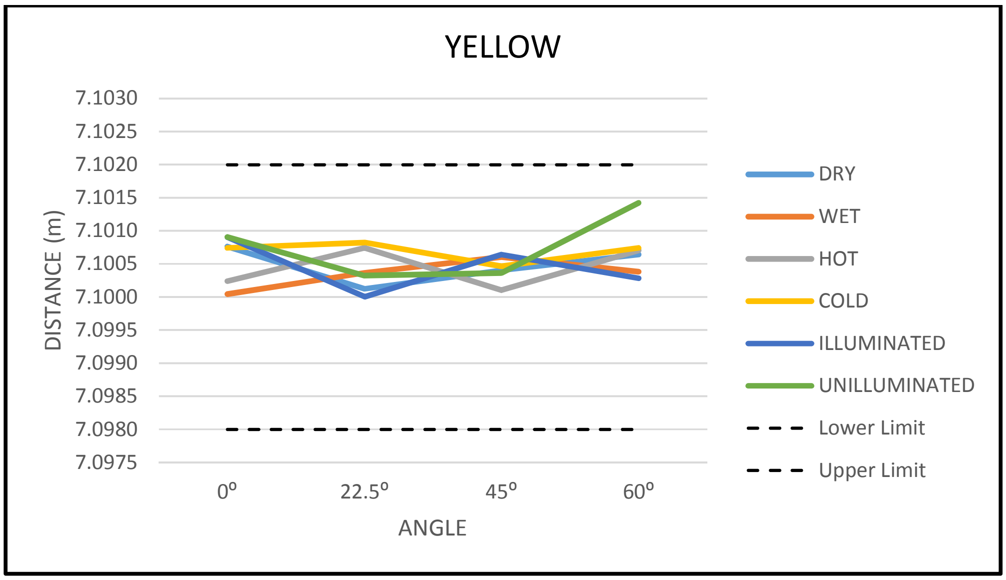


Figure 4-15 Graphed Yellow Results

The mean of the data is slightly smaller compared to the prism baseline data and the range is only 0.4mm more. The distance is slightly longer than the true distance. The data set is said to be accurate and somewhat precise. The general trend is different compared to the trend set from the prism data.

4.16 Green

The results for the green testing are displayed in Figure 4.16 below. The mean for the data is 7.1011m and has a range of 3.2mm. The general trend for the data is to be relatively flat between the angles of 0^0 and 45^0 before an increase in distance in the 60^0 angle measurement. A more specific trend for the illuminated and unilluminated conditions was to increase in distance at the 22.5^0 measurement before decreasing at the 45^0 and then increasing again at the 60^0 mark. The hot and cold conditions were the only one not to have a measurement outside the manufactures specifications of +/-2mm. the other four conditions had the measurement of 60^0 outside this tolerance. The angle of 45^0 had the smallest mean and the angle of 0^0 has the smallest range of only 0.5mm. The angle of 60^0 has both the greatest mean and range of the four angles. The cold condition has the smallest range and the hot condition has the smallest mean. The unilluminated condition has the largest means and the wet condition has the largest range out of the six different conditions.

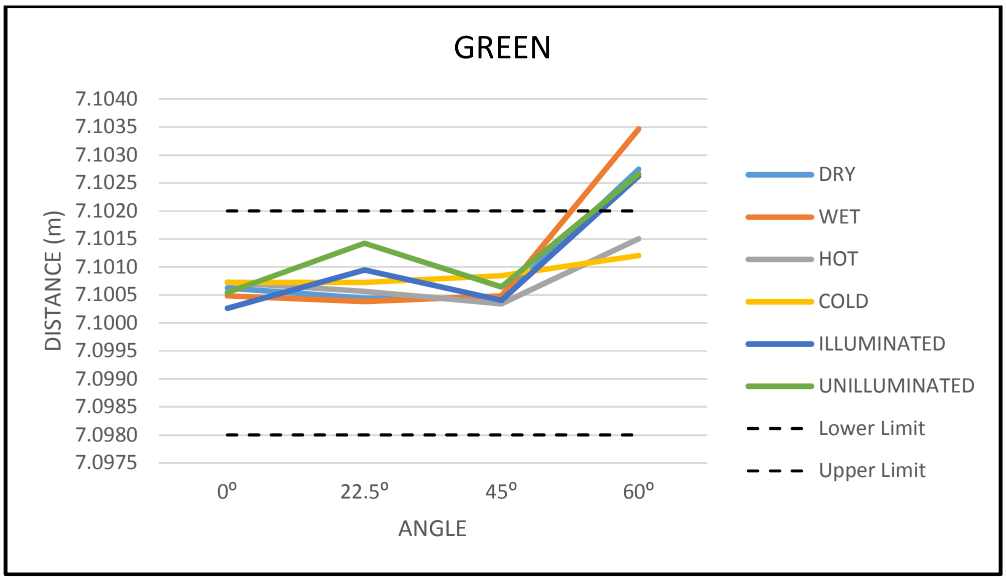


Figure 4-16 Graphed Green Results

The mean distance compared to the true distance is 1.1mm longer and 0.3mm longer than the baseline measurement. If the results from the angle of 60^0 were excluded from the results the results would be much closer. The general trend is similar to the prism data and the range is much larger. As a results the data can be considered as somewhat accurate and not precise.

4.17 Orange

The results for the orange data are displayed in Figure 4.17 below. The mean of the data is 7.1008m and the range is 1.3mm. The condition with the smallest range is cold and the condition with the highest range is the illuminated. The condition with the smallest mean is the illuminated data and the highest is the wet condition. The angle of 60^0 has the highest range and the angle of 22.5^0 has the smallest. The angle with the smallest mean is 45^0 and the highest is 0^0. The trend of the illuminated, dry and wet conditions is to be flat or decrease in distance over the angles of 0^0 to 45^0 before then increasing in distance at the angle of 60^0. The hot condition performed in an opposite trend, being an increase in distance before decreasing at the angle of 60^0. The cold condition was flat, the unilluminated condition had a general trend of decreasing in distance as the angles became grater. All measurements were inside the tolerance of the instrument.

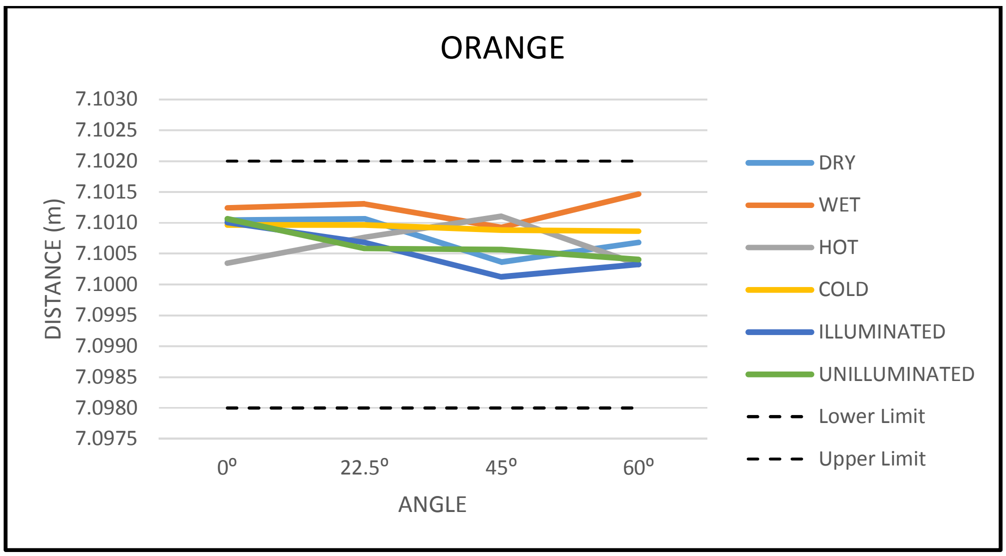


Figure 4-17 Graphed Orange Results

The mean distance is longer than the true and baseline distance and the range is also larger. The general trend seems to be a bit different to the trend set by the prism. The data is said to be accurate and somewhat precise.

4.18 Pink

The pink target produced the results as displayed in Figure 4.18 below. The general trend of the data is for a slight decrease in distance as the angle became bigger. The mean for the data set is 7.1008m and the data has a range of 1mm. All the measurements are within the +/-2mm tolerance set up by the manufacture. The angle that has produced the smallest mean and range out of the four angles is 45^0. The angle with the largest mean was the angle of 0^0 and the angle with the largest range was produced by the angle of 22.5^0. The condition with the smallest range was the hot condition and biggest range was the unilluminated. The unilluminated condition also had the smallest mean and the highest mean was produced from the illuminated condition.

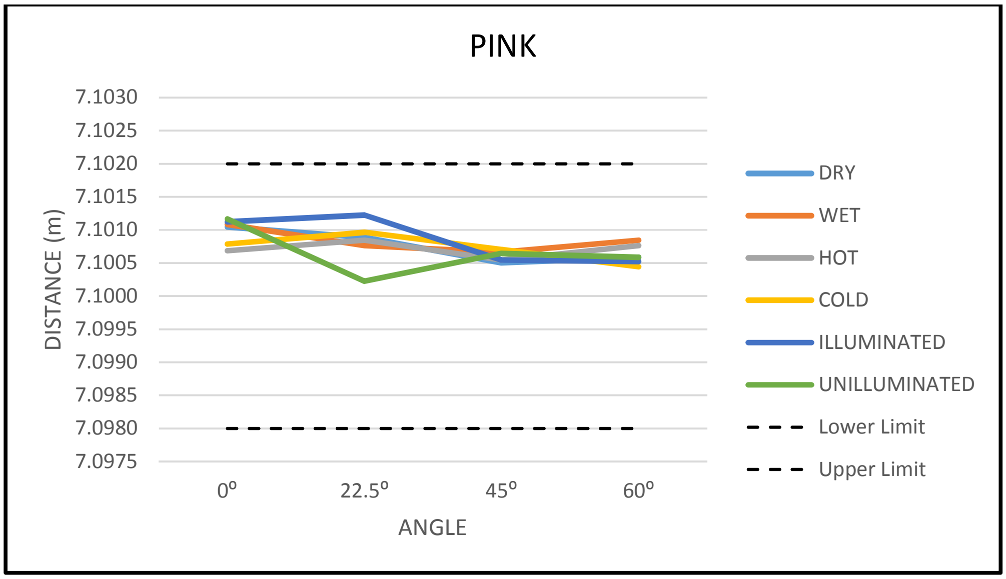


Figure 4-18 Graphed Pink Results

The mean for this data compared to the baseline data is the same. The distance is also longer than the true distance of 7.1000m. The range produced by this data is the same as the base line data. The general trend is opposite to the trend produced by the prism. This data is accurate and precise.

4.19 Purple

The purple data is displayed in Figure 4.19 below. The general trend for the data is quite flat with a slight decrease in distance as the angle becomes greater. The mean for this data set is 7.1015m and has a range of 0.8mm. All the measurements are within the tolerance specified by the manufacture. The results are however towards the higher end of the tolerance. The angle with the smallest range and mean was the angle of 60^0. The angle of 0^0 had the highest mean and the angle of 22.5^0 had the largest range. The condition with smallest mean was cold condition and the condition with the highest condition was the hot condition. The dry condition had the largest range and the illuminated condition had the smallest range of only 0.2mm.

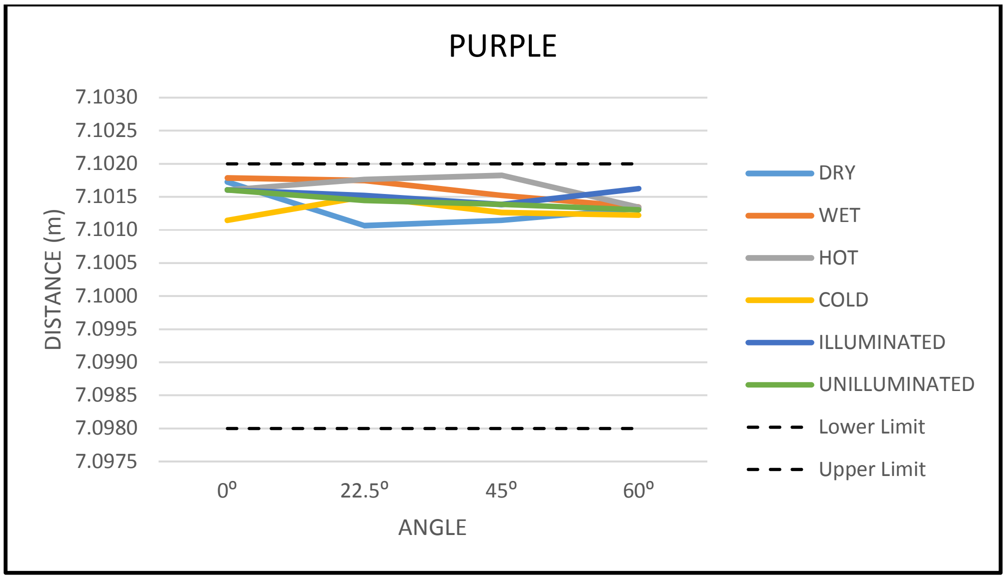


Figure 4-19 Graphed Purple Results

The range for this data is better than the base line data set by the prism. The mean however is 0.7mm longer and also means a longer distance by 1.5mm compared to the true distance. The general trend is different to the trend set by the prism. The data somewhat accurate and precise.

4.20 Grey

The data for the results of the grey testing are displayed in Figure 4.20 below. This data set has a range of 2mm and a mean of 7.1008m. The general trend for this data is to be flat or a slight decrease in distance over the angles of 0^0 to 45^0 before an increase in distance over the angle of 60^0. There was only one measurement that is outside the manufactures specification and that is the unilluminated condition at the angle of 60^0. The condition with the greatest range was the unilluminated condition and the cold condition had the smallest range out of the six different conditions. The dry condition had the largest mean and the hot condition had the smallest. The angle of 45^0 has the greatest range out of the four angles and the smallest range was produced by the angle 22.5^0. The angle of 22.5^0 also produced the smallest mean. The largest mean was from the angle of 60^0.

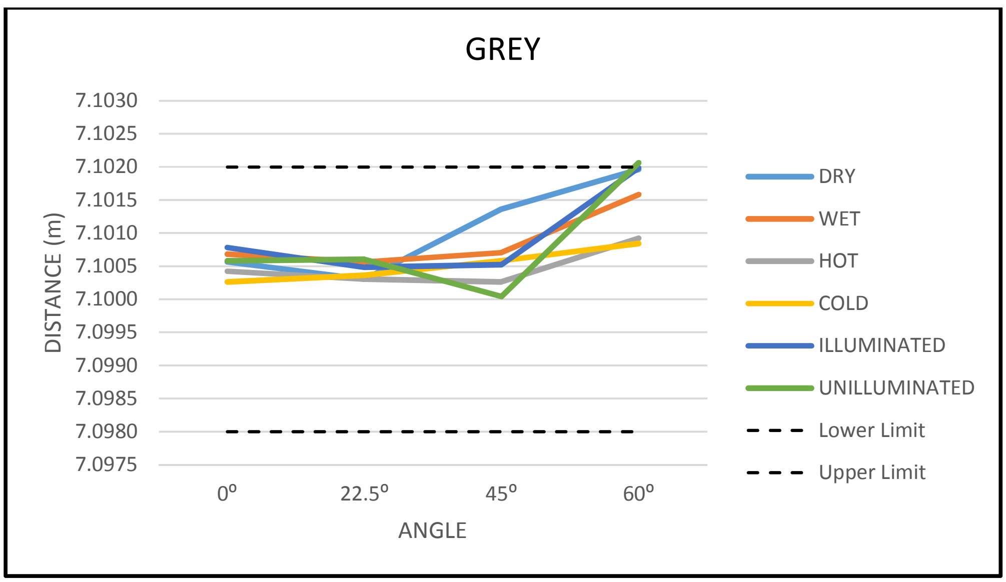


Figure 4-20 Graphed Grey Results

The mean of the data is the same as the baseline data produced by the prism. The distance is still longer than the true distance of 7.100m. The general trend is slightly different comparted to the trend set by the prism data. The range is double, however if the angle of 60^0 was removed from the data the results would be much closer. Based on the results the data set is accurate and somewhat precise.

4.21 Black

The results for the black target are displayed in Figure 4.21 below. The general trend for the data is to increase in distance as the angle becomes greater. Also with a sharp increase in distance at the angle of 60^0. The mean of the data is 7.1037 and has a range of 15.2mm. The angle with the highest range is the angle of 60^0, this angle also has the highest mean for any one angle. The angle of 0^0 has both the smallest range and mean for an angle for this target. The condition with the smallest mean was the cold condition. This condition also had the smallest range out of the six conditions tested. The dry condition had the highest mean and the unilluminated condition had the highest range. All the measurements at the angle of 60^0 were outside the manufactures specification for tolerance. At the angle of 45^0 both the dry and illuminated conditions were also outside this tolerance.

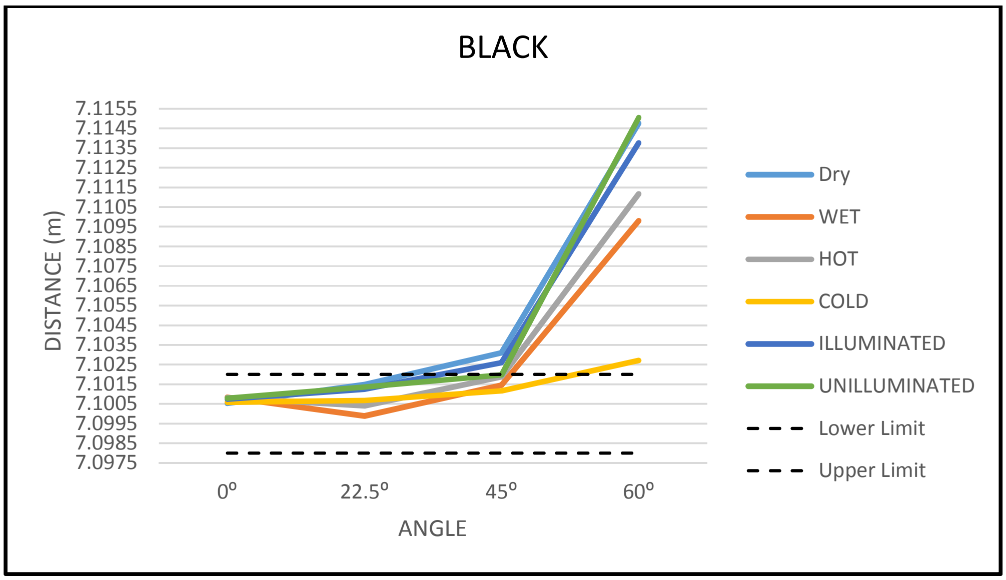


Figure 4-21 Graphed Black Results

The mean and range are very different compared to the baseline data and the mean is 3.7mm longer than the true distance. The general trend follows the same trend set by the prism. Based on the results obtained the data set can be said to be not accurate and not precise.

4.22 White

The results for this set of data are displayed in Figure 4.22 below. The mean for the white target is 7.1007 and the range is 0.8mm for this set of data. The angle of 0^0 has the smallest range and the angle of 45^0 has the largest. The angle of 45^0 also has the smallest mean and the angle of 60^0 has produced the largest mean out of the four angles. The hot condition produced the smallest mean and the largest range out of the six tested conditions. The Wet condition has produced the largest mean and also the smallest range. All the measurements are inside the tolerance set by the manufacture of +/- 2mm. The general trend for the data is to be quite flat and the biggest range is the data is in the angles of 45^0 and 60^0.

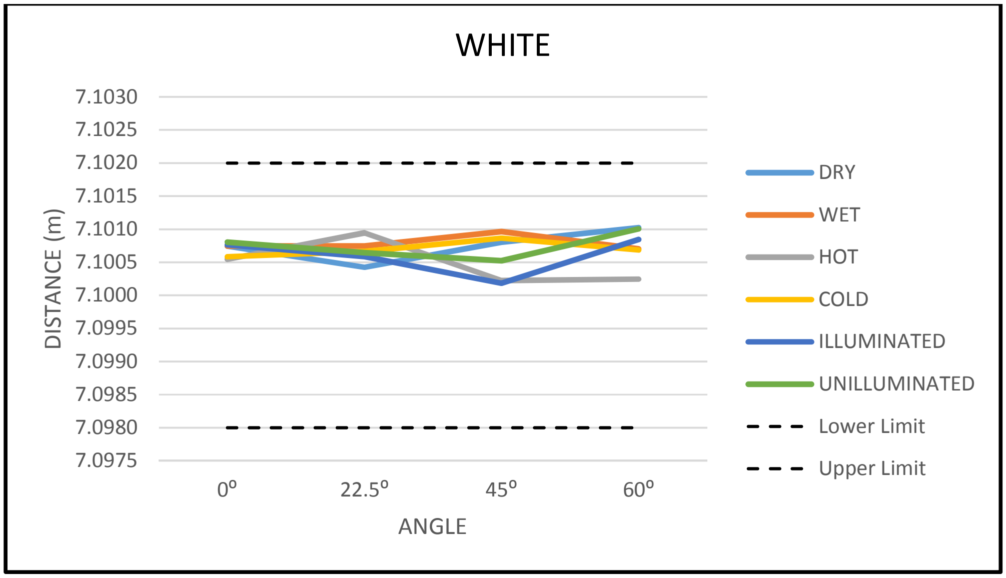


Figure 4-22 Graphed White Results

The mean is 0.7mm away from the true value. The mean of the data is smaller than the data obtained from the baseline prism data set. The range is also smaller compared to the baseline. The trend is different to the baseline data. The data set is said to be accurate and precise.

5 Discussion

The results obtained from the testing provided some interesting, situations and patterns for REDM technology and data capture from a total station. Throughout this chapter these situations and patterns will be explored to determine why they happened and occurred. Determining if angle plays a role in changing a REDM, if a condition plays a role, if the colour plays a role and finally if the material plays a role. These four key potential influencing factors will be analysed to determine the effect that materials and conditions have on a REDM from a total station.

5.1 Angle

For the testing, four angles were chosen to be explored; 0^0, 22.5^0, 45^0 and 60^0. All angles provided sufficient data to produce reliable and worthwhile outcomes. There was no standout common trend that showed the angles having a direct and significant influence on the REDM over such a short distance. As any deviations at certain angles could have occurred from the beam being influenced by the material or condition that was tested at the same time. This will be explored later in this chapter. It can be said that 96.6% of average distances obtained at angles measured longer than the true distance.

Some reasons why no common trend was able to be established with angles can be due to the short testing range and in particular the distance in relation to beam divergence. As discussed in section 2.3.2 beam divergence. Table 5.1 below shows the amount of beam divergence present at each angle for a distance of 7.100m using the Leica TS15.

Table 5.1 Beam Divergence

0^0	1.4 x 2.2 mm
22.5^0	1.6 x 2.4 mm
45^0	2.0 x 3.0 mm
60^0	2.8 x 4.2 mm

As can be seen from the table the amount of divergence available did not allow for a great amount of deviation to have an effect and produce a common trend for how REDMs are changed due to the divergence present at different angles.

5.1.1 Best performing angle

Over all the different sets of data the angle that has produced the best results on average for being closest to the true value of 7.100m was the angle of 22.5^0 with a value of 7.10079m. The angle of 0^0 and 45^0 on average were only a maximum of 0.03mm longer. The measurement on average for the angle of 22.5^0 ended up being 0.79mm longer than the true distance and is well within the manufactures specification for accuracy set for the Leica TS15 REDM mode. Table 5.2 below shows the results for the different angles.

Table 5.2 Angle mean and range

Mean	
22.5^0	7.10079m
0^0	7.10080m
45^0	7.10082m
60^0	7.10211m

Range	
0^0	0.00072m
45^0	0.00077m
22.5^0	0.00088m
60^0	0.00211m

It would have been expected that the angle of 0^0 should have produced the best results due to this angle having the smallest area of beam divergence available, however this did not happen. A potential reasoning for this would be the range of data form which the average was calculated, as all data had material and condition influence applied at each angle measurement. The angle of 22.5^0 had an average range of 0.88mm where the 0^0 angle had the best average range of 0.72mm. From this the angle of 0^0 provided the most consistent results and the larger range from the angle of 22.5^0 provided a wider spread of data which has resulted in a shift of the average result closer to the true distance. With the mean values of 0^0, 22.5^0 and 45^0 being so close to one another, if the testing was to re conducted a different order of results could very easily be obtained.

5.1.2 Worst performing angle

The angle of 60^0 was the worst performing angle out of the four angles tested. This angle had a mean value of 7.10211m and had a data range of 2.11mm. These numbers place the results for this particular angle outside the Leica TS15 speciation of tolerance for REDM. From the average data obtained it can be said that the angle of 60^0 measures longer than the true distance and longer than the other angles by a significant amount. With the difference in the average means from the best to the worst performing angle being 1.32mm.

It would have been expected that the angle of 60^0 would have produced the data for the worst angle to capture data at. This is because of the increased potential error as a result of the beam divergence. However, it would have not been expected to be outside the manufactures specification at such a short distance. This goes to show how much effect beam divergence can have on REDM.

Reasoning why the angle measurements are consistently longer rather than shorter, is an area of unknown understanding as the error from the beam divergence is meant to be random. This is not present in the results. However, with beam divergence there is typically a distortion in the returned signal (Key, 2005). A distortion in the wavelength will cause a delay in the time it takes to return the signal back to the emitting device. In this case the total station. This factor could be the reason why the measurements at all angles are longer than the true distance and in particular the angle with the greatest amount of beam divergence has a significantly greater mean distance and greater mean range.

5.1.3 Conclusion

From the data obtained for angles it can be concluded that the angles of 0^0, 22.5^0 and 45^0 can be considered angles that will produce reliable data on average. It would be expected to achieve these results and be within an acceptable tolerance for the majority of applications over a short distance. The angle of 60^0 can be considered a non-reliable angle of data capture for high accuracy work. An error of slightly over 2mm will be acceptable for some data capture applications and work.

5.2 Condition

During testing six different conditions were tested to determine if they have an effect on REDM. The conditions that were tested were dry, wet, hot, cold, illuminated and unilluminated targets. Based on the average data obtained there is no common trend that has been set. As the range of the different means of the different conditions is only 0.189mm. They are however all approximately 1mm longer than the true distance of 7.100m.

Once again longer distances have been acquired and this would most probably be linked to the distortions in the reflected signal back to the total station as mentioned in section 5.1.2 above. There is not enough definitive data to determine that the conditions have a significant direct effect of the REDM. The results obtained for the average mean and average range is displayed in table 5.3 below.

Table 5.3 Condition mean and range

Mean	
Cold	7.100988m
Hot	7.101123m
Unilluminated	7.101125m
Wet	7.101136m
Dry	7.101140m
Illuminated	7.101177m

Range	
Cold	0.00108m
Wet	0.00189m
Hot	0.00196m
Illuminated	0.00208m
Dry	0.00214m
Unilluminated	0.00225m

5.2.1 Best performing condition

The condition that performed the best was the cold condition. This condition had the lowest mean of 7.100988m and also the lowest average range of 1.08mm. All the means of the conditions are very close together. The biggest difference is in the range, which has a bigger spread over the six different conditions. The cold condition, which produced a range of 1.08mm is significantly smaller than the other five conditions which have an average range of 1.89mm – 2.25mm.

Possible reasons for this occurrence are due to the thermal mass properties and the temperature of objects. As a target becomes colder the targets molecular structure is altered and makes the target more stable as the molecules and atoms move slower and at absolute zero do not move at all. This creates a situation for the laser to bounce off the target that will not absorb much energy, meaning little energy is wasted by being absorbed into the target and the target will return a signal with minimal distortion back to the emitting device (Williamson Corporation, 2008). As the target becomes warmer the target becomes less stable as the molecules and atoms start moving around faster. With a faster moving molecular structure more friction is created and as a result of friction, heat and energy is expelled from the target. The energy that is expelled from the target is infrared and as a result can interfere with the laser contacting the target. Simultaneously when the laser comes into contact with the target, energy is absorbed and distorts the returned signal. It is important to know that the temperature to absorption rate is not lineal or even exponential as temperature increases and it is more like a lop sided bell curve (Williamson Corporation, 2008). There are optimum temperatures for high absorption and also high reflectance and every target has a different molecular structure which creates a different set of ideal thermal mass parameters. Thermal mass principles can be the reason behind why there was such a big difference between the cold target range the rest of the conditions that were tested.

5.2.2 Worst performing condition

Based on the evidence above it could have been expected that the hot target would have been the worst performing condition, however the worst performing condition is a mixture of different conditions. The illuminated targets had on average the worst average mean out of the six different conditions tested with an average mean of 7.101177mm. The unilluminated condition had the worst average range with an average range valve of 2.25mm.

This result could have been obtained because of the illumination affecting the targets percentage of reflectance. Every target has a percentage reflectance value, ranging from 0% reflectance to 100% reflectance. The other four conditions were tested under the same level of illumination from natural light in the shade. As the testing days were overcast the atmospheric conditions had very little change making for consistent testing conditions. It was only the illuminated target which where illumination was amplified with artificial light and the unilluminated condition which had no light illumination. The changing of a targets percentage of reflectance is associated with the level of light illumination present. Every target has a different percentage of reflectance and the adjustment of this percentage of reflectance value varies depending on the amount of light illumination and the original reflectance properties of the target (Gilchrist & Kossyfidis, 1999). If a white target with a high percentage of reflectance is illuminated the percentage of reflectance has little change. If a black target is illuminated the percentage of reflectance change is much greater as the percentage of reflectance of the black target will change to a percentage of reflectance similar to a grey target. Similarly, with a black target under no illumination the percentage of reflectance of that particular target will little to no change. If a white target is placed under no illumination it has the same effect as a black target illuminated, the percentage of reflectance will change to a percentage similar to a grey target (Gilchrist & Kossyfidis, 1999). As every target was different the percentage of reflectance of each target will be different and not constant. This explains why the illuminated and unilluminated conditions had the worst results for their respective average mean and average range.

5.2.3 Conclusion

It can be concluded that over the six different conditions that were tested, there doesn't seem to be a significant effect on REDM over a short distance. The temperature of targets can change the molecular activity of the target causing an interference by allowing the absorption of more energy. Illumination changes the percentage of reflectance for a target by increasing or decreasing the brightness and as a result giving the appearance of a different colour and associated percentage of reflectance. Previous research conducted by E. Lambrou and G. Pantazis has stated that illumination of the target surface has an effect on the REDM result. This statement has been confirmed throughout this testing. Although different conditions effect the properties and the percentage of reflectance of the different targets, on average changes and results are minimal.

5.3 Colour

Whilst some previous research has concluded that colour has no significant effect on REDM, the results obtained in this research provide a different result. This research tested ten different colours on the same material. The paint was also the same brand throughout to eliminate any potential inconsistencies in the paint mix. The colours chosen were; blue, red, yellow, green, orange, pink, purple, grey, black and white. A common trend that has been established for colour testing is that if the colour is light or bright, then the mean distance is closer to the true distance. It also shows that the range is generally smaller as well with the light and bright colours. Similar to the light and bright colours, the dark colours tended to be further away from the true distance of 7.1000m and the range was generally greater as well. Table 5.4 below shows the ranking of the colours in respect to their mean and range.

Table 5.4 Colour mean and range

Mean	
Yellow	7.10053m
White	7.10068m
Pink	7.10076m
Grey	7.10078m
Orange	7.10079m
Red	7.10083m
Green	7.10105m
Purple	7.10147m
Blue	7.10221m
Black	7.10370m

Range	
Red	0.00070m
Purple	0.00076m
White	0.00084m
Pink	0.00100m
Orange	0.00134m
Yellow	0.00142m
Grey	0.00202m
Green	0.00320m
Blue	0.00800m
Black	0.01516m

This trend is because of spectral reflectance. Spectral reflectance is the ability of a surface to reflect radiant energy. Radiant energy is energy used in electromagnetic waves. A key component to this is the wavelength in which the wave travels. Different wavelengths have different spectral reflectance for different colours. Figure 5.1 below shows the relationship of spectral reflectance at different wavelengths. For this testing the Leica TS15 uses a wavelength of 650 (µm) – 690 (µm) for it REDM capabilities. At this wavelength it can be seen that the light and bright colours will have a high reflectance and the darker ones will have a low spectral reflectance.

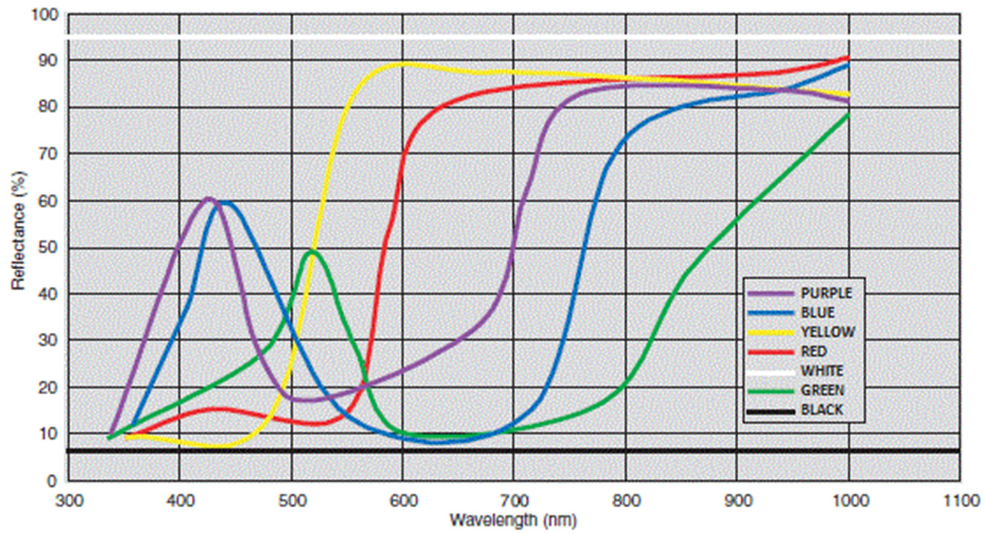


Figure 5-1 Spectral Reflectance

5.3.1 Best performing colour

The best performing colour for the mean was the yellow target with a mean value of 7.10053m. Second to the yellow target was the white target with a value of 7.10068m. The target that had the best range was the red target with a value of 0.7mm and closely followed in second place by the purple target with a value of 0.76mm

The results obtained for the best performing colour are consistent with the spectral reflectance figure 5.1 above. Whilst the yellow target doesn't have the highest percentage of spectral reflectance it is it still has a high percentage. The five brightest and lightest colours that were tested were all in the top six positions. This is a similar situation with the range, with only one dark colour in the tops six positions. With a higher reflectance percentage for targets, when the laser beam comes into contact with the target more energy is reflected back to the emitting device. As a result, there is less distortion of the laser beam, there is less scatter and less absorption which results means a quicker return time. Associated with quicker return times is a distance closer to the true value of the baseline.

5.3.2 Worst performing colour

The worst performing colour target was the black one. The next worst performing colours in relation to the mean was the blue, purple and then green targets. The black target had a mean value of 7.1024m. This value is outside Leica's TS15 specification of tolerance for REDM. The black target also has the highest range of 15.2mm. The blue target has the second worst range with a value of 8mm. Ranges in the vicinity of these values are concerning as it puts doubt in the operator if the target can be trusted as a reliable reflective surface.

The results for the worst performing colour are expected based on figure 5.1 above. With a low spectral reflectance percentage more energy is absorbed into the material. A black target absorbs all wavelengths and as a result the targets becomes less stable. With the present of more energy being absorbed, the molecules and atoms inside the target become more active, which creates heat as discussed in 5.2.1. Due to all these factors with a black target when the laser beam of the REDM creates contact with the target more of the energy of the beam is absorbed, scattered and interfered with. Resulting in a longer and more unreliable distance.

5.3.3 Conclusion

Previous research conducted by E. Lambrou and G. Pantazis states that darker colours generally measure longer than the true distance. This conclusion is confirmed with the results obtained in this research. They also go on to state that the lighter colours measure shorter than the true distance. This statement was not replicated throughout this research, whilst the lighter colours measured shorter than the darker colours they still managed to measure longer than the true distance on average. The work conducted by K. Kowalczyk and J. Rapinski states that the colour of a target doesn't have an effect on the REDM measurement. This research doesn't agree with this concluding statement as the results obtained under controlled conditions are producing significantly different and varying results. Base on the research that has been conducted it is evident that colour plays a role as a direct relation to spectral reflectance. Each colour will have a different spectral reflectance percentage as there is the ability to have different shades of different colours. A dark red could be expected to produce different results compared to a bright red.

5.4 Material

Out of the 12 different materials tested there was no real common trend that was present across all the materials. The 12 different material tested were; prism, reflective tape, softwood, hardwood, plasterboard, plastic, ceramic tile, concrete, besser block, brick, aluminium and galvanised steel. If broken down into more specific groups some trends can be obtained. For the metal materials of aluminium and galvanised steel, the common trend present among these two material was to be relatively flat or slight decrease in distance before increasing significantly over the last measurement. They both had a high range of readings but their means were at different ends of the scale. The aggregated materials of concrete, besser block and brick all trended to decrease in distance over the first two measurements and then start to flatten out over the last two except for the besser block that increased in distance. This may have been because of the texture that was present in the besser block. This will be explored later in this chapter. Both the timbered products of hardwood and softwood were generally flat with little deviation except for some spikes.

The materials that presented a smoother surface generated a result much closer to the true distance of 7.100m than materials that provided a rough surface. Materials that presented with a matte finish provided more a more consistent range irrespective of their corresponding mean. Table 5.5 below ranks the materials in relation to their mean and range.

Table 5.5 Material mean and range

Mean	
Brick	7.09986m
Aluminium	7.10048m
Concrete	7.10052m
Plasterboard	7.10061m
Hardwood	7.10062m
Prism	7.10079m
Reflective Tape	7.10098m
Softwood	7.10099m
Galvanised Steel	7.10123m
Ceramic Tile	7.10161m
Besser Block	7.10165m
Plastic	7.10238

Range	
Prism	0.0010m
Plasterboard	0.0011m
Besser Block	0.0012m
Concrete	0.0013m
Softwood	0.0015m
Reflective Tape	0.0016m
Brick	0.0019m
Ceramic Tile	0.0020m
Hardwood	0.0022m
Aluminium	0.0039m
Galvanised Steel	0.0047m
Plastic	0.0100m

5.4.1 Best performing material

The material that produced a mean result closest to the true value of the baseline was the brick material. It produced a mean of 7.09986m, the next closest material was 0.62mm longer. The prism produced the best range out of all the materials tested with a range of 1.0mm. The plasterboard came in second and the besser block came third with ranges of 1.1mm and 1.2mm respectively.

Reasons for the brick material performing well could be that the material was a red brick and also was smooth and had a matte finish. Two of these components could be regarded as components that produce good and reliable results. These components being the colour, that was red which has a high spectral reflectance and the smooth surface which provides less ambiguities and distortion of the reflected beam. This goes against common knowledge that matte surfaces absorb more light as they have less reflectance. A matte finish can have a reflectance percentage of less than 10% (Outram, 2009). Where gloss finishes have a high reflectance percentage. In comparison to a similar material being the ceramic tile which had a white surface colour and a smooth and glossy finish. Once again white has a high spectral reflectance and a smooth surface provides for less distortion in the reflected beam. With a gloss finish with a high reflectance it would have been expected that this material would have produced very good results. However, the ceramic tile was one of the worst performing materials for both the mean distance and the range. Research conducted is showing a trend that high reflective surfaces aren't reliable for REDM.

5.4.2 Worst performing material

The worst performing material in context of the mean and the range was the plastic material. However, the plastic material was black in colour and this could have a lot to do with the colour of the object rather than the material itself as discussed in 5.3.2. To be able to identify the worst performing material the plastic material will not be used for the discussion, meaning that the second worst material for the mean was the besser block, and the worst performing material for the second largest range was the galvanised steel.

Reasons for these results can be to do with the texture of the material. Both the besser block and the galvanised steel had a rough surface finish. They were also grey and silver in colour and generally had a matte look finish to them. A rough surface will create ambiguities on the reflected surface for which the laser beam will reflect. This will create distortion for the reflected beam returning to the total station. The research presented by E. Lambrou and G. Pantazis confirms this outcome within their results. An interesting point to make about the besser block is that although the mean was large, the range was quite small. This might show that whilst a rough surface will produce a larger mean it will provide less of a range as it might concentrate a scatter of the reflected beam in a particular way.

5.4.3 Conclusion

A s a result of testing the different materials conclusions on the surface properties appear to have an influence on the REDM. The results provided some generally consistent outcomes in relation to the different surface properties of the materials. The results were interesting as the gloss or matte finish surfaces have not followed expected trends. The besser block produced a high mean and a low range where it would have been expected to produce a high and high result. Whereas the ceramic tile has produced a high and high mean and range where it would have been expected to produce a two low results.

6 Conclusion

The practice of surveying has evolved over hundreds of year through the advancements in skills, designs and technology. With every change the question of credibility and accuracy is also the first topic of conversation. REDM is not new technology but the application in which it is being used it. The findings from this paper have provided some valuable insight in how materials and conditions affect a REDM.

6.1 Findings

The findings that this research has provided are going to be valuable to the to the surveyor now and into the future. The first important finding is the limitation for the angle of incidence. Based on the research it can be safe to say that all angles of 45^0 or less provide results that are consistent and reliable to any surveying task over a short distance. Angles up to and including 60^0 still produce reliable data for most surveying activities at a short distance.

The second important finding from this research is the analysis of how the different conditions can have an influence on the REDM. Importantly the effect that the temperature has on the molecular structure of a target is important. It can be stated that a cold target will provide reliable and constant results, due to the stability of the target. Overall the differences are small and for all surveying activities over a short distance a hot or cold target will be sufficient.

The third important finding is the effect of illumination on the target. The illumination of the target provides an illusion of the reflective percentage. This is done by lightening or darkening a target to give the appearance of a different target. Whilst illumination has an effect on the REDM it is not significant enough to provide any worrying results over a short distance.

The fourth important finding is the effect of colour on the target. This is really important and a major finding in this research. As all colours have a spectral reflectance percentage value. This value has a direct influence on how a REDM is reflected back to the total station. Lighter and brighter colours perform well as they have a higher spectral reflectance percentage. The darker colours do not perform so well. From this if the choice of either a light or dark target is available of data capture over a short distance, the lighter target should be chosen. Depending on the survey task at present and the tolerances allowed, dark materials may still be acceptable.

The fifth finding of this research is the effect of gloss and matte finished to surfaces. It would be expected that high gloss and surfaces with a high reflectance percentage would produce better results compared to the matte finished surfaces. This was not the case as the matte finished surfaces generally produced better results. Any target that displays a matte finish would be expected to produce accurate and reliable data over a short distance.

The sixth finding from this research is the role that texture plays in effecting a REDM. A smooth surface is expected to produce better results when compared to a rough surface over a short distance. The rough surface will produce more constant data but at a length longer than the true distance. A smooth target will produce a result with more precision but less accuracy.

The seventh finding is that a REDM will generally measure longer at a short distance. This is due to any distortions in the laser beam will generally result in a longer time taken to return to the total station. As distance is calculated based on time travel of the laser it would be expected to measure longer. Generally, the longer measurement is minimal and is still fine for most surveying activities and tasks.

6.2 Further research

In this area of research there is lot of scope for further research. A few key recommendations are made below which if conducted will provide more knowledge to the surveyor on how REDM interacts with targets.

As this research was only conducted over a short baseline a point of further research would be to explore the findings of REDM over longer distances. This would provide insight into if the findings over a short distance create to results over longer distances. And determine if the influences of REDM targets are lineal or constant.

Another point for further research would be to test different materials to provide more understanding and expand the knowledge base of surveyors. With forever changing building materials and composite materials being made there will be a requirement know what affect these materials have on a REDM.

Along with different materials, different conditions can be tested as well. Not only different conditions but a combination of conditions in the one test can also be useful to know. To determine if there are compounding condition factors present in the natural environment.

Finally, further testing can be made using different lasers. Different manufactures will have different specifications for the lasers that the place in their total stations. Along with this the laser technology is getting better and therefore it will be valuable to determine if a particular laser can eliminate some of the potential errors associated with REDM.

6.3 Recommendations

From this research it is recommended that surveyors take the knowledge obtained and use it to make their own judgement when surveying in practice. It is important to know what although some of the presented errors are quite small, there is the ability for these errors to compound into a one large error. Just the same as the different components in atmospheric conditions combine to create a value of PPM.

Because of this a quick reference guide has been created based on the data obtained during testing and can be sued to make quick judgements. An example of a quick reference guide is shown in Figure 6.1 below and a full set of guide can be found in appendix F.

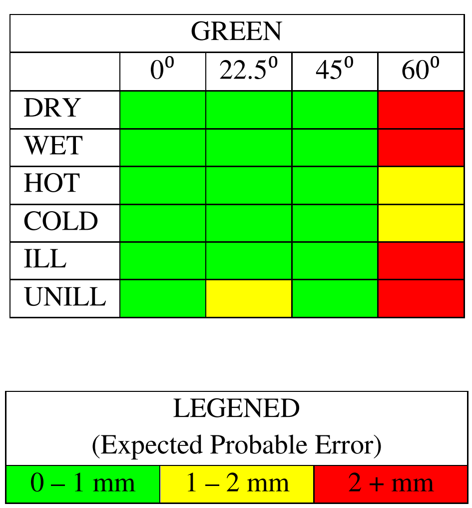


Figure 6-1 Quick Reference Guide

The way to read this guide is associated with colour. Green having an expected error of 0 - 1mm, yellow having an expected error of 1 – 2mm and red having an expected error of 2+mm. In this example of a green target at an angle of 22.5^0 and under an unilluminated condition an error of 1 -2 mm can be expected. This would have to be cross referenced with a material card and a judgement made.

6.4 Conclusion

This research can conclude that materials and conditions do have an effect on a REDM and the surveyor should become familiar with the potential errors associated as it will make judgement and expected errors known before they can become a potential problem when reducing data.

References

Anon., n.d. *MODULE 6 LASER DISTANCE MEASUREMENT.* [Online] Available at: http://pe2bz.philpem.me.uk/Lights/-%20Laser/Info-999-LaserCourse/C00-M06-LaserDistanceMeasurement/module6.htm
[Accessed 16 April 2016].

Arseni, M., Georgescu, L. P. & Circiumaru, A., 2015. Analysis of the infulence of relative humidity on the accuracy of distance measurement with surveying total stations. *Annals of "Dunarea De Jos",* II(1), pp. 33-39.

Arseni, M., Georgescu, L. P., Circiumaru, A. & Enache, C. M., 2015. The influence of the atmospheric temperature value on the accuracy of distance measurement with the surveying total station. *Annals of "Dunarea De Jos",* II(1), pp. 20-25.

Australian Government - Bureau of Meteorology, 2016. *Phase Changes and Velocity Measurement.* [Online]
Available at: http://www.bom.gov.au/australia/radar/about/phase_changes.shtml
[Accessed 16 Apri 2016].

Commonwealth of Australia , Bureau of Meteorology, 2016. *Canberra Climate.* [Online]
Available at: http://www.bom.gov.au/nsw/canberra/climate.shtml
[Accessed 18 June 2016].

Gilchrist, A. & Kossyfidis, C., 1999. Psycholo Review. *An Anchoring Theory of Lightness Perception,* 106(4), pp. 765 - 834.

Hoglund, R. & Large, P., 2005. Direct Reflex EDM Technology for Surveyor and Civil Engineer. *White Paper,* pp. 1-13.

Jaycar Electronics, 2016. *Mini Non-Contact IR IP67 Thermometer.* [Online]
Available at: https://www.jaycar.com.au/mini-non-contact-ir-ip67-thermometer/p/QM7218
[Accessed 16 April 2016].

Kestrel Meters, 2016. *Kestrel 5000 Environmental Meter.* [Online]
Available at: https://kestrelmeters.com/products/kestrel-5000-environmental-meter
[Accessed 16 April 2016].

Key, H., 2005. *Reflectorless Laser Distance Measurement.* [Online]
Available at: http://www.gim-international.com/content/article/reflectorless-laser-distance-measurement
[Accessed 5 October 2015].

Kowalczyk, K. & Rapinski, J., 2014. Investigating the error sources in reflectorless EDM. *Journal of Surveying Engineering,* 140(9).

Lambrou, E. & Pantazis, G., 2010. Evaluation of the credibility of reflectorless distance measurement. *Journal of Surveying Engineering,* 136(4), pp. 165-171.

Leica Geosystems, 2011. *Leica TS11/TS15 User Manual.* Heerbrugg: Leica Geosystems AG.

One Point Survey, 2016. *Leica Viva TS15 Total Station.* [Online] Available at: http://www.onepointsurvey.com/products/leica-viva-ts15-total-station [Accessed 16 April 2016].

Outram, B., 2009. *Black Coatings to Reduce Stray Light,* s.l.: s.n.

Queensland Government, 2016. *Measuring distances.* [Online] Available at: https://www.qld.gov.au/recreation/arts/heritage/museum-of-lands/survey-process/distances/
[Accessed 16 April 2016].

Reda, A. & Bedada, B., 2012. *Accuracy analysis and Calibration of Total Station based on the Reflectorless Distance Measurement,* Stockholm: Royal Institues of Technology.

Safe Work Australia, 2012. *Laser classifications and potential hazards.* [Online] Available at: http://www.safeworkaustralia.gov.au/sites/SWA/about/Publications/Documents/685/Laser_classification_and_potential_hazards.pdf
[Accessed 16 April 2016].

Stanley, 2012. *Fatmax® Rotary Laser.* [Online] Available at: https://www.stanleytools.co.uk/product/188720 [Accessed 16 April 2016].

Talend, D., 2009. Robotic station reduces survey risks. *Engineering and Mining Journal,* 210(10), pp. 80-81.

Trimble, 2016. *Yuma 2 Rugged Tablet Computer.* [Online] Available at: http://www.trimble.com/mappingGIS/yuma2_rugged_tablet.aspx [Accessed 16 Aprl 2016].

Wild Heerbrugg , n.d. *NEW Nikon Used Leica Wild Heerbrugg Topcon Pentax Sokkia Trimble Geodimeter.* [Online]

Available at: http://www.bujorel.com/id9.html [Accessed 16 April 2016].

Williamson Corporation, 2008. *Infrared Energy, Emissivity, Reflection & Transmission,* Massachusetts: s.n.

Wolf, P. R., 2002. Surveying and Mapping: History, Current Status and Future Projections. *Journal of Surveying and Engineering,* 16 April.pp. 79-107.

Wright, B., n.d. *Gunter's Chain Early Surveying in America.* [Online] Available at: http://www.colonialsense.com/Society-Lifestyle/Signs_of_the_Times/Gunter's_Chain.php [Accessed 16 April 2016].

Zenith, 2016. *Leica TS15.* [Online] Available at: https://www.zenithsurvey.co.uk/uploaded/thumbnails/db_file_img_2960_1024x1024.jpg [Accessed 16 April 2016].

Appendix A

ENG4111/4112 Research Project

Project Specification

For: Jeffrey James

Title: The effect of materials and conditions on reflectorless electronic distance measurements from a total station.

Major: Surveying

Supervisor: Ms Zahra Gharineiat

Enrolment: ENG4111 - EXT S1, 2016
ENG4112 - EXT S1, 2016

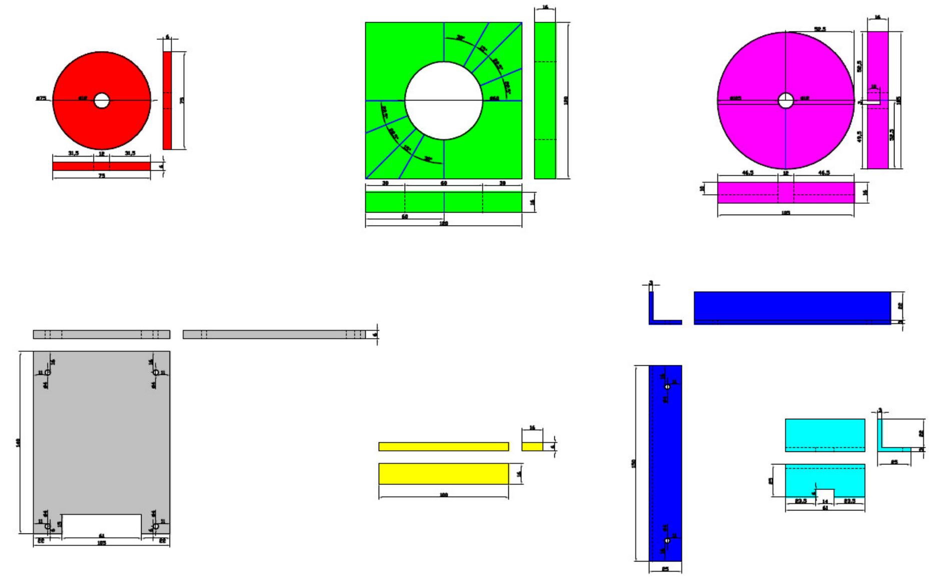
Project Aim: To determine what effect different materials and conditions have on a reflectorless electronic distance measurement.

Programme: Issue B, 16th March 2016

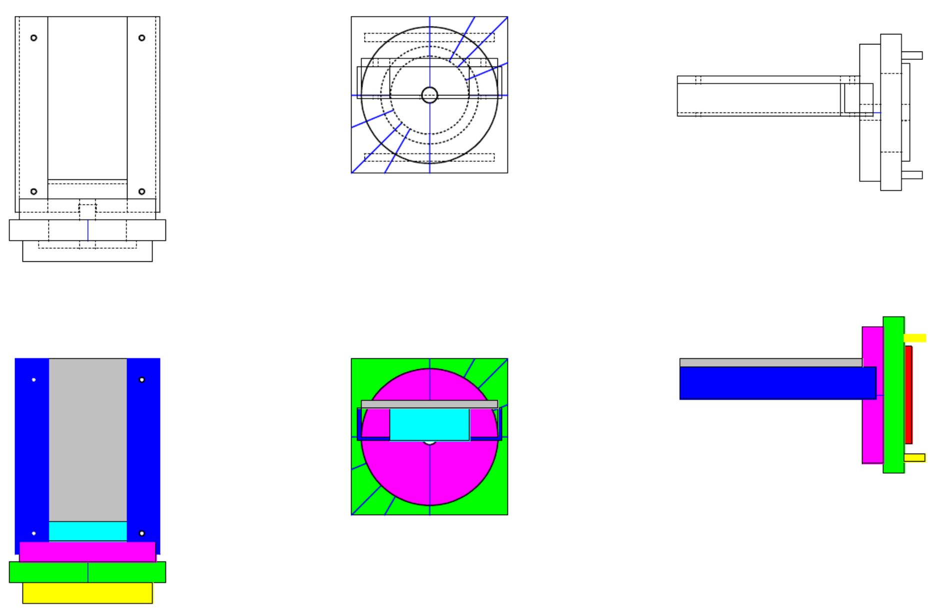
1. Search for existing research to identify pervious testing methods, materials, conditions and results.
2. Identify commonly used building materials where reflectorless electronic distance measurements would be taken and identify conditions that might also effect the measurement.
3. Develop a testing method, facility and equipment to accurately acquire specific information on the error in focus.
4. Test all materials and conditions identified.
5. Analysis of the captured data.
6. Create graphs and charts as a quick reference guide in analysing potential error in reflectorless electronic distance measurements.
7. Present outcomes and make recommendations on how to accurately measure distances using reflectorless electronic distance measurement technology.

Appendix B

Bracket drawings



SCHEDULE				
COLOUR	QUANTITY	MATERIAL	SIZE	NOTES
	1	MDF	6mm	Board
	1	MDF	16mm	Board
	2	MDF	16mm	Board
	1	MDF	16mm	Board
	2	ALUMINIUM	3mm	L Section
	1	ALUMINIUM	3mm	L Section
	1	MDF	6mm	Board
Bolts	4	STEEL	4mm	50mm Long
Nuts	4	STEEL	4mm	



Appendix C

Total station calibration certificate

Job Identification:TS15 1667749

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Observation Date: 7/12/2015 **Computation Date:** 10/12/2015
Instrument Operator: L.Pooley **Computation Time:** 10:52:32 AM

Equipment Details

Instrument Owner: Bereza Surveying
Owner Address: Unit 11, Molonglo Mall, Fyshwick
EDM Instrument Make: Leica
EDM Instrument Model: TS15
EDM Serial Number: 1667749

Reflector Make: Leica
Reflector Model: GPR 121
Serial Number: 5702458
Reflector Constant: 0 mm

Baseline Details

Name Watson **Location:** ACT
Authority: ACT Surveyor-General **Last calibration Date:** 8/09/2015
Authority Address:GPO Box 1908 Canberra ACT 2601

This baseline consists of known lengths, which are the certified distances between the pillars of the baseline. All certified distances are on the same horizontal plane and on the same vertical plane running through the first and last stations.

The baseline distances are traceable to standards specified by the Verifying Authority.

Instrument Correction (IC) in mm (to be added to the instrument reading)

IC = 0.99 - 0.00216 L

Where L = distance in metres

The reflector constant has been entered into the instrument

CYCLIC ERRORS ARE INSIGNIFICANT

Calibration Parameters	Value	Uncertainty(95%)
Index	0.99 mm	± 0.60 mm
Scale	-2.16 ppm	± 2.00 ppm

The instrument correction has been determined from measurements in the range of 47 to 1118 metres

Job Identification:TS15 1667749

EDM Calibration Certificate

This report has been generated by program Baseline Version 6.1.0.3, developed by the Western Australian Land Information Agency.

Use of this application elsewhere should rely on baseline distances certified by the relevant authority.

Uncertainty of the Instrument Correction

Minimum standard for the uncertainty of calibration of an EDM instrument is ±(4.00 mm + 20.00 ppm) as described in terms of Recommendation No.8 of the Working Party of the National Standards Commision on the calibration of EDM Equipment of 1 February, 1983. All uncertainties are specified at the 95 % confidence level. A coverage factor of 2 has been used for the uncertainty computations. The Least Uncertainty of Measurement as specified by the Accreditation Authority has been used for the uncertainty of the instrument correction.

Uncertainty of instrument correction: ±(0.60 mm + 2.00 ppm)

Distance (metres)	Instrument Uncertainty (mm)	Minimum Standard (mm)	Comparison Test
50	±0.70	±5.00	PASS
100	±0.80	±6.00	PASS
300	±1.20	±10.00	PASS
500	±1.60	±14.00	PASS
800	±2.20	±20.00	PASS
1100	±2.80	±26.00	PASS

This instrument satisfies the National Measurement Institute standards.

First Velocity Correction (Atmospheric Correction)

The atmospheric correction dial of the EDM instrument was set for all observations. Therefore the observed distances have already been corrected for atmospheric effects.

To obtain a Regulation 13 Certificate for the purpose of legal traceability to the Australian standard of length contact the Verifying Authority responsible for length measurements in your State or Territory.

The calibration of the EDM Instrument has been carried out according to Work Instructions provided by the Office of the Surveyor-General, Environment & Planning Directorate, ACT Government.

Data entry by: L. WOOD | Results checked by:

Position: SURVEY MANANGER | Position:

Signature: | Approved Signatory:

Date: 17/12/15 | Date:

GEOFF DUAL SCREEN.

EDM CALIBRATION SHEET – WATSON BASE

ACT Government Environment and Planning

DATE	OBSERVER	ASSISTANT	ORGANISATION	INSTR. MAKE	INSTRUMENT MODEL	INSTRUMENT SERIAL No.	REFL. MAKE	REFLECTOR MODEL	REFLECTOR SERIAL No.	REFLECTOR CONSTANT
07/12/15	L. Pooley	S. Jamet	Berezo Civil Surveys	Leica	TS 15	1667749	Leica	GPR121	5702458	0.0

(SEE OVER FOR ADDITIONAL REQUIRED EDM DETAILS)

THERMOMETERS

	SERIAL No.	CORR'N
INSTR.	973 80483	± – °C
REFL.	974 90164	± – °C

BAROMETER

INSTRUMENT	SERIAL No.	CORR'N
KESTREL 4000	508801	± +1.1 mb

WEATHER CONDITIONS

overcast light wind

CHECKLIST ☑ Instrument shaded ☑ Met. Equipment shaded ☑ Index constant set to ZERO ☑ Instr. Re-pointed for each meas. ☑ *SLOPE DISTANCES*

Is the EDM a Pulse Distance Meter? ☐ NO: PPM set to ZERO ☑ YES: Enter Temperature and Pressure into EDM for each inter-pillar distance

FROM PILLAR	TO PILLAR	Ht. of Inst.	Ht. of Reflector	INSTR. TEMP (°C)	REFL. TEMP (°C)	MEAN TEMP (°C)	PRESSURE (mb)	SLOPE DISTANCES (1)	(2)	(3)	(4)	(5)	TIME	COMMENTS
1	4	0.239	0.240	28.1	28.0		947.1	548.870	.869	.870	.870	.870	13:50	
	5		.241	27.6	29.9		947.0	171.340	.340	.339	.340	.340	13:54	
	6		.240	27.8	29.6		947.0	337.204	.204	.204	.204	.204	13:57	
	7		.241	27.5	28.9		946.9	503.264	.263	.263	.263	.263	13:59	
	8		.241	27.7	28.2		946.9	669.253	.253	.253	.253	.254	14:03	
	9		.241	27.4	28.5		946.8	835.322	.322	.323	.322	.322	14:06	
	10		.240	27.5	28.7		946.8	1001.355	.355	.355	.355	.355	14:09	
	11		.239	27.8	29.4		946.9	1117.830	.831	.831	.831	.831	14:12	
4	11	0.239	0.239	28.4	30.2		947.3	1062.995	.995	.994	.995	.994	14:17	
	10		.237	28.0	29.3		947.1	946.516	.516	.516	.516	.516	14:20	
	9		.240	28.2	28.8		947.1	780.481	.481	.481	.481	.481	14:24	
	8		.240	28.6	29.4		947.1	614.409	.410	.409	.409	.409	14:26	
	7		.241	27.3	28.9		947.0	448.414	.414	.415	.415	.415	14.30	
	6		.240	27.1	28.1		946.9	282.353	.353	.353	.354	.353	14:33	
	5		.241	27.8	28.2		946.9	116.485	.485	.485	.485	.485	14:36	
	3		.240	28.2	27.9		946.9	47.357	.357	.357	.357	.357	14:40	
	2		.240	28.8	29.0		947.0	49.860	.860	.860	.860	.860	14:42	
	1		.240	28.3	28.8		947.0	54.871	.871	.871	.871	.871	14:44	

→ 49.860

Signed: .... Postal Address: .... Page ..... of .....

Appendix D

Kestrel Calibration Certificate

Kestrel — **Certificate of Conformity**

This instrument was produced under rigorous factory production control and documented standard procedures. It was individually inspected and leak tested and the functioning of the display, backlight, buttons and firmware were verified. The accuracy of each of its primary measurements was individually calibrated and /or validated according to documented standard test procedures against the standards detailed below. This instrument is warrantied to perform at the date of first consumer purchase in compliance with the published specifications, including stated drift since the date of manufacture, for the specific measurements and features of its model number. *(See Kestrel Limited Warranty for full warranty terms.)*

Standards Used in Testing

Wind Speed:

The Kestrel Weather & Environmental Meter impeller installed in this unit was individually tested in a subsonic wind tunnel operating at approximately 300 fpm (1.5 m/s) and 1200 fpm (6.1 m/s) monitored by a Gill Instruments Model 1350 ultrasonic time-of-flight anemometer. The Standard's maximum combined uncertainty is ±1.04% within the airspeed range 706.6 to 3923.9 fpm (3.59 to 19.93 m/s), and ±1.66% within the airspeed range 166.6 to 706.6 fpm (0.85 to 3.59 m/s).

Temperature:

Temperature response is verified in comparison with an Ametek DTI-050 Digital Temperature Indicator and STS Reference Sensor. The DTI-050 is calibrated annually and is traceable to NIST with a maximum relative expanded uncertainty of ± 0.40C.

Direction / Heading

The sensitivity of the magnetic directional sensor is verified after assembly by orienting the unit to the cardinal directions and confirming the magnetic field output. The compass output is accurate to within ± 5 degrees as compared to a Suunto KB-14/360R G precision compass.

Relative Humidity:

Relative humidity is verified in comparison with an Edgetech HT120 Humidity Transmitter. The HT120 is calibrated annually and is traceable to NIST with a maximum relative expanded uncertainty of ±1.0%RH.

Barometric Pressure:

Pressure response is verified against a Vaisala PTB210A Digital Barometer. The Vaisala Barometer is calibrated annually and is traceable to NIST with a maximum relative expanded uncertainty of ± 0.3hPa.

Approved By:

Nils Steffensen

Nils Steffensen, Director of Engineering

Appendix E

Booking sheets

PRISM

Condition	Temp (ºC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (ºC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.9	1007.8	87.6	3.6		0º	7.0995	7.0995	7.0997	7.0996	7.0997	7.0996	7.1006
						22.5º	7.0995	7.0995	7.0996	7.0997	7.0996	7.0996	7.1006
						45º	7.1001	7.1001	7.1001	7.1001	7.1001	7.1001	7.1011
						60º	-	-	-	-	-		
Wet	13.9	1007.7	87.5	3.6		0º	7.0996	7.0997	7.0996	7.0997	7.0996	7.0996	7.1006
						22.5º	7.0997	7.0997	7.0997	7.0997	7.0996	7.0997	7.1007
						45º	7.1005	7.1004	7.1004	7.1005	7.1003	7.1004	7.1014
						60º	-	-	-	-	-		
Hot	14.4	1001.6	93	5.9	71.6	0º	7.0996	7.0995	7.0996	7.0996	7.0996	7.0996	7.1006
					68.7	22.5º	7.0995	7.0997	7.0997	7.0996	7.0997	7.0996	7.1006
					67.6	45º	7.1004	7.1003	7.1004	7.1005	7.1002	7.1004	7.1013
					63.8	60º	-	-	-	-	-		
Cold	13.3	1011.2	89.3	2.1	0.8	0º	7.0994	7.0994	7.0996	7.0995	7.0996	7.0995	7.1005
					4.8	22.5º	7.0997	7.0998	7.0998	7.0998	7.0998	7.0998	7.1008
					4.4	45º	7.1003	7.1003	7.1005	7.1004	7.1005	7.1004	7.1014
					4.6	60º	-	-	-	-	-		
Illuminated	13.8	1007.8	87.9	3.5		0º	7.0994	7.0994	7.0994	7.0994	7.0995	7.0994	7.1004
						22.5º	7.0994	7.0995	7.0995	7.0997	7.0996	7.0995	7.1005
						45º	7.1001	7.1001	7.1002	7.1001	7.1002	7.1001	7.1011
						60º	-	-	-	-	-		
Unilluminated	13.8	1007.8	87.8	3.5		0º	7.0993	7.0995	7.0994	7.0995	7.0995	7.0994	7.1004
						22.5º	7.0994	7.0996	7.0996	7.0996	7.0995	7.0995	7.1005
						45º	7.1003	7.1004	7.1005	7.1004	7.1002	7.1004	7.1013
						60º	-	-	-	-	-		

Mean	7.1008
Median	7.1006
Mode	7.1006
Standard Diviation	0.00037

Lowest	7.1004
Highest	7.1014
Range	0.0010
Variance	1.3E-07

Condition				Angle			
Mean		Range		Mean		Range	
Illumin	7.1007	Dry	0.0005	0º	7.1005	0º	0.0002
Wet	7.1009	Unillumin	0.0009	45º	7.1013	45º	0.0003

REFLECTIVE TAPE

Condition	Temp (ºC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (ºC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.2	1010.4	90.1	2.2		0º	7.1014	7.1014	7.1014	7.1015	7.1014	7.1014	7.1014
						22.5º	7.1013	7.1013	7.1013	7.1013	7.1014	7.1013	7.1013
						45º	7.1007	7.1007	7.1007	7.1006	7.1006	7.1007	7.1006
						60º	7.1006	7.1008	7.1005	7.1007	7.1006	7.1006	7.1006
Wet	13.4	1010	88.9	2.5		0º	7.1006	7.1005	7.1007	7.1005	7.1005	7.1006	7.1005
						22.5º	7.1001	7.101	7.1011	7.1011	7.101	7.1009	7.1008
						45º	7.1016	7.1017	7.1016	7.1016	7.1018	7.1017	7.1016
						60º	7.1009	7.1011	7.1011	7.101	7.1011	7.1010	7.1010
Hot	14.4	1001.8	92.8	5.9	73.6	0º	7.1018	7.1015	7.1017	7.1017	7.1018	7.1017	7.1017
					70.6	22.5º	7.1012	7.1013	7.1013	7.1011	7.1014	7.1013	7.1012
					68.8	45º	7.1003	7.1003	7.1004	7.1003	7.1002	7.1003	7.1003
					66.6	60º	7.1	7.0999	7.1002	7.1002	7.1002	7.1001	7.1001
Cold	13.2	1013.9	89.3	1.2	0.4	0º	7.101	7.1011	7.1014	7.1014	7.1015	7.1013	7.1013
					1.2	22.5º	7.101	7.1007	7.1009	7.101	7.101	7.1009	7.1009
					1.6	45º	7.1009	7.1008	7.1009	7.101	7.1009	7.1009	7.1009
					2.2	60º	7.1016	7.1016	7.1014	7.1014	7.1016	7.1015	7.1015
Illuminated	13.7	1008.2	88.1	3.3		0º	7.1007	7.1008	7.101	7.101	7.1009	7.1009	7.1009
						22.5º	7.1017	7.1017	7.1016	7.1017	7.1018	7.1017	7.1017
						45º	7.1009	7.1011	7.1008	7.1009	7.1009	7.1009	7.1009
						60º	7.1003	7.1005	7.1004	7.1004	7.1003	7.1004	7.1004
Unilluminated	13.3	1010.4	89.9	2.3		0º	7.1015	7.1015	7.1014	7.1014	7.1014	7.1014	7.1014
						22.5º	7.1005	7.1004	7.1007	7.1007	7.1005	7.1006	7.1005
						45º	7.1005	7.1005	7.1007	7.1006	7.1005	7.1006	7.1005
						60º	7.1012	7.1012	7.1014	7.1013	7.1012	7.1013	7.1012

Mean	7.1010
Median	7.1009
Mode	7.1005
Standard Diviation	0.00046

Lowest	7.1001
Highest	7.1017
Range	0.0016
Variance	2.1E-07

Condition				Angle			
Mean		Range		Mean		Range	
Hot	7.1008	Cold	0.0006	60º	7.1008	0º	0.0011
Cold	7.1011	Hot	0.0016	0º	7.1012	60º	0.0014

SOFTWOOD

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.3	1010	89	2.4		0^o	7.1011	7.1012	7.1012	7.1012	7.1012	7.1012	7.1012
						22.5^o	7.1015	7.1014	7.1014	7.1016	7.1015	7.1015	7.1015
						45^o	7.101	7.1009	7.1012	7.1012	7.101	7.1011	7.1010
						60^o	7.1006	7.1006	7.1006	7.1006	7.1006	7.1006	7.1006
Wet	13.4	10098	88.4	2.6		0^o	7.1008	7.1011	7.1009	7.101	7.1007	7.1009	7.1009
						22.5^o	7.1015	7.1014	7.1013	7.1014	7.1016	7.1014	7.1014
						45^o	7.1011	7.1016	7.1016	7.1013	7.1012	7.1014	7.1013
						60^o	7.1015	7.1013	7.1013	7.1014	7.1012	7.1013	7.1013
Hot	14.3	1002.6	93	5.5	57.4	0^o	7.1011	7.1011	7.1011	7.1012	7.1011	7.1011	7.1011
					54.8	22.5^o	7.1009	7.1009	7.101	7.101	7.101	7.1010	7.1009
					53.2	45^o	7.1003	7.1005	7.1005	7.1006	7.1006	7.1005	7.1005
					50.2	60^o	7.1001	7.1	7.0998	7.0999	7.0999	7.0999	7.0999
Cold	13.2	1014	89.3	1.2	0	0^o	7.1015	7.1014	7.1014	7.1013	7.1011	7.1013	7.1013
					0.8	22.5^o	7.1009	7.1012	7.1012	7.1013	7.1011	7.1011	7.1011
					1.4	45^o	7.1012	7.1011	7.1012	7.101	7.101	7.1011	7.1011
					1.8	60^o	7.1012	7.1009	7.1011	7.1007	7.1007	7.1009	7.1009
Illuminated	13.8	1007.9	87.6	3.5		0^o	7.1008	7.1009	7.1009	7.1009	7.1007	7.1008	7.1008
						22.5^o	7.1009	7.101	7.101	7.1008	7.1008	7.1009	7.1009
						45^o	7.101	7.1009	7.101	7.1009	7.1009	7.1009	7.1009
						60^o	7.1008	7.101	7.101	7.101	7.101	7.1010	7.1009
Unilluminated	13.4	1010	89.1	2.5		0^o	7.1005	7.1005	7.1005	7.1006	7.1007	7.1006	7.1005
						22.5^o	7.1012	7.1012	7.1012	7.1012	7.1013	7.1012	7.1012
						45^o	7.1011	7.1013	7.1013	7.1013	7.1012	7.1012	7.1012
						60^o	7.1011	7.1011	7.1011	7.1011	7.101	7.1011	7.1011

Mean	7.1010
Median	7.1011
Mode	#N/A
Standard Diviation	0.00035

Lowest	7.0999
Highest	7.1015
Range	0.0015
Variance	1.2E-07

Condition				Angle			
Mean		Range		Mean		Range	
Hot	7.1006	Illumin	0.0001	60^o	7.1008	22.5^o	0.0006
Wet	7.1012	Hot	0.0012	22.5^o	7.1012	60^o	0.0014

HARDWOOD

Condition	Temp (°C)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (°C)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.2	1009.7	90	2.4		0°	7.1003	7.1004	7.1003	7.1003	7.1002	7.1003	7.1003
						22.5°	7.1001	7.1002	7.1003	7.1004	7.1002	7.1002	7.1002
						45°	7.1006	7.1009	7.1007	7.1008	7.1006	7.1007	7.1007
						60°	7.1005	7.1006	7.1004	7.1004	7.1003	7.1004	7.1004
Wet	13.4	1009.4	88.3	2.7		0°	7.1002	7.1002	7.0995	7.0996	7.0999	7.0999	7.0999
						22.5°	7.1	7.1002	7.1004	7.1002	7.1001	7.1002	7.1002
						45°	7.101	7.1015	7.1011	7.101	7.1009	7.1011	7.1011
						60°	7.1023	7.1014	7.1019	7.102	7.1021	7.1019	7.1019
Hot	14.3	1002.7	93.1	5.5	65.6	0°	7.101	7.1009	7.101	7.101	7.101	7.1010	7.1010
					61.8	22.5°	7.1009	7.1011	7.1011	7.101	7.101	7.1010	7.1010
					60.6	45°	7.1004	7.1004	7.1006	7.1003	7.1004	7.1004	7.1004
					59.4	60°	7.1001	7.1002	7.0999	7.1	7.1002	7.1001	7.1001
Cold	13.4	1014.1	88.6	1.4	0.6	0°	7.1004	7.1	7.0996	7.0998	7.1	7.1000	7.0999
					0.8	22.5°	7.101	7.1012	7.1006	7.1007	7.1007	7.1008	7.1008
					2	45°	7.1008	7.1006	7.1005	7.1011	7.1007	7.1007	7.1007
					2	60°	7.1021	7.1016	7.1021	7.1023	7.1023	7.1021	7.1021
Illuminated	13.8	1008.1	87.7	3.5		0°	7.101	7.1009	7.1008	7.1009	7.1008	7.1009	7.1009
						22.5°	7.1002	7.1002	7.1002	7.1003	7.1003	7.1002	7.1002
						45°	7.1009	7.1007	7.1011	7.1008	7.1005	7.1008	7.1008
						60°	7.1011	7.1012	7.1011	7.1013	7.101	7.1011	7.1011
Unilluminated	13.2	1009.5	89.4	2.5		0°	7.1004	7.1002	7.1004	7.1003	7.1004	7.1003	7.1003
						22.5°	7.1006	7.1008	7.1007	7.1007	7.1008	7.1007	7.1007
						45°	7.0999	7.1001	7.1002	7.0999	7.1002	7.1001	7.1000
						60°	7.1	7.1002	7.1002	7.1003	7.1003	7.1002	7.1002

Mean	7.1006
Median	7.1006
Mode	7.1002
Standard Diviation	0.00056

Lowest	7.0999
Highest	7.1021
Range	0.0022
Variance	3.2E-07

Condition				Angle			
Mean		Range		Mean		Range	
Unillumin	7.1003	Dry	0.0005	0°	7.1004	22.5°	0.0008
Cold	7.1009	Cold	0.0021	60°	7.1010	60°	0.0020

PLASTERBOARD

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.4	1009.4	88.8	2.7		0^o	7.1002	7.1003	7.1004	7.1005	7.1006	7.1004	7.1004
						22.5^o	7.1003	7.1005	7.1003	7.1003	7.1003	7.1003	7.1003
						45^o	7.1002	7.1004	7.1004	7.1003	7.1003	7.1003	7.1003
						60^o	7.1005	7.1005	7.1005	7.1004	7.1003	7.1004	7.1004
Wet	13.6	1009.2	88.5	2.9		0^o	7.0999	7.1004	7.1006	7.1008	7.1004	7.1004	7.1004
						22.5^o	7.1002	7.1005	7.1003	7.1008	7.1005	7.1005	7.1004
						45^o	7.1003	7.1008	7.1003	7.1005	7.1005	7.1005	7.1005
						60^o	7.1006	7.1004	7.1005	7.1009	7.1005	7.1006	7.1006
Hot	14.3	1002.1	93.1	5.7	73.8	0^o	7.1014	7.1014	7.1014	7.1011	7.101	7.1013	7.1012
					68.6	22.5^o	7.101	7.101	7.1013	7.1012	7.1013	7.1012	7.1011
					64	45^o	7.1005	7.1007	7.1006	7.1006	7.1005	7.1006	7.1006
					59.6	60^o	7.1007	7.1006	7.1009	7.1009	7.1008	7.1008	7.1008
Cold	13.3	1014.2	88.6	1.2	0.2	0^o	7.1018	7.1015	7.1013	7.1008	7.1007	7.1012	7.1012
					2.2	22.5^o	7.1008	7.1009	7.1009	7.1009	7.101	7.1009	7.1009
					3	45^o	7.1005	7.1005	7.1006	7.1008	7.1009	7.1007	7.1006
					3.8	60^o	7.1001	7.1003	7.1001	7.1	7.1001	7.1001	7.1001
Illuminated	13.8	1008.1	87.7	3.5		0^o	7.1007	7.1007	7.1007	7.1007	7.1007	7.1007	7.1007
						22.5^o	7.1011	7.1009	7.1009	7.1009	7.1011	7.1010	7.1010
						45^o	7.1005	7.1006	7.1007	7.1005	7.1006	7.1006	7.1006
						60^o	7.1006	7.1006	7.1006	7.1005	7.1006	7.1006	7.1006
Unilluminated	13.2	1009.4	89.7	2.5		0^o	7.0999	7.1002	7.1002	7.1001	7.1002	7.1001	7.1001
						22.5^o	7.1008	7.1006	7.1007	7.1008	7.1007	7.1007	7.1007
						45^o	7.1005	7.1006	7.1004	7.1003	7.1005	7.1005	7.1004
						60^o	7.1008	7.1008	7.1007	7.1007	7.1007	7.1007	7.1007

Mean	7.1006
Median	7.1006
Mode	7.1006
Standard Diviation	0.00031

Lowest	7.1001
Highest	7.1012
Range	0.0011
Variance	9.5E-08

Condition				Angle			
Mean		Range		Mean		Range	
Dry	7.1004	Dry	0.0001	45^o	7.1005	45^o	0.0003
Hot	7.1009	Cold	0.0011	22.5^o	7.1007	0^o	0.0011

PLASTIC

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.4	1009	89	2.8		0°	7.1005	7.1006	7.1005	7.1006	7.1005	7.1005	7.1005
						22.5°	7.1007	7.1008	7.1009	7.1011	7.101	7.1009	7.1009
						45°	7.1011	7.1017	7.1014	7.1011	7.1016	7.1014	7.1014
						60°	7.1048	7.1047	7.1052	7.1051	7.1051	7.1050	7.1050
Wet	13.5	1008.6	88.2	3		0°	7.1004	7.0997	7.1002	7.1006	7.1006	7.1003	7.1003
						22.5°	7.1008	7.1006	7.1009	7.1011	7.1005	7.1008	7.1008
						45°	7.1018	7.1022	7.1023	7.1014	7.1019	7.1019	7.1019
						60°	7.1103	7.1104	7.1101	7.1104	7.1104	7.1103	7.1103
Hot	14.4	1002	93.1	5.8	71.2	0°	7.1008	7.1008	7.101	7.1009	7.101	7.1009	7.1009
					64.4	22.5°	7.1002	7.1005	7.1004	7.1005	7.1008	7.1005	7.1005
					59.6	45°	7.1015	7.1015	7.1018	7.1019	7.1011	7.1016	7.1015
					55	60°	7.1058	7.1057	7.1052	7.1058	7.1057	7.1056	7.1056
Cold	13.1	1013.6	89.3	1.2	0.6	0°	7.1007	7.1008	7.1008	7.1011	7.1011	7.1009	7.1009
					2.2	22.5°	7.1019	7.1016	7.1016	7.102	7.1019	7.1018	7.1018
					4	45°	7.1009	7.1014	7.1011	7.1014	7.1013	7.1012	7.1012
					4.6	60°	7.106	7.1061	7.106	7.1064	7.1068	7.1063	7.1062
Illuminated	13.5	1008.8	88.8	3		0°	7.1002	7.1003	7.1003	7.1003	7.1003	7.1003	7.1003
						22.5°	7.101	7.1007	7.1009	7.111	7.1014	7.1030	7.1030
						45°	7.102	7.1016	7.1018	7.1016	7.1028	7.1020	7.1019
						60°	7.1047	7.1047	7.1054	7.1054	7.1048	7.1050	7.1050
Unilluminated	13.5	1008.8	88.8	3		0°	7.1003	7.1003	7.1001	7.1005	7.1003	7.1003	7.1003
						22.5°	7.1014	7.1013	7.1013	7.1014	7.1015	7.1014	7.1014
						45°	7.1013	7.1012	7.1009	7.1011	7.1013	7.1012	7.1011
						60°	7.1044	7.1043	7.1053	7.1044	7.1043	7.1045	7.1045

Mean	7.1024
Median	7.1014
Mode	7.1009
Standard Diviation	0.00249

Lowest	7.1003
Highest	7.1103
Range	0.0100
Variance	6.2E-06

Condition				Angle			
Mean		Range		Mean		Range	
Unillumin	7.1018	Unillumin	0.0042	0°	7.1005	0°	0.0006
Wet	7.1033	Wet	0.0100	60°	7.1061	60°	0.0058

CERAMIC TILE

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.2	1008.5	89.4	2.7		0°	7.1003	7.1004	7.1004	7.1005	7.1005	7.1004	7.1004
						22.5°	7.1018	7.1018	7.102	7.102	7.1019	7.1019	7.1019
						45°	7.1013	7.1016	7.1015	7.1015	7.1015	7.1015	7.1015
						60°	7.1019	7.102	7.1018	7.1019	7.1019	7.1019	7.1019
Wet	13.5	1008.3	88.3	3.1		0°	7.101	7.1012	7.1014	7.101	7.1012	7.1012	7.1011
						22.5°	7.1018	7.102	7.1019	7.1019	7.1021	7.1019	7.1019
						45°	7.1018	7.102	7.1017	7.1019	7.1018	7.1018	7.1018
						60°	7.1018	7.1017	7.1017	7.1016	7.1016	7.1017	7.1017
Hot	14.3	1002.4	93	5.6	79.6	0°	7.101	7.1013	7.1012	7.1012	7.1013	7.1012	7.1012
					73.4	22.5°	7.1019	7.102	7.1019	7.1021	7.1022	7.1020	7.1020
					69.2	45°	7.1018	7.1018	7.1018	7.1019	7.1018	7.1018	7.1018
					65	60°	7.1017	7.1017	7.1015	7.1015	7.1016	7.1016	7.1016
Cold	13.3	1014.6	88.7	1.1	2.2	0°	7.1017	7.1019	7.1017	7.1019	7.102	7.1018	7.1018
					2.6	22.5°	7.1024	7.1022	7.1023	7.1022	7.1025	7.1023	7.1023
					2.6	45°	7.1017	7.1018	7.1017	7.1016	7.1015	7.1017	7.1016
					3	60°	7.1015	7.1012	7.1014	7.1016	7.1017	7.1015	7.1015
Illuminated	13.4	1008.3	88.8	3		0°	7.1008	7.101	7.1009	7.101	7.101	7.1009	7.1009
						22.5°	7.1019	7.102	7.102	7.1019	7.1021	7.1020	7.1020
						45°	7.1019	7.102	7.1021	7.1021	7.102	7.1020	7.1020
						60°	7.1017	7.1016	7.1017	7.1016	7.1016	7.1016	7.1016
Unilluminated	13.3	1008.5	89.1	2.8		0°	7.1	7.1005	7.1004	7.1003	7.1004	7.1003	7.1003
						22.5°	7.1019	7.102	7.102	7.102	7.1021	7.1020	7.1020
						45°	7.1018	7.1019	7.1019	7.1019	7.1017	7.1018	7.1018
						60°	7.1018	7.1021	7.102	7.1019	7.1019	7.1019	7.1019

Mean	7.1016
Median	7.1018
Mode	7.1018
Standard Diviation	0.0005

Lowest	7.1003
Highest	7.1023
Range	0.0020
Variance	2.5E-07

Condition				Angle			
Mean		Range		Mean		Range	
Dry	7.1014	Wet	0.0008	0°	7.1010	22.5°	0.0004
Cold	7.1018	Unillumin	0.0017	22.5°	7.1020	0°	0.0015

CONCRETE

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.3	1008.1	89.2	3		0^o	7.1013	7.1011	7.1013	7.1014	7.1014	7.1013	7.1013
						22.5^o	7.1002	7.1003	7.1003	7.1003	7.1004	7.1003	7.1003
						45^o	7.1003	7.1002	7.1002	7.1003	7.1003	7.1003	7.1002
						60^o	7.1003	7.1002	7.1003	7.1003	7.1001	7.1002	7.1002
Wet	13.5	1008.1	88.6	3.2		0^o	7.1003	7.1001	7.1004	7.1002	7.1003	7.1003	7.1002
						22.5^o	7.1004	7.1007	7.1005	7.1001	7.1006	7.1005	7.1004
						45^o	7.1006	7.1006	7.1002	7.1004	7.1008	7.1005	7.1005
						60^o	7.1006	7.1008	7.1006	7.1008	7.1009	7.1007	7.1007
Hot	14.2	1002.9	93.5	5.4	62.6	0^o	7.1007	7.1007	7.1007	7.1007	7.1007	7.1007	7.1007
					62	22.5^o	7.1007	7.1008	7.1007	7.1007	7.1007	7.1007	7.1007
					61.6	45^o	7.1	7.1002	7.1001	7.1	7.1	7.1001	7.1000
					60.4	60^o	7.1003	7.1004	7.1004	7.1005	7.1002	7.1004	7.1003
Cold	13.4	1013.4	88.3	1.6	0	0^o	7.1008	7.1006	7.1006	7.1006	7.1009	7.1007	7.1007
					0	22.5^o	7.1002	7.1003	7.1003	7.1003	7.1004	7.1003	7.1003
					0	45^o	7.1004	7.1006	7.1005	7.1004	7.1006	7.1005	7.1005
					0	60^o	7.101	7.1008	7.1008	7.1008	7.101	7.1009	7.1009
Illuminated	13.4	1008.1	88.8	3.1		0^o	7.1012	7.1012	7.1011	7.1012	7.101	7.1011	7.1011
						22.5^o	7.1003	7.1001	7.1002	7.1002	7.1002	7.1002	7.1002
						45^o	7.1004	7.1004	7.1006	7.1003	7.1005	7.1004	7.1004
						60^o	7.1003	7.1004	7.1005	7.1006	7.1005	7.1005	7.1004
Unilluminated	13.3	1008.2	89.4	2.9		0^o	7.1015	7.1014	7.1013	7.1014	7.1013	7.1014	7.1014
						22.5^o	7.1002	7.1002	7.1003	7.1003	7.1003	7.1003	7.1002
						45^o	7.1005	7.1006	7.1004	7.1005	7.1003	7.1005	7.1004
						60^o	7.1001	7.1003	7.1002	7.1003	7.1004	7.1003	7.1002

Mean	7.1005
Median	7.1004
Mode	7.1002
Standard Diviation	0.00035

Lowest	7.1000
Highest	7.1014
Range	0.0013
Variance	1.2E-07

Condition				Angle			
Mean		Range		Mean		Range	
Hot	7.1004	Wet	0.0005	45^o	7.1004	45^o	0.0005
Cold	7.1006	Unillumin	0.0011	0^o	7.1009	0^o	0.0011

BESSER BLOCK

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.5	1008.2	88.9	3.1		0^o	7.1016	7.1018	7.1017	7.1016	7.1016	7.1017	7.1016
						22.5^o	7.101	7.1011	7.1011	7.1011	7.1011	7.1011	7.1011
						45^o	7.1017	7.1017	7.1018	7.1018	7.1018	7.1018	7.1017
						60^o	7.1021	7.1021	7.1019	7.1022	7.102	7.1021	7.1020
Wet	13.6	1008.2	88.4	3.2		0^o	7.1015	7.1014	7.1012	7.1018	7.1017	7.1015	7.1015
						22.5^o	7.1013	7.1017	7.1018	7.1014	7.1014	7.1015	7.1015
						45^o	7.1019	7.1018	7.1019	7.1017	7.1014	7.1017	7.1017
						60^o	7.102	7.1019	7.1019	7.1017	7.1018	7.1019	7.1018
Hot	14.2	1002.8	93.2	5.4	64.2	0^o	7.1022	7.1023	7.1023	7.1023	7.1024	7.1023	7.1023
					63	22.5^o	7.1014	7.1015	7.1015	7.1014	7.1013	7.1014	7.1014
					62.6	45^o	7.1015	7.1016	7.1016	7.1016	7.1015	7.1016	7.1015
					61.4	60^o	7.1022	7.1023	7.1023	7.1024	7.1023	7.1023	7.1023
Cold	13.3	1012.4	88.4	1.7	0	0^o	7.1008	7.1011	7.1012	7.1015	7.1019	7.1013	7.1013
					0	22.5^o	7.1009	7.1014	7.101	7.1012	7.1008	7.1011	7.1010
					1	45^o	7.1015	7.1016	7.1017	7.1014	7.1014	7.1015	7.1015
					1.6	60^o	7.1018	7.1018	7.1018	7.1019	7.1018	7.1018	7.1018
Illuminated	13.5	1008.3	88.8	3.1		0^o	7.102	7.102	7.102	7.1019	7.1019	7.1020	7.1019
						22.5^o	7.1011	7.1012	7.1012	7.1012	7.1012	7.1012	7.1012
						45^o	7.1013	7.1013	7.1015	7.1015	7.1015	7.1014	7.1014
						60^o	7.1019	7.1022	7.1021	7.1022	7.1021	7.1021	7.1021
Unilluminated	13.4	1008.2	89.2	3		0^o	7.1017	7.1019	7.102	7.102	7.1019	7.1019	7.1019
						22.5^o	7.1015	7.1017	7.1017	7.1016	7.1017	7.1016	7.1016
						45^o	7.1012	7.1011	7.1013	7.1013	7.1012	7.1012	7.1012
						60^o	7.102	7.102	7.1022	7.1021	7.1022	7.1021	7.1021

Mean	7.1017
Median	7.1016
Mode	7.1015
Standard Diviation	0.00036

Lowest	7.1010
Highest	7.1023
Range	0.0012
Variance	1.3E-07

Condition				Angle			
Mean		Range		Mean		Range	
Cold	7.1014	Wet	0.0003	22.5^o	7.1013	60^o	0.0005
Hot	7.1019	Dry	0.0010	60^o	7.1020	0^o	0.0010

BRICK

Condition	Temp (^{o}C)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^{o}C)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.5	1008.3	88.9	3.1		0^{o}	7.1	7.1002	7.1002	7.1003	7.1003	7.1002	7.1002
						22.5^{o}	7.0997	7.0997	7.0998	7.0998	7.0997	7.0997	7.0997
						45^{o}	7.0997	7.0997	7.0997	7.0996	7.0997	7.0997	7.0997
						60^{o}	7.0991	7.0992	7.0993	7.0992	7.0993	7.0992	7.0992
Wet	13.6	1008.3	88.2	3.2		0^{o}	7.0995	7.0998	7.0998	7.1001	7.1	7.0998	7.0998
						22.5^{o}	7.1001	7.1001	7.1002	7.1002	7.1004	7.1002	7.1002
						45^{o}	7.0997	7.0994	7.0996	7.0996	7.0997	7.0996	7.0996
						60^{o}	7.1001	7.1002	7.1003	7.1	7.1	7.1001	7.1001
Hot	14.2	1002.9	93.1	5.4	77.8	0^{o}	7.1008	7.1012	7.1012	7.1013	7.1011	7.1011	7.1011
					75.6	22.5^{o}	7.1011	7.101	7.101	7.101	7.101	7.1010	7.1010
					74.4	45^{o}	7.0999	7.0998	7.0998	7.0999	7.0999	7.0999	7.0998
					71.6	60^{o}	7.0996	7.0996	7.0996	7.0996	7.0995	7.0996	7.0996
Cold	13.3	1013.6	88.4	1.4	0	0^{o}	7.1006	7.1002	7.1007	7.1005	7.1005	7.1005	7.1005
					0.6	22.5^{o}	7.1002	7.0997	7.0998	7.1002	7.1002	7.1000	7.1000
					1.2	45^{o}	7.0999	7.0997	7.0997	7.0998	7.0996	7.0997	7.0997
					2	60^{o}	7.0993	7.0993	7.0993	7.0991	7.0993	7.0993	7.0992
Illuminated	13.5	1008.3	88.5	3.1		0^{o}	7.1001	7.1002	7.1002	7.1003	7.1	7.1002	7.1001
						22.5^{o}	7.0995	7.0996	7.0995	7.0995	7.0996	7.0995	7.0995
						45^{o}	7.0997	7.0998	7.0997	7.0996	7.0997	7.0997	7.0997
						60^{o}	7.0996	7.0996	7.0994	7.0997	7.0994	7.0995	7.0995
Unilluminated	13.5	1008.2	88.8	3.1		0^{o}	7.1002	7.1003	7.1001	7.1002	7.1001	7.1002	7.1002
						22.5^{o}	7.0996	7.0995	7.0995	7.0996	7.0996	7.0996	7.0995
						45^{o}	7.0992	7.0993	7.0992	7.0994	7.0993	7.0993	7.0993
						60^{o}	7.0993	7.0994	7.0994	7.0994	7.0994	7.0994	7.0994

Mean	7.0999
Median	7.0997
Mode	7.1002
Standard Diviation	0.0005

Lowest	7.0992
Highest	7.1011
Range	0.0019
Variance	2.5E-07

Condition				Angle			
Mean		Range		Mean		Range	
Unillumin	7.0996	Wet	0.0006	60^{o}	7.0995	45^{o}	0.0006
Hot	7.1004	Hot	0.0015	0^{o}	7.1003	22.5^{o}	0.0015

ALUMINIUM

Condition	Temp (°C)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (°C)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.6	1008.2	88.3	3.2		0°	7.0999	7.1002	7.1002	7.1002	7.1003	7.1002	7.1001
						22.5°	7.1004	7.1005	7.1006	7.1005	7.1004	7.1005	7.1005
						45°	7.0998	7.1001	7.0999	7.0997	7.0996	7.0998	7.0998
						60°	7.1015	7.1016	7.1017	7.1017	7.1016	7.1016	7.1016
Wet	13.7	1008	87.8	3.4		0°	7.1001	7.1003	7.1001	7.1006	7.1005	7.1003	7.1003
						22.5°	7.1004	7.0998	7.0998	7.0996	7.0999	7.0999	7.0999
						45°	7.0996	7.0994	7.0995	7.0995	7.0994	7.0995	7.0995
						60°	7.1005	7.1005	7.1005	7.1005	7.1009	7.1006	7.1006
Hot	14.2	1003	93	5.3	21.8	0°	7.1002	7.1002	7.1002	7.1003	7.1003	7.1002	7.1002
					20.6	22.5°	7.1002	7.1004	7.1004	7.1004	7.1006	7.1004	7.1004
					20.4	45°	7.1	7.1003	7.1002	7.1004	7.1002	7.1002	7.1002
					20	60°	7.1031	7.1032	7.1031	7.1031	7.1031	7.1031	7.1031
Cold	13.4	1013.1	88.3	1.6	0	0°	7.1009	7.1006	7.1003	7.1003	7.1004	7.1005	7.1005
					2	22.5°	7.1	7.1005	7.1005	7.1007	7.1009	7.1005	7.1005
					3.2	45°	7.101	7.1004	7.1001	7.1001	7.1003	7.1004	7.1004
					3.2	60°	7.1011	7.1013	7.1013	7.101	7.1011	7.1012	7.1011
Illuminated	13.7	1008.1	87.9	3.4		0°	7.1005	7.1006	7.1007	7.1006	7.1007	7.1006	7.1006
						22.5°	7.1006	7.1004	7.1004	7.1005	7.1004	7.1005	7.1004
						45°	7.0995	7.0995	7.0995	7.0994	7.0994	7.0995	7.0994
						60°	7.1011	7.1011	7.1013	7.1012	7.1011	7.1012	7.1011
Unilluminated	13.6	1008.2	88.3	3.2		0°	7.1002	7.1004	7.1005	7.1004	7.1004	7.1004	7.1004
						22.5°	7.099	7.0991	7.0994	7.0992	7.0993	7.0992	7.0992
						45°	7.0999	7.1001	7.1	7.1001	7.1	7.1000	7.1000
						60°	7.1016	7.1016	7.1019	7.1018	7.1018	7.1017	7.1017

Mean	7.1005
Median	7.1004
Mode	7.1004
Standard Diviation	0.00083

Lowest	7.0992
Highest	7.1031
Range	0.0039
Variance	6.8E-07

Condition				Angle			
Mean		Range		Mean		Range	
Wet	7.1001	Cold	0.0008	45°	7.0999	0°	0.0005
Hot	7.1010	Hot	0.0029	60°	7.1015	60°	0.0025

GALVANISED STEEL

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.7	1008.1	88.1	3.4		0°	7.1	7.1002	7.1004	7.1005	7.1003	7.1003	7.1003
						22.5°	7.1004	7.1005	7.1002	7.1002	7.1002	7.1003	7.1003
						45°	7.1002	7.1005	7.1004	7.1005	7.1004	7.1004	7.1004
						60°	7.1043	7.104	7.1044	7.1042	7.1042	7.1042	7.1042
Wet	13.8	1008.2	87.8	3.4		0°	7.1002	7.1001	7.1007	7.101	7.1009	7.1006	7.1006
						22.5°	7.1001	7.1005	7.1005	7.1005	7.1003	7.1004	7.1004
						45°	7.0998	7.1002	7.0998	7.0998	7.1	7.0999	7.0999
						60°	7.1024	7.1029	7.1028	7.1025	7.1025	7.1026	7.1026
Hot	14.2	1003.2	92.7	5.3	41.8	0°	7.1004	7.1006	7.1007	7.101	7.101	7.1007	7.1007
					36.6	22.5°	7.1005	7.1004	7.1006	7.1007	7.1006	7.1006	7.1005
					35.2	45°	7.101	7.1012	7.1011	7.1009	7.101	7.1010	7.1010
					32.4	60°	7.1043	7.1041	7.1043	7.1043	7.1045	7.1043	7.1043
Cold	13.4	1013	88.2	1.7	0	0°	7.1007	7.1007	7.1007	7.1004	7.1003	7.1006	7.1005
					0.2	22.5°	7.1009	7.1007	7.1008	7.1005	7.1005	7.1007	7.1007
					2.6	45°	7.101	7.1003	7.1005	7.1004	7.1009	7.1006	7.1006
					3.4	60°	7.1028	7.1029	7.1025	7.1028	7.1031	7.1028	7.1028
Illuminated	13.8	1008.2	87.6	3.4		0°	7.1007	7.1008	7.1008	7.1008	7.1008	7.1008	7.1008
						22.5°	7.1	7.1	7.1003	7.1002	7.1	7.1001	7.1001
						45°	7.1003	7.1006	7.1006	7.1006	7.1005	7.1005	7.1005
						60°	7.104	7.1037	7.1038	7.1037	7.1039	7.1038	7.1038
Unilluminated	13.7	1008.1	87.9	3.4		0°	7.1006	7.1008	7.1008	7.1006	7.1008	7.1007	7.1007
						22.5°	7.0995	7.0995	7.0996	7.0998	7.0997	7.0996	7.0996
						45°	7.1006	7.1007	7.1007	7.1006	7.1006	7.1006	7.1006
						60°	7.1036	7.1038	7.1037	7.1038	7.1039	7.1038	7.1037

Mean	7.1012
Median	7.1006
Mode	7.1005
Standard Diviation	0.00145

Lowest	7.0996
Highest	7.1043
Range	0.0047
Variance	2.1E-06

Condition				Angle			
Mean		Range		Mean		Range	
Wet	7.1009	Cold	0.0023	22.5°	7.1003	0°	0.0005
Hot	7.1016	Unillumin	0.0041	60°	7.1036	60°	0.0017

BLUE

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.9	1007.7	87.6	3.7		0^o	7.1007	7.1009	7.1009	7.101	7.1009	7.1009	7.1009
						22.5^o	7.0999	7.1003	7.1006	7.1006	7.1005	7.1004	7.1004
						45^o	7.101	7.1008	7.1014	7.1012	7.1013	7.1011	7.1011
						60^o	7.1079	7.1085	7.1083	7.108	7.1085	7.1082	7.1082
Wet	14.1	1007.7	87.1	3.9		0^o	7.1005	7.1006	7.1006	7.1005	7.1006	7.1006	7.1005
						22.5^o	7.1008	7.1009	7.101	7.1007	7.1007	7.1008	7.1008
						45^o	7.1012	7.1012	7.1011	7.1009	7.1013	7.1011	7.1011
						60^o	7.1042	7.1052	7.1052	7.1047	7.1049	7.1048	7.1048
Hot	14.1	1003.4	92.9	5.1	71.6	0^o	7.1006	7.10008	7.1009	7.1008	7.1008	7.1006	7.1006
					69	22.5^o	7.1008	7.1009	7.1008	7.1006	7.101	7.1008	7.1008
					66.2	45^o	7.1006	7.1007	7.1008	7.1011	7.1007	7.1008	7.1008
					63.8	60^o	7.1067	7.1066	7.1067	7.1067	7.1069	7.1067	7.1067
Cold	13.2	1012.6	88.8	1.6	0	0^o	7.1003	7.1007	7.1009	7.101	7.1007	7.1007	7.1007
					1.6	22.5^o	7.1011	7.1017	7.1006	7.1007	7.1007	7.1010	7.1009
					2.6	45^o	7.1005	7.1013	7.101	7.1013	7.1	7.1008	7.1008
					2.6	60^o	7.1022	7.1021	7.1024	7.1026	7.102	7.1023	7.1022
Illuminated	14	1007.7	87.3	3.8		0^o	7.1007	7.1008	7.1009	7.1008	7.1007	7.1008	7.1008
						22.5^o	7.1001	7.1006	7.1004	7.1007	7.1007	7.1005	7.1005
						45^o	7.1016	7.1017	7.1013	7.1013	7.1013	7.1014	7.1014
						60^o	7.1081	7.1084	7.1082	7.1086	7.1086	7.1084	7.1084
Unilluminated	14	1007.7	87.4	3.8		0^o	7.1006	7.1006	7.1006	7.1006	7.1007	7.1006	7.1006
						22.5^o	7.1004	7.1006	7.1007	7.1003	7.1005	7.1005	7.1005
						45^o	7.1007	7.1013	7.1014	7.1012	7.1008	7.1011	7.1011
						60^o	7.1081	7.1083	7.1086	7.1081	7.1084	7.1083	7.1083

Mean	7.1022
Median	7.1008
Mode	7.1011
Standard Diviation	0.00276

Lowest	7.1004
Highest	7.1084
Range	0.0080
Variance	7.6E-06

Condition				Angle			
Mean		Range		Mean		Range	
Cold	7.1012	Cold	0.0015	22.5^o	7.1006	0^o	0.0003
Illumin	7.1028	Illumin	0.0079	60^o	7.1064	60^o	0.0061

RED

Condition	Temp (°C)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (°C)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	14	1007.7	87.2	3.8		0°	7.101	7.1011	7.1009	7.1011	7.101	7.1010	7.1010
						22.5°	7.1004	7.1005	7.1006	7.1007	7.1005	7.1005	7.1005
						45°	7.1006	7.1008	7.1007	7.1009	7.1008	7.1008	7.1007
						60°	7.1007	7.1008	7.1007	7.1006	7.1007	7.1007	7.1007
Wet	14.1	1007.7	87	3.9		0°	7.1011	7.101	7.1012	7.1013	7.1012	7.1012	7.1011
						22.5°	7.1007	7.1012	7.1009	7.101	7.101	7.1010	7.1009
						45°	7.1009	7.1009	7.1007	7.101	7.1008	7.1009	7.1008
						60°	7.1009	7.1011	7.101	7.1009	7.101	7.1010	7.1010
Hot	14.1	1003.6	93.2	5.1	71.4	0°	7.1008	7.101	7.1011	7.1011	7.1013	7.1011	7.1010
					68.4	22.5°	7.1009	7.1009	7.1009	7.1008	7.101	7.1009	7.1009
					65.2	45°	7.1009	7.1009	7.101	7.1009	7.101	7.1009	7.1009
					62.8	60°	7.1003	7.1005	7.1006	7.1005	7.1004	7.1005	7.1004
Cold	13.4	1012.2	87.9	1.9	1.6	0°	7.101	7.1011	7.1012	7.101	7.1009	7.1010	7.1010
					1.8	22.5°	7.1012	7.101	7.1009	7.1009	7.101	7.1010	7.1010
					2.2	45°	7.101	7.101	7.1009	7.101	7.1009	7.1010	7.1009
					2.6	60°	7.1005	7.1004	7.1004	7.1006	7.1009	7.1006	7.1005
Illuminated	14.1	1007.7	87	3.9		0°	7.1011	7.1011	7.1011	7.1011	7.1012	7.1011	7.1011
						22.5°	7.1009	7.1008	7.1007	7.1008	7.1008	7.1008	7.1008
						45°	7.1005	7.1005	7.1005	7.1006	7.1007	7.1006	7.1005
						60°	7.1007	7.1008	7.1009	7.1008	7.1008	7.1008	7.1008
Unilluminated	14.1	1007.7	87.3	3.9		0°	7.101	7.1012	7.1011	7.1012	7.1011	7.1011	7.1011
						22.5°	7.1006	7.1005	7.1007	7.1006	7.1008	7.1006	7.1006
						45°	7.1005	7.1007	7.1006	7.1007	7.1006	7.1006	7.1006
						60°	7.1007	7.1007	7.1007	7.1007	7.1007	7.1007	7.1007

Mean	7.1008
Median	7.1009
Mode	7.1007
Standard Diviation	0.00021

Lowest	7.1004
Highest	7.1011
Range	0.0007
Variance	4.3E-08

Condition				Angle			
Mean		Range		Mean		Range	
Dry	7.1007	Wet	0.0003	60°	7.1007	0°	0.0001
Wet	7.1010	Hot	0.0006	0°	7.1011	60°	0.0005

YELLOW

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	14.1	1007.7	87.2	3.9		0^o	7.1006	7.1008	7.1008	7.1008	7.1009	7.1008	7.1008
						22.5^o	7.1	7.1002	7.1002	7.1002	7.1001	7.1001	7.1001
						45^o	7.1004	7.1005	7.1004	7.1004	7.1004	7.1004	7.1004
						60^o	7.1005	7.1006	7.1007	7.1007	7.1008	7.1007	7.1006
Wet	14.1	1007.6	86.6	4	3.9	0^o	7.1001	7.0999	7.0999	7.1005	7.0999	7.1001	7.1000
						22.5^o	7.1009	7.1002	7.0999	7.1007	7.1002	7.1004	7.1004
						45^o	7.1005	7.1005	7.1007	7.1006	7.1008	7.1006	7.1006
						60^o	7.1004	7.1001	7.1005	7.1003	7.1007	7.1004	7.1004
Hot	14.1	1003.7	92.9	5	73.4	0^o	7.1005	7.1001	7.1002	7.1003	7.1002	7.1003	7.1002
					69.8	22.5^o	7.1007	7.1008	7.1008	7.1007	7.1008	7.1008	7.1007
					67.2	45^o	7.1001	7.1002	7.1001	7.1001	7.1001	7.1001	7.1001
					64.8	60^o	7.1007	7.1008	7.1007	7.1007	7.1007	7.1007	7.1007
Cold	13.3	1012.1	88.3	1.8	0	0^o	7.1009	7.101	7.1004	7.1006	7.1009	7.1008	7.1007
					0	22.5^o	7.1009	7.1007	7.1009	7.1011	7.1006	7.1008	7.1008
					0.8	45^o	7.1001	7.1006	7.1007	7.1007	7.1003	7.1005	7.1005
					1.6	60^o	7.1007	7.1007	7.1008	7.1009	7.1007	7.1008	7.1007
Illuminated	14.2	1007.7	86.7	4		0^o	7.1009	7.1008	7.101	7.101	7.1009	7.1009	7.1009
						22.5^o	7.0999	7.1001	7.1	7.1001	7.1	7.1000	7.1000
						45^o	7.1006	7.1007	7.1007	7.1006	7.1007	7.1007	7.1006
						60^o	7.1003	7.1003	7.1003	7.1003	7.1003	7.1003	7.1003
Unilluminated	14.1	1007.7	87.2	3.9		0^o	7.1008	7.1011	7.1009	7.1009	7.1009	7.1009	7.1009
						22.5^o	7.1003	7.1003	7.1003	7.1004	7.1004	7.1003	7.1003
						45^o	7.1004	7.1003	7.1003	7.1005	7.1004	7.1004	7.1004
						60^o	7.1006	7.1006	7.1006	7.1004	7.105	7.1014	7.1014

Mean	7.1005
Median	7.1005
Mode	7.1007
Standard Diviation	0.00033

Lowest	7.1000
Highest	7.1014
Range	0.0014
Variance	1.1E-07

Condition				Angle			
Mean		Range		Mean		Range	
Wet	7.1003	Cold	0.0004	22.5^o	7.1004	45^o	0.0005
Unillumin	7.1008	Unillumin	0.0011	60^o	7.1007	60^o	0.0011

GREEN

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	14.1	1007.7	86.6	3.9		0^o	7.1006	7.1006	7.1008	7.1005	7.1007	7.1006	7.1006
						22.5^o	7.1005	7.1006	7.1001	7.1005	7.1006	7.1005	7.1004
						45^o	7.1006	7.1002	7.1004	7.1005	7.1006	7.1005	7.1004
						60^o	7.1027	7.1025	7.1029	7.103	7.1027	7.1028	7.1027
Wet	14.2	1007.8	85.6	3.9		0^o	7.1004	7.1004	7.1006	7.1003	7.1008	7.1005	7.1005
						22.5^o	7.1003	7.1004	7.1005	7.1005	7.1003	7.1004	7.1004
						45^o	7.1002	7.1008	7.1006	7.1002	7.1007	7.1005	7.1005
						60^o	7.1038	7.1035	7.1033	7.1037	7.1031	7.1035	7.1035
Hot	14.2	1003.9	92.9	5.1	71	0^o	7.1006	7.1006	7.1009	7.1007	7.1009	7.1007	7.1007
					67	22.5^o	7.1005	7.1004	7.1008	7.1006	7.1006	7.1006	7.1006
					64.8	45^o	7.1003	7.1004	7.1001	7.1007	7.1003	7.1004	7.1003
					62.6	60^o	7.1014	7.1015	7.1017	7.1014	7.1016	7.1015	7.1015
Cold	13.3	1012	88.3	1.9	0	0^o	7.1008	7.1011	7.1005	7.1004	7.1009	7.1007	7.1007
					0.8	22.5^o	7.1007	7.101	7.1005	7.1008	7.1007	7.1007	7.1007
					1.4	45^o	7.1009	7.101	7.1006	7.1011	7.1007	7.1009	7.1008
					2.2	60^o	7.101	7.101	7.1012	7.1015	7.1014	7.1012	7.1012
Illuminated	14.2	1007.8	86	3.9		0^o	7.1003	7.1004	7.1002	7.1002	7.1003	7.1003	7.1003
						22.5^o	7.1009	7.1009	7.101	7.101	7.101	7.1010	7.1009
						45^o	7.1003	7.1007	7.1	7.1006	7.1005	7.1004	7.1004
						60^o	7.1025	7.1027	7.1026	7.1027	7.1027	7.1026	7.1026
Unilluminated	14.1	1007.7	86.4	3.9		0^o	7.1005	7.1006	7.1006	7.1006	7.1005	7.1006	7.1005
						22.5^o	7.1014	7.1018	7.1013	7.1013	7.1014	7.1014	7.1014
						45^o	7.1006	7.1008	7.1004	7.1007	7.1008	7.1007	7.1006
						60^o	7.1028	7.1024	7.1028	7.1025	7.1029	7.1027	7.1027

Mean	7.1011
Median	7.1007
Mode	7.1004
Standard Diviation	0.0009

Lowest	7.1003
Highest	7.1035
Range	0.0032
Variance	8.1E-07

Condition				Angle			
Mean		Range		Mean		Range	
Hot	7.1008	Cold	0.0005	45^o	7.1005	0^o	0.0005
Unillumin	7.1013	Wet	0.0031	60^o	7.1024	60^o	0.0023

ORANGE

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.1	1006.1	91.2	3.3		0^o	7.1011	7.101	7.101	7.1011	7.1011	7.1011	7.1010
						22.5^o	7.101	7.1011	7.1011	7.1011	7.1011	7.1011	7.1011
						45^o	7.1002	7.1005	7.1005	7.1003	7.1004	7.1004	7.1004
						60^o	7.1006	7.1007	7.1007	7.1008	7.1007	7.1007	7.1007
Wet	13.4	1006.1	91	3.6		0^o	7.1012	7.1014	7.1014	7.1011	7.1012	7.1013	7.1012
						22.5^o	7.1013	7.1014	7.1013	7.1014	7.1012	7.1013	7.1013
						45^o	7.101	7.1011	7.1009	7.1009	7.1008	7.1009	7.1009
						60^o	7.1015	7.1015	7.1014	7.1016	7.1014	7.1015	7.1015
Hot	14	1004.6	92.8	4.7	72.4	0^o	7.1004	7.1004	7.1003	7.1004	7.1003	7.1004	7.1003
					68.8	22.5^o	7.1006	7.1007	7.1007	7.101	7.1009	7.1008	7.1008
					65.8	45^o	7.1009	7.1012	7.1011	7.1012	7.1012	7.1011	7.1011
					63.2	60^o	7.1004	7.1005	7.1003	7.1002	7.1003	7.1003	7.1003
Cold	13.3	1011.7	88.3	1.9	1.2	0^o	7.1009	7.1011	7.1011	7.1009	7.1009	7.1010	7.1010
					1.8	22.5^o	7.101	7.1006	7.101	7.1011	7.1012	7.1010	7.1010
					2.6	45^o	7.1012	7.1009	7.1009	7.1007	7.1008	7.1009	7.1009
					3	60^o	7.1008	7.1007	7.1012	7.101	7.1007	7.1009	7.1009
Illuminated	13.3	1006.1	91.4	3.5		0^o	7.101	7.101	7.101	7.1011	7.101	7.1010	7.1010
						22.5^o	7.1007	7.1008	7.1007	7.1007	7.1006	7.1007	7.1007
						45^o	7.1001	7.1002	7.1002	7.1001	7.1001	7.1001	7.1001
						60^o	7.1003	7.1004	7.1004	7.1003	7.1003	7.1003	7.1003
Unilluminated	13.3	1006.2	91.4	3.5		0^o	7.101	7.101	7.1011	7.1011	7.1012	7.1011	7.1011
						22.5^o	7.1005	7.1007	7.1007	7.1006	7.1005	7.1006	7.1006
						45^o	7.1006	7.1006	7.1005	7.1005	7.1007	7.1006	7.1006
						60^o	7.1004	7.1004	7.1004	7.1005	7.1004	7.1004	7.1004

Mean	7.1008
Median	7.1009
Mode	7.1011
Standard Diviation	0.00036

Lowest	7.1001
Highest	7.1015
Range	0.0013
Variance	1.3E-07

Condition				Angle			
Mean		Range		Mean		Range	
Illumin	7.1005	Cold	0.0001	45^o	7.1007	22.5^o	0.0007
Wet	7.1012	Illumin	0.0009	0^o	7.1009	60^o	0.0011

PINK

Condition	Temp (°C)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (°C)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.4	1006.1	91.4	3.6		0°	7.1009	7.1012	7.1011	7.1011	7.101	7.1011	7.1010
						22.5°	7.1008	7.1009	7.1009	7.1009	7.101	7.1009	7.1009
						45°	7.1005	7.1006	7.1007	7.1003	7.1005	7.1005	7.1005
						60°	7.1006	7.1005	7.1007	7.1006	7.1006	7.1006	7.1006
Wet	13.5	1006.1	91.1	3.7		0°	7.1011	7.1012	7.1012	7.101	7.101	7.1011	7.1011
						22.5°	7.1005	7.1006	7.1007	7.101	7.1011	7.1008	7.1008
						45°	7.1008	7.1006	7.1007	7.1006	7.1007	7.1007	7.1007
						60°	7.101	7.101	7.1009	7.1007	7.1007	7.1009	7.1008
Hot	14	1004.9	92.9	4.6	63.8	0°	7.1007	7.1008	7.1006	7.1008	7.1006	7.1007	7.1007
					61.8	22.5°	7.1008	7.1009	7.1009	7.1008	7.1009	7.1009	7.1008
					59	45°	7.1005	7.1006	7.1007	7.1005	7.1005	7.1006	7.1005
					57.2	60°	7.1007	7.1009	7.1007	7.1009	7.1007	7.1008	7.1008
Cold	13.3	1011.7	88.3	1.9	2.2	0°	7.1008	7.101	7.1006	7.1008	7.1008	7.1008	7.1008
					2.6	22.5°	7.1006	7.1008	7.1011	7.1011	7.1013	7.1010	7.1010
					2.6	45°	7.1004	7.101	7.1007	7.1007	7.1008	7.1007	7.1007
					3	60°	7.1004	7.1005	7.1003	7.1006	7.1005	7.1005	7.1004
Illuminated	13.5	1006.1	91.4	3.7		0°	7.1011	7.1011	7.1012	7.1012	7.1011	7.1011	7.1011
						22.5°	7.1012	7.1013	7.1013	7.1012	7.1012	7.1012	7.1012
						45°	7.1004	7.1007	7.1005	7.1006	7.1006	7.1006	7.1005
						60°	7.1004	7.1006	7.1006	7.1007	7.1004	7.1005	7.1005
Unilluminated	13.6	1006.1	91.3	3.8		0°	7.101	7.1013	7.1011	7.1012	7.1013	7.1012	7.1012
						22.5°	7.1001	7.1002	7.1004	7.1002	7.1003	7.1002	7.1002
						45°	7.1006	7.1007	7.1007	7.1006	7.1007	7.1007	7.1006
						60°	7.1005	7.1004	7.1006	7.1007	7.1008	7.1006	7.1006

Mean	7.1008
Median	7.1007
Mode	7.1006
Standard Diviation	0.00025

Lowest	7.1002
Highest	7.1012
Range	0.0010
Variance	6.4E-08

Condition				Angle			
Mean		Range		Mean		Range	
Unillumin	7.1007	Hot	0.0003	45°	7.1006	45°	0.0002
Illumin	7.1009	Unillumin	0.0009	0°	7.1010	22.5°	0.0010

PURPLE

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.5	1006.1	91.3	3.7		0°	7.1017	7.1017	7.1017	7.1018	7.1018	7.1017	7.1017
						22.5°	7.1011	7.1012	7.1011	7.101	7.101	7.1011	7.1011
						45°	7.101	7.1012	7.1012	7.1012	7.1012	7.1012	7.1011
						60°	7.1013	7.1015	7.1013	7.1014	7.1012	7.1013	7.1013
Wet	13.6	1006	91	3.9		0°	7.1015	7.1019	7.102	7.1019	7.1017	7.1018	7.1018
						22.5°	7.1016	7.1018	7.1018	7.1018	7.1018	7.1018	7.1017
						45°	7.1013	7.1017	7.1016	7.1015	7.1016	7.1015	7.1015
						60°	7.1012	7.1014	7.1014	7.1014	7.1014	7.1014	7.1013
Hot	13.8	1004.8	93.5	4.4	57.6	0°	7.1017	7.1017	7.1016	7.1015	7.1016	7.1016	7.1016
					55.6	22.5°	7.1017	7.1017	7.1017	7.1019	7.1019	7.1018	7.1018
					53.2	45°	7.1018	7.1017	7.1019	7.1018	7.102	7.1018	7.1018
					51.8	60°	7.1013	7.1014	7.1014	7.1013	7.1014	7.1014	7.1013
Cold	13.3	1011.5	88.3	2	0.6	0°	7.1015	7.1011	7.101	7.1013	7.1009	7.1012	7.1011
					1.6	22.5°	7.1017	7.1014	7.1015	7.1014	7.1016	7.1015	7.1015
					2.4	45°	7.1012	7.1011	7.1012	7.1014	7.1015	7.1013	7.1013
					2.6	60°	7.1013	7.1013	7.1012	7.1012	7.1012	7.1012	7.1012
Illuminated	13.6	1006	91.3	3.9		0°	7.1016	7.1016	7.1016	7.1017	7.1016	7.1016	7.1016
						22.5°	7.1015	7.1016	7.1016	7.1015	7.1015	7.1015	7.1015
						45°	7.1014	7.1014	7.1014	7.1014	7.1014	7.1014	7.1014
						60°	7.1017	7.1016	7.1016	7.1016	7.1017	7.1016	7.1016
Unilluminated	13.6	1006	91.4	3.9		0°	7.1015	7.1016	7.1018	7.1016	7.1016	7.1016	7.1016
						22.5°	7.1014	7.1014	7.1015	7.1015	7.1015	7.1015	7.1014
						45°	7.1014	7.1015	7.1014	7.1014	7.1013	7.1014	7.1014
						60°	7.1012	7.1013	7.1014	7.1014	7.1013	7.1013	7.1013

Mean	7.1015
Median	7.1015
Mode	7.1016
Standard Diviation	0.00022

Lowest	7.1011
Highest	7.1018
Range	0.0008
Variance	4.8E-08

Condition				Angle			
Mean		Range		Mean		Range	
Cold	7.1013	Illumin	0.0002	60°	7.1014	60°	0.0004
Hot	7.1016	Dry	0.0007	0°	7.1016	22.5°	0.0007

GREY

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.6	1005.9	90.9	3.8		0^o	7.1006	7.1006	7.1004	7.1007	7.1006	7.1006	7.1006
						22.5^o	7.1003	7.1004	7.1003	7.1003	7.1003	7.1003	7.1003
						45^o	7.1014	7.1013	7.1015	7.1013	7.1014	7.1014	7.1014
						60^o	7.1019	7.102	7.1022	7.1019	7.1019	7.1020	7.1020
Wet	13.7	1005.7	90.8	4.1		0^o	7.1006	7.1007	7.1008	7.1008	7.1006	7.1007	7.1007
						22.5^o	7.1005	7.1007	7.1005	7.1007	7.1005	7.1006	7.1006
						45^o	7.1007	7.1004	7.1011	7.1008	7.1006	7.1007	7.1007
						60^o	7.1016	7.1016	7.1017	7.1017	7.1014	7.1016	7.1016
Hot	14	1004.4	92.7	4.7	74.4	0^o	7.1002	7.1003	7.1004	7.1006	7.1007	7.1004	7.1004
					71.6	22.5^o	7.1003	7.1003	7.1002	7.1004	7.1004	7.1003	7.1003
					67.8	45^o	7.1001	7.1003	7.1003	7.1003	7.1004	7.1003	7.1003
					65.6	60^o	7.101	7.1008	7.101	7.1011	7.1008	7.1009	7.1009
Cold	13.3	1011.4	88.3	2	0	0^o	7.1003	7.1	7.1002	7.1006	7.1003	7.1003	7.1003
					0.6	22.5^o	7.1002	7.1005	7.1001	7.1004	7.1007	7.1004	7.1004
					1.8	45^o	7.1005	7.1008	7.1007	7.1004	7.1006	7.1006	7.1006
					2	60^o	7.1008	7.1008	7.1008	7.1009	7.101	7.1009	7.1008
Illuminated	13.7	1005.7	91.1	4.1		0^o	7.1006	7.1009	7.1008	7.1008	7.1009	7.1008	7.1008
						22.5^o	7.1004	7.1004	7.1005	7.1005	7.1007	7.1005	7.1005
						45^o	7.1006	7.1005	7.1006	7.1006	7.1004	7.1005	7.1005
						60^o	7.102	7.1021	7.102	7.1019	7.102	7.1020	7.1020
Unilluminated	13.7	1005.9	91.2	4		0^o	7.1004	7.1006	7.1006	7.1007	7.1007	7.1006	7.1006
						22.5^o	7.1006	7.1007	7.1007	7.1005	7.1006	7.1006	7.1006
						45^o	7.0999	7.1001	7.1001	7.1001	7.1001	7.1001	7.1000
						60^o	7.102	7.1023	7.1021	7.1019	7.1021	7.1021	7.1021

Mean	7.1008
Median	7.1006
Mode	7.1006
Standard Diviation	0.00058

Lowest	7.1000
Highest	7.1021
Range	0.0020
Variance	3.4E-07

Condition				Angle			
Mean		Range		Mean		Range	
Hot	7.1005	Cold	0.0006	22.5^o	7.1004	22.5^o	0.0003
Dry	7.1010	Unillumin	0.0020	60^o	7.1016	45^o	0.0013

BLACK

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.7	1005.6	90.9	4.1		0^o	7.1004	7.1006	7.1007	7.1005	7.1005	7.1005	7.1005
						22.5^o	7.1009	7.1012	7.1017	7.1018	7.1019	7.1015	7.1015
						45^o	7.1034	7.1033	7.1028	7.1032	7.1029	7.1031	7.1031
						60^o	7.1146	7.1146	7.1146	7.1151	7.115	7.1148	7.1148
Wet	13.8	1005.2	90.7	4.3		0^o	7.1005	7.1007	7.1011	7.101	7.101	7.1009	7.1008
						22.5^o	7.1001	7.0998	7.0996	7.0999	7.1001	7.0999	7.0999
						45^o	7.1015	7.1008	7.1014	7.1017	7.1019	7.1015	7.1014
						60^o	7.1093	7.1102	7.1095	7.1099	7.1102	7.1098	7.1098
Hot	14.2	1004.3	92.8	5	77	0^o	7.1007	7.1009	7.101	7.1007	7.1008	7.1008	7.1008
					74	22.5^o	7.1003	7.1005	7.1001	7.1005	7.1007	7.1004	7.1004
					71.4	45^o	7.1017	7.1022	7.1023	7.1021	7.1012	7.1019	7.1019
					67.6	60^o	7.1106	7.1111	7.1113	7.1115	7.1114	7.1112	7.1112
Cold	13.4	1011.6	88.1	2.1	1.8	0^o	7.1007	7.1005	7.1006	7.1008	7.1004	7.1006	7.1006
					1.8	22.5^o	7.1007	7.1005	7.0998	7.1013	7.1011	7.1007	7.1007
					2.4	45^o	7.1014	7.1014	7.101	7.1012	7.1009	7.1012	7.1012
					2.6	60^o	7.1029	7.1029	7.1023	7.1027	7.1028	7.1027	7.1027
Illuminated	13.8	1005.4	91.2	4.2		0^o	7.1006	7.1008	7.1008	7.1008	7.1008	7.1008	7.1007
						22.5^o	7.1013	7.1012	7.1017	7.1012	7.1009	7.1013	7.1012
						45^o	7.1026	7.1028	7.1028	7.1023	7.1026	7.1026	7.1026
						60^o	7.1142	7.114	7.1136	7.1134	7.1137	7.1138	7.1138
Unilluminated	13.8	1005.4	91.3	4.2		0^o	7.1008	7.1008	7.1009	7.1007	7.1008	7.1008	7.1008
						22.5^o	7.1012	7.1015	7.1016	7.1012	7.1014	7.1014	7.1014
						45^o	7.1016	7.1014	7.1023	7.1023	7.1023	7.1020	7.1020
						60^o	7.1146	7.1149	7.1151	7.1157	7.115	7.1151	7.1150

Mean	7.1037
Median	7.1014
Mode	#N/A
Standard Diviation	0.00498

Lowest	7.0999
Highest	7.1150
Range	0.0152
Variance	2.5E-05

Condition				Angle			
Mean		Range		Mean		Range	
Cold	7.1013	Cold	0.0021	0^o	7.1007	0^o	0.0003
Dry	7.1050	Unillumin	0.0143	60^o	7.1112	60^o	0.0123

WHITE

Condition	Temp (^oC)	Pressure (mbar)	Humidity %	PPM (mm)	Target Temp (^oC)	Angle	Horizontal Distance (1)	(2)	(3)	(4)	(5)	Average	Adjusted
Dry	13.9	1005.2	91.2	4.4		0°	7.1007	7.1007	7.1008	7.1008	7.1008	7.1008	7.1007
						22.5°	7.1004	7.1004	7.1005	7.1005	7.1004	7.1004	7.1004
						45°	7.1009	7.1009	7.1007	7.1007	7.1009	7.1008	7.1008
						60°	7.101	7.101	7.1011	7.1011	7.101	7.1010	7.1010
Wet	13.9	1005.2	90.7	4.4		0°	7.1005	7.1006	7.1009	7.1008	7.101	7.1008	7.1007
						22.5°	7.1007	7.1008	7.1006	7.1007	7.101	7.1008	7.1007
						45°	7.1007	7.101	7.101	7.1012	7.101	7.1010	7.1010
						60°	7.1008	7.1007	7.1006	7.1008	7.1007	7.1007	7.1007
Hot	14.1	1004.1	93	4.9	73.8	0°	7.1001	7.1004	7.1008	7.1008	7.1007	7.1006	7.1005
					70.6	22.5°	7.1009	7.101	7.101	7.101	7.1009	7.1010	7.1009
					67.2	45°	7.1001	7.1003	7.1004	7.1001	7.1003	7.1002	7.1002
					65	60°	7.1003	7.1003	7.1002	7.1002	7.1003	7.1003	7.1002
Cold	13.3	1011.4	88.4	2	0	0°	7.1003	7.101	7.1007	7.1003	7.1007	7.1006	7.1006
					0	22.5°	7.1006	7.101	7.1008	7.1005	7.1005	7.1007	7.1007
					0.8	45°	7.1008	7.1011	7.1007	7.1009	7.1009	7.1009	7.1009
					1.4	60°	7.1006	7.1008	7.1007	7.1006	7.1008	7.1007	7.1007
Illuminated	13.9	1005.1	91	4.4		0°	7.1006	7.1009	7.1008	7.1009	7.1007	7.1008	7.1008
						22.5°	7.1006	7.1005	7.1006	7.1007	7.1006	7.1006	7.1006
						45°	7.1	7.1002	7.1002	7.1003	7.1003	7.1002	7.1002
						60°	7.1009	7.1009	7.1007	7.1009	7.1009	7.1009	7.1008
Unilluminated	13.9	1005.2	91.2	4.4		0°	7.1008	7.1009	7.1008	7.1008	7.1008	7.1008	7.1008
						22.5°	7.1006	7.1007	7.1007	7.1007	7.1006	7.1007	7.1006
						45°	7.1005	7.1004	7.1006	7.1006	7.1006	7.1005	7.1005
						60°	7.1009	7.1009	7.101	7.1012	7.1011	7.1010	7.1010

Mean	7.1007
Median	7.1007
Mode	7.1007
Standard Diviation	0.00023

Lowest	7.1002
Highest	7.1010
Range	0.0008
Variance	5.5E-08

Condition				Angle			
Mean		Range		Mean		Range	
Hot	7.1005	Wet	0.0003	45°	7.1006	0°	0.0003
Wet	7.1008	Hot	0.0007	60°	7.1008	45°	0.0008

Appendix F

Reference cards

LEGENED (Expected Probable Error)		
0 – 1 mm	1 – 2 mm	2 + mm

PRISIM				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

REFLECTIVE TAPE				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

SOFTWOOD				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

HARDWOOD				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

PLASTER BOARD				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

PLASTIC				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

CERAMIC TILE				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

CONCRETE				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

BESSER BLOCK				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

BRICK				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

ALUMINIUM				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

GALVANISED STEEL				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

BLUE				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

RED				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

YELLOW				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

GREEN				
	0^0	22.5^0	45^0	60^0
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

ORANGE				
	0^{0}	22.5^{0}	45^{0}	60^{0}
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

PINK				
	0^{0}	22.5^{0}	45^{0}	60^{0}
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

PURPLE				
	0^{0}	22.5^{0}	45^{0}	60^{0}
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

GREY				
	0^{0}	22.5^{0}	45^{0}	60^{0}
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

BLACK				
	0^{0}	22.5^{0}	45^{0}	60^{0}
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				

WHITE				
	0^{0}	22.5^{0}	45^{0}	60^{0}
DRY				
WET				
HOT				
COLD				
ILL				
UNILL				