University of Southern Queensland

Faculty of Health, Engineering & Sciences

Insulated Container Testing & Rating system Development

A Dissertation submitted by

Mr. Thierry-Jacques Patrick Vever

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Abstract

This research project seeks to develop a cheap, accurate, objective, repeatable and universal testing & rating system for insulated containers (eskies, chilly bins, coolers, ice boxes, cooler bags, pizza pouches, etc), similar to the star ratings for white goods, plumbing fixtures and motor vehicles, whether used for cold or hot items. Currently, there is no such system available on the domestic market, and none has been observed in any other market.

The testing consists of placing an empty vessel in a chamber at 5°C, and waiting until its temperature is in equilibrium with that chamber, then transferring it to a chamber at 55°C, and again waiting until equilibrium is reached, and the time taken to reach equilibrium is observed. This process is then reversed as a double check to compare heat ingress and heat egress.

The rating consists of taking the temperature differential and the time taken to reach steady-state and applying them to the volume of the vessel and the internal heat of air in the volume to determine a numerical result in W/K. The resultant number is the rating. This is far simpler than converting this into a number of stars (as is common with other ratings systems), and very quickly, consumers will begin to know the general range of numbers and be able to compare them to know what is sufficient for each of their needs.

Successful tests have been carried out to demonstrate that this is a viable testing & rating system which stands to benefit the general community whenever a consumer chooses to purchase an insulated container. By displaying the results of such a testing & rating system, manufacturers can instil confidence for their customers that their purchase will meet their needs with respect to the thermal performance of the chosen product.

This research project is ready to progress to a level of formulating a standard and a set of protocols with a view to starting commercial testing in established laboratories for existing manufacturers.

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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.

TJ Vever

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Glossary of Terms

Term	**Definition**
ATM	Normally this notation means ‘atmosphere’ in the context of the pressure of air in the atmosphere, such as 1atm=101.325kPa. However, in this document it is mostly used as shorthand to denote atmospheric pressure in general, as opposed to any other pressure, allowing for the fact that atmospheric pressure changes with elevation.
ISC	Insulated Shipping Containers – these are typically cardboard boxes lined with insulating material such as foam.
PCM	Phase Change Material – any substance which changes state with the addition or subtraction of heat, specifically with the aim of achieving a desired temperature, ice being the most obvious (and natural) example.
Product	Any insulated vessel from the manufacturer’s perspective
Stock	Any contents in a vessel from the producer’s perspective which may ordinarily be referred to as a product

Nomenclature

Symbol	Definition
L (m)	Length along a heat flow path, equivalent to material thickness
r (m)	Characteristic length of a shape with respect to the unit volume. For a sphere it is the radius, while for a cube it is the side.
$V{:}A_s$ (m)	Ratio of volume and surface area of a 3D shape.

1. Introduction

Esky is a brand name. It is so common in general Australian parlance that many may not know that. In New Zealand, they are known as chilly bins (possibly also a brand name), while other countries may refer to them as ice boxes, ice chests, coolers or other terms. These are portable, hard-cased, insulated vessels designed to keep food and drink cool by repelling heat ingress. There are drink specific ones, known as a Thermos (also a brand name) or soft versions known as cooler bags, and others designed to keep food hot, such as pizza pouches. There are even disposable vessels such as the foam boxes for fruit and vegetables, or the more specialised insulated shipping containers, used for transporting medicines and other temperature sensitive products.

1.1. Selection Confusion

Whatever the name and whatever the use, selecting the correct one is not an easy task since no information about the thermal performance of each product on the market is provided by the manufacturers. Commercial consumers, who develop strong relationships with their suppliers will come to know the right product for their needs, but may sustain unnecessary expense leading to that arrangement. A retail consumer entering a shop with the intent of purchasing such a product could easily struggle to determine which one would meet their specific needs. Is it to be for camping, a picnic, or just bringing frozen foods home from the shops?

Whatever the need, even the most fastidious consumer will be relying heavily on the knowledge of the sales person, who may only use one or two types for only a couple of purposes; certainly not all products in all situations, and unless consumers return to tell the sales person about their experience, there is not likely to be much genuine feedback from the field for the sales industry, leaving their view rather biased and varied from one outlet to the next. Granted, there are consumer groups such as Choice Magazine Australia, who provide comparisons to assist the general public, however their tests are not universal and may have different criteria, one from another, which can prolong the consumer's uncertainty about which product is most suitable for a given need.

So how can a consumer, commercial or retail, know for sure which product has the best thermal performance that suits their particular need? What is needed is an objective testing & rating system that allows any consumer to interpret the result to their specific needs.

1.2. Project Aim

This project aims to create a universal, independent, transparent and repeatable testing & rating system for portable, insulated vessels that allows consumers to purchase the right product for each purpose with confidence. The outcome should be similar to the energy-efficiency ratings for refrigerators, the water-efficiency ratings for showers or the fuel-efficiency ratings for cars. With rating labels on every product on display in any commercial or retail environment, any consumer can determine for themselves, based on their own individual interpretation of what the ratings mean to them, the right product they may need for any given situation they may encounter.

To ensure consumer confidence, it is important that the testing is carried out by independent bodies, rather than the manufacturers. These bodies should also be above reproach by being authorised by an independent accreditation body, such as NATA (National Association of Testing Authorities, Australia) who carry out the accreditation programs for laboratories and provides them with support in their obligations, while the tests themselves should be approved by independent bodies such as NMI (National Measurement Institute, Australia) who oversee the right and wrong ways of measuring things in industry. Although, the general public would not necessarily understand what these bodies do, they are more likely to have confidence in a labelled rating which cites such bodies as being involved in the process. Meanwhile, the commercial market will have a greater level of assurance in their selections knowing that the data is not manipulated by an over-eager manufacturer seeking to increase market presence at the expense of their potential client base. For the manufacturer, it means they can state ‘hand-on-heart’ that their products achieve a certain rating, while also being able to fast track R&D[1] processes to fulfil market demand.

1.3. Project Focus

The work in this project is divided into two distinct parts. Firstly, there is the scientific aspect which looks at the insulated vessels thermal efficiency and how this affects stock in the vessels. Secondly, there is the human aspect which looks at meeting the perceived understanding of the consumer to whom this system is targeted. From the scientific perspective, the testing system must look at both ingress and egress of heat, if the application is to extend to both hot and cold requirements. From the human perspective, the rating system must have a meaningful reading, such as the stars on refrigerators and showers.

1.4. Limitations

It is important to state at this stage that the aim of this project in not to rate the quality of the products. This is only aiming to rate the thermal efficiency which will determine the products effectiveness in resisting temperature change over time. To this end, cooler bags used for keeping lunch or shopping cool for a few hours (or a pouch to keep pizza warm for a similar timeframe) will not require as high a rating to be considered a quality product for the task, while ice boxes that are used on fishing trips (keeping the prized catch cold for days) will require a much higher rating to be considered fit for purpose.

This system is also aimed only at passively cooled or heated vessels, not any actively controlled vessels such as fridges or ovens, and is only aimed at enclosed vessels, which excludes ‘stubbie’[2] coolers for keeping single-serve drink bottles cold once opened, or any other similar open insulators.

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[1] R&D stands for Research and Development.

[2] Stubbie, or stubby, is Australian slang for a small bottle of beer. Summers, E, Kuether, J, Isaacs, A, Butterfield, J, Holmes, A & Law, J 2003, *Collins English Dictionary: Complete and Unabridged*, HarperCollins.

This project does not aspire to limit the freedom of manufacturers to design products in any shape or choice of construction materials or construction processes that may reduce their opportunity to meet market demands. They should be free to do whatever they deem necessary to meet all their other consumer demands as a function of meeting the desired thermal performance requirements stipulated by their customer base.

2. Literature Review

The literature review for this project has been carried out through 4 key searching processes. Initial searches via the internet and databases failed to return any meaningful results. As a consequence of this, manufacturers were contacted for information on how they have carried out the tests for their performance claims, as well as any literature that they may have used. This allowed returning to the internet and database searches with more specific search terms. This lead to more fruitful information, which in turn allowed further research based on the references in some of those documents.

2.1. Current Industry Practice

Three local manufacturers were contacted in order to ascertain current industry practices. The selection was relatively random, and no favour was placed on any manufacturers over any others. One of the three firms selected suggested contacting a fourth, which was done. The manufacturers contacted were Coleman – Esky, Evakool, Techniice and Waeco.

Each company was quick to share current practices over the phone, all of which showed similar thinking with variations on a theme. Emails were sent to each firm with questions regarding existing rating systems that they were aware of (either internal or from other sources, such as Choice Magazine), or the use of R-values for raw materials in product development, and any literature that may have been accessed, such as journal articles, papers standards or procedures. Each was also invited to share policy or procedure documents used for the testing of performance characteristics of their products.

The responses, either by phone or email, were similar: No literature is available at present, R-values are for pre-fabricated sheets, and each manufacturer carries out their own testing. Two of them were kind enough to provide some written details of their testing procedures.

2.1.1. Industry Tests & Ratings

In an email from Evakool (R Mendes 2015, pers. comm., 22 May) it was demonstrated that their current testing regime consists of using a control room at 32^{o}C, in which a test specimen is placed. It is loaded fully with ice (not specified whether block ice or party ice – bags of ice cubes) and opened thrice daily (time open was not stated). The quantity of ice is observed daily and once no ice is observed the number of days is noted. The melted water was left in the vessel. The rating for this test was simply the number of days of keeping ice frozen.

Similarly, Waeco provided their procedure in an email (S Elliott 2015, pers.comm., 31 May). Waeco, who are better known for actively-refrigerated portable vessels, pointed out that they are relatively new to the market with passively-cooled vessels, and therefore developed their system based on the claims of the competition. They observed that their competitors were claiming numbers of days for keeping contents cold and set about doing the same. Their test consists of a control room at 30^{o}C and the use of 6 blocks of 5kg ice as well as a 4kg bag of party ice. The lid is opened once daily for 1 minute and water is removed daily during the lid opening. In one example test of one of their models, they observed enough ice left for 'effective use' after 11 days, 1kg of ice left after 12 days, and no ice remaining on day 13. The published result was '10 days', allowing a conservative experimental margin of error, however no scientific explanation was provided for this factor of safety.

2.1.2. Similar Industry Processes

In order to determine whether processes could be replicated from similar industries, a brief search for other products was also made: In particular, the use of insulated materials as a construction material for industrial cold storage. However, as expected, this industry is inclined to conform to the methodology of the construction industry. As an example, insulated panels (Kingspan 2012) are given an R-value for the individual panels, rather than a particular construction being given an energy rating. Given the custom nature of each construction, the fact that active chilling of air with air-conditioning systems is used, and each building design is modelled in complex programs to determine the overall energy efficiency, this isolated material rating (as opposed to a complete package rating) makes sense in that industry, which means that borrowing from that industry would not lend itself well to this particular project, since the aim here is to have a rating for a complete product.

2.2. Industry Observers

Choice Magazine has been a household name in Australia for quite some time, and was targeted in the initial searches for any testing of this range of products. One of the manufacturers contacted also suggested contacting Choice, which provided kudos for this rationale. Other reviews were also found, two of which are shared here.

Choice Magazine has actually been regularly reviewing ‘eskies’ for about 20 years (M Steen 2015, pers. comm., 26 May) using a test and rating that has satisfied their readers over time. In their most recent test (Steen 2014) a variety of products were put to the test for not only their thermal performance, but also their features, which was far more subjective. Their thermal testing consists of filling each vessel with bottles equivalent to 20% of the vessel volume (no details on the temperature or contents of the bottles was provided, but it is assumed that they had sensors inserted for the ensuing results) as well as ice also equivalent to 20% of the vessel volume (again no mention of the type, but assumed to be party ice to fit around the bottles) and placing them in a control room at 32^{o}C (each specimen was preconditioned to this temperature). The temperature of the bottles was measured over time for ranges of 0^{o}C-2^{o}C and 2^{o}C-8^{o}C, but not enough detail was provided to determine whether the bottles were already at 0^{o}C or had to initially cool to this temperature within the test (this would provide uncontrolled variables in the testing process which could skew the results). Each vessel was opened for a few seconds to ‘tamp down the ice’ but the frequency of this task is not defined. Each product was given a percentage score; however the method of determining this was not explained. The best performer achieved 95%, which leads to questions such as ‘was this based against the rest of the products tested, against some uncited benchmark, against manufacturers claims, or some other yard stick’.

In another review, this time of fluid vessels – as in Dewar flasks or Thermos flasks - (Martinet 2013), a small sample of new and used vessels, including a mug as a reference specimen, were filled with hot liquid to a set temperature and measured regularly for their temperature change over time. The control room was a domestic apartment, which would have had fluctuations, however all samples were together so this should not have impacted significantly for the purposes of this analysis. The products in question were not given a rating as such, but were ranked in terms of which held the liquid at the highest temperature for the duration of an average 8 hour work day: An objective outcome, but nonetheless specific to one subjective perception of performance.

In a third review, again with insulated vessels, called coolers in this instance – as it was performed in the USA - a number of specimens were tested with boating needs in mind (Vance 2013). This review also looked at a number of factors, including the ratio of internal and external volumes; therefore the thermal performance was not necessarily the most important consideration. In this test, each vessel was filled to full with ice (not specified as to whether block, party or otherwise, however the article stated ‘slight crushing of ice’ when closing the lid which suggests party ice). They were then placed in the sun (the first test to hint at radiant heat and not just assume conductive or convective heat alone), and water was drained daily for one week, at the end of which the quantity of ice was calculated as a percentage of the original ice. The remaining ice percentage acted as the rating of thermal performance.

2.3. Researchers Insights

Research was also carried out to determine what other researchers may have uncovered or developed over time. There was very limited material found, suggesting that (as far as this particular product type is concerned) little emphasis has been placed on thermal performance in the past. Given that until recent decades there has been little emphasis on thermal performance in other more significant industries, such as the built environment, this is a plausible deduction.

One particular paper is quite anecdotal of this. An analysis was carried out nearly a century ago on refrigerated domestic vessels. In those days the choices were either ice, or a brine circuit. It would be some time before the modern ‘fridge’ using the compression-expansion cycle would be used in homes; therefore performance would have been a critical factor for food preservation. In an article titled “Food In The House Refrigerator” (Broadhurst & Van Arsdale 1924), in which 3 vessels are tested for bacterial changes with respect to temperature and humidity, there is little mention of the physical or thermal aspects of the test specimens. There is mention of the materials in a casual way – with more focus on the shape for convective air flow inside – but no mention of the thermal performance of each construction (as if this aspect was not a consideration in that era), other than one sample having a metal lined wood with a density conducive to resisting heat, but certainly no R-value or even an indication of W/m-K or similar parameter for any material combination.

At the other end of the spectrum, a Paper on insulated shipping containers (ISC) proved to be very useful for this analysis. In this particular study (Singh, Burgess & Singh 2008) there is a dedicated focus on determining the R-values of various package systems. This involved an 'ice-melt' test which preconditioned slabs of ice (by allowing a small amount of water to be produced to ensure a 0^{o}C temperature of the ice) with which the actual test was carried out. Each shipping container was then left in a control room of 23^{o}C such that air could contact the top and all sides of each specimen, containing a preconditioned ice slab within a bucket, which was taped up as per industry practice. These were left for 12 or 24 hours (ensuring a minimum of ice remained) after which the quantity of water was measured and divided by the timeframe to determine the 'melt rate'. From this a system specific R-value was created for each sample. This is the first test that takes the specimen surface area into consideration, showing an understanding that variations in volume and surface area can skew the results if not taken into account in the tests.

It is important to note here that this study focused on the combination of a package type and an anticipated product thermal load, making it more industry specific than would be useful for this project. This paper even discussed how the commercial operator would calculate the quantity of ice required to adequately ship products without excursion from their desired temperature range during shipment. This would certainly not be adopted by domestic consumers who are more likely to guess their requirements than perform any computations.

2.4. Regulators

There were also two rather interesting test procedures discovered which also focused on ISCs, however these were from regulators within industry; one independent, and one governmental.

The International Safe Transit Association has developed numerous procedures for a variety of issues for the container shipping industry, one of which (ISTA 2007) focuses particularly on the thermal performance of ISCs. Their test methodology is similar to the process outlined above for ISCs by researchers; however there is more focus on a specific product/package combination, as well as the actual trip taken by the parcel. The testing consists of a sequence of different temperatures over varying timeframes, with ramping up and down in some cases, intended to simulate generalised shipping lanes for their clients' products. In more recent work (Cox 2012), they have greatly increased their research on temperature fluctuations of actual shipping lanes within the USA and developed software simulation models for determining the exact packaging requirements for any client's product's trip from door to door. The aim is to maintain the product within an acceptable temperature bandwidth (measured with sensors inside the packaging) for each given product throughout the sequence of test cycles. The rating in this instance is simply pass or fail.

The other testing process is one developed by the World Health Organisation (WHO) specifically for the transport of vaccines (and similar temperature-sensitive medical products, such as pathology samples) where refrigeration is not possible. Their methodology (World Health Organisation 2010) is quite similar to that defined for ISTA above, however their focus is on not exceeding a critical temperature, either up or down (depending on the requirements), within a minimum timeframe. The ratings of this test are known as 'cold life', 'cool life' and 'warm life', of which only the cold life rating must meet a minimum timeframe, suggesting that for the others the methodology is still in a developmental phase of its life.

2.5. Applicability of Literature

There is a fair range of information within this literature review to prepare a suitable methodology and subsequent testing & rating system. There are strong and weak points about each of the processes outlined above.

On one hand, the current industry players are obviously responding to market demand, but this does not mean that the average consumer knows and demands the best possible testing methodology. The common use of ice is certainly analogous to how most consumers might use the vessels, however it is clear that ice comes in different forms and at different temperatures which would make comparisons very difficult. Since water holds much more heat than air (due to a much higher specific heat value) or certain food items, any test using large quantities of ice will favour larger vessels which have more ice to thaw. These tests also make broad assumptions about how the products will be used by all consumers, rather than being as objective as possible and allowing each consumer to interpret the ratings, tailored to their own usage patterns. Much the same can be said for the comparisons carried out by the 3rd party observers. There is also noticeable vagueness in the ratings, some of which are very subjective. The best is the percentage ice remaining, followed by the final temperature at the end of a work day, but others don't necessarily reflect a result that can be easily repeated by any other tester/consumer.

On the other hand, the commercial systems are obviously applying science to achieve a commercially viable outcome, but for very specific applications. These tests and ratings are far more objective in their nature and apply more controls to ensure repeatable results; however they may not lend themselves to such a broad application as for this analysis, since each has been designed for a particular outcome. For example, the Paper on ISCs used only cube shaped boxes with the same insulation and cold packs, however coolers come in all different shapes and sizes and consumers will use a variety of cooling media from gel packs to dry ice, and will be needing to preserve a wide variety of food items for a number of different scenarios, so such a test may not cover all these combinations and permutations. Similarly, a rating which does not exceed a temperature within a timeframe is very precise for vaccines being transported in a predetermined way, but may be meaningless to a variety of consumers using the same product in different ways. Also, these systems are designed to ensure that a specific temperature sensitive product is preserved over the same repeated transit on a regular basis, which again does not reflect the random usage patterns of the average consumer using an esky for different activities at different times of year.

This raises another important point. All the tests have been carried out with control temperatures, some using just one temperature while others use multiple bands: ISTA in particular has summer and winter profiles to ensure that their clients' needs are met throughout the year, while WHO have 3 different ratings for use in different climates around the world. However, a domestic consumer will be using a cooler which is exposed to a variety of random temperature changes during each usage. For example a cooler may be in the sun in the back of a vehicle at nearly 60°C at one point and then sitting on the ground outside a tent at nearly 0°C during the night. Therefore testing to a set temperature or to a set of temperatures is not indicative of how a domestic consumer will use their cooler, even if it can be seen as appropriate for replicating the shipment of a commercial product in a predictable and repeatable process.

It is also worth pointing out that some tests involve opening the samples while others don't. This is based on predicted usage patterns. For example a domestic consumer is likely to want to access stock from a vessel at various times, but an ISC will remain closed from the start to the finish of its transportation. Similarly, some tests use ice and gel packs or phase change materials (PCMs) while others have air gaps, or a combination. These practices are also intended to mimic usage patterns; however it is less likely to be precise for consumer applications than for known commercial applications.

The combination of air and water will greatly affect the temperature change patterns, so there must be care taken in determining such combination, which of course is again less likely to be precise domestically than commercially. This is even more important with the use of PCMs which are capable of maintaining a particular temperature for long periods of time, perfect for a known stock requirement. The same can be said of ice melting, which will maintain food at 0°C for longer than at other temperatures when the water is either solid or liquid, which could greatly skew any results as a function of the quantity of ice.

Extending from this point is the fact that one test left melted ice in the cooler, while the others drained the water: This will allow heat transfer in two different ways, which again can skew the results. The commercial ratings are also clearly based on a stock/product combination, and in some cases a stock/product/trip combination, while the domestic ratings are limited to assessing the product (insulated vessel) only, as the contents in real applications will not be what was tested.

Lastly, it is important to discuss some short comings that may arise if performance metrics were to be developed along the same lines as the construction industry. Each building is almost unique in shape, while each esky is mass-produced. Equally, each building tends to have relatively simple shapes – parallel surfaces with even thicknesses – while coolers are moulded to a more free-form shape to allow for wheels, handles, hinges, clasps and other practical considerations which ultimately vary the thicknesses and densities of all the surfaces. The construction industry relies on complex software programs which model the design of a building and allow for the R-values of each material used. This is highly complex, open to interpretation, which leads to differences in results from one modeller to another, and is also very expensive to carry out, which can be justified for a large building that will stand for several decades, but not to a cooler that may only last 5-10 years. Applying such a process to eskies would require determining the R-values of the materials, which is not as easy for blown insulators in a custom mould as it is for more uniform shapes with even densities, such as the insulated panels mentioned earlier. Even if this could be carried out with a high degree of accuracy, it is then incumbent on the designer of the insulated vessel to carry out energy models on each product design within their software, which would be fraught with the same dangers of interpretation as for the construction industry. This would be an expensive exercise which may not lead to the desired market confidence, so a simpler system should be developed rather than replicating what the construction industry has determined is suitable for its needs.

3. Methodology

The methodology for this project consists of firstly defining the specific range of products to be included in the analysis, followed by analysing current processes by manufacturers and other testing & rating bodies. There must be a review of heat transfer principles with an analysis of what is pertinent to this project. Next, a testing procedure can be developed. This can then be followed by mathematical analysis, using software, to determine approximate ranges of results, and then also by experimental testing, using laboratory equipment at the USQ Toowoomba campus. The experimental results must be analysed against the mathematical results to determine whether the testing process achieves the objectives of this project. Finally, a rating system can be devised to reflect the testing results in a meaningful way for the consumer.

3.1. Target Products

As has been mentioned in the sections above, this analysis primarily aims at developing a system to meet consumer needs, but is not limited to just that sector of the market. The previous section has demonstrated that there are viable systems in place for the commercial market which appear to be limited to very specific circumstances such as the repetitive delivery of a specific product along the same transit path each time; however they do not appear to be universal for other applications. That does not mean that this system (being developed here) could not or would not be adopted by the manufacturers of ISCs.

However, there may be certain commercial requirements that may lead to a preference for the system developed in this project. For example, agricultural producers, using foam boxes, may prefer the flexibility of different products from different suppliers from season to season, based on different produce of differing sizes, which may not allow the other systems to be easily adopted by a foam box manufacturer whose clients have many varied needs and don't seek to have lock-in contracts for the supply of insulated shipping containers when their needs may go up and down based on seasonal variations.

3.1.1. Consumer Market Testing

The current testing regimen by the manufacturers tends to be based on simulation of consumer usage, with a rating of meeting a number of ‘days cold’, rather than assessing the thermal resistance of the unit as a whole and having a more objective rating. This is fraught with too many assumptions about what the consumer needs, which simply reflects the many varied usage patterns of so many different consumers.

There are also too many variations in the test procedures, such as keeping water in the vessel or removing it on a regular basis. This will greatly influence the results since the water in the vessel will act as a bridge for the heat path to the ice, where air would act as a barrier. Equally, the use of ice does not define the temperature of the ice to begin with, so additional time may be gained by using very cold ice and draining it regularly, compared with one of the commercial tests, which ensures the ice is at 0^{o}C before commencing the process and retains the water for measuring the heat gain.

The risk with this for consumers is that they may naïvely assume that the claimed number of days cold is based on their own usage patterns rather than anyone else’s usage patterns, not stopping to think about the fact that different people use the product in different ways. This leads to consumer dissatisfaction and lack of consumer confidence for the manufacturers, who are actually trying to achieve the very opposite.

3.1.2. Commercial Market Testing

Similarly, the commercial sector of the market also tests products based on client usage patterns, although in this case the clients usage patterns are well determined and repeatable, and in some cases almost able to be completely simulated in a laboratory, as alluded to by ISTA’s paper on the applications of lane data (Cox 2012). Since monetary demands control supply in such an industry, one must assume that these systems are effective for their target market, or else other systems would be being developed. That does not mean that the system being developed in this analysis could not be adopted by operators within the commercial market, but this analysis is certainly not trying to compete with or replace those application-specific systems.

3.2. The Science Within

Past assessments have focused more on temperature than heat; however heat is more important as it is the source which creates any resultant temperature. In particular the heat transfer from one side of the vessel walls to the other (due to a temperature differential across the wall, driving the heat transfer from hot to cold) is more important than the heat holding capacity of the volume of the vessel itself.

Therefore, the requirements for assessing thermal performance of an insulated vessel is about heat, but only as limited to the effects of heat passing through the vessel walls. In particular, this is about the rate of heat transfer (Watts, or Joules per second) rather than the quantity of heat being transferred (Joules), as that is limited to the volume of the vessel and the thermal properties of its contents, while the rate of transfer will impact directly on the success of maintaining an internal temperature within a desired bandwidth over a desired timeframe for the preservation of the vessel's contents.

Fluid mechanics (such as any convective flows of air within or around the vessel), however, are not aspects of the science that need to be addressed in this analysis. These would be for any entity choosing to educate the consumer on how to maximise the use of their cooler. Such an objective is clearly beyond the scope of this analysis.

Likewise, the assessment of the different thermal properties of various materials should be kept within the realm of the manufacturer's design processes, as the testing & rating system being proposed in this analysis is not attempting to define the best designs, but simply to rate what has been designed. This obviously extends to shape and size of each product.

3.3. The Concept of Heat

There are different modes of heat which can transfer from one point to another: These are known as radiant, convective and conductive heat. Likewise, there are different media in which heat can exist: These are commonly, food, drink, ice, gel packs, air, and other contents of a typical insulated vessel. These can all be considered in many different ways, as a function of the total usage patterns of these media by a consumer, so it is important to consider the limitations of this analysis.

A consumer would understandably be keen to know good practices for keeping food colder longer, such as allowing air flow around items, and draining water from the vessel regularly: One touches on convective heat, while the other touches on conductive heat (although heat through water is convective, the transfer of heat from the vessel wall to the ice, via the water, involves conduction, which is relevant to this project[3]). They may also be keen to know that leaving their esky in the sun is worse than having it in the shade, even though the air may have the same temperature in both places. This touches on radiative heat. Alas, all these are beyond the scope of this project, simply because the way that a consumer chooses to use their cooler is beyond the control of this testing & rating system.

Similarly, the analysis of heat transfer within the contents is beyond the scope of this project, because the aim here is not to prescribe to the consumer what they can and cannot transport in their cooler, but to allow them to learn to determine for themselves, based on experience using this system, which vessel will meet a particular need.

Another aspect of heat transfer is how it travels through the walls of the vessel. A Dewar flask has a vacuum between an inner and outer lining, while a budget model cooler might have an air gap between two layers of moulded plastic, and a premium ice box could be made of polyurethane. The considerations of radiant, convective and conductive heat in each application are different; however these are ultimately beyond the scope of this analysis since it is the prerogative of the manufacturer, based on a multitude of customer demands, to determine what construction materials are used.

3.3.1. Modes of Heat

All heat ultimately comes from the sun, with the possible exception of the heat rising to the earth's crust from within: however since this is highly insulated (other than via volcanoes or geothermal applications, far removed from this analysis), it can be ignored and only the sun's

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[3] Note that the same can be said of the air; however since far less heat would be transferred through the air compared with the water, this point is ignored.

heat will be considered. There are also other forms of heat, such as a fire or an electric heater, but they do ultimately get their energy from the sun, stored in wood or fossil fuels.

The heat from the sun is radiant, so this form of heat should be discussed first. As the sun's heat reaches earth, it interacts with the earth's atmosphere, which is gaseous (a fluid) and is the subject of convective heat, which will be discussed second. Finally, the radiant and convective heats, identified herein, come into contact with solids, such as the soil, plants & animals, humans, and humanity's entire built environment, converting to conductive heat: Logically this will be discussed third.

Radiant heat flow can be estimated mathematically by

$$\dot{Q}_{rad} = -\varepsilon\sigma A(T_s^4 - T_{surr}^4)$$

Equation 3.1

measured in Watts (W), based on the Stefan-Boltzmann law, using the Stefan-Boltzmann constant

$$\sigma = 5.67 \times 10^{-8}\, W/m^2 \cdot K^4$$

Equation 3.2

and ε is the emissivity of a grey body[4], A is the surface area (more regularly referred to as A_s in this report) and T_s is the surface temperature of the grey body in question, and T_{surr} is the surface temperature of the surrounding surface, such as a room's extremities or the atmosphere, (Cengel & Boles 2007).

Convective heat flow can be estimated mathematically by

$$\dot{Q}_{conv} = h_c A(T_s - T_f)$$

Equation 3.3

using Newtons' law of cooling, where T_f is the fluid temperature and h_c is the convective heat transfer coefficient, which is far too complicated to calculate easily (as each instance

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[4] It is assumed that the reader of this analysis is familiar with the concepts of black bodies and grey bodies.

requires a variety of preliminary calculations which make each situation unique), and is not necessary to meet the scope of this project, but suffice to say that it ranges from 2-100,000 (Cengel & Boles 2007).

Conductive heat flow can be estimated mathematically by

$$\dot{Q}_{cond} = -k_t A \frac{dT}{dx}$$

Equation 3.4

as per Fourier's law of heat conduction, where k_t is the thermal conductivity and dT/dx is the temperature differential with respect to the thickness, x, of the conducting material, otherwise identified as L in this analysis (Cengel & Boles 2007).

According to The Principles of Heat Transfer (Kreith, Manglik & Bohn 2010) only conduction and radiation are heat transfer processes, suggesting that convection requires not just a temperature differential (like the other two) but also mechanical mass transport. This would be for a fluid, whether gas or liquid. This may be a consideration for PCMs as they change phase and convective flows start to occur within, however this analysis in not intending to cover the efficacy of such aids in the temperature control process. Another example that could look at convection is in the simpler coolers which have an air gap between the inner and outer shells. However, since this is a small, contained volume of fluid, which is only demonstrating mass transport perpendicular to the overall heat flow direction, it is not necessary to investigate this when ultimately it will be converted from conductive heat, to convective heat, and back to conductive heat through the walls of the vessel at the micro level, equating to one overall conductive heat transfer at the macro level.

Similarly, much work could be carried out for the effects of radiant heat transfer, however, as noted in Thermodynamics: An Engineering Approach (Cengel & Boles 2007), radiation that is incident on an opaque solid body (as hard and soft coolers invariably are) is only absorbed to within a few microns of the surface, after which it becomes conductive heat transfer (which is what makes the vessel surface hotter than the ambient air surrounding it).

Common terms can be observed in each equation shown above. Each has a surface area and a temperature differential, and each has other factors which can be manipulated to represent a similar construct that is interchangeably representative of each form of heat, known as the overall heat transfer coefficient. This is most obvious in the equation for convective heat, by the use of the letter h with the subscript c; h_c. In fact it could be defined as h_{conv}, while for radiant heat it could be defined as h_{rad} – although this requires some manipulation with respect to temperature, given the power of 4 in the equation and the Stefan-Boltzmann constant – and as h_{cond} (sometimes written as h_k[5]) for the conductive heat, which is mathematically equivalent to k_t/L, where L is the thickness of the conductive material (as mentioned above), also referred to as the thermal conductance per unit area (Kreith, Manglik & Bohn 2010): The thermal conductance being defined as

$$K = k_t A/L \ (W/K).$$

Equation 3.5

Alternatively, this can also be considered in terms of

$$R = 1/K$$

Equation 3.6

being the mathematical reciprocal which looks at the thermal resistance of the vessel rather than its conductance; perhaps more pertinent for the understanding of the end user in this application when selecting an appropriate vessel for their needs.

The heat transfer coefficient, measured in W/m^2-K, is heat flux (in W/m^2) divided by the temperature (measured in K or ^oC), effectively making it the heat flow rate (in W) per unit area (in m^2) per unit temperature (in seconds). All things being equal in our testing of each vessel (the surface area of the vessel, and the temperature differential of the test), this is the characteristic of each vessel which will determine its performance. Given that, in the case of the conductive heat transfer coefficient, h_{cond}, it is governed by the thermal conductivity, k_t, and the material thickness, L, both of which are entirely in the hands of the manufacturer to correctly select materials according to their thermal properties and correctly design the vessel body based on thermal requirements, as a function of other requirements driven by market demand.

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[5] The letter k is often used to represent the word conductive, as opposed to the letter c which tends to represent the word convective, to avoid confusion in using both in various equations.

3.3.2. Media for Heat

Consideration must be given to the medium through which heat is transferred. This is complex, since there is the outside environment through which heat is transferred, there are the vessel walls, through which heat is transferred, and then there is the stock within the vessel through which heat is also transferred.

Ultimately, it is all about the stock in the vessel. Each individual item has a preferential temperature at which it is best to be stored: Milk requires a different temperature from frozen meat, while a pizza heading towards an excited ‘footy’ fan has an entirely different ideal temperature altogether. All of these are outside the control of the manufacturer of the vessel (who cannot dictate to the consumer how to use the vessel), and therefore beyond the scope of this project (other than the ratings guiding manufacturers to improve their designs for better ratings).

What is within the scope of this project is the temperature change across the vessel walls, within the limitations of simply observing and reporting on the changes. Current industry testing tends to use ice, mimicking the most common current practice of the consumer. However, this may not be conducive to carrying out an accurate, repeatable, universal testing methodology. Testing needs to be objective, repeatable and universal, if it is to be acceptable, therefore the methodology must remove any subjective criteria which create ‘noise’[6] in the testing regimen. Furthermore, testing should be quick and cheap in order to gain industry acceptance. No manufacturer is going to go through the arduous process of some horribly convoluted, expensive, uncertain testing regimen which then fails to instil any confidence in their customer base, therefore this analysis must aim to achieve a fast and cost-effective system which is accepted primarily by the consumer and then, by consequence, by the manufacturer.

If one looks at the contents of any insulated vessel there will always be a minimum amount of air in the mix, with the exception of a vessel with a convex internal lid profile which is filled to the brim with a liquid on a perfectly flat surface (with respect to gravity, where a liquid is concerned). Therefore, any fully conclusive scientific analysis of a vessel with a variety of stock must consider the properties of each constituent, which includes the air in between

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[6] In recording terms, noise is defined as ‘unwanted sound’ as opposed to the sounds being recorded. In this case, the ‘noise’ is any deviation from an accurate result due to extra variables which are not necessary.

everything. Effectively, the air makes up the balance of the volume regardless of the contents, and therefore must always be part of any heat transfer consideration, whether simply through the walls – as in this project – or within the confined space (as every keen camper or fisher may want to discover in order to prolong their pleasure).

Looking at air as a testing medium, one can quickly find some simple comparisons with the ice/water combination. Firstly, air holds far less heat than water; whether the water is liquid or solid: This means that the temperature change will be faster in air. Secondly, in the temperature range that most consumers are likely to use there insulated vessels, the ice/water combination will go through a phase change: This means that during that phase change there will be no change in temperature, and is the key attraction to modern phase change materials (PCMs) designed to change phase at a particular desired temperature. This is a good thing for the consumer; however it adds time to any test for the testing laboratory. The test is not meant to replicate applications in real life, but to provide an idea of efficiency for any application in real life: This can be done with a test which is different from real life situations, but provides the understanding required for interpretation and application to a real life scenario (which will be interpreted differently for each consumer – this is the crux of this project; to develop a universal testing regimen which can be interpreted by all users to their own benefit!).

If the temperature change of air is faster than that of an ice/water mixture then the results must happen faster, which leads to a cheaper testing process in the laboratory. Equally, if there is no phase change in the testing process, then the heat transfer is truly a function of temperature differential at any value, making all tests comparable, regardless of the temperature range or the contents or PCMs used, effectively isolating such variables from an objective universal and repeatable testing regimen.

Given that the volume of a vessel has already been identified as an issue for comparing the performance of vessels, the use of air as a heat sink reduces the variance from one sized vessel to another, leading to more controlled testing times regardless of product size.

3.4. Testing Processes

Traditionally, there are two main approaches that can be employed in any research project of this nature. Firstly, there is always some form of mathematical analysis, starting from simple sums and calculations to complex numerical modelling approaches employing such concepts as Finite Difference Method (FDM), Finite Element Method (FEM) – also known as Finite Element Analysis (FEA) – or Boundary Element Method (BEM), as examples. All of which have their strengths and weaknesses, depending on what needs to be achieved. Similarly, there is also the experimental approach, which can range from a simple laboratory confirmation of the numerical analysis, to more complex empirical processes, in the field, which actually drive the scientific and engineering understanding of the nature of life on earth which surrounds us. Both of these processes are discussed below.

3.4.1. Mathematical Analysis

Mathematical analysis involves making calculations that predict a desired outcome. If done correctly, this may also identify errors, anomalies and even derivations from our current understanding.

Given the complex shapes and the variety of materials of insulated vessels, one could easily start to think that some incredibly complex software program would be required to carry out a viable analysis of these products, involving one of the numerical methods listed above. This might be of interest to a manufacturer who wants to know exactly where in their product the heat is passing through so that they can improve the design, but for the intent of this project such complex analysis is not necessary. Counter-intuitive to this initial thinking, the best option is to simply carry out some quick sums in any simple software, such as Microsoft Excel (or similar open software program) or even with a calculator and a notepad.

Since this analysis is about developing a real testing process that will be carried out in laboratories, then the focus should be on experimental testing. This shifts the focus away from the mathematical analysis, which can be used simply to provide direction and any necessary order of grandeur for setting up the experimental testing process.

Such a mathematical analysis process has been developed in MS[7] Excel, which is expanded upon in Section 4 below.

3.4.2. Experimental Testing

Experimental testing involves actual replication of a real-life situation, or at least a simulation which is as close as possible to the real situation. Again, if done correctly, may identify errors, anomalies and even derivations from our current understanding.

Herein lies the most important part of this whole project. The point of this research is to develop a testing methodology which can be replicated anywhere at any time by any accredited organisation, so it makes sense to carry out such a testing regimen as part of the experimental testing for this project. The purpose of carrying out experimental testing is to determine whether such a testing regimen actually works or not. The aim, here, is to determine exactly what such an effective testing process is.

Testing for the thermal performance of raw materials (either individually or in composition) already exists. A common test is the hot plate test, which is a simpler version of the guarded hot box test used in the construction industry for determining R-values of building fabric constructions (Sugo, Page & Inglis 2007a). Such testing consists of placing a sheet of the material in question between two environments of dissimilar temperature and measuring the heat exchange across the material. This is acceptable for any homogeneous material that is effectively 1-dimensional (1D), meaning that the heat transfer is in one direction through its thickness and the area does not impose any impact on the result, since the output will be measured in W/m^2-K.

This is not initially a suitable option for a vessel which is intrinsically a 3D object, through which heat will transfer in all 3 dimensions, and has non uniform thickness or density throughout its surfaces: i.e. we are looking at heat transfer in or out of the object, not just through a sample of the walls of the vessel in isolation, and we are also looking at that heat transfer through variable thicknesses, densities and materials (as these vessels are often made of more than one material in their construction), rather than a homogeneous thickness of one

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[7] MS stands for Microsoft: The manufacturer of the Excel spreadsheet program.

individual material or a consistent composition of materials. However, with a little lateral thinking this testing methodology can be adapted to achieve a similar outcome in a 3D application.

The guarded hot box tests require two chambers from which the heat is transferred through the medium in real time, with the chambers butted up to each other. If we look at the possibility of storing the heat in the medium, momentarily, and transferring it from one chamber to the other (the chambers may not be butted up together, to avoid excessive insulation between them, but should be in close proximity to each other to reduce the transfer time to a minimum), then the same assessment could be achieved. Effectively, the proposed testing regimen in this analysis is a 3D equivalent of the hot box test, and it is not too dissimilar from the testing carried out by ISTA and WHO (as outlined earlier).

In brief, this project attempts to determine whether it is possible to create a universal rating system for all insulated vessels with this one simple test.

The test involves the use of two chambers at dissimilar (but stable) temperatures. A test specimen is placed in one chamber and allowed to equalise its internal temperature with the chamber (this can be accelerated with the vessel open). At this time, the specimen should be transferred swiftly to the other chamber, preferably via an intermediary space with thermal properties lying between those of both chambers (i.e. the temperature, relative humidity or air pressure are not outliers for the test, but are all between the high and low equivalents in each chamber) to mitigate any ‘noise’ in the data such that the transfer happens faster than any heat exchange could happen across the vessel wall.

The test should then be repeated in reverse order as a double check and to determine whether there is any difference between heat ingress and heat egress as a function of the design (such as a weakness in the lid/body interface) because heat in a natural convective flow tends to move upwards, although in many cases this may not be a detrimental issue (however cooler bags with zippers at the top may prove to need this double test, as an example).

Any such test requires sensors to measure the required properties (such as temperature). These sensors must be beyond reproach; therefore a calibration regimen is intrinsic with any such testing regimen. To obtain accurate results, it is best to avoid opening the vessels during testing (once closed after the initial acceleration of reaching steady-state at the beginning of the testing process), which is a departure from the testing procedures in the current domestic industry, but in line with the current commercial industry. Although not analogous to how the consumer uses the product, it avoids further ‘noise’ in the data collection.

The primary sensors required are temperature sensors. These are ideally cordless and capable of transmitting feedback to a computer which can track real-time changes for more accurate results in this analysis, for determining the best commercially viable test regimen for this industry.

Equally, relative humidity (RH), ϕ, and atmospheric pressure (ATM) should also be controlled. If the RH in one chamber is vastly different from the other, then the water vapour present in one chamber will impact the heat transfer one way or the other, depending on the chamber in which it is present. Equally, if the air pressure is different from one chamber to the other (due to different fan pressures), then again the results could be skewed. Either of these possibilities is far less likely than the difference between one test (on one product in one laboratory at one time of year) compared with another test (of another product in another laboratory at another time of year), especially where altitude is involved. This is where the importance of universal testing comes to light.

To a lesser degree, but still important, is the need to ensure that the chambers operate at consistent temperatures, RH and ATM. This is attested in the hot box testing protocol which requires an internal control box and an outer supply box[8], although in this particular testing methodology the stability of these parameters is less critical. This can be mitigated by the use of chambers with modern HVAC systems which operate with VSD (variable speed drive) mechanisms and inverter technology to reduce hysteresis for small variations in the identified parameters.

A final consideration, only within the context of this project, is the age of any specimen used for the experimental tests. The ideal would be to use brand new products, however if any specimen is used that has been in service, there is a possibility that damage or degradation may reduce its performance and skew the results. This however should not be an issue for this project, as the aim here is not to test every current product and rate them all, but to

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[8] It is left to the reader to find the freely available information on the internet regarding the basic understanding of the hot box test, although it is demonstrated in the UoN paper cited herein Sugo, H, Page, A & Inglis, C 2007b, 'Thermal performance studies at the University of Newcastle', in *Solar 07*: *proceedings of theSolar 07* ANZSES, Alice Springs, Australia. Images of the apparatus have been provided in the appendices for a quick visual understanding for the reader.

establish a possible testing & rating methodology, therefore any sample that has seen service will not be representative of that product, but simply an example for this analysis.

3.5. Testing Procedure

In order to be certain of the best testing procedure, there must be a discussion of the variables that can be measured. Given that the materials, shape and size are all determined by the manufacturer, the remaining variables are the ratio of volume to surface area ($V:A_s$), the temperature differential (ΔT)and the time elapsed (Δt).

3.5.1. Volume & Surface Area

Thermal energy is a function of both the volume of a vessel and its surface area. The volume can store only so much thermal energy, based on the thermal properties of its stock (air, water/ice, food, etc.) while the volume boundary can transfer that quantity of thermal energy, but only at a rate determined by the thermal properties of the material in question. Therefore, the stored thermal energy of the volume governs the timeframe of the heat transfer, as a function of the temperature differential, ΔT and the heat transfer coefficient, k/L (h_{cond}), and the surface area of the volume.

Volume and surface area are related in some geometric shapes. In such cases, surface area is the derivative of the volume with respect to their shared characteristic length. For example, a sphere has a volume,

$$V = \frac{4}{3}\pi r^3$$

Equation 3.7

and a surface area,

$$A_s = 4\pi r^2.$$

Equation 3.8

Differentiating the volume with respect to the radius gives

$$\frac{dV}{dr} = 3 \times \frac{4}{3}\pi r^2$$

Equation 3.9

reducing to

$$\frac{dV}{dr} = 4\pi r^2$$

Equation 3.10

which is the surface area. Similarly, a cube, with a side, s, and a half-side, a, has a volume

$$V \ = \ s^3 = (2a)^3 = 8a^3$$

Equation 3.11

and a surface area

$$A_s \ = 6(2a)^2 = 24a^2.$$

Equation 3.12

Differentiating the volume with respect to the half side, a, gives

$$\frac{dV}{dr} = 3 \times 8a^2$$

Equation 3.13

reducing to

$$\frac{dV}{dr} = 24a^2$$

Equation 3.14

which is the surface area, again. Likewise, the same could be done with an open cylinder of length, l, as

$$V = \pi r^2 l$$

Equation 3.15

And

$$A_s = 2\pi r l.$$

Equation 3.16

However this relationship is only valid for certain shapes. If one tried the same with an enclosed (or solid) cylinder, for example, the two end circles must be added which would change the relationship.

However a more important relationship exists between volume and surface area. There is a ratio between them which is different for different shapes. It is well known that a sphere has the smallest surface area for a unit volume, while a cube will have a smaller surface area than a cuboid of the same volume. Therefore, applying this to the shape of our insulated vessels, it would be best to have a spherical shape, but this would be impractical. Coolers tend to be of cuboidal shape; even cooler bags are inclined to be cuboidal rather than cubic, cylindrical or spherical. This obviously will impact the thermal efficiency of the vessel.

More important than the impact of the shape is the impact of the size. If the characteristic length, r, of the sphere above is doubled the volume would then be 8 times larger (2^3) but the surface area would only be 4 times larger (2^2). Therefore the ratio of the volume to the surface area gets larger as the size increases, which means the quantity of heat stored increases more than the surface area through which it can pass. This unfairly favours larger vessels while smaller vessels suffer greater heat loss or gain.

Initially one might be tempted to develop a test that compensates for this so that regardless of shape and size all vessels are rated on their own merits. This would be true if one wanted to rate vessels on some other metric, however this is actually counter-intuitive to the whole aim of this testing & rating system development. For example, if the ratio of V:A_s were taken into account, then smaller vessels would appear to perform better than reality while larger vessels would appear to perform worse. This would favour the manufacturers of smaller vessels but it would actually give the consumer a false belief that a smaller vessel actually performs like a larger one when this is not true. This would only lead to eventual lack of confidence in the system, therefore such an approach must be quite intentionally avoided in order to provide consumers with an understanding that larger vessels tend to perform better than smaller ones. The manufacturers are then left to find the balance between providing the thermal performance demanded by the consumer and the practicality of size and shape also demanded. This may ultimately prove to drive manufacturers to tweak the ratio of the dimensions of the shape to improve performance rather than to just increase size, although it may also ultimately drive consumers to purchase larger vessels as they will provide better performance for the money spent.

That said, the effects of volume impacting on performance can be offset by the manufacturers by adjusting the vessel wall thickness to compensate, which would have to be done as a function of the penalty of product mass and physical footprint for the effective storage capacity, something which was rated by Boating Magazine in their assessment of various products (Vance 2013).

3.5.2. Temperature Versus Time

After all is said and done (and this project has attempted to do just that), there are just 2 parameters that can be considered for a meaningful assessment of the thermal performance of insulated vessels: These are the internal temperature change, as a result of heat transfer across the vessel walls, and the timeframe over which this happens; These are known as ΔT, and Δt, respectively.

Since these are the only parameters left, it is mathematically clear to pick either one arbitrarily and carry out a test. However if there is a very large insulated vessel with an incredibly resistant construction it may take a very long time to achieve a rating for a set temperature differential, if time is the variable, which would make for an inefficient, albeit accurate assessment: After all, '*time is money*' as they say.

On the other hand, if the timeframe is fixed and there should be a very small vessel with a very poor insulating material, the result may be achieved so quickly that accuracy would be questioned. This is far less likely than the first scenario for obvious commercial reasons (poor products create poor sales), however poor products exist in all industries, so such an outcome should not be considered impossible.

It now becomes important to consider mathematical analysis. The results achieved analytically will greatly determine whether temperature or time should be the variable. Section 4 below expands on this as the core of this analysis is developed.

3.6. Rating Procedure

Testing is of little use unless the results are used in some way. In this case, the results of any test are used to compare with other results of other tests, which is the tool for rating each vessel. This is the process of rating the tested specimens.

3.6.1. Human Interpretation

Each different person has their own views in life, and this will influence everything one does. Each person developing a testing & rating system will be influenced by their world view as to what makes a good test. This can be seen in the variety of tests that already exist, and it is the reason why this particular analysis is looking to develop a system that is as objective as possible in order to remove such differences.

Equally, each person selecting a rated product will interpret the testing & rating system based on their world views. This is actually useful in this analysis since the results are as objective as possible: It leaves the consumer with the freedom to have their own perspective of what the results mean to them, as opposed to what they might mean to the next person.

3.6.2. Shifting the Interpretative Function

The analysis in this report looks to shift the interpretive function from the manufacturer to the consumer. The manufacturers cannot possible know how every single potential customer will view their products, and should not be expected to do so, and should not attempt it as it has more chance of failure than success. Consumers, however, know how they think and are not concerned about other consumers' needs or views, as they are not needed in making an appropriate selection for their own needs.

By having a universal, objective, transparent and repeatable testing & rating system, the manufacturer no longer has to make any assumptions about how the product will be used in order to determine how best to test its thermal efficiency. At the same time, with a simple result labelled on every product on display, the consumer can easily compare one product from another, even if they don't yet understand what that means for them.

Very soon after the introduction of such a system, consumers will come to understand what ratings suit their needs, in much the same way that consumers also interpret the ratings of white goods or passenger vehicles to suit their own needs.

3.6.3. Rating System Options

The key to making this system work is to ensure that the rating is user-friendly. If the results provided are too complicated they will cause confusion and disinterest. If they are too simplistic, they may not allow consumers to perceive full value, and this will cause frustration and disinterest. For example, a rating that uses complex terms that only scientists would know will not work, equally rating products as "Good" or "Bad" or "Excellent" will not work either.

3.6.3.1. Rating Metrics

Possible metrics for the rating system include representative integers, percentages, absolute values, and asymptotic or parabolic curves. Each will be considered for their strengths and weaknesses.

But what should be the basis of this rating? Perfection? Existing practice (aka 'Business as usual')? The risk with using perfection is that it is unachievable, and it is possible that the results will always appear very small which could fail to generate consumer confidence. The risk with comparing with existing practice is that, with large improvements during major uptake of the system by the industry, the results could start to get cramped around 1 ultimate value leaving nowhere for the ratings to go in the future. This would then force the system to either be extended (like NABERS[9]) or have values reassigned (like Green Star[10]) in order to continue. Extending the results would make past ratings look bad by comparison, while reassigning values would keep an understanding of the 'value' of any given rating throughout time.

3.6.3.1.1. Representative Integers

There are already rating systems on the market that use this type of metric. Star ratings are the most common. These consist of assigning a value from the results to be worth one star. These can either by linear or non-linear: i.e. 2 stars are just twice one star, or the value of 2 stars might be the square of the 1 star value, or another value defined as appropriate for that rating system.

Given that stars are so common, it might be better to find another symbol for this rating system, such as snowflakes or ice cubes for coolers, and flames or hot coals for pizza pouches.

3.6.3.1.2. Percentages

Percentages are also common for rating things. By its very nature, a percentage rating is a comparison with something else. This could either be an absolute rating where everything rated is compared with the same initial value, or a relative rating where they are all compared against each other.

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[9] The National Australian Built Environment Rating System is an environmental rating system for the built environment, administered by the federal Department of Industry, Innovation and Science.

[10] Green Star is an environmental rating system for the built environment, administered by the Green Building Council of Australia.

3.6.3.1.3. Absolute Values

Absolute values are simply the results from the testing, left un-interpreted. As the testing process involves a volume of air going through a temperature differential over a timeframe, the key parameters which could be used are the heat in the volume of air at the start and finish temperatures, the temperature range and the time taken. There are also secondary values to consider such as the heat transfer coefficient of the vessel material, the thermal conductance of the vessel walls and the thermal conductivity of the volume of air.

These could be used to look at the heat flow or the resistance to heat flow. This is the case for R-values used for construction materials in the building industry (BCA[11]). Generally materials that allow much of the heat to pass are rated by their conductive properties (such as the U-value for glass), while materials that block much of the heat are rated by their resistive properties. Some possible absolute values include:

- Heat transfer coefficient, k/L, aka U-value (W/m^2-K)
- Thermal conductivity, k (W/m-K)
- Thermal conductance, K (W/K), which equates to the U-value times the surface area
- K/s-m^3 (temperature change per unit time per unit volume)
- K/s-m^2 (temperature change per unit time per unit surface area)
- K/s (ignoring size and shape)

3.6.3.1.4. Asymptotic and Parabolic Curves

Curves are good visual cues for any observer with limited understanding of the science in question, however they are limited to when values are broad and are in the main part of the curve; any values at the ends don’t appear as contrasting, one from another, as those in the middle of the curve.

Asymptotic curves are useful when showing that something is reducing to a limit of zero, while parabolic curves are useful when showing that something is approaching infinity. However, there are risks with both of these for the purposes of rating insulated vessels.

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[11] The Building Code of Australia is part of the National Construction Code (NCC), administered by the Australian Building Codes Board.

Asymptotic curves risk making poor results seem better than they are, while excellent results may not seem to stand out as much, while parabolic curves could make poor results seem much worse than they are, while excellent results may seem to look much better than they really are. This means that manufacturers of products that are at either end of the spectrum may not be as willing to use the system; either way this makes for a poor uptake in industry which can only reduce the consumer's experience.

3.7. Sustainability

The very nature of this project is sustainable. This is two-fold. Firstly, this project does not aim to produce a product which can destroy the environment. Secondly, this project aims to improve the sustainability of future products in the insulated container market.

The development of a testing & rating system leads to better user selection, which leads to less waste that ends up in landfill. As a flow-on effect, this leads to better quality products, which will also lead to less waste from manufacturers.

From a global/local aspect, the ratings will allow consumers in different locales to choose only those products that meet their needs, reducing the wasted stock that is shipped around the world where it's not of use (including the embodied energy to ship that stock pointlessly).

Industry is normally happy with the status quo; however this testing & rating system will empower the consumers to expect more from the manufacturers, which in turn will improve outcomes and reduce waste and destruction of our valuable resources.

The outcome of this project stands to benefit manufacturers, retailers and consumers alike.

4. Analysis (Results)

This section provides the results from the mathematical and experimental testing processes which have been carried out for this project.

4.1. Mathematical Results from MS Excel

The following simple calculations were performed in Microsoft Excel in order to confirm the rationale for this testing & rating system, as well as to provide some key inputs for the experimental testing.

4.1.1. Air/Water Comparison

Firstly, calculations were made to look at how air compares with water. Since most other tests involve a combination of water and ice, it is important to look at the energy in both states.

The specific heat values provide an understanding of the difference between both. From Table 28 of Appendix 2 from Principles of Heat Transfer (Kreith, Manglik & Bohn 2010), the specific heat at constant pressure, c_p, for air at 0°C is 1.011 kJ/kg-K, while from Table A-3 from Thermodynamics: An Engineering Approach (Cengel & Boles 2007), the equivalent for water at the same temperature is 4.22 kJ/kg-K.

However these values are for the mass of each substance and this project is centred on a volumetric analysis, therefore these values need to be multiplied by their respective densities at the same temperature in order to compare the specific heat by volume. Again from the respective tables cited in the previous paragraph, the density of air at 0°C is 1.252 kg/m^3 and the equivalent for water is 1000 kg/m^3. Immediately, it can be seen that there is a vast difference between the two. Multiplying these values provides the following enlightening results, which shed some light on the difference in energy between air and water:

$$\rho \times c_{p\,(Air\ @0°C)} = 1.252\ kg/m^3 \times 1.011\,kJ/kg - K = 1.2658\,kJ/m^3 - K$$

Equation 4.1

$$\rho \times c_{p\,(Water\ @0°C)} = 1000\ kg/m^3 \times 4.22\,kJ/kg - K = 4{,}220\,kJ/m^3 - K$$

Equation 4.2

One can see immediately that a 1°C change in temperature would require far more energy for water than for air. In fact dividing one by the other shows a difference of over 3,300 times the energy required for water than for air.

Now this is only looking at water as a liquid. In order for the ice to melt it must take on even more heat just to change state. This is the latent heat of fusion, h_{if}, which is measured in kJ/kg and happens at 0°C. From Table A-3 (Cengel & Boles 2007) again, the latent heat of fusion of water is 333.7kJ/kg. Converting again to a volumetric value achieves the following result:

$$\rho \times h_{if\,(Water\ @0°C)} = 1000\ kg/m^3 \times 333.7\,kJ/kg = 333{,}700\,kJ/m^3$$

Equation 4.3

Immediately, one can see that this is a vastly larger energy requirement. In fact, if the two values for ice/water are compared by dividing one by the other, it can be shown that the water could change temperature by nearly 80°C with the same energy as it takes to change state, as shown here:

$$333{,}700\,kJ/m^3 \div 4{,}220\,kJ/m^3 - K = 79.076\,K$$

Equation 4.4

This not only means that the water could nearly boil for the same energy; it also implies that any testing regimen using ice melting is going to be a very long test. This explains why the current tests are rated in number of days: Because that is how long the tests are taking (S Elliott 2015, pers.comm., 31 May).

4.1.2. Shape Impacts

As discussed in 3.5.1 above, the shape has a significant impact with respect to the ratio of the volume to the surface area. Table 4.1, below, demonstrates this more clearly for a sphere, a cube and a cuboid (for which one side is twice the length of the other two).

Table 4.1 – Volume to Surface Area Ratio w.r.t. Shape

Shape	**Volume**	**Surface Area**	**Comparison**
Sphere	1.00m^3	4.84m^2	100%
Cube	1.00m^3	6m^2	124% of sphere
Cuboid	1.00m^3	6.30m^2	130% of sphere 105% of cube

Needless to say, this can become more accentuated depending on the shape used for the vessel. Given that some ice boxes for fishing can be very long compared with their depth and height, the surface area could be much greater than those shown above.

4.1.3. Size Impacts

Also discussed in 3.5.1 above, the size has a considerable impact as well. Table 4.2, below shows how the surface area of a sphere does not increase at the same rate as the volume (the proportions can be demonstrated to be the same for the cube – r=1m – and the cuboid – r=0.794m).

Table 4.2 – Volume to Surface Area Ratio w.r.t. Size

Characteristic Radius, r (0.620m)	**Volume**	**Surface Area**	**Comparison**
1r	$1.00m^3$	$4.84m^2$	None
2r	$8.00m^3$	$19.3m^2$	8V $4A_S$
4r	$64.00m^3$	$77.4m^2$	64V $16A_S$
6r	$216.00m^3$	$174m^2$	216V $36A_S$

This clearly shows that larger vessels can store far more heat whilst not having the same proportion of surface area through which the heat can transfer, making larger vessels intrinsically more efficient. Manufacturers can compensate this in smaller vessels by using thicker vessel walls; however the weight gain for the effective storage volume would compromise the products appeal and would remain a marketing dilemma for the manufacturers.

4.1.4. Total Internal Energy

The key piece of information for this test is the quantity of heat energy that the air in a vessel can hold. This is the total internal energy, U. To find U requires finding the specific internal energy, u, for a unit volume and then multiplying that by the volume of a given vessel to determine its total internal energy.

To do this there must be some initial calculations performed using the specific heat of air, dry air to be exact, and the temperatures being considered. Firstly, it can be safely assumed that air in the temperature range of interest for this project can be taken to be an ideal gas, therefore it obeys the Ideal Gas Equation of State, as given by Equation 3-10 in Thermodynamics: An Engineering Approach (Cengel & Boles 2007):

$$PV = RT$$

Equation 4.5

From the same text (Cengel & Boles 2007), Equation 4-23 shows that:

$$du = c_V(T)dT$$

Equation 4.6

du being the change in internal energy, $c_v(T)$ being the specific heat at constant volume with respect to temperature, and dT being the change in temperature. This means that the change in internal energy is the result of the specific heat at constant volume with respect to temperature multiplied by the change in temperature in the process.

Earlier calculations, in 4.1.1 above, worked with c_p, the specific heat at constant pressure, as it was comparing air and water in general terms where using constant pressure for the purposes of comparison is acceptable, and values for both were more easily available. However, since this project is specifically working with closed vessels with constant volume, c_v is required because the pressure theoretically can increase or decrease with temperature change since the volume of air does not change, and therefore c_p would not be valid.

So Equation 4.6, above, can be used to establish the change in internal energy for the temperature range being used for the tests. However the use of values for c_v would create a level of accuracy which would seem absurd for the process, given that the tests themselves will always have margins of error in the temperature settings and the time recordings which would create results that need not rely on a very accurate value for U. Furthermore, it has been observed during the research for this project that tables in different sources have differing values one from another, suggesting that values in tables are often approximations, which is understandable given the empirical practices used to develop those tables.

A better rationale would be to use values for u which are provided in such tables as this simplifies the process and ensures fewer errors throughout the process. Of greater importance than the values selected is the use of the same values by all testing facilities. Therefore the selection of a specific value for the internal energy of air should be confined to within the protocol which would define any commercial testing procedures, such as Australian or International Standards.

Table A-17 in Thermodynamics: An Engineering Approach (Cengel & Boles 2007) provides u values for a range of temperatures of air as an ideal gas. These values are used to interpolate for the chosen temperature values for this project, which will be discussed below.

4.1.5. Temperature Selection

Another key decision to be taken for this project is the selection of an appropriate temperature range and what the best upper and lower values should be. The temperatures chosen have been based on the properties of air and water vapour in the air, and the temperatures which various cooler vessel materials can handle, as well as the equipment available.

The lower temperature is the most important due to the ever present water vapour in air. As has been shown earlier, water requires enormous quantities of heat to change state; therefore it is best to avoid this change of state for simplicity and assurance of conformity for all tests. As a result of this rationale the lower temperature has been set at 5°C.

The upper temperature is more arbitrary, but also important. The key determining factor in the selection of the upper temperature for this project was the accuracy of the loggers used in the experimental tests. The loggers supplied by USQ have an accuracy of 0.5°C. By selecting a temperature range of 50°C, the tests would effectively have an accuracy of ±1%, which is appropriate for this project, given the discussion above regarding the accuracy of values in available tables. Therefore the upper temperature has been set at55°C.

Both these temperatures are appropriate for most vessels on the market, given that they tend to hold frozen goods (especially ice) and are often subjected to greater temperatures during use (such as the cabin of a closed-up vehicle in the sun in summer).

4.1.6. Specific Internal Energy

Having now defined the temperature range, ΔT, and more particularly, the upper and lower temperature values, values for u, from Table A-17(Cengel & Boles 2007), can now be used to find the specific internal heat. This was carried out in MS Excel, in a process which required interpolating values from the table. As the table values are in Kelvin, and the temperatures defined above are in °C, it is necessary to convert the target temperatures to Kelvin in order to interpolate. Table 4.3, below, shows the extracts from Table A-17 followed by the interpolated values. The values of interest are the bold values in the last column, which are the internal specific energy at both temperatures.

Table 4.3 – Interpolation for Specific Internal Energy

Sourced Values		**Interpolation**		
Temperature (K)	**u (kJ/kg)**	**Temperature (°C)**	**Temperature (K)**	**u (kJ/kg)**
270	192.60			
		5°C	278.15	**198.427**
280	199.75			
325	232.02			
		55°C	328.15	**234.282**
330	235.61			

These values, however, are not yet usable, as the testing process in this analysis is using a volumetric approach, therefore these values must also be multiplied by the densities of air at both temperatures to find the volumetric internal energy for this temperature range. Table 28 in Principles of Heat Transfer (Kreith, Manglik & Bohn 2010) provides density values, ρ, for air which can be used to interpolate once again to find the necessary densities for the upper and lower temperatures used for this testing process. These are shown in Table 4.4 below (again the values of interest are in bold font in the last column).

Table 4.4 – Interpolation for Density

Sourced Values		Interpolation	
Temperature (°C)	**ρ (kg/m^3)**	**Temperature (°C)**	**ρ (kg/m^3)**
0	1.252		
		5°C	**1.230**
20	1.164		
40	1.092		
		55°C	**1.042**
60	1.025		

Now, from the calculated values for u and ρ, the volumetric specific internal energy can be computed, from which the internal energy of any vessel can be determined.

$$u(55°\mathrm{C}) \times \rho(55°\mathrm{C}) = 234.282\, kJ/kg \times 1.042\, kg/m^3 = 244.1218\, kJ/m^3$$

Equation 4.7

$$u(5°\mathrm{C}) \times \rho(5°\mathrm{C}) = 198.427\, kJ/kg \times 1.230\, kg/m^3 = 244.0652\, kJ/m^3$$

Equation 4.8

Equation 4.7 and Equation 4.8, above, can now be used to find the difference which is the volumetric specific internal energy.

$$244.1218\,kJ/m^3 - 244.0652\,kJ/m^3 = 0.056634\,kJ/m^3 = 56.6\,J/m^3$$

Equation 4.9

This value is very small. This is due to the change in density of air, which is quite significant. This has been used because it cannot be assumed that a vessel would be pressurised to maintain its density, and therefore its original mass of air. If that were the case then the following results would occur:

$$u(55°\mathrm{C}) \times \rho(55°\mathrm{C}) = 234.282\,kJ/kg \times 1.230\,kg/m^3 = 288.1669\,kJ/m^3$$

Equation 4.10

$$288.1669\,kJ/m^3 - 244.0652\,kJ/m^3 = 44.10165\,kJ/m^3$$

Equation 4.11

This immediately shows the importance of sealing where air is concerned. With some commercially available coolers, there is sufficient sealing to inhibit air ingress and egress to the point that there would be some pressurisation (or vacuum), especially for those models with retaining clasps, however this cannot be assumed for cheaper models on the market which would be subjected to significant air leakage. The reality is that further analysis would be required to define assumptions in a standard for applying to all vessels, where the internal pressure is concerned, but these figures are sufficient for the purpose of demonstrating that this testing procedure is viable.

4.1.7. Material Impacts

At this point, there is room for a brief observation of the impacts of materials on how the heat would pass through the vessel walls. This is more of interest to designers; however such an understanding can also assist testers to anticipate test run times for different products.

Since the size and shape are predetermined by the design of the vessel, and the temperature range has been set within this project, there is just the thermal conductivity, k, left to consider in observing the impacts of material selection. Table 4.5, below, shows extracts of k values of common materials from a table sourced on the internet from Georgia State University (Nave 2012). As is expected, metals are very good conductors of heat, while air and typical insulating materials are not.

Table 4.5 – Thermal Conductivity of Some Common Materials

Material	k (W/m-K)
Aluminium	205
Steel	50.2
Ice	1.6
Water (20°C)	0.6
Fibreglass	0.04
Cork board	0.04
Polystyrene	0.033
Polyurethane	0.02
Air (0°C)	0.024

Using the cuboidal shape, which is typical for many ice boxes, and the unit volume defined in 4.1.3 above, and the higher U-value of Equation 4.9, the following results can be shown for the energy transfer and the time taken to reach equilibrium for the materials shown in Table 4.5.

The equations required to find these two results are:

$$\dot{Q} = U - value \times A_s \times dT$$

Equation 4.12

$$t = \frac{U}{\dot{Q}}$$

Equation 4.13

where $\dot{Q}$ is the heat transfer rate in Watts (J/s), the U-value is the heat transfer coefficient (in W/m^2-K), A_s is the surface area of the vessel (in m^2), dT is the temperature differential (in K or °C), and t is the time (in seconds). Table 4.6, below, shows the results for 3 different thicknesses of the materials shown (for ease of reading, the energy columns are italicised, while the time columns are in bold font).

Table 4.6 – Heat Transfer Rates and Timeframes

Material	**1mm**		**25mm**		**50mm**	
	$\dot{Q}$ **(W)**	**t (sec)**	$\dot{Q}$ **(W)**	**t (sec)**	$\dot{Q}$ **(W)**	**t (sec)**
Aluminium	*6.46E+07*	**6.83E-04**	*2.58E+06*	**1.71E-02**	*1.29E+06*	**3.41E-02**
Steel	*1.58E+07*	**2.79E-03**	*6.32E+05*	**6.97E-02**	*3.16E+05*	**1.39E-01**
Ice	*5.04E+05*	**8.75E-02**	*2.02E+04*	**2.19E+00**	*1.01E+04*	**4.38E+00**
Water (20°C)	*1.89E+05*	**2.33E-01**	*7.56E+03*	**5.83E+00**	*3.78E+03*	**1.17E+01**
Fibreglass	*1.26E+04*	**3.50E+00**	*5.04E+02*	**8.75E+01**	*2.52E+02*	**1.75E+02**
Cork board	*1.26E+04*	**3.50E+00**	*5.04E+02*	**8.75E+01**	*2.52E+02*	**1.75E+02**
Polystyrene	*1.04E+04*	**4.24E+00**	*4.16E+02*	**1.06E+02**	*2.08E+02*	**2.12E+02**
Polyurethane	*6.30E+03*	**7.00E+00**	*2.52E+02*	**1.75E+02**	*1.26E+02*	**3.50E+02**
Air (0°C)	*7.56E+03*	**5.83E+00**	*3.02E+02*	**1.46E+02**	*1.51E+02*	**2.92E+02**

These figures have been shown in scientific notation because some are very large. In particular the metals show that they can transfer an incredibly large amount of heat for a ΔT of 50K, while they also show that it takes a very short period of time to transfer the available heat in the unit volume. Conversely, polystyrene and polyurethane show much smaller heat transfer quantities and much longer timeframes.

It is important to note that these calculations only reflect the rate of heat transfer once the material is saturated with heat. This means that the materials have already absorbed enough heat that they can no longer store any more heat and are therefore passing the heat on one-for-one as it enters via the higher temperature side and exits via the lower temperature side. This can be better seen in Section 6-2 of Thermodynamics: An Engineering Approach (Cengel & Boles 2007) which discusses how thermal sources and thermal sinks work together. In this case, the atmospheric air surrounding the vessel is the thermal source providing thermal energy, while the vessel walls are the thermal sink absorbing thermal energy. As long as the vessel walls can continue to absorb that energy, based on the product of its mass and its specific heat, there will be no temperature change inside the vessel. This time taken to absorb sufficient heat to transfer it is known as thermal lag.

Thermal lag is based on the thermal mass of the material as a function of time. Unfortunately, due to the complexities of determining the thermal lag of different vessels, far more time would be required in this research project involving the participation of manufacturers to provide very specific details of their product designs. Even to do so for one product would be excessive, and would add nothing to the development of this testing & rating system. However, it is clearly understood within this research that the thermal lag of the materials is a key part of the success of an insulated vessel, but remains in the domain of the manufacturer and not the developer of a testing & rating system for such products.

4.2. Experimental Results from USQ Laboratory

The following subsection presents the results of the tests carried out at the USQ laboratory to determine whether the testing approach is viable or not. All necessary precautions were taken for safety, including carrying out a risk assessment and completing a USQ induction and obtaining a work permit for the experiments. These documents have been attached in the appendices.

4.2.1. Sample Specimen Selection

In order to carry out tests in the laboratory, a sample range of vessels was required. For budgetary reasons, the tester chose to use pre-owned samples. These include a Willow Sixer cooler, an EvaKool IceMate IM070-W ice box, and an Outdoor Plus cooler bag. These were selected for their variations in shape, size and material, and are shown in the figures below.

Figure 4.1 – The Willow Sixer cooler (image courtesy of Willow)

Figure 4.2 – The EvaKool IceMate ice box (image courtesy of EvaKool)

Figure 4.3 – The Outdoor Plus cooler bag

The first two figures have images taken from the respective manufacturer's websites, while the third image was taken by the tester as no such product was traceable on the internet. It is obvious from Figure 4.3 that the cooler bag has been in service for some time. The same is so for the other two, even though the images do not show it. No specimen showed any evidence of damage, such as cracks or tears, which might adversely affect the test results.

4.2.2. Laboratory Equipment

In order to carryout experimental tests, a minimum of equipment was needed. The testing process rationale aimed to keep cost and time to a minimum, in keeping with this project being an undergraduate task, rather than being a commercially funded R&D process. The general idea was to place a specimen in a chamber at a steady temperature and wait until it reached equilibrium, and then transfer it to a chamber of another temperature and wait until it reached equilibrium again, and then measure the time taken from one steady-state to the other.

The equipment selected for use in the testing process consisted of the following, extracted from the test plan which is reproduced in the appendices (note that some items were eventually not used due to the tests not being carried out to plan, or being cancelled due to circumstances beyond the control of this project):

- Cold room
- Oven
- 3x Data Loggers
- 1x live sensor for tracking when to shift vessels between chambers
- Willow 6-Can vessel
- Evakool Ice Mate vessel
- Outdoor Plus cooler bag
- Sowing thread (for stringing up logger in vessels)
- Sticky tape and blue tack (for attaching thread to vessel)
- Towel (for soaking in hot water for RH test)
- Large plastic bag (for increasing pressure for ATM test)
- Motor for compressing plastic bag
- Barometer to measure ATM inside plastic bag (Terry to determine if this will be possible)
- Atomiser bottle (for spraying inside cold room to create 100% RH)
- “KEEP DOOR CLOSED TO MAINTAIN CONDITIONS – TESTING IN PROGRESS” signs for cold room and oven doors
- “DON’T RESET TEMPERATURE – TESTING IN PROGRESS” signs for cold room and oven thermostats (as others may want to adjust them during tests)
- “DON’T TOUCH – TESTING IN PROGRESS” sign for vessel and logger in cold room (as others may be in the cold room)

The cold room and the oven are the two chambers used for the tests, while the 3 loggers where used to log information about the chambers and the test specimen in each test. The live sensor was created by Terry Byrne of the USQ staff for tracking the temperature change in the closed vessel in either chamber, as the loggers could not provide a live feed for knowing when steady-state had been reached. This was a two-part piece of equipment which consisted of a sensor and transmitter, with batteries, housed in a simple shell made with an in-house 3D printer, and a receiver and display, also with batteries, and also housed in a ‘home-made’ shell. An incredible debt of gratitude is extended to Terry Byrne, without whom none of this testing would have been possible. This is particularly so, as the live sensor malfunctioned midway through the first test, and modifications had to be made under intense pressure to maintain the testing schedule, whilst also adding complexity to the compromised, in-progress first test due to having to resort to first principles to estimate when steady-state would be reached so that the test would be a success, and not have to be repeated.

The key piece of equipment, apart from the vessels and chambers, was the data logger, which can be seen in Figure 4.4, below. This is a Lascar EL-USB-2-LCD Temperature and humidity USB data logger with LCD display (Lascar Electronics 2015), designed to log data for temperature, relative humidity and dew point. It has a USB connection (visible under the plastic cover) which allows for fast download of information to any computer. With the right software from the manufacturer, the data can then be read in a program called EasyLogGraph (ELG).

Figure 4.4 – The data logger used for testing (image courtesy of Lascar)

One can observe the mention of signs in the list of equipment. These were considered a necessity given the importance of keeping the chambers at constant temperatures during the tests in an environment where other staff and students could be accessing the laboratory environment and perhaps needing to access items from either chamber.

4.2.3. The Test Plan

Testing was carried out to achieve a simple objective: Observe the process of heat ingress and egress through placing specimens in chambers of different temperature, from which comparisons about thermal efficiency could be made.

A test plan was developed to maximise the time spend in the laboratory, to be certain of achieving effective results in a short space of time, and to be sure to remain on task during a complicated process. The test plan consisted of the list of equipment required (shown above), the personnel required, and the individual tests to be carried out. To be certain of success, a special trip was made to the USQ campus ahead of the testing schedule to inspect all the on-site equipment in order to finalise the test plan with greater knowledge of the testing environment.

Individual tests were developed to investigate separate aspects of the testing process. Each test consisted of an objective and a task run. The objective was to provide a practical reminder of the purpose of the tests (of benefit to the USQ staff assisting in the process), while the task run was provided to ensure that no critical step was missed throughout the testing process (of most benefit to those carrying out individual tasks).

4.2.3.1. Test 1 –Standard Test

The first test consisted of placing the Willow Sixer in the cold room, followed by the oven, and then back to the cold room and waiting for the vessel temperature to reach equilibrium with the chamber temperature each time. There was no regard for the control of relative humidity (RH) or the air pressure (ATM), as it was already understood that RH values would be logged to provide information with which to make a comparison in subsequent tests, while the pressure was assumed to be unchanged throughout the test, based on an assumption of sufficient air leakage through the lid and body of the vessel. This is considered the standard test because the focus is on temperature change in both directions regardless of the other parameters. This test is used as the reference for the remaining tests. The idea behind testing for heat ingress as well as heat egress was to see if there was a difference in the timeframes to determine whether there might be other parameters not considered in this project (consider this an insurance policy against lack of knowledge in a new field).

4.2.3.2. Test 2 – Half Standard Test with Volume Change

This test consisted of placing the EvaKool IceMate in the oven to begin with, and then transferring it to the cold room, once equilibrium was reached, and then waiting for that steady-state to occur again. This is only half the standard test, but involved a much larger vessel (the idea behind the half test was simply to conserve time, as the tester was commuting intercity and was able to leave vessels in a chamber overnight rather than waiting for steady-state before removal).

The astute observer will also note that the vessel construction is not identical to that in Test 1. This is true, and unfortunately, a limitation of such modest projects. However, it can be noted, from the data shown in Table 4.5, above, that insulating materials all have similar k values, compared with other materials, and since the volume change is far greater than the k value change in this test, it is still anecdotal of how volume impacts the length of the tests. (Note that this experimental testing is not intended to establish a yardstick, but to demonstrate that the process is feasible.)

4.2.3.3. Test 3 – Half Standard Test with RH Change

This test consisted of placing the original specimen, the Willow Sixer, in the oven and then transferring it to the cold room with the usual steady-state requirements. However, on this occasion both the oven and the cold room were primed to achieve 100% RH (as best as practically possible). This was done by soaking a large towel in hot water and placing it in the oven to raise the RH of the oven, while using a spray bottle to charge the supply air of the cold room with added water vapour. As the test results came to prove, neither chamber actually achieved 100% RH, however the Δ%RH was sufficient in both chambers to demonstrate that RH has a significant impact on the testing regimen.

4.2.3.4. Test 4 – Standard Test with Design & Material Change

This test was a replica of Test 1, only using the soft cooler bag instead. This test was far less important than the others, and was only an additional ‘what if’ test to see if the zipper opening at the top of the bag would have a significant impact on the difference between heat ingress and heat egress, given that hot air rises. It also served to show how different materials impact the timeframes.

Again, the astute observer will note that the vessel construction is not identical to that in Test 1. However, on this occasion, the volumes are similar but the materials are vastly different, so the test is still anecdotal of how the material impacts the length of the tests.

4.2.3.5. Test 5 – Half Standard Test with ATM Change

Unfortunately, this test never saw the light of day. As can be noted in the full Test Plan in the appendices, this test was still being developed at the time of starting the laboratory work.

At the time of planning the tests, the intention was to place the Willow Sixer inside a large plastic bag (of strong material such as see-through weather awnings in alfresco dining areas) which could be compressed by scrolling the excess material around a rod operated by a motor, such that the motor could increase or decrease the pressure based on a pressure sensor inside the bag, all-the-while having the live sensor and the data logger inside the vessel to track the temperature and RH throughout the test. For simplicity, this test was also intended to cover just half the process of the standard test.

Alas, the logistics of creating a pressure sensor with remote live access and data logging capacity proved too difficult for the time and budget constraints of this humble project. Again, much gratitude is extended to Terry Byrne of the USQ staff for going well beyond the bounds of dedication to make this test a reality, including endless hours working on complex coding algorithms to convert sensor outputs to meaningful air pressure values that could be used in the results.

The intent of this test was to observe whether changes in atmospheric pressure would significantly impact the test results. This is more important when considering the possibility of testing laboratories at significantly different altitudes, rather than the effects of pressure changes between or within the chambers and the test specimens. Although experimental data is not available on this occasion, it can now be noted (rather than in the theoretical testing section, where it would be out of context) that density of air changes less with altitude than with temperature. This is easily observed in most of the reference texts from which tables have been used for this project. It is also important to note that the affordable technology of modern HVAC systems in the current market would allow for controlling air pressure, through the use of VSD fans (variable speed drive), as easily as controlling temperature and relative humidity, therefore this absence in testing has not negatively impacted the outcome of this project.

4.2.4. Outputs

Having completed the tests, each logger was read to analyse the data obtained. From this data, an amalgam of information had to be created in order to create meaningful results.

The key information for each test was combined in order to graph the information. For Test 1, the key information was the temperature of the vessel, the cold room and the oven compared with each other. This was the same for Test 2, although only for the heat egress. Test 3 was more complicated as it required both the temperature and RH of all 3 loggers, even though it was only for the heat egress. Test 4 required the temperature of all 3 loggers for the different vessel for both heat ingress and egress, while Test 5, which did not happen, would have had a similar complexity to Test 3, albeit with ATM rather than RH.

In general, the results proved the testing process to be successful, although the outcome was not a perfect success. As with all new ventures, there are always unexpected issues as well as failures in particular aspects. This project lived up to that scenario, but still achieved some valuable insight.

4.2.4.1. ELG Graphs

The following images are of the graphs produced by the ELG software from the data collected by the loggers for Test 1. These are just an indicative sample, while the whole collection is presented in the appendices. The key curves to observe are the temperature (red lines) and the RH (blue lines); while the dew point (green lines) curves are only of interest in demonstrating how dew point is clearly analogous to temperature, as a function of relative humidity (the dew point curves are not used in the Excel graphs in the following section).

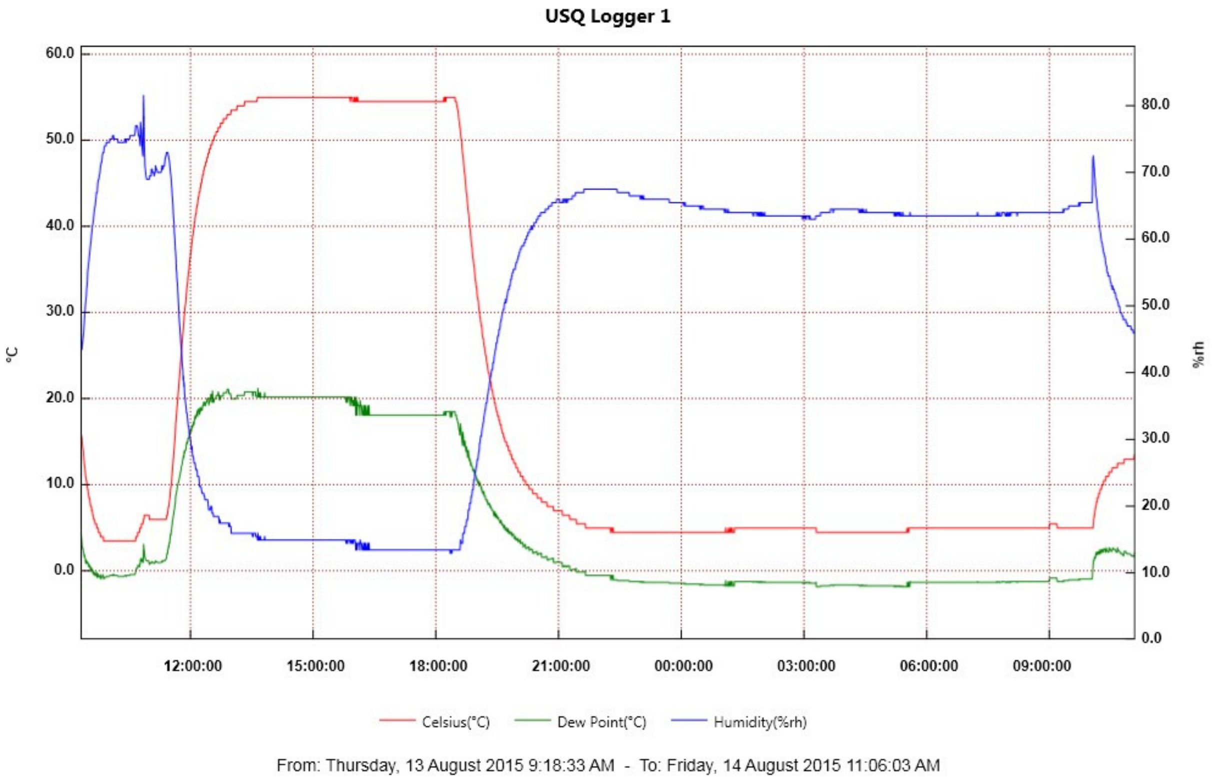

Figure 4.5 – ELG graph of the logger from the vessel for Test 1

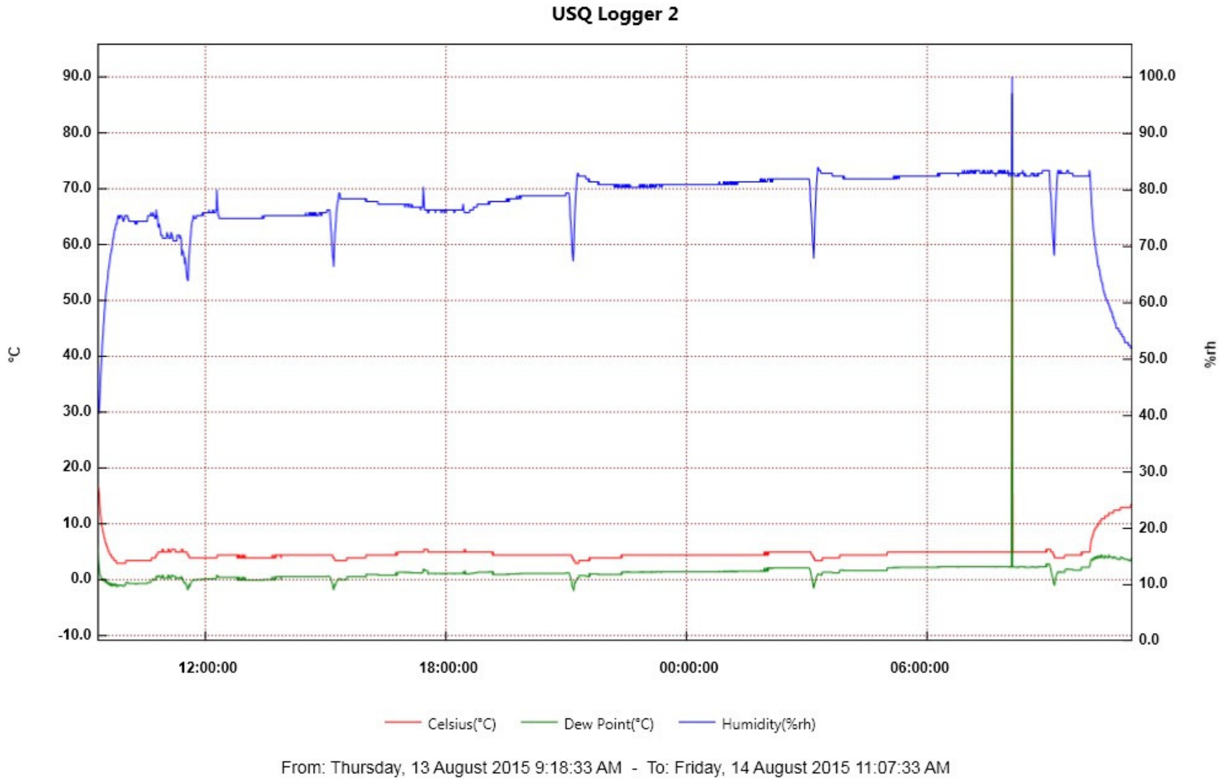

Figure 4.6 – ELG graph of the logger from the cold room for Test 1

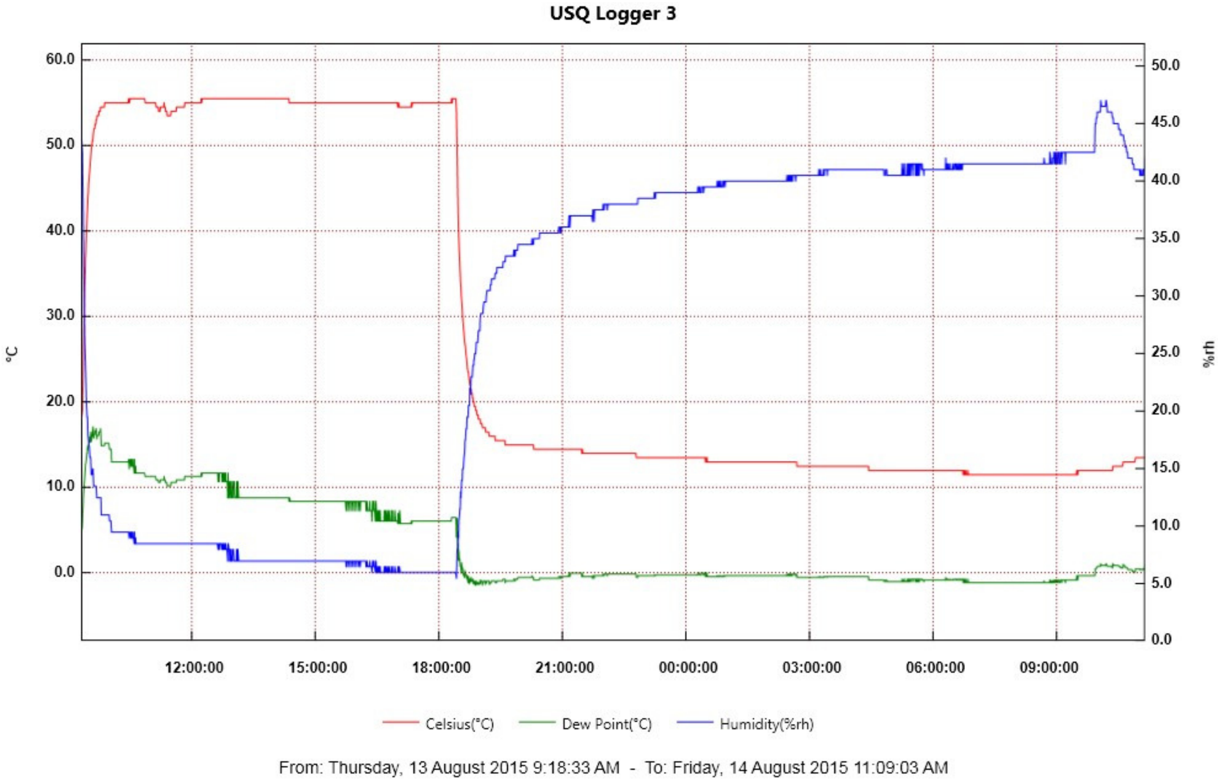

Figure 4.7 – ELG graph of the logger from the oven for Test 1

Two observations can be made from the graphs above. Firstly, and rather unimportantly, there is a spike in the readings from Logger 2, for the cold room. However this spike occurred well after the test was complete and therefore did not affect any results. It was due to old batteries in the logger and did not occur again for the remaining tests once the batteries were replaced (the same occurred in the same logger during a preliminary home test, which lead to suspect the batteries, since that logger was the only one to have already been in service).

The other interesting observation, which will prove to be of note later in this report, is that the steady-state temperature of the cold room is less even than that of the oven. This is due to the design of the cycling process of the refrigerant equipment for the cold room compared with the cycling process of the heating equipment for the oven.

4.2.4.2. Excel Graphs

The following images are of the graphs developed in MS Excel in order to view the relevant information from all 3 loggers for each test. Note that the graphs of the oven temperature appear to drop markedly after the vessel is transferred to the cold room in each experiment (including in the ELG graphs). This is because the logger was removed from the oven each time and the oven switched off to conserve energy, while the logger in the cold room was placed in the cold room immediately upon commencing each test, because the cold room was left on constantly and to ensure that the logger was tracking cold room temperature correctly at whatever time the vessel was transferred into it. (The oven logger was also placed in the oven at the start of each test to ensure it was ready whenever the transfer happened. It was only left on in case the oven might be required again during testing.)

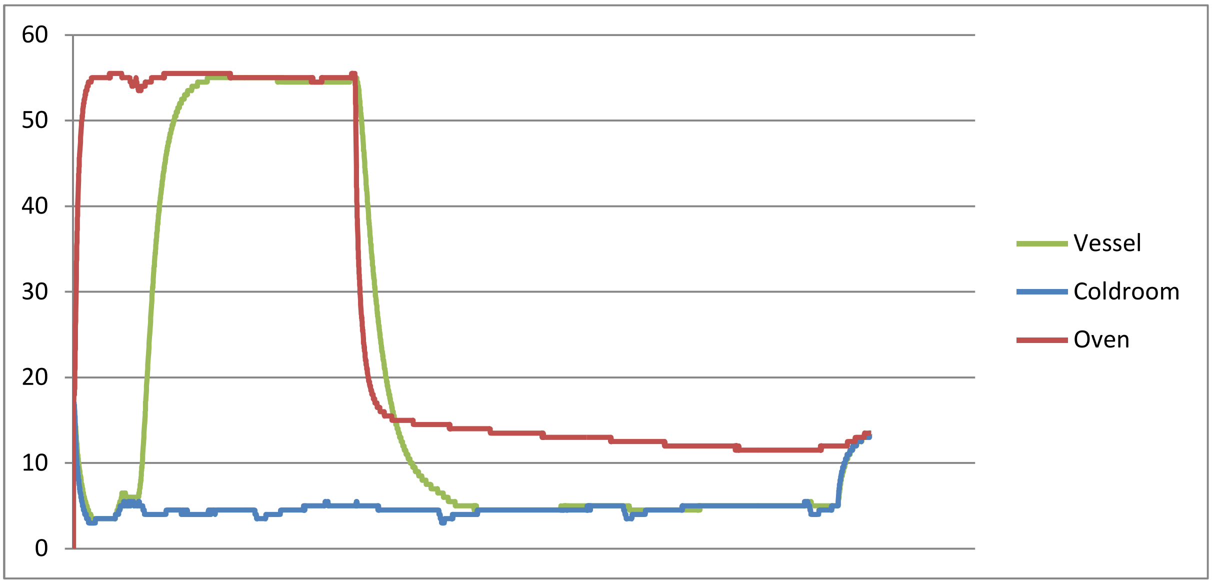

Figure 4.8 – Excel temperature graphs of the loggers for Test 1 showing both the heat ingress and egress processes

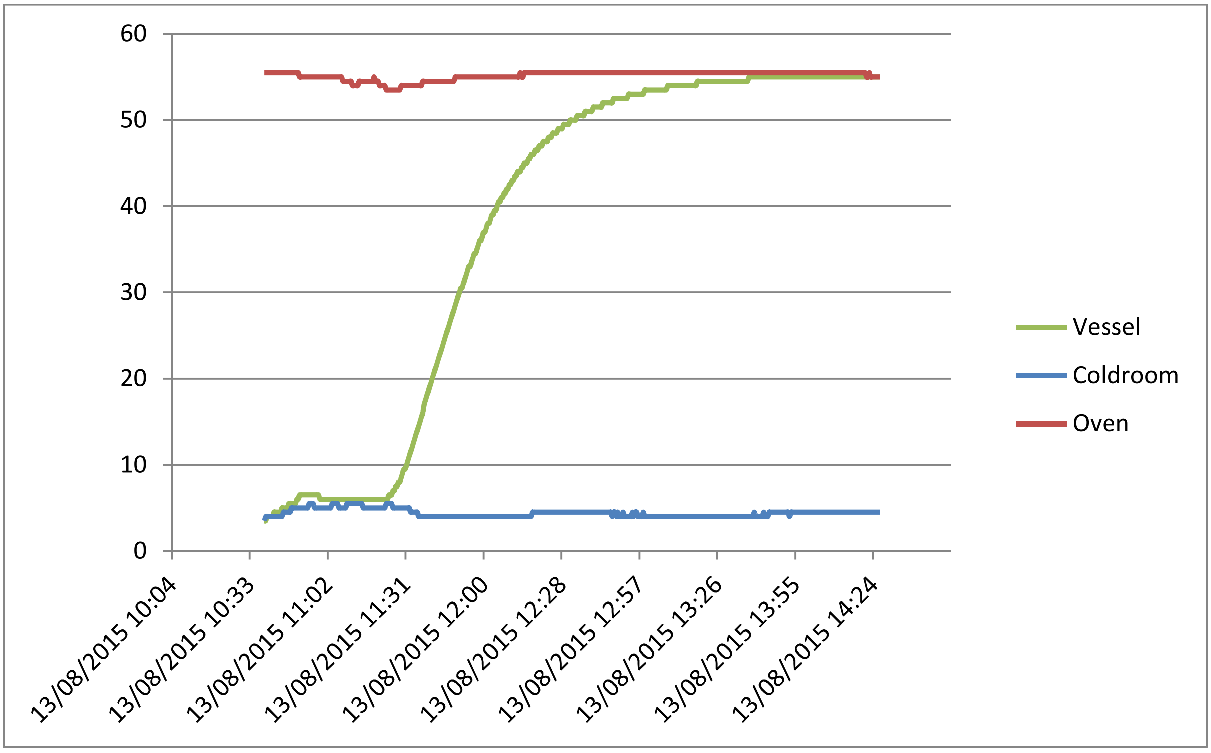

Figure 4.9 – Excel temperature graphs of the loggers for Test 1 showing the heat ingress with greater clarity

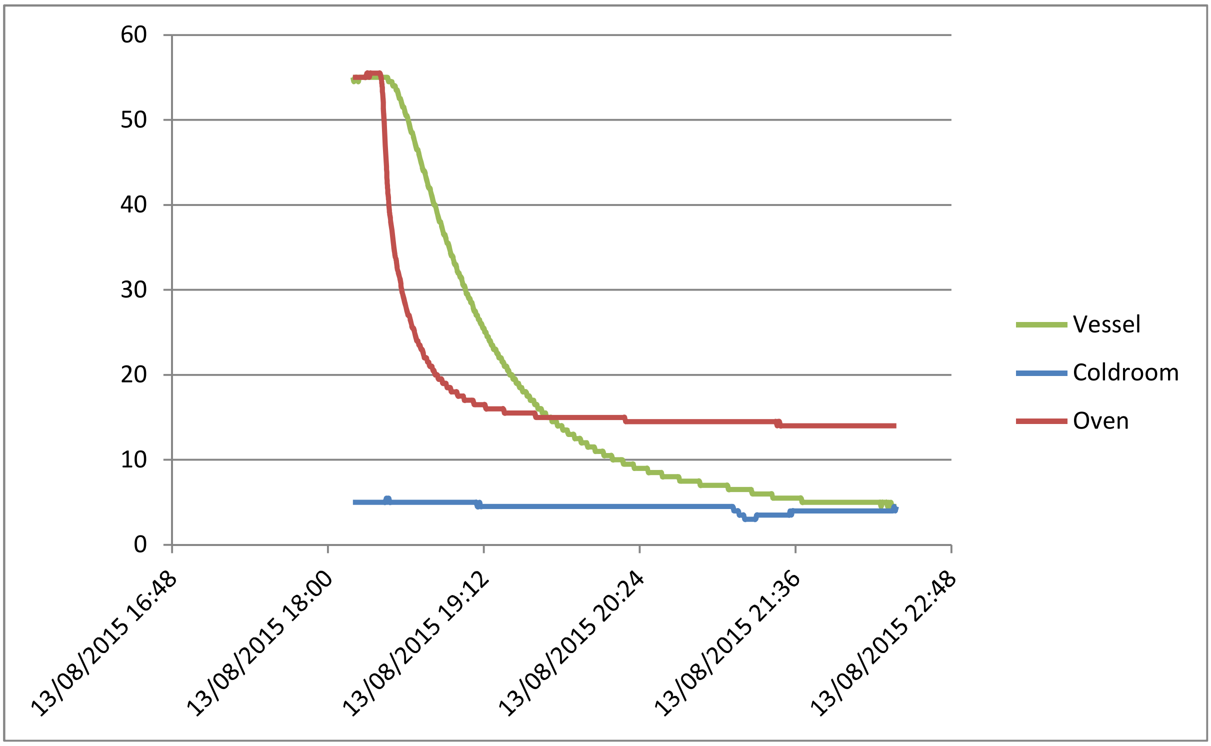

Figure 4.10 – Excel temperature graphs of the loggers for Test 1 showing the heat egress with greater clarity

One clear observation with the above graphs is that the cold room temperature is less even than the oven temperature, as noted in 4.2.4.1 above (ignoring the even graph in

Figure 4.10, as it was left running outside the oven until the end of the test). At the time of commencing the tests, the USQ maintenance staff (in charge of all HVAC equipment on campus) came and provided instructions on the use of the cold room. They stated that the cold room would cycle ±1°C, however the loggers suggest that the cold room would chill to 5°C and then slowly reheat to 7°C. This means that the mean temperature was actually 6°C which leaves the results based on slightly less than the desired ΔT of 50°C. However, this is not a major setback for the purposes of this project, since the start and finish temperatures are taken from the loggers and used to provide 'per Kelvin' results.

Another observation which can be gleaned from Figure 4.9 and Figure 4.10 is that the steady-state readings for the vessel and cold room do not appear very steady. Alas, this is a result of the cold room not cycling efficiently enough to hold a steady temperature. However, this did not pose too much of a problem, and simply required some additional analysis of the data to determine a correct start time for the first part of the test. This was achieved by observing the patterns of the cold room temperature around that point and superimposing the timeframes to estimate, with relative accuracy, what the start time would have been with a more efficiently cycling system.

The following graphs are from Test 3, which have the inclusion of RH for the analysis. The confusion of colour in Figure 4.11 shows the difficulty experienced in achieving 100% RH in the oven before commencing the test (partly due to the lack of a live RH sensor, meaning that the oven had to be opened each time to read the RH level on the logger). In particular, the purple line shows how it struggled to reach a significantly high figure even remotely close to 100%. The obvious dip in the middle of that initial period represents when the wet towel in the oven was removed for rehydration. The test was eventually started with an oven RH value of 52.5% while the oven RH in Test 1 was only 6%, therefore there was sufficient difference to register any change in time to equilibrium. Ironically, the oven reached its maximum RH value of 56.5% within the first 2 hours, however it could not be determined at the time, and the vessel walls may not have reached heat saturation at that point, which would have skewed the accuracy of the data. That said, the more important line is the orange line showing the RH level in the vessel, which spikes just before the test started, directly as a result of deciding to close the vessel lid in the hopes that the RH value would increase thereafter. That, at least, was a success.

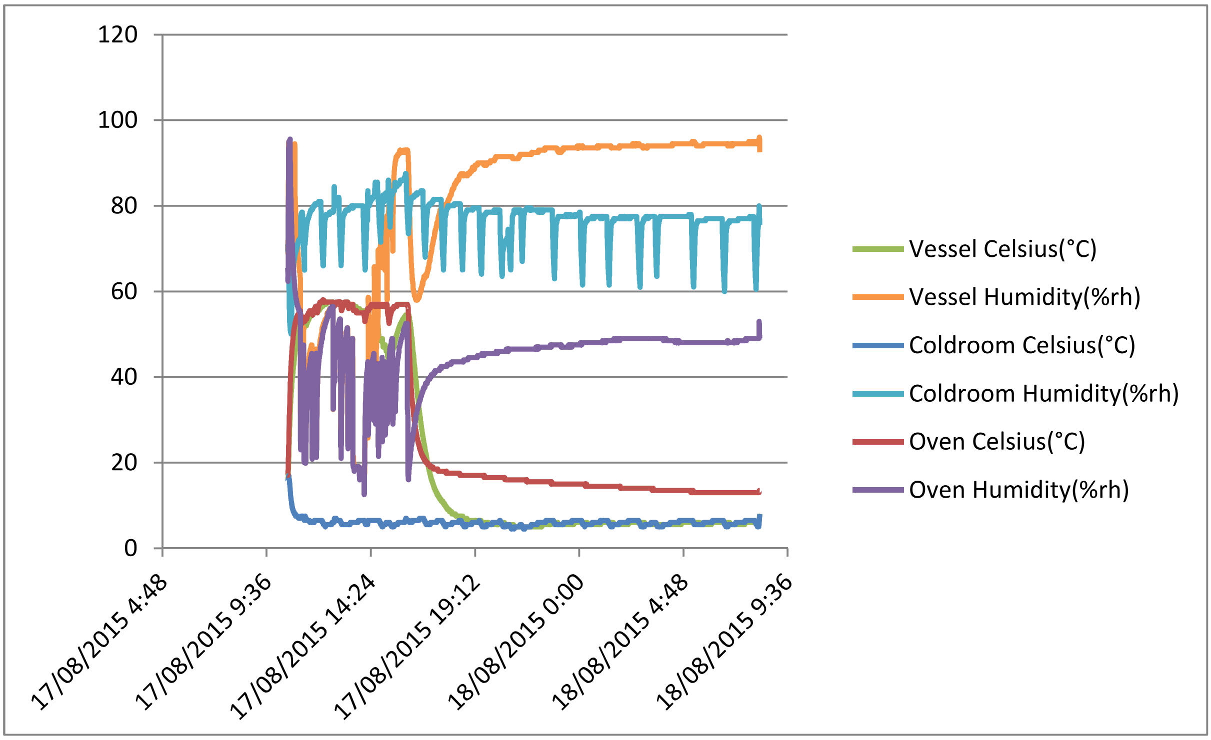

Figure 4.11 – Excel temperature graphs of the loggers for Test 3 showing the time taken to gain a maximum RH in the oven and vessel

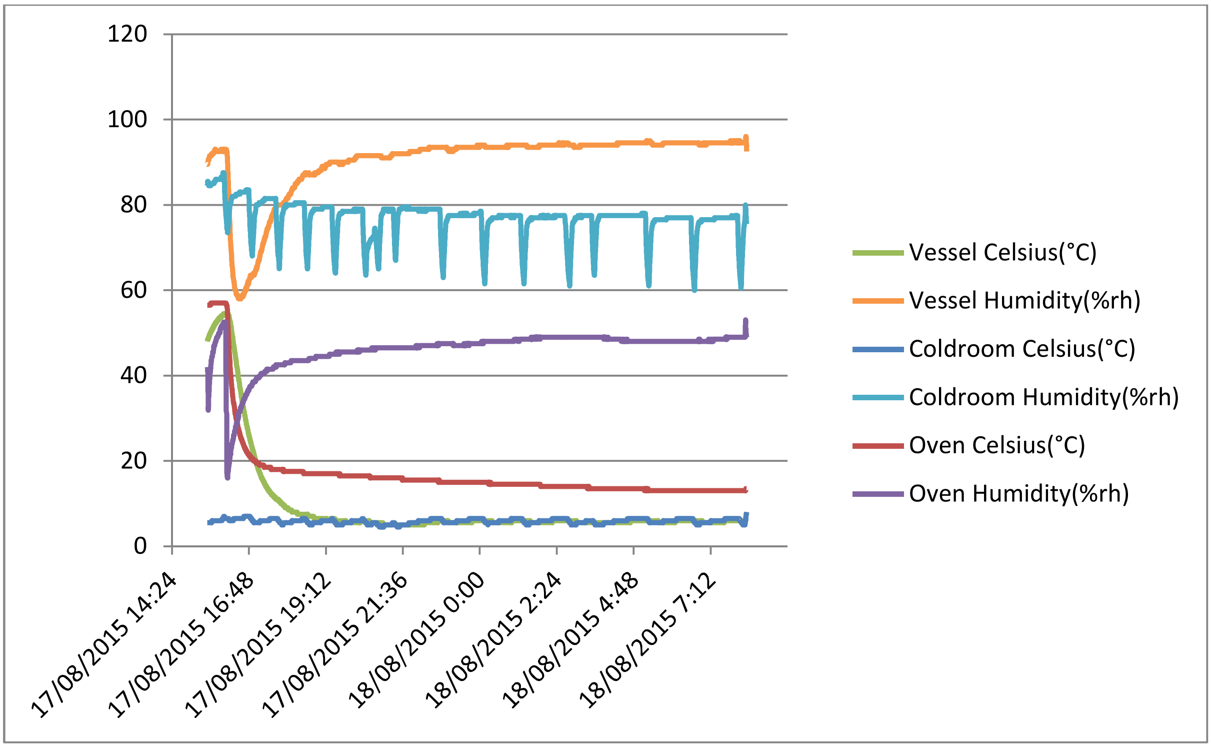

Figure 4.12 – Excel temperature graphs of the loggers for Test 3 showing the heat egress with greater clarity

Two interesting observations come from this result. Firstly, the fact that the oven could not reach 100% RH leads the analyst to wonder whether the oven was equipped to control RH and this was never communicated to the USQ staff involved.

The other is that the vessel RH has a downward spiral just after transfer from the oven to the cold room. One would expect that a sudden drop in temperature would see a sudden rise in relative humidity, yet this did not occur. Perhaps there was a significant pressurisation in the vessel that the temperature drop was accompanied by a sudden pressure change which may have impacted the RH reading until the air leakage allowed equalisation and the opportunity for the RH to increase again.

4.2.5. Analysis of Experiments

Very large spreadsheets of data were logged by each logger for each test. Although the data also provided user-friendly graphs for easy visual interpretation, more particular work was possible by analysing the spreadsheets to determine correct start and finish times and temperatures. By importing the data to MS Excel, manipulation of the data for interpretation was made easy.

4.2.5.1. Time & Temperature

Given that the key outputs from the tests are the temperature and the time, it is quite fitting to look at the relationship between the two from the tests carried out. Table 4.7, below, shows the selected start and finish times and temperatures for the heat ingress and heat egress processes of Test 1.

Table 4.7 – Test 1 Raw Data

Log №	Time Reading	Vessel Temperature (°C)	Cold room Temperature (°C)	Oven Temperature (°C)
253	13/08/2015 11:24	6	5.5	53.5
607	13/08/2015 14:21	55	4.5	55
1093	13/08/2015 18:24	55	5	55
1565	13/08/2015 22:20	4.5	4	14

From these readings, the total time, in seconds, and the temperature differential, in Kelvin, can be calculated through some simple problem solving in MS Excel. For Test 1, the following results were achieved.

Table 4.8 – Test 1 Outputs

Test	Heat Ingress		Heat Egress	
	Timeframe (s)	Temperature Change (K)	Timeframe (s)	Temperature Change (K)
1	10,620	49	14,160	50.5

By dividing one by the other produces either K/s or s/K: both of which could be useful information for further manipulation or as the simplest rating system. In the case of Test 1, the 4 possible results are:

Table 4.9 – Ratio of Test 1 Outputs

Test	Heat Ingress		Heat Egress	
	K/s	s/K	K/s	s/K
1	4.61E-03	2.17E+02	3.57E-03	2.80E+02

With a little further manipulation, it can be observed that the heat ingress process is only 77.3% as long as the heat egress process, and conversely the heat egress process is 129% the length of the heat ingress process.

4.2.5.2. Applying Vessel Volume & Internal Energy

If other metrics are desired for the rating system, then extra information is required. By applying the time and temperature results from above to the volume of the vessel and then applying the calculated value of the volumetric internal energy from 4.1.6 above, a new result in W/K (J/s-K) can be produced. Alternatively, this could be a K/W results.

Firstly, the vessel volume needs to be determined. Willow and EvaKool were both contacted for their data sheets, which were hoped to contain the gross internal volume of the vessels, however this information was not available. No response was received from Willow, however EvaKool provided data for the internal and external dimensions of their product range in a simple MS Excel spreadsheet. From other conversations with manufacturers throughout this project, it appears that manufacturers do not currently use CAD programs or similar software for designing products, from which to draw precise information such as the gross internal volume.

For the EvaKool IceMate, the product is known as a 70L vessel, while the contact at EvaKool suggested that it was more likely to be about 76L. Using their internal dimensions produced a value of 87L, which does not allow for the rounded internal corners of the vessel. Clearly, this is insufficient for an accurate calculation, and more precise information would be required.

Likewise for the Willow Sixer, internal dimensions were taken and multiplied to produce a figure of 6.95L. The vessel was then filled with water measured in a domestic kitchen measuring jug to produce a figure of 6.75L. Although both of these are lacking in accuracy, there is a difference that would be equivalent to the effect of the rounded internal corners of the vessel.

It is anticipated that the implementation of such a testing & rating system as this would drive manufacturers to more performant designs which may well see them switch to designing in CAD type programs. Alternatively, a more accurate way of measuring the gross internal volume of a vessel would be to submerge it with an open lid into a precisely measured volume of water, close the lid, remove the vessel, allow it to drip any excess water from the external surfaces back into the volume of water, and then measure the difference between the starting and finishing volumes of water.

In the meantime, for the purposes of this analysis, the approximated volume of the Willow Sixer is sufficient to demonstrate how the W/K (or K/W) measurement would work. Using the more conservative value of 6.75L as the vessel volume, and taking the average of the values from Equation 4.9 and Equation 4.11 (assuming this vessel might partially inhibit air leakage), the results can be calculated as follows:

$$\frac{(44.10165\,kJ/m^3 + 0.056634\,kJ/m^3)}{2} = 22.079142\,kJ/m^3 = 22.1\,kJ/m^3$$

Equation 4.14

$$U = V \times u = 0.00675m^3 \times 22.1\,kJ/m^3 = 0.149175kJ = 149J$$

Equation 4.15

Now applying this value with the values for time and temperature differential, the final figure can be calculated. Firstly, using the heat ingress values achieves:

$$K = \frac{U}{\Delta t \times \Delta T} = \frac{149J}{10{,}620s \times 49K} = 2.86 \times 10^{-4}\,W/K$$

Equation 4.16

While using the heat egress values achieves:

$$K = \frac{U}{\Delta t \times \Delta T} = \frac{149J}{14{,}160s \times 50.5K} = 2.08 \times 10^{-4}\,W/K$$

Equation 4.17

Alternatively, these figures could be inverted to find their reciprocal R values:

$$R = \frac{\Delta t \times \Delta T}{U} = \frac{10{,}620s \times 49K}{149J} = 3.49 \times 10^{3}\,K/W$$

Equation 4.18

$$R = \frac{\Delta t \times \Delta T}{U} = \frac{14{,}160s \times 50.5K}{149J} = 4.80 \times 10^{3}\,K/W$$

Equation 4.19

4.2.5.3. Result Variations

All the calculations for Test 1, above, can be reproduced within the body of this report for each test; however that would consume enormous space for little interest. That which is of greater interest is the difference in the results from one test to another. The results of the other tests are provided in the tables below.

Table 4.10 – Test 2 Raw Data

Log №	**Time Reading**	**Vessel Temperature (°C)**	**Cold room Temperature (°C)**	**Oven Temperature (°C)**
201	14/08/2015 13:06	55	7	55
1503	14/08/2015 23:57	7	7	13.5

Table 4.11 – Test 3 Raw Data (See for %RH results)

Log №	**Time Reading**	**Vessel Temperature (°C)**	**Cold room Temperature (°C)**	**Oven Temperature (°C)**
663	17/08/2015 16:05	54.5	6.5	57
1254	17/08/2015 21:00	5	5	16

Table 4.12 – Test 4 Raw Data

Log №	Time Reading	Vessel Temperature (°C)	Cold room Temperature (°C)	Oven Temperature (°C)
396	18/08/2015 11:57	5.5	5.5	54.5
558	18/08/2015 13:18	55.5	5.5	55.5
747	18/08/2015 14:52	55.5	5	5.5
1094	18/08/2015 17:46	6.5	6.5	17.5

Table 4.13 – Test 2 Outputs

Test	Heat Egress	
	Timeframe (s)	Temperature Change (K)
2	39,060	48

Table 4.14 – Test 3 Outputs

Test	Heat Egress	
	Timeframe (s)	Temperature Change (K)
3	17,730	49.5

Table 4.15 – Test 4 Outputs

Test	Heat Ingress		Heat Egress	
	Timeframe (s)	Temperature Change (K)	Timeframe (s)	Temperature Change (K)
4	4,860	50	10,410	49

The results in the table above show clearly that the larger vessel took longer to reach a steady-state, while the soft cooler bag took far less time to do so. The Test 3 results also show a significantly longer time with a higher level of relative humidity. The results below show the relative humidity for tests 1 & 3, which show that, although 100% was not attained as desired, the difference in relative humidity that was possible demonstrated from the times above that it is important to control the level of moisture content in the test air during the testing procedure.

Table 4.16 – Test 1 Raw Data for %RH (heat egress only to match Test 3)

Log №	Time Reading	Vessel Temperature (%RH)	Cold room Temperature (°C)	Oven Temperature (°C)
1093	13/08/2015 18:24	13.5	76.5	6
1565	13/08/2015 22:20	67.5	80.5	38

Table 4.17 – Test 3 Raw Data for %RH

Log №	Time Reading	Vessel Temperature (°C)	Cold room Temperature (°C)	Oven Temperature (°C)
663	17/08/2015 16:05	93	77	32.5
1254	17/08/2015 21:00	91	79	46.5

4.2.5.4. *Interpreting Data*

In instances where the steady-state conditions were not obvious, the data was analysed from one logger to another to determine when the vessel would have been at equilibrium with the chamber. The loggers provide data every 30 seconds, and in 0.5°C increments, so for most readings it was obvious how to interpret the data sets. The hardest test data to interpret was from Test 3 with the high relative humidity, which must have impacted either the loggers to read data or for the cold room and oven to cycle steadily.

One observation which allowed insight for interpretation of data was that in some cases two loggers would maintain steady temperatures for long periods of time with only 0.5°C difference, and then would switch values for a further long period of time. From this it was deduced that both were actually at steady-state, but because of the rounding they were either just above or below the cut off and therefore appeared to have oscillating temperatures, when in fact loggers with an accuracy of 0.1°C would have been far easier to interpret as being at steady-state.

4.3. Rating System Selection

Originally, there was a plan to carry out a survey of USQ staff and students to determine how technical and non-technical people understood the results and what rating metric would make the most sense for the general public, however it was discovered, too late, that the university has an important but lengthy process of approving surveys, through their ethics committee, which would have left insufficient time for the survey to be carried out in time. Therefore the selection process has been carried out purely within this project, without any external input.

A number of possible rating metrics were presented in 3.6.3 above. The final choice is the K-value, which is the thermal conductance, measured in W/K. Although others have their merits, this one is considered to be the easiest to learn, yet far enough removed that the consumers will not misinterpret it, as could be the case for K/s or others. Plus it is actually J/s-K which uses the heat (J) which is important for demonstrating the impact of size changes, and time is a key indicator for most people. The use of Kelvin to divide the result simply reduces the number and allows for any future changes in testing methodology which may increase or decrease the temperature range of tests.

The use of K/s-m^3 or K/s-m^2 were quickly discounted as they would create a compensating factor for size and shape, which is counterproductive to the point of this testing & rating system, while K/s or s/K were also considered less likely to make sense to lay people, but more importantly, stock that holds more heat will take longer to change temperature but these options would not show this. Watts, on the other hand, are used in a number of ways, and although the lay person may not fully understand Watts there is a general understanding that it means work, heat or energy, which can more easily be related to an insulated vessel avoiding heat accessing their stock.

It would also be possible to use the reciprocal of the K-value, known as the R-value, however two factors dampen this. Firstly, the R-value is used in many industries and can either represent the reciprocal of k, K or U, all of which have different units. Therefore the units for the R-value must also be different from one usage to another. This may be acceptable in learned circles (where one must be careful to define the terms), but for lay people this may simply cause confusion when trying to relate an esky to insulation batts. Secondly, using the K/W value would make less sense and cause the lay person to question what it means, and the values would increase with performance which may be counter-intuitive to their perception of a larger number meaning more heat transfer. Therefore having W/K, showing ever-decreasing values with increased performance, would meet the lay persons perception that the smaller numbers mean less heat gets in, keeping their ‘stuff’ colder longer.

5. Conclusion (Discussion)

After the initial conclusion of realising that this testing & rating system can work, and is therefore worth developing further, the key conclusion is that the testing process is measured in hours, rather than days. This means that commercially viable laboratories, set up to carry out these tests, can charge fees that manufacturers would be prepared to pay, due to the great reduction in testing time. Coupled with the transparency of having a third party carry out the tests, manufacturers are likely to see great value in this process as a marketing tool for improving sales. It is also quite likely that this will drive the manufacturers to improve designs and research better materials in order to keep up with their competitors' ratings.

Another conclusion that is easy to draw is that this test is very simple and this rating is very simple. Both of which lend themselves to being repeatable and understandable, therefore making this testing & rating system a possible universal system for all insulated containers.

5.1. Observations

One of the key observations, from the experimental tests carried out, is that the time to equilibrium was different depending on whether heat ingress or heat egress was being tracked. Initially, this was considered to be due to the fact that convective flows take hot air upwards and cold air downwards, however this was quickly discounted when it was realised that the heating process was faster, which would require the hot air to move down into the vessel. One would expect the opposite: hot air in the vessel would rise to the lid/body joint and be expelled, making the cooling process faster.

However, a more likely result would be that the specific heat changes with temperature. Since they are proportional, it would make sense that at a higher temperature more heat can be gained or lost, than at a lower temperature. A further observation (albeit too late to control) was that the specimen was placed on racks in the oven and placed on a solid surface in the cold room. It is possible that the solid surface in the cold room had an impact on the heat transfer. It is very important that the conditions in both chambers are identical to avoid any such variations causing 'noise' in the data.

5.2. Considerations

Another observation leads to considering the importance of the testing order. During the tests it was observed that the relative humidity in the vessel changed differently from that of the chambers. Because the vessel is closed there is limited air transfer, depending on the quality of the seal between the lid and the body. Once the test commences, the moisture content in the air within the vessel will remain, which will impact the relative humidity in a different way from the chamber which processes moisture differently due to its equipment. It is therefore important that the testing process always includes both the heat ingress and heat egress process and that the relative humidity is balanced between the primary chamber and the vessel before the lid is closed, and then kept closed throughout the duration of the testing process.

This is equally applicable to the air pressure inside the vessel, as temperature changes will cause density changes. If the test were to start in the hot chamber, and finish in the cold chamber then there would be an increase in density which, without sufficient air leakage due to a good lid/body seal, the vessel would be under vacuum at the end of the test (something that many an esky user has witnessed in the real world when they put cold items in a hot vessel and try to open it again later). For this reason, it would be best that the test procedure always starts from the cold chamber, and it would also be best that it always includes both ingress and egress, returning to its initial conditions.

5.3. Reflections

The sensors used for this project were selected because the university happened to own them already, which helped to reduce costs of running the tests. However, on reflection, it would have been better to have sensors which provided air pressure data rather than the unused dew point data. Even if a method for pressurising the vessel could not be realised, it may still have been possible to observe air pressure changes during the tests, which may have provided greater insight into the importance of air pressure regarding the timeframes of the tests.

5.4. Looking Forward

There are a number of key aspects of this project to consider for the future. These are touched on in the subsections below, but could never be considered exhaustive as long as the future remains unknown.

5.4.1. System Development

All in all, this has been a successful project by establishing the feasibility of such a simple, repeatable, universal and cost effective testing & rating system for insulated containers. However, there is more work to be done before this could be a viable commercial program that would attract an uptake from the industry and its customers.

Further work must be done for finding the most appropriate total internal heat value for a unit volume, based on experimental tests on pressurisation of vessels across the standard range of products on the market. This would become the universal value which all laboratories would apply to the test results, and it would be defined in a standard or protocol for this testing & rating methodology.

Some of the results in the experimental testing, along with some of the figures derived in the mathematical analysis, demonstrate quite clearly that more rigorous testing is required to define the most appropriate testing regimen. This would allow finer control of the results which would greatly assist in determining the most likely order of grandeur for the rating system. With a large variety of specimen vessels being tested, it would be possible to see what the most common W/K values would be, which would allow refinement of the rating system: whether it would be in whole units, or milliwatts or just a number for which the exponential of base 10 is not shown (provided that most tests are returning results within the same range).

In order to ensure consistent testing from one laboratory to another, it would be best to develop a design for the chambers which can be replicated cheaply by any HVAC firm such that temperature, relative humidity and air pressure are all controllable within acceptable tolerances for the purposes of creating steady-states in each chamber so that the vessel readings can easily be identified as reaching equilibrium without the extent of interpretation of data as was required in the experimental tests of this project. In hindsight, it was obvious that having the cold room cycling with a 2°C margin proved to be excessive for testing, even if it is considered acceptable for keeping stock at a constant temperature over time. This may be controlled more cost-effectively by the use of a 'guarded hot box' design within the HVAC design (a highly controlled volume within a larger well controlled volume).

Where the atmospheric pressure is concerned, particularly with respect to laboratories at different altitudes, it could be possible to develop a conversion factor from published tables such that laboratories could simply take the air pressure reading for their location and use that in the adjustment factor to convert their results to values equivalent to readings that would be taken at sea level (1atm). This may be more cost-effective in the long run for HVAC design, but would require considerable extra testing to determine the impact of air pressure changes on the test results.

Equally, the same could be achieved for the relative humidity, however this would be far more complicated due to the more complex impacts of moisture content in the air, particularly on the changes of RH with temperature and pressure, and it would not be cost-effective compared with the existing processes within standard HVAC design for controlling RH in the built environment.

Any such future developments should not be considered without the input and collaboration of important bodies such as JASANZ (Joint Accreditation System of Australia and New Zealand), NATA (National Association of Testing Authorities, Australia), Standards Australia, NMI (National Measurements Institute) and any equivalent international bodies, and, of course, as many manufacturers as possible, including any industry associations that represent their interests, as well as consumer advocacy bodies such as Choice Australia and various leisure activity organisations.

For the rating system, it would be worthwhile taking a sample of the general public to find out which ratings discussed in this project have the most meaning, before finalising the metric used.

5.4.2. System Ownership

There is obviously an inherent level of intellectual property (IP) for this testing & rating system, which can be demonstrated within this project document, which can be proven to belong to the author, however all legal considerations at a national and international level must be considered by anybody wanting to be a party to the development of this system. There may be a necessity for trademarks, copyrights or patents before any further work is carried out.

5.4.3. Remuneration Options

There is also a need to consider any monetary aspects to this system. This is broken into two parts: the cost of testing, and the worth of the rating.

Any laboratory carrying out testing will incur costs which must be recuperated. Since laboratories are likely to be commercial businesses intending to make a profit, they are entitled to charge a fee for each test performed, as they see fit, as a function of what competing laboratories may be charging. Since they are making money from such testing, it is only fair that they should provide a portion of their turnover to the owner of the IP as a mark of respect for their source of income.

Any manufacturer obtaining a rating will be in a position to use the outcome as a marketing tool to achieve increased sales. Therefore, it is only fair that they too should provide a portion of their turnover to the owner of the IP as a mark of respect for their source of increased income.

There are strategies that should be considered to maximise both of these aspects. By developing a cost effective testing process, manufacturers are more likely to pay for the tests to be carried out. At the same time if the cost of displaying the rating is in proportion to the revenue, then again they are more likely to pay for the rating.

The costs of testing are more in the hands of the laboratories which will compete with each other to be viable, therefore the IP owner is less likely to control that aspect. However, the value of advertising the rating can be fully controlled by the IP owner. If the cost is an absolute value (such as $X/sticker) then this will favour more expensive vessels and be of less interest to less expensive vessels, or be of more interest to high turnover items and show less favour for the small turnover items. It would be farer to charge a portion of the sale price for each item (%RRP[12]/sticker) considering that the IP owner has already incurred all (or at least most) expenses prior to the first test being carried out or the first rating being promoted, meaning that revenue from this system is more likely to be pure profit over time.

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[12] RRP means recommended Retail Price. This is better than using the sale price, as it discourages the manufacturers from having too many sales which could water down the revenue of the IP owner.

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Appendices

Appendix A is a prerequisite for this student project, the remaining appendices are specific to the development of text in this report.

A. Project Specification

University of Southern Queensland

FACULTY OF HEALTH, ENGINEERING & SCIENCE

ENG4111/4112

Engineering Research Project 2015

Project Specification

For: Thierry-Jacques Vever (0050078313)

Topic: Insulated Container Testing & Rating System Development

Supervisor: Ruth Mossad

Enrolment: ENG4111 EXT – S1,2015
ENG4112 EXT – S2, 2015

Project Aim: This project seeks to investigate and develop an independent testing & rating system for insulated containers ('Eskies', etc.) for their capacity to repel or retain heat (like pizza pouches) for consumers to compare products on the market.

Sponsorship: None at present

Program:

1. Define the range of products subject to such a system, such as (ice chests, cooler bags, insulated lunch boxes, fruit & vegetable containers, pizza pouches, etc.) including limitations
2. Investigate the current market to assess manufacturers' claims of thermal performance
3. Research other rating systems, including standards, and the methodologies of accrediting bodies such as NATA (the National Association of Testing Authorities, Australia)
4. Develop a testing methodology for application to selected product types on the market (with an intent for it to be universal for all products on the market if possible)
5. Investigate impacts and variations of conductive, convective and radiant heat transfer on the heat transfer process through container walls
6. Carry out experimental testing on selected products following the methodology developed
7. Carry out theoretical estimates to validate experimental results
8. Develop an objective rating system based on test results for comparison of products

As Time Permits:

9. Survey ERP2015 students to determine an appropriate rating scheme (Stars, Snow Flakes, values, etc.)
10. Develop a logo for the rating system
11. Develop a system of royalties which would be equitable across all products types and costs

B. Timeline & Resources

Vever ERP2015 Timeline & Resources

Timeline

Literature review, market review, learning LaTeX, etc	End May
Define draft test method, theoretical analysis, preliminary report	End Jun
Experimental testing of sample products, compare with theoretical analysis	End Jul
Finalise test method based on results, format to suit industry norms	End Aug
Final report, prepare presentation & dissertation	End Sept
Review and correct any outstanding issues & submit	End Oct

Resources (required in July)

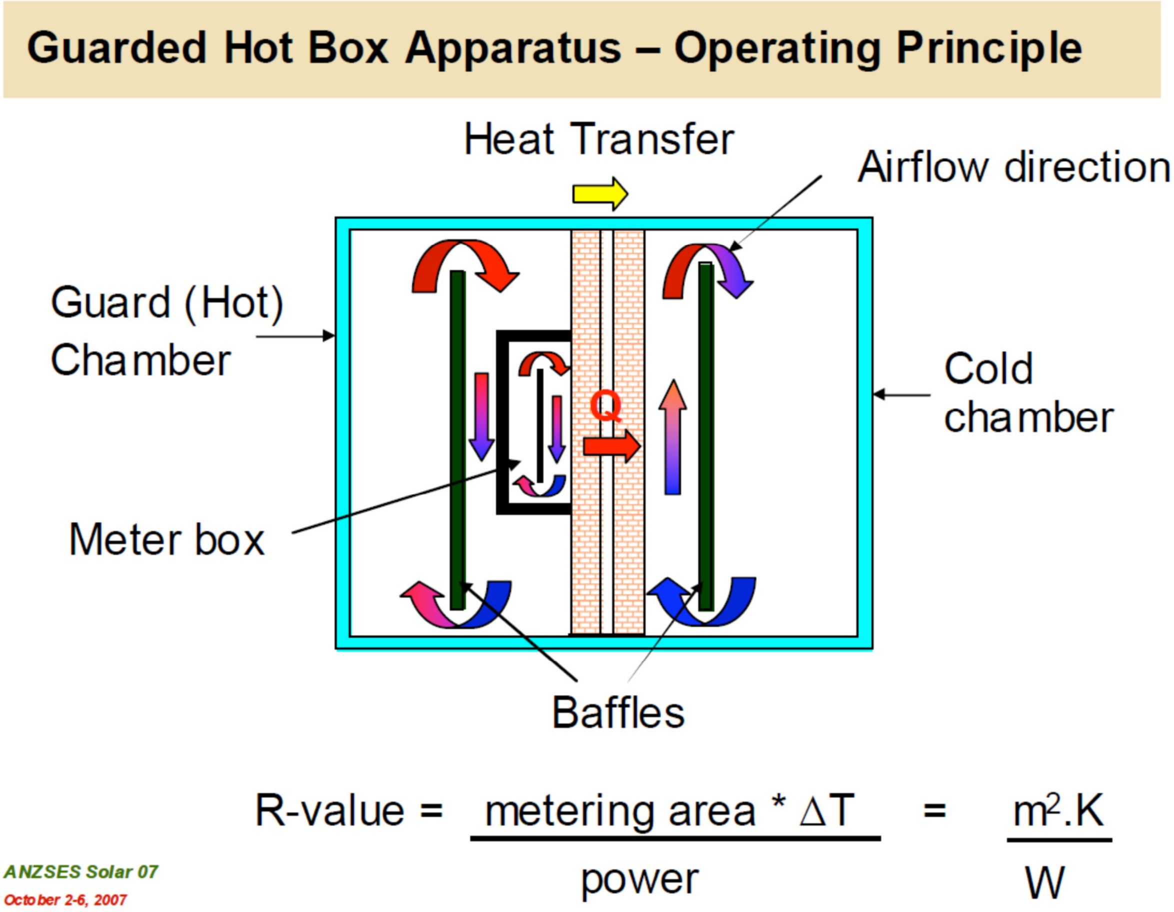
- A hot room (or chamber)
- A cold room (or chamber)
- Some test specimens
- 3 remote sensors (one in hot room, one in cold room, one in test specimen)

Is USQ already in possession of these resources? If not, they will need to be sourced. Sensors should be easily purchasable, while test specimens might be provided from local manufacturers interested in supporting this research (otherwise borrowed from staff/students or purchased). The rooms (chambers) will require additional work to source, and will need to be in close proximity to allow rapid transfer of specimens from one to the other. They may be in another location which could be used either at cost or free of charge (such as an industrial kitchen with large ovens and fridges).

Are any associated costs covered by USQ, or is the researcher expected to cover such costs?

C. Guarded Hot Box Apparatus

The following images are taken from the Conference Proceedings for the Thermal Performance Studies at The University of Newcastle (Sugo, Page & Inglis 2007b) to provide the reader with a quick visual understanding of the guarded hot box apparatus.



Guarded Hot Box Apparatus – Operating Principle

$$\text{R-value} = \frac{\text{metering area} * \Delta T}{\text{power}} = \frac{m^2.K}{W}$$

ANZSES Solar 07

October 2-6, 2007

Figure C.1 – Schematic diagram of the operation of a guarded hot box apparatus

Figure C.2 – A guarded hot box apparatus in use

D. Test Plan

ERP 2015 Test Plan and Risk Assessment & Management

Insulated Container Testing & Rating System Development

Test Plan

Equipment & Personnel

Equipment

- Cold room
- Oven
- 3x Data Loggers
- 1x live sensor for tracking when to shift vessels between chambers
- Willow 6-Can vessel
- Evakool Ice Mate vessel
- Outdoor Plus cooler bag
- Sowing thread (for stringing up logger in vessels)
- Sticky tape and blue tack (for attaching thread to vessel)
- Towel (for soaking in hot water for RH test)
- Large plastic bag (for increasing pressure for ATM test)
- Motor for compressing plastic bag
- Barometer to measure ATM inside plastic bag (Terry to determine if this will be possible)
- Atomiser bottle (for spraying inside cold room to create 100% RH)
- "KEEP DOOR CLOSED TO MAINTAIN CONDITIONS – TESTING IN PROGRESS" signs for cold room and oven doors
- "DON'T RESET TEMPERATURE – TESTING IN PROGRESS" signs for cold room and oven thermostats (as others may want to adjust them during tests)
- "DON'T TOUCH – TESTING IN PROGRESS" sign for vessel and logger in cold room (as others may be in the cold room)

Personnel

- 2 people for set-up and transfer tasks, such as opening and closing the oven, cold room and lab doors (**Jacques +1**)
- 1 person for monitoring tasks (**Jacques**)

Test 1 – Standard Test

Willow 6-Can vessel placed through ingress and egress tests – no control of RH or ATM

Objective

Determine whether ingress and egress are equal and establish timeframes for other tests.

Task Run

- Set cold room and oven to 5°C & 55°C, respectively, to have a 50K ΔT – **Thursday AM**
- Place a logger in the cold room and a logger in the vessel – as well as the live sensor – and place the vessel in the cold room with the lid open to allow equalising temperatures ASAP – **Thursday AM**
- Place a logger in the oven in anticipation of the vessel transfer – **Thursday AM**
- Monitor live sensor reading until reading 5°C, and then allow a significant time delay to be certain that the logger is also getting the same reading (cycling with the cold room would indicate being beyond equilibrium) – **Thursday AM**
- Once temperature in the vessel is at 5°C, swiftly open the cold room, close the lid, pick up the vessel, exit the cold room and close it, and then transfer the vessel swiftly to the oven, opening and closing the oven as quickly as possible to avoid a significant variation in the oven temperature, noting the time lapse the door is open to jot down later – **Thursday AM (possibly an hour or so later)**
- Monitor live sensor reading and attempt to determine the timeframe for reaching equilibrium (anticipated being about 5-12 based on hours from initial 'Home Test'[13]) – **Thursday AM (This could take a few hours)**
- Once sensor reading reaches 55°C, allow a significant time delay to be certain that the logger is also getting the same reading (cycling with the oven would indicate being beyond equilibrium) – **Thursday PM**
- Once temperature in the vessel is at 55°C, transfer the vessel swiftly back to the cold room, opening and closing the cold room as quickly as possible to avoid a significant variation in the cold room temperature, noting the time lapse the door is open to jot down later – **Thursday PM (possibly quite late into the evening)**
- Leave the vessel in the cold room overnight (it can remain well beyond equilibrium, as any subsequent readings should only show cycling with the cold room) – **Thursday PM**
- Remove vessel and loggers from cold room and oven (oven logger can be removed after oven portion of test is completed the night before), and download information from loggers to computer and save files for analysis at a later stage – **Friday AM**

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[13] Jacques carried out a practice test at home using a typical domestic kitchen oven at approximately 50-60°C and a domestic refrigerator at approximately 4°C over an approximately 12 hour period, which provided valuable insight for setting up this Test Plan.

Test 2 – Half Standard Test with Volume Change

Evakool Ice Mate vessel placed through egress test – no control of RH or ATM (This is only going from oven to cold room due to potential time issues with such a large volume of air to be subjected to such a large change in heat).

Objective

Determine difference in heat egress in comparison with the Test 1 results.

Task Run

- Set cold room and oven to 5°C & 55°C, respectively, to have a 50K ΔT – **Friday AM**
- Place a logger in the oven and a logger in the vessel – as well as the live sensor – and place the vessel in the oven (it will have to be on its end) with the lid open to allow equalising temperatures ASAP – **Friday AM**
- Place a logger in the cold room in anticipation of the vessel transfer – **Friday AM**
- Monitor live sensor reading until reading 55°C, and then allow a significant time delay to be certain that the logger is also getting the same reading (cycling with the oven would indicate being beyond equilibrium) – **Friday AM**
- Once temperature in the vessel is at 55°C, swiftly open the oven, close the lid, pick up the vessel, remove it from the oven, and then transfer the vessel swiftly to the cold room, opening and closing the cold room as quickly as possible to avoid a significant variation in the cold room temperature, noting the time lapse the door is open to jot down later – **Friday AM (possibly an hour or so later)**
- Leave the vessel in the cold room over the weekend (it can remain well beyond equilibrium, as any subsequent readings should only show cycling with the cold room) – **Friday AM**
- Remove vessel and loggers from cold room and oven (oven logger can be removed after oven portion of test is completed on Friday), and download information from loggers to computer and save files for analysis at a later stage – **Monday AM (Jacques will be late to campus due to school drop-off)**

Test 3 – Half Standard Test with RH Change

Willow 6-Can vessel placed through egress test with 100% RH – no control of ATM (only completing egress portion due to lack of control of RH in vessel from cold room to oven, and due to time restrictions as a function of intercity commuting)

Objective

Determine difference in heat egress in comparison with the Test 1 results.

Task Run

- Set cold room and oven to 5°C & 55°C, respectively, to have a 50K ΔT – **Monday AM**
- Soak a large towel in hot water, wring to drip-dry, and place in oven to create moisture to achieve 100% RH (towel should still be moist at 100% RH, otherwise RH will peak early once towel is dry, if so resoak and re-wring towel and continue to equilibrium) – **Monday AM**
- Place a logger in the oven and a logger in the vessel – as well as the live sensor – and place the vessel in the oven with the lid open to allow equalising temperatures ASAP – **Monday AM**
- Place a logger in the cold room in anticipation of the vessel transfer, spray atomiser bottle to increase RH in cold room to 100% and monitor logger to determine RH (respray if RH too low) – **Monday AM**
- Monitor live sensor reading until reading 55°C & 100% RH, and then allow a significant time delay to be certain that the logger is also getting the same reading (cycling with the oven would indicate being beyond equilibrium – it may be necessary to open the oven and check the RH on the logger if the live sensor cannot provide an RH reading) – **Monday AM**
- Once temperature in the vessel is at 55°C & 100% RH, swiftly open the oven, close the lid, pick up the vessel, remove it from the oven, and then transfer the vessel swiftly to the cold room, opening and closing the cold room as quickly as possible to avoid a significant variation in the cold room temperature, noting the time lapse the door is open to jot down later – **Monday AM or PM depending on start time (possibly an hour or so later)**
- Leave the vessel in the cold room overnight (it can remain well beyond equilibrium, as any subsequent readings should only show cycling with the cold room) – **Monday AM or PM depending on start time**
- Remove vessel and loggers from cold room and oven (oven logger can be removed after oven portion of test is completed the night before), and download information from loggers to computer and save files for analysis at a later stage – **Tuesday AM**

Test 4 – Standard Test with Design & Material Change

Outdoor Plus cooler bag placed through ingress and egress tests – no control of RH or ATM

Objective

Determine whether ingress and egress are equal, possibly due to the zipper at the top of the bag, as well as time frame changes due to different materials.

Task Run

- Set cold room and oven to 5°C & 55°C, respectively, to have a 50K ΔT – **Tuesday AM**
- Place a logger in the cold room and a logger in the cooler bag – as well as the live sensor – and place the cooler bag in the cold room with the zipper open to allow equalising temperatures ASAP – **Tuesday AM**
- Place a logger in the oven in anticipation of the vessel transfer – **Tuesday AM**
- Monitor live sensor reading until reading 5°C, and then allow a significant time delay to be certain that the logger is also getting the same reading (cycling with the cold room would indicate being beyond equilibrium) – **Tuesday AM**
- Once temperature in the cooler bag is at 5°C, swiftly open the cold room, close the zipper, pick up the cooler bag, exit the cold room and close it, and then transfer the cooler bag swiftly to the oven, opening and closing the oven as quickly as possible to avoid a significant variation in the oven temperature, noting the time lapse the door is open to jot down later – **Tuesday AM (possibly an hour or so later)**
- Monitor live sensor reading and attempt to determine the timeframe for reaching equilibrium (anticipated being faster than Test 1 due to less performant material) – **Tuesday AM (This could take a few hours)**
- Once sensor reading reaches 55°C, allow a significant time delay to be certain that the logger is also getting the same reading (cycling with the oven would indicate being beyond equilibrium) – **Tuesday PM**
- Once temperature in the vessel is at 55°C, transfer the cooler bag swiftly back to the cold room, opening and closing the cold room as quickly as possible to avoid a significant variation in the cold room temperature, noting the time lapse the door is open to jot down later – **Tuesday PM (possibly not quite as late as Test 1 due to less performant material)**
- Leave the cooler bag in the cold room overnight (it can remain well beyond equilibrium, as any subsequent readings should only show cycling with the cold room) – **Tuesday PM**
- Remove cooler bag and loggers from cold room and oven (oven logger can be removed after oven portion of test is completed the night before), and download information from loggers to computer and save files for analysis at a later stage – **Wednesday AM**

Test 5 – Half Standard Test with ATM Change

Willow 6-Can vessel placed through egress test with significant increase in pressure – no control of RH (only completing egress portion in keeping with Test 3, and due to time restrictions as a function of intercity commuting)

Objective

Determine difference in heat egress in comparison with the Test 1 results.

Task Run *

- Set cold room and oven to 5°C & 55°C, respectively, to have a 50K ΔT – **Wednesday AM**
- Place a logger in the oven and a logger in the vessel – as well as the live sensor – and place the vessel in the plastic bag with the motor attached (pressurise the bag such that the lid can be left open and then closed for transfer), and then place the package in the oven with the lid open to allow equalising temperatures ASAP – **Wednesday AM**
- Place a logger in the cold room in anticipation of the vessel transfer – **Wednesday AM**
- Monitor live sensor reading until reading 55°C, and then allow a significant time delay to be certain that the logger is also getting the same reading (cycling with the oven would indicate being beyond equilibrium) – **Wednesday AM**
- Once temperature in the vessel is at 55°C, swiftly open the oven, close the lid, pick up the package, remove it from the oven, read the barometer and make mental note for jotting down later *(if Terry doesn't have one that can log ATM)*, and then transfer the package swiftly to the cold room, opening and closing the cold room as quickly as possible to avoid a significant variation in the cold room temperature, noting the time lapse the door is open to jot down later – **Wednesday AM (possibly an hour or so later)**
- Leave the package in the cold room overnight (it can remain well beyond equilibrium, as any subsequent readings should only show cycling with the cold room) – **Wednesday AM**
- Remove package and loggers from cold room and oven (oven logger can be removed after oven portion of test is completed the day before), read the barometer and make mental note for jotting down later *(if Terry doesn't have one that can log ATM)*, and download information from loggers to computer and save files for analysis at a later stage – **Thursday AM**

**** Note: This Task Run may change as the method of controlling pressure is finalised between the print date of this document and the scheduled time of carrying out this test.***

E. Risk Assessment & Management

ERP 2015 Test Plan and Risk Assessment & Management

Insulated Container Testing & Rating System Development

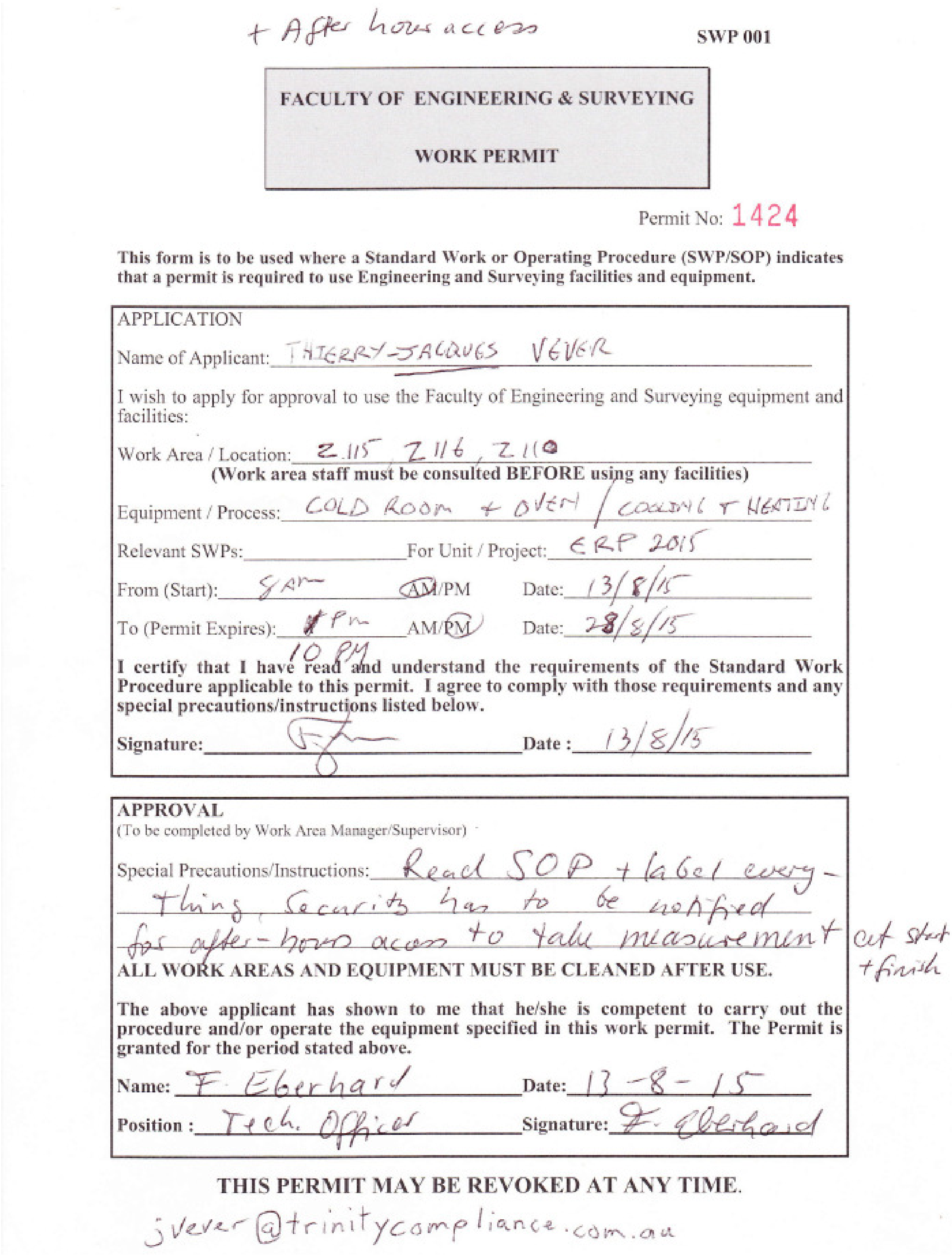
Risk Assessment & Management

This table refers only to the risks associated with the tests defined about, to be carried out in Z Block at the Toowoomba Campus of The University of Southern Queensland.

Risk Identification		**Risk Evaluation**				**Risk Control**
Sources	**Hazards**	**Likelihood**	**Justification**	**Exposure**	**Consequences**	**Control Mechanism**
Oven	Burns	Extremely slight	Planned temperature not to exceed approximately 55^{o}C.	Briefly when loading vessels in the oven.	Minor Injury	Instruct all operators of hot surfaces to avoid, and do not linger next to oven.
Cold Room	Chills	very slight	Although planned temperature to reduce to 5^{o}C, exposure is not planned to be very long.	Briefly when loading vessels in the cold room.	Minor Injury	Instruct all operators of cold surfaces to avoid, and do not linger in the cold room.
Hot Wet Towel	Scalding	slight	Hot water from taps is tempered to avoid scalds.	Only when first soaking and wringing out towel.	Minor Injury	Ensure operator checks temperature of towel before picking it up.
Loads	Strains/sprains	slight	Vessels are not intended to be filled, so only those operators already suffering are likely to sustain an injury or exacerbate a pre-existing condition.	Briefly when loading vessels in the chambers.	Minor Injury	Survey operators for any back/arm/leg joint injuries, and use only competent operators. Instruct correct procedure for lifting (bend knees, not back), recommending 2 operators for large, heavy vessels.

Risk Identification		**Risk Evaluation**				**Risk Control**
Sources	**Hazards**	**Likelihood**	**Justification**	**Exposure**	**Consequences**	**Control Mechanism**
Electricity	Electrocution	very slight	Although electrical faults occur, most equipment is designed to shut down before electrocution.	Only when connecting or disconnecting equipment.	Possible Death	Rubber souled shoes to be worn when connecting equipment. Use only recently tested equipment. Minimise connection/disconnection tasks.
Refrigerant Gas	Poisoning	Extremely slight	Although a gas leak could occur, it will be within a large environment, and personnel are not required to stay in the space throughout the duration of the tests.	Only if testers stay in the test area, and there is no ventilation or pump-down mechanism for the equipment.	Major Illness	Ensure adequate ventilation for refrigerant gas system. Check for pump-down mechanism, or have open windows. Operators to monitor from a different space.
Plastic Bag Compression	Pinching	slight	The operator is likely to be conscious of pinching as the motor takes up the plastic bag, and be vigilant to keep fingers clear.	Only when first attaching the motor and gear to the bag.	Minor Injury	Ensure an observer is present to remind the operator to be careful to avoid a pinch injury.

F. Work Permit



+ After hours access

SWP 001

FACULTY OF ENGINEERING & SURVEYING

WORK PERMIT

Permit No: 1424

This form is to be used where a Standard Work or Operating Procedure (SWP/SOP) indicates that a permit is required to use Engineering and Surveying facilities and equipment.

APPLICATION

Name of Applicant: THIERRY-JACQUES VEVER

I wish to apply for approval to use the Faculty of Engineering and Surveying equipment and facilities:

Work Area / Location: Z.115, Z116, Z110

(Work area staff must be consulted BEFORE using any facilities)

Equipment / Process: COLD ROOM + OVEN / COOLING + HEATING

Relevant SWPs: For Unit / Project: ERP 2015

From (Start): 8Am [✓ AM]/PM Date: 13/8/15

To (Permit Expires): ~~8~~ Pm 10 PM AM/[✓ PM] Date: 28/8/15

I certify that I have read and understand the requirements of the Standard Work Procedure applicable to this permit. I agree to comply with those requirements and any special precautions/instructions listed below.

Signature: **Date :** 13/8/15

APPROVAL

(To be completed by Work Area Manager/Supervisor)

Special Precautions/Instructions: Read SOP + label everything, Security has to be notified for after-hours access to take measurement at start + finish

ALL WORK AREAS AND EQUIPMENT MUST BE CLEANED AFTER USE.

The above applicant has shown to me that he/she is competent to carry out the procedure and/or operate the equipment specified in this work permit. The Permit is granted for the period stated above.

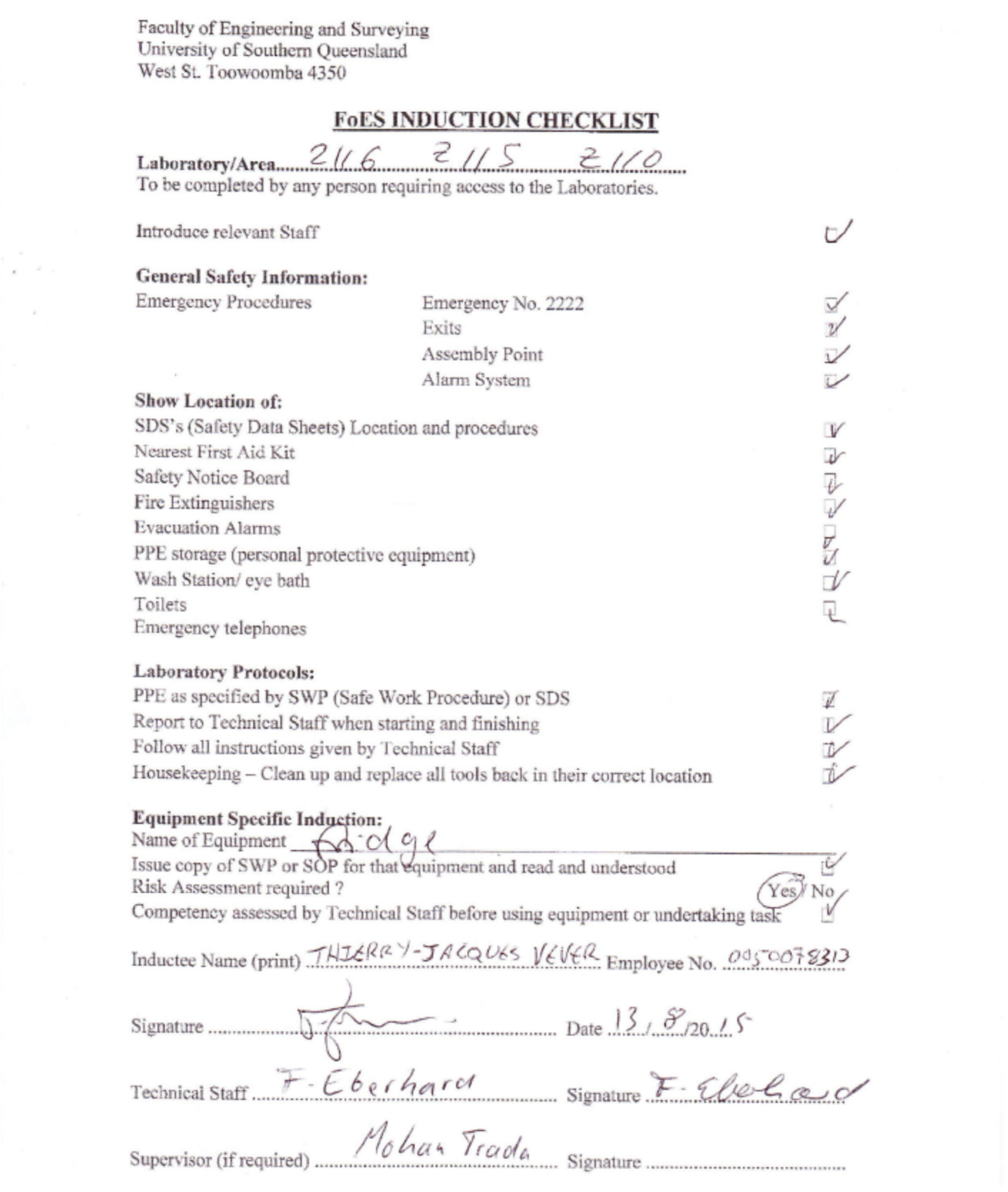
Name: F. Eberhard **Date:** 13-8-15

Position : Tech. Officer **Signature:** F. Eberhard

THIS PERMIT MAY BE REVOKED AT ANY TIME.

jvever@trinitycompliance.com.au

G. Induction Checklist



Faculty of Engineering and Surveying
University of Southern Queensland
West St. Toowoomba 4350

FoES INDUCTION CHECKLIST

Laboratory/Area 2116 Z115 Z110
To be completed by any person requiring access to the Laboratories.

Introduce relevant Staff ☑

General Safety Information:

Emergency Procedures
- Emergency No. 2222 ☑
- Exits ☑
- Assembly Point ☑
- Alarm System ☑

Show Location of:

- SDS's (Safety Data Sheets) Location and procedures ☑
- Nearest First Aid Kit ☑
- Safety Notice Board ☑
- Fire Extinguishers ☑
- Evacuation Alarms ☑
- PPE storage (personal protective equipment) ☑
- Wash Station/ eye bath ☑
- Toilets ☑
- Emergency telephones

Laboratory Protocols:

- PPE as specified by SWP (Safe Work Procedure) or SDS ☑
- Report to Technical Staff when starting and finishing ☑
- Follow all instructions given by Technical Staff ☑
- Housekeeping – Clean up and replace all tools back in their correct location ☑

Equipment Specific Induction:

Name of Equipment Fridge
Issue copy of SWP or SOP for that equipment and read and understood ☑
Risk Assessment required ? [✓ Yes]/ No
Competency assessed by Technical Staff before using equipment or undertaking task ☑

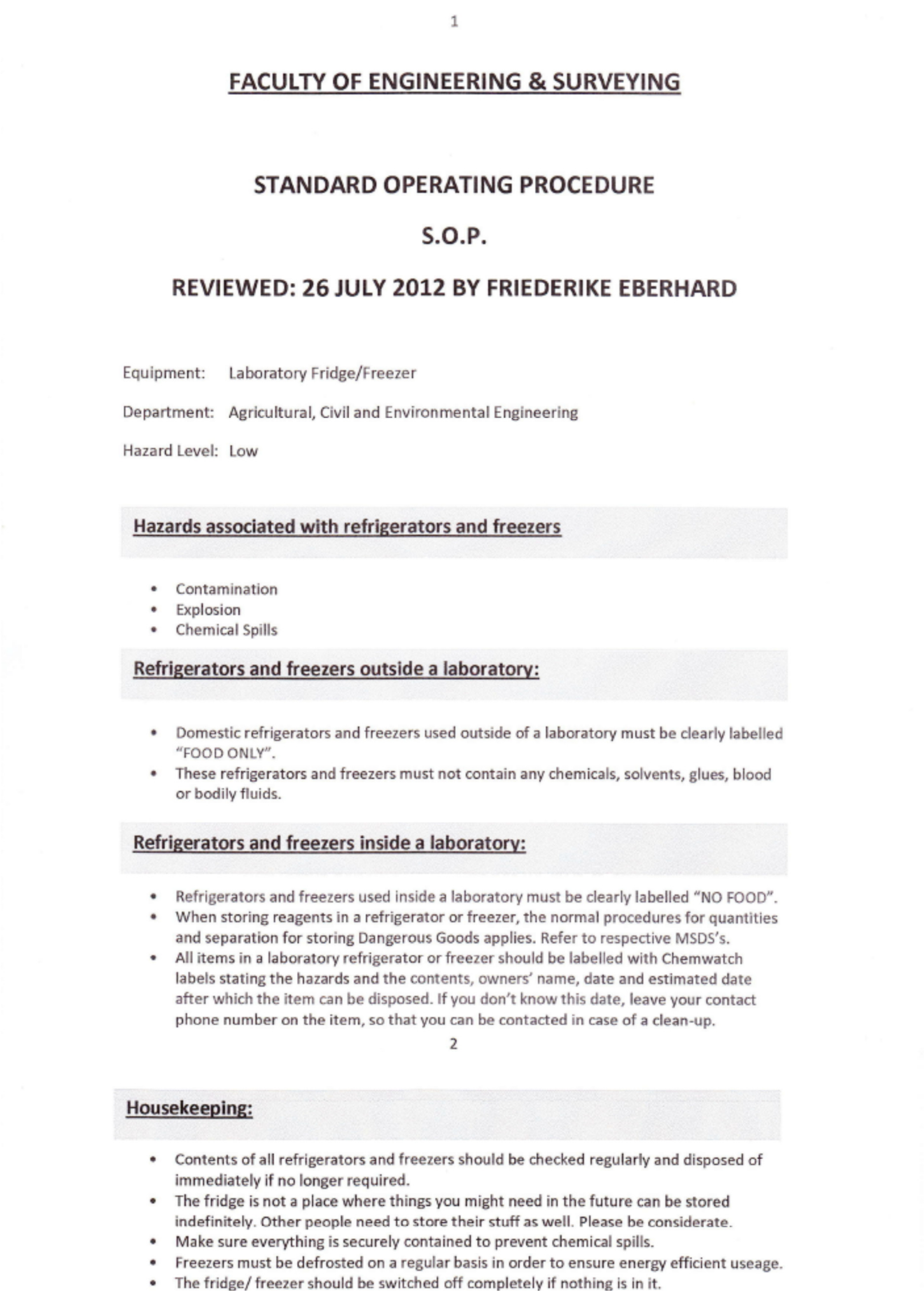
Inductee Name (print) THIERRY-JACQUES VEVER Employee No. 0050078313

Signature Date 13/8/2015

Technical Staff F. Eberhard Signature F. Eberhard

Supervisor (if required) Mohan Trada Signature

H. Standard Operating Procedure



FACULTY OF ENGINEERING & SURVEYING

STANDARD OPERATING PROCEDURE

S.O.P.

REVIEWED: 26 JULY 2012 BY FRIEDERIKE EBERHARD

Equipment: Laboratory Fridge/Freezer

Department: Agricultural, Civil and Environmental Engineering

Hazard Level: Low

Hazards associated with refrigerators and freezers

- Contamination
- Explosion
- Chemical Spills

Refrigerators and freezers outside a laboratory:

- Domestic refrigerators and freezers used outside of a laboratory must be clearly labelled "FOOD ONLY".
- These refrigerators and freezers must not contain any chemicals, solvents, glues, blood or bodily fluids.

Refrigerators and freezers inside a laboratory:

- Refrigerators and freezers used inside a laboratory must be clearly labelled "NO FOOD".
- When storing reagents in a refrigerator or freezer, the normal procedures for quantities and separation for storing Dangerous Goods applies. Refer to respective MSDS's.
- All items in a laboratory refrigerator or freezer should be labelled with Chemwatch labels stating the hazards and the contents, owners' name, date and estimated date after which the item can be disposed. If you don't know this date, leave your contact phone number on the item, so that you can be contacted in case of a clean-up.

Housekeeping:

- Contents of all refrigerators and freezers should be checked regularly and disposed of immediately if no longer required.
- The fridge is not a place where things you might need in the future can be stored indefinitely. Other people need to store their stuff as well. Please be considerate.
- Make sure everything is securely contained to prevent chemical spills.
- Freezers must be defrosted on a regular basis in order to ensure energy efficient useage.
- The fridge/ freezer should be switched off completely if nothing is in it.

I. ELG Logger Graphs

The following graphs are from the ELG software showing the remainder of the logger graphs that were not shown in the body of the report.

a. Test 2

These are the ELG logger graphs for Test 2.

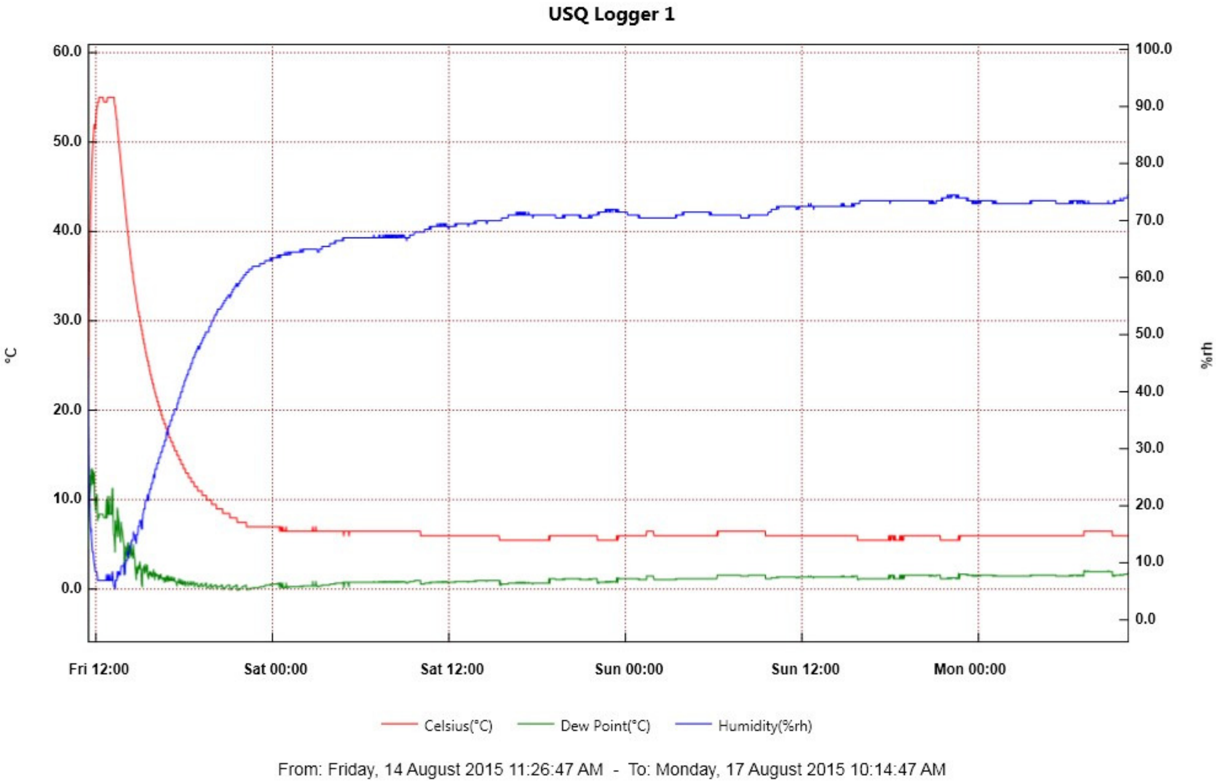


Figure I.1 – ELG graph of the logger from the vessel for Test 2

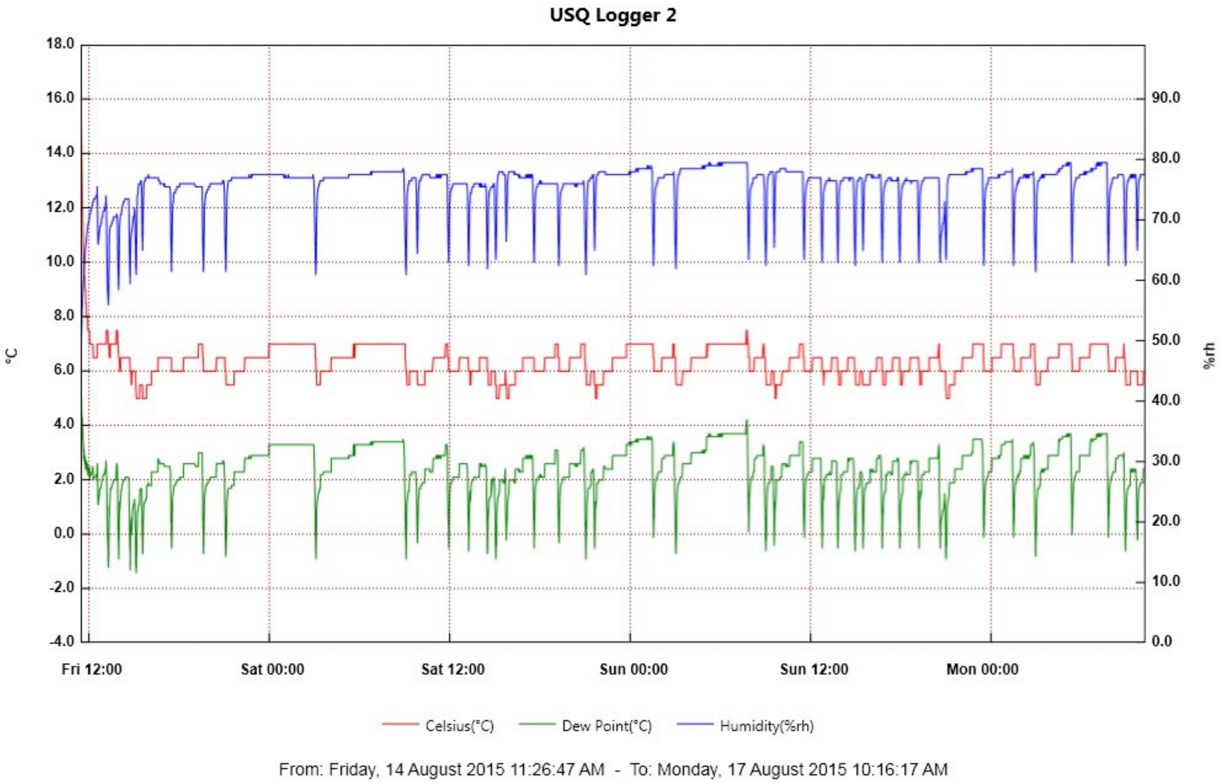


Figure I.2 – ELG graph of the logger from the cold room for Test 2

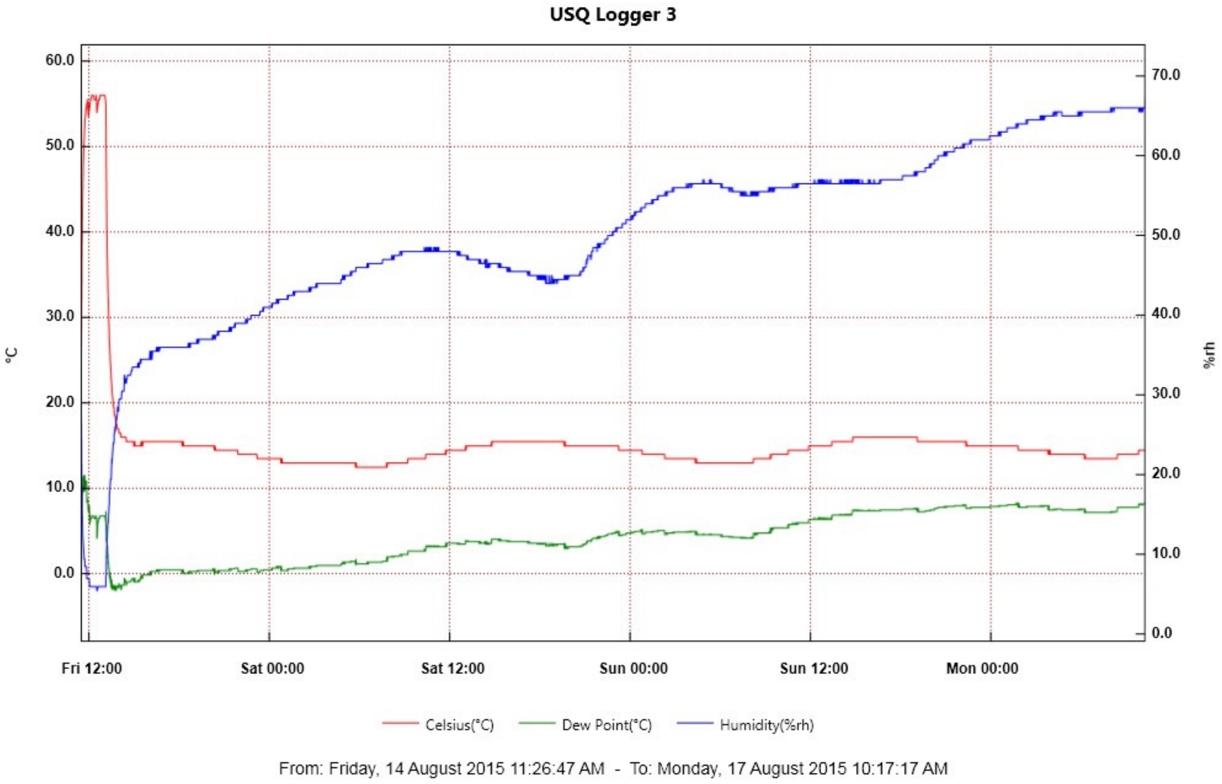


Figure I.3 – ELG graph of the logger from the oven for Test 2

b. Test 3

These are the ELG logger graphs for Test 3.

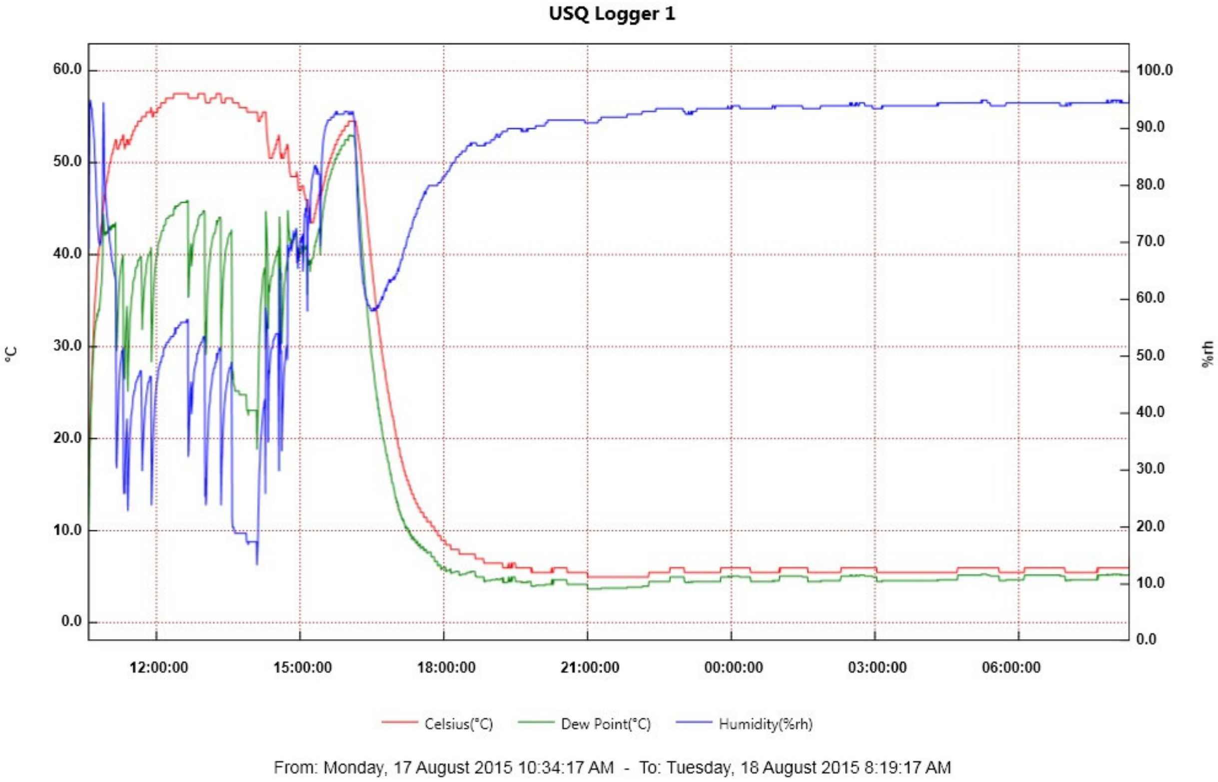


Figure I.4 – ELG graph of the logger from the vessel for Test 3

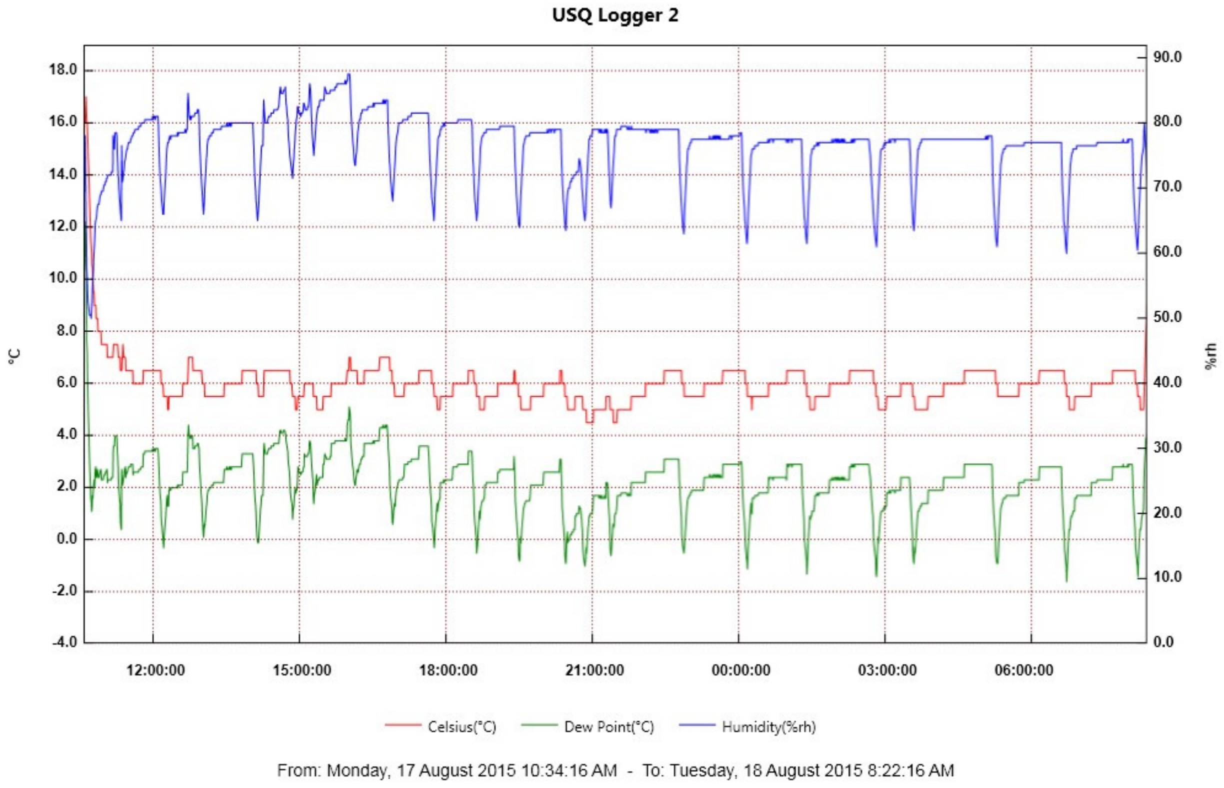


Figure I.5 – ELG graph of the logger from the cold room for Test 3

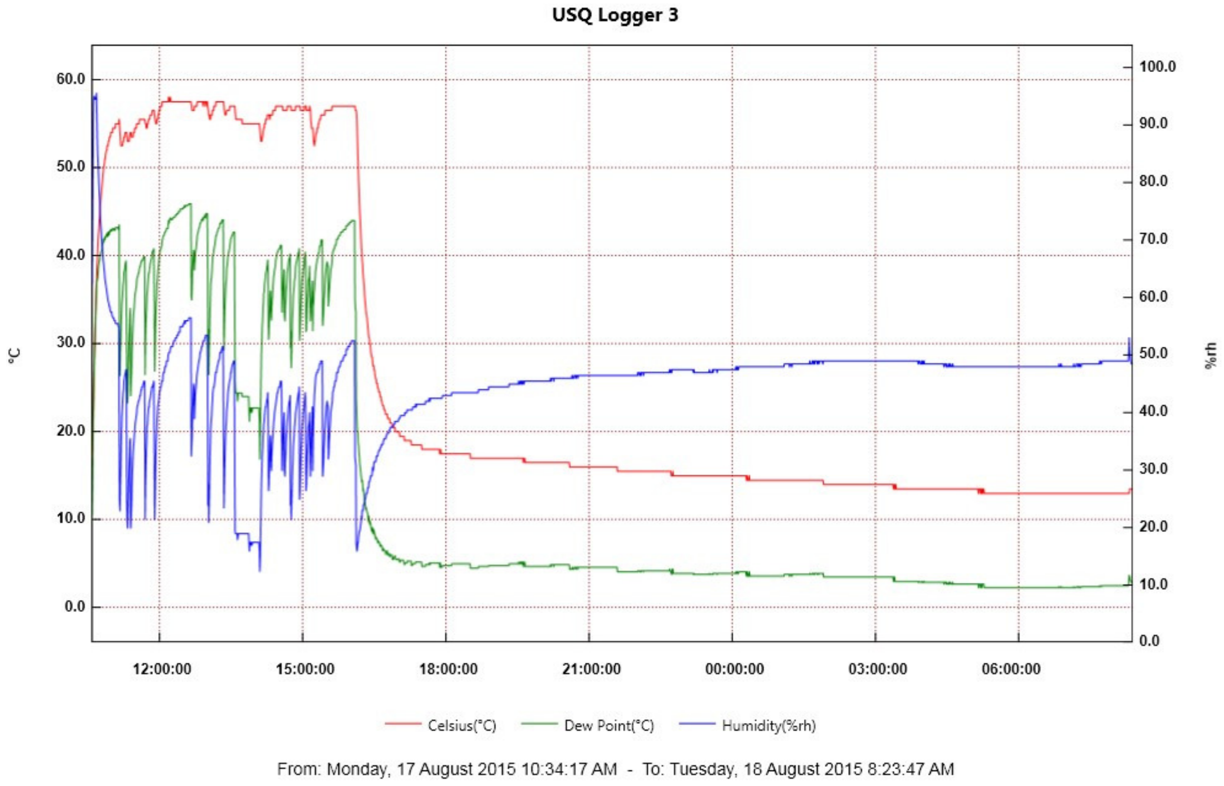


Figure I.6 – ELG graph of the logger from the oven for Test 3

c. Test 4

These are the ELG logger graphs for Test 4.

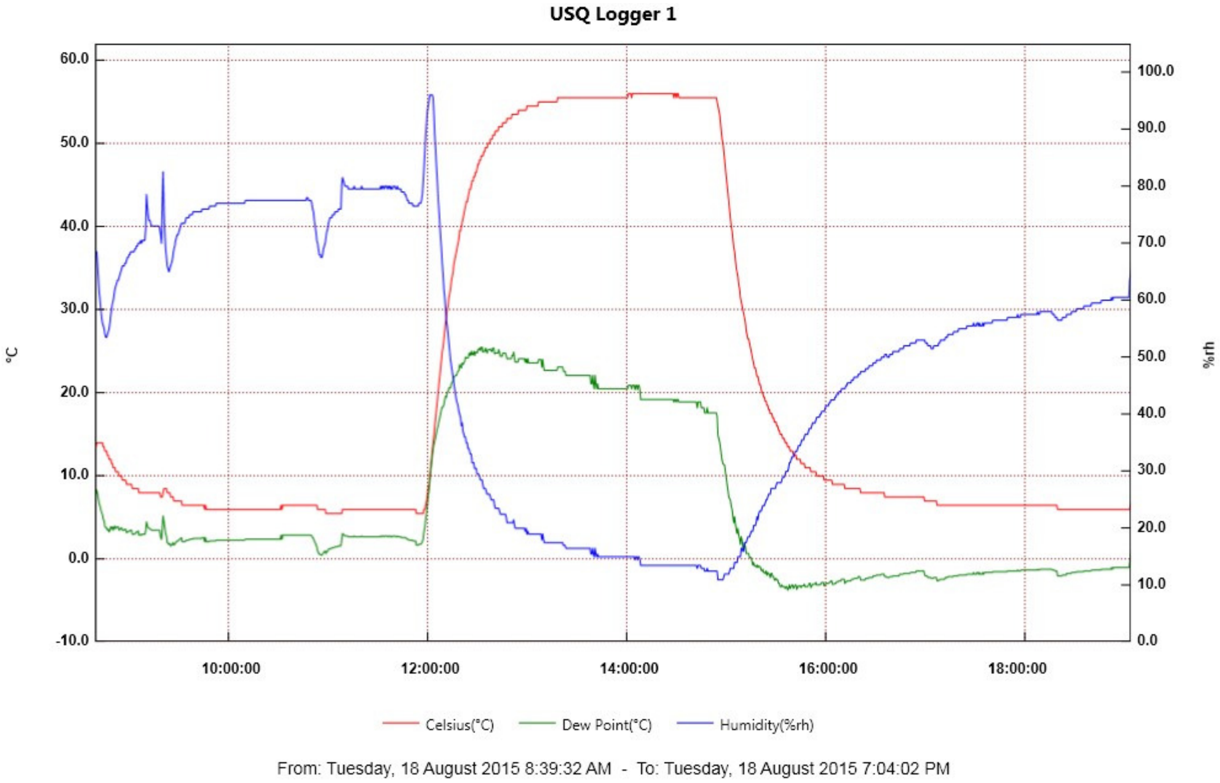


Figure I.7 – ELG graph of the logger from the vessel for Test 4

Figure I.8 – ELG graph of the logger from the cold room for Test 4

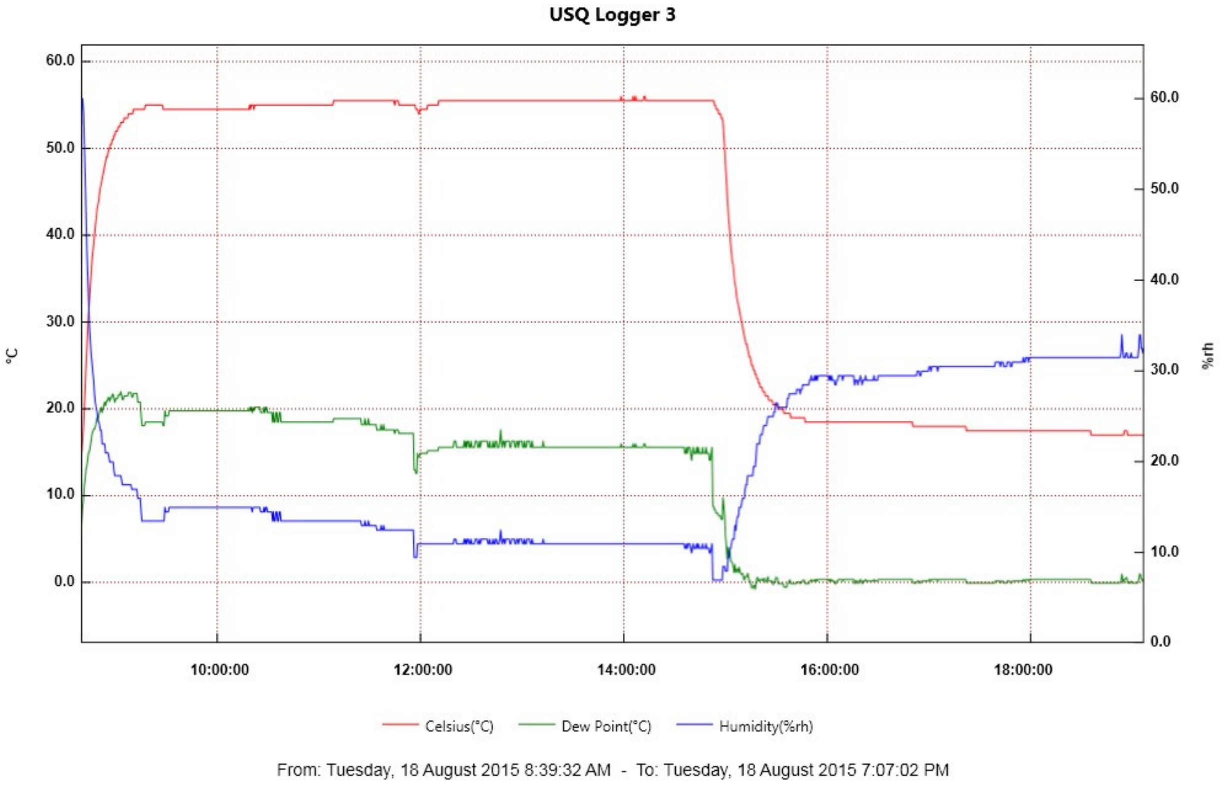


Figure I.9 – ELG graph of the logger from the oven for Test 4

J. Excel Temperature Graphs

The following graphs are from MS Excel showing the remainder of the temperature graphs (including those showing greater clarity) that were not shown in the body of the report.

d. Test 2

These are the Excel temperature graphs for Test 2. It is interesting to note the oscillations in the red line of Figure J.10 which represents the oven logger which was left on in the laboratory. This effectively tracks the diurnal swing in that vented, unconditioned space in winter.

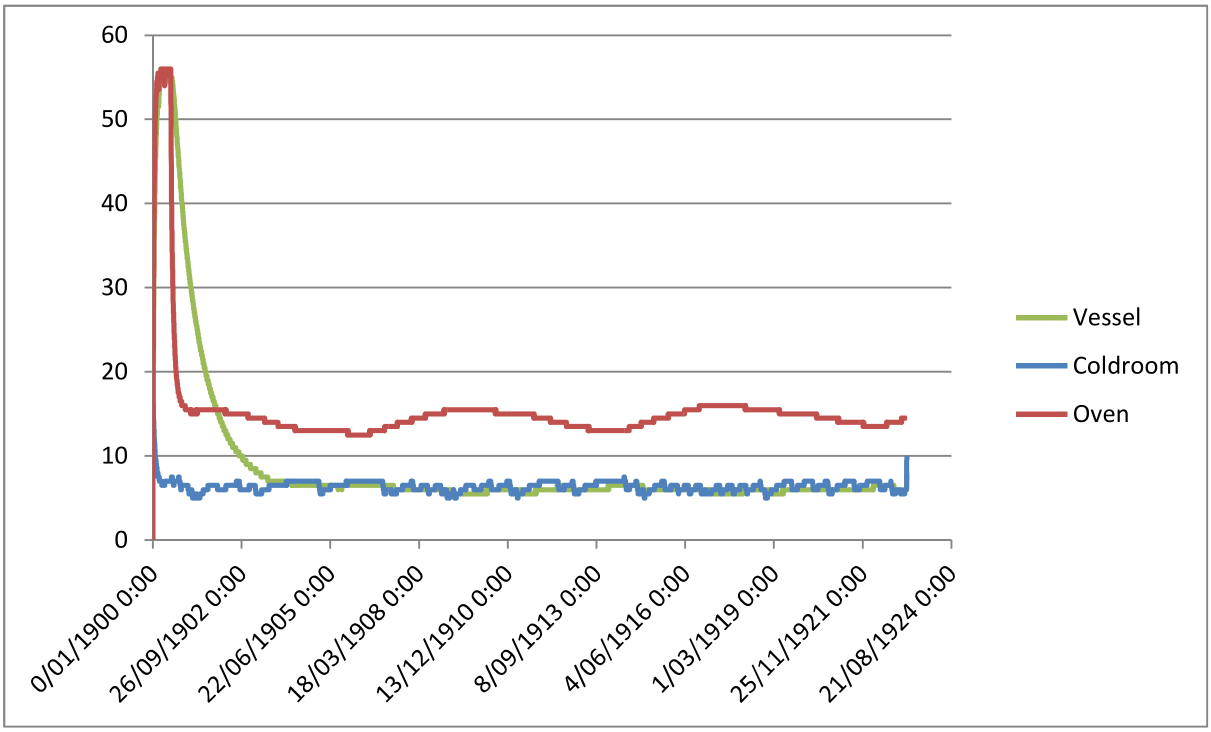


Figure J.10 – Excel temperature graphs of the loggers for Test 2 showing the heat egress process

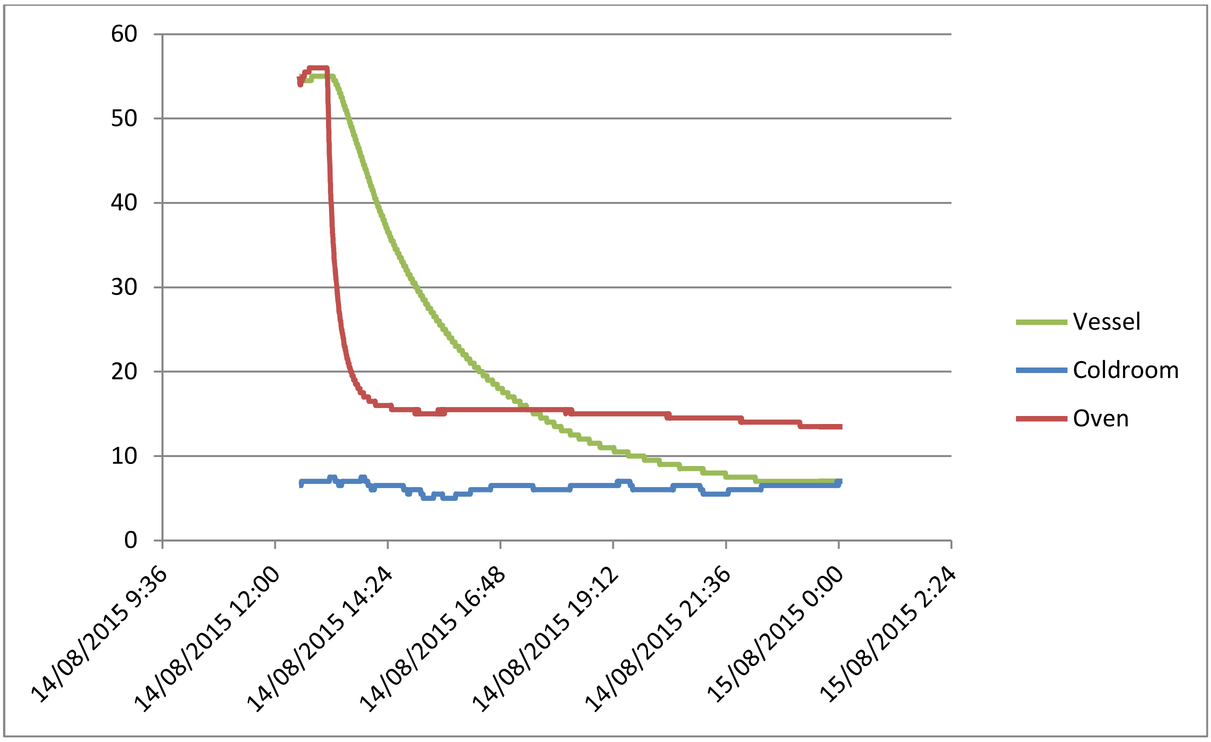


Figure J.11 – Excel temperature graphs of the loggers for Test 2 showing the heat egress with greater clarity

e. Test 4

These are the Excel temperature graphs for Test 4.

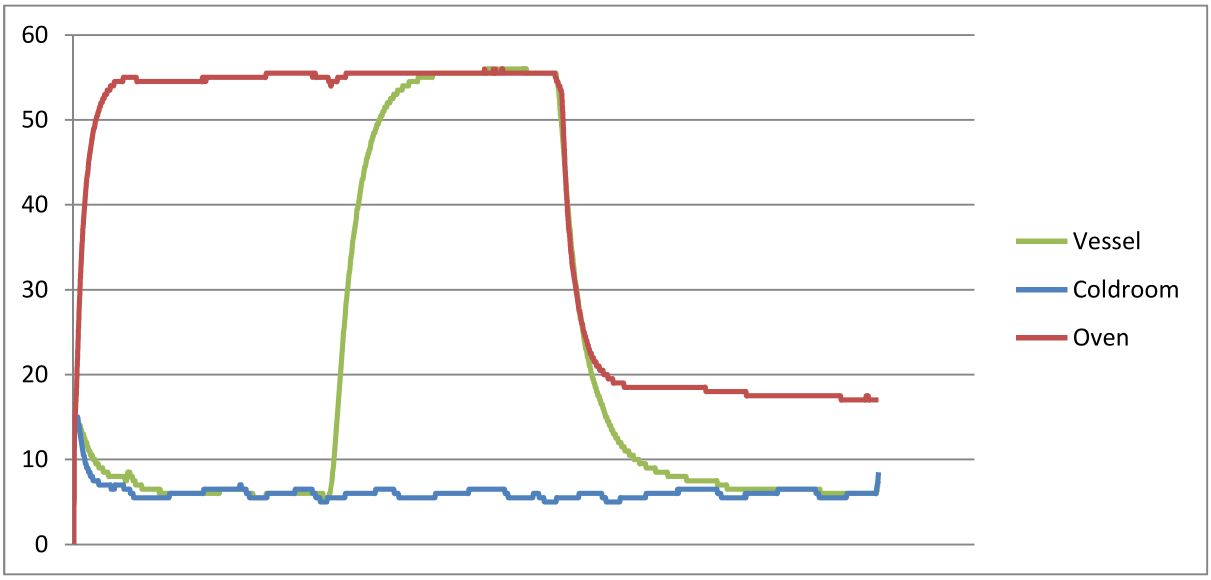


Figure J.12 – Excel temperature graphs of the loggers for Test 4 showing both the heat ingress and egress processes

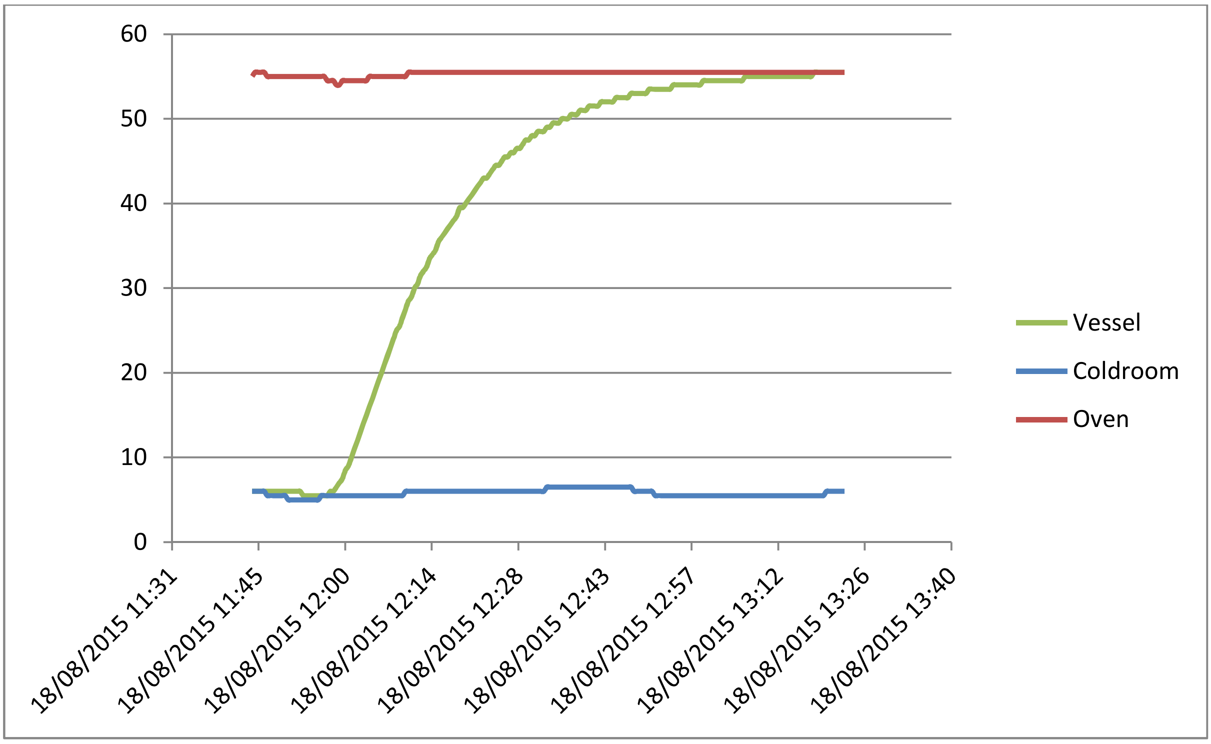


Figure J.13 – Excel temperature graphs of the loggers for Test 4 showing the heat ingress with greater clarity

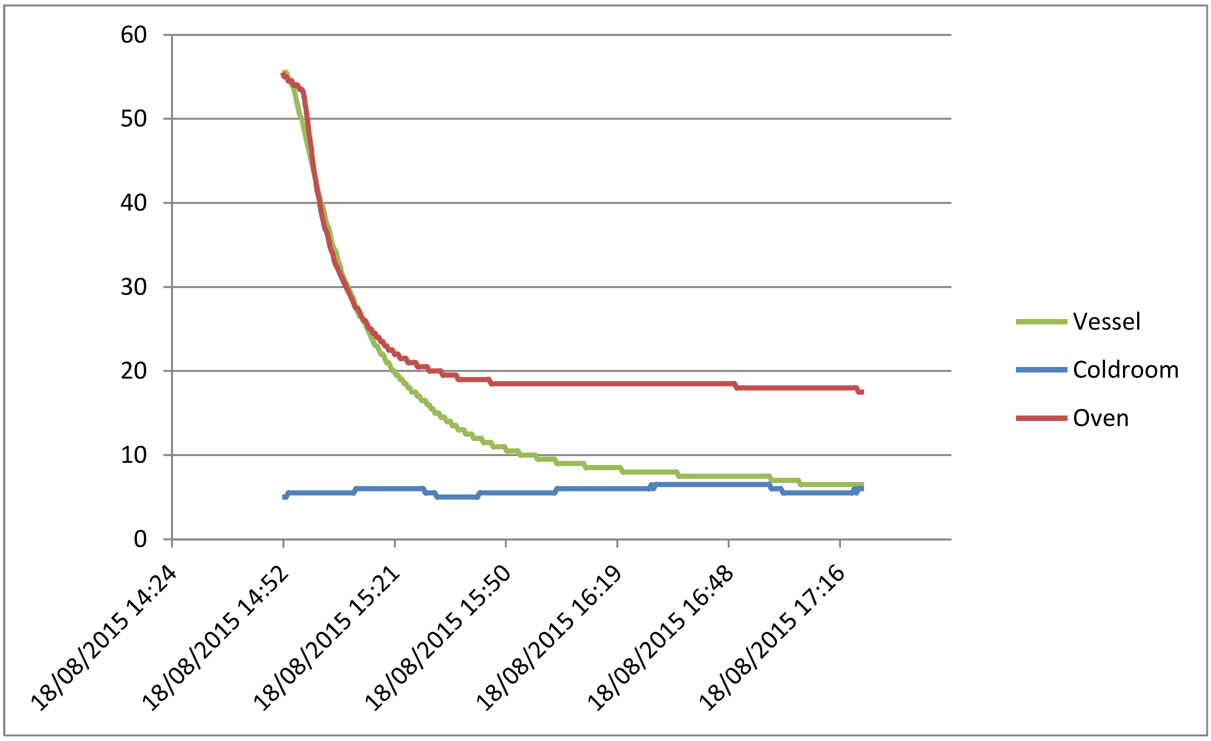


Figure J.14 – Excel temperature graphs of the loggers for Test 4 showing the heat egress with greater clarity