The Thermal Performance of an Earth Sheltered Shipping Container

A Dissertation Submitted by

Tyler Carey

In fulfilment of the requirements of courses ENG4111 & ENG4112 Research Project, towards the degree of Bachelor of Engineering (Honours) Major Civil Engineering

sponsored by

University of Southern Queensland
Faculty of Health, Engineering and Sciences
1 Abstract

The aim of this dissertation is to document the process of gaining approval for habitable structurally modified shipping container structures. This work was completed in union with an experimental study into the thermal affect that earth sheltering has on a shipping container, subsequently providing the NEC with an earth sheltered shipping container for storage purposes.

Data logging thermometers were used to record the outdoor temperature in Albury, NSW, along with the interior temperatures of two shipping containers. After a period of research, design and application for development, one of these containers was earth sheltered on two sides. Temperatures were logged throughout the process allowing comparisons to be drawn between the two containers before and after construction.

Results of this dissertation indicate that earth sheltering has a significant affect on the thermal performance of a shipping container. However, due to an uninsulated shipping containers high thermal conductivity, other contributing factors such as the colour of the container, the aspect of the container and the amount of solar radiation the container is exposed to, can have potentially larger impacts on the shipping containers thermal performance.
2 Limitations of Use

The Council of the University of Southern Queensland, its Faculty of Health, Engineering & Sciences, and the staff of the University of Southern Queensland, do not accept any responsibility for the truth, accuracy or completeness of material contained within or associated with this dissertation.

Persons using all or any part of this material do so at their own risk, and not at the risk of the Council of the University of Southern Queensland, its Faculty of Health, Engineering & Sciences or the staff of the University of Southern Queensland.

This dissertation reports an educational exercise and has no purpose or validity beyond this exercise. The sole purpose of the course pair entitled Research Project is to contribute to the overall education within the students chosen degree program. This document, the associated hardware, software, drawings, and other material set out in the associated appendices should not be used for any other purpose: if they are so used, it is entirely at the risk of the user.
3 Certification

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.

T. Carey, 0050105877
4 Acknowledgements

I would like to thank my supervisor, Dr Steven Goh for his guidance and support throughout this dissertation.

Experienced industry professionals, Lindsay Pearson, Mick Garvey, Matt Johnson, Janae Holland, Ross Wheeler and Neil Wright, I would like to thank you for your technical advice and assistance in completing this dissertation.

To Brad Ferris and the Albury City Council, an earnest thank you, without your faith, guidance and sponsorship from this projects inception, it would never have eventuated.

To John Brader and Rocla, also a sincere thank you, without your kind donation of the Massbloc units, this construction work would not have been possible.

To Rob Fenton, James Anderson and the National Environmental Centre, thank you for your assistance and enthusiasm whilst working on this project along your permaculture know how which helped the project develop with ease.

And finally thanks to Jess and my family for their assistance and support throughout the year.
## Contents

1 Abstract .......................................................... 3

2 Limitations of Use ............................................. 5

3 Certification ...................................................... 7

4 Acknowledgements ............................................... 9

List of Figures .................................................... 14

List of Tables ..................................................... 15

5 Abbreviations .................................................... 16

6 Introduction .................................................... 17
   6.1 Introduction .................................................. 17
      6.1.1 Project Background .................................. 17
      6.1.2 The Problem .......................................... 17
   6.2 Scope .......................................................... 18
      6.2.1 Research Objectives ................................ 18
   6.3 Justification ................................................ 19
      6.3.1 Consequential Effects .............................. 20
   6.4 Conclusion ................................................... 20

7 Literature Review .............................................. 21
   7.1 Shipping Containers ..................................... 21
   7.2 Policies, Procedures & Approval of Shipping Container Structures . . . . 22
   7.3 Earth Sheltered Structures ................................ 23
   7.4 Green Roofs .................................................. 24
   7.5 Conclusions Drawn From Literature Reviewed ................. 26

8 Research Design & Methodology ................................ 27
   8.1 Resources ..................................................... 27
      8.1.1 Resource Requirements .............................. 27
      8.1.2 Shipping Container .................................. 27
      8.1.3 Work Site ............................................. 28
8.1.4 Retaining Wall ............................................. 28
8.1.5 Machinery & Labour ....................................... 29
8.1.6 Data Logging Thermometers .............................. 29

8.2 Methodology .................................................. 30
8.2.1 Planning & Construction ................................... 30
8.2.2 Data Collection ............................................ 31

8.3 Risk Assessment ............................................... 32
8.3.1 Dissertation Risk Register ................................. 32
8.3.2 Individual Risk Assessments .............................. 34
8.3.3 Risks Associated with Planning & Approval ............. 36
8.3.4 Risks Associated with Construction ....................... 36
8.3.5 Risks Associated with Data Collection & Research .... 36

9 Results & Discussion ........................................... 40
9.1 Initial Results .................................................. 40
9.2 Approval ...................................................... 42
9.2.1 Process ...................................................... 42
9.2.2 Town Planners, Building Inspector and Certifiers Perspective .............................................. 42
9.2.3 Structural Engineers Perspective ......................... 44
9.3 Earth Sheltering ............................................... 46
9.3.1 Initial Data Collection ..................................... 46
9.3.2 Effect on Temperature .................................... 48
9.3.3 Weighted Arithmetic Mean Temperature ................ 51
9.4 Permaculture Alterations .................................... 54

10 Conclusions ..................................................... 56
10.1 Introduction .................................................... 56
10.2 Conclusion ..................................................... 57
10.3 Recommendations ........................................... 58
10.3.1 Shipping Container Structures ......................... 58
10.3.2 Earth Sheltering .......................................... 58
10.3.3 Earth Sheltered Shipping Container at the NEC .... 59

11 Timeline .......................................................... 60

References .......................................................... 62
List of Figures

1. Contour Map of National Environmental Centre .......................... 27
2. Rocla Massbloc Unit Retaining Wall ...................................... 28
3. Franner Crane Unloading Massblocs from Truck and Dog .......... 29
4. An RC-4 Unit ...................................................................... 30
5. Earth Sheltered Container from North East Face ...................... 31
6. RC-4 vs Force Aspirated Triple-Semi-Conductor Comparison .... 38
7. Effect of Solar Radiation on Variation Between Logger ............ 38
8. Fitted RC-4 Data and Row Force Aspirated Unit Data .......... 39
9. Temperature Comparison Prior to Works ............................... 41
10. Approval Process for Habitable Modified Shipping Container Structures 44
11. Temperature Comparison After Construction, Problematic Data 47
12. Temperature Comparison After Construction, Control Data .... 50
13. Heat Map of Earth Sheltered Side, October 28th, 10:00 AM ...... 53
14. Recycled Insulative Panel, Ready to be Hung ......................... 55
15. Gantt Chart of Task Order and Duration ............................... 61
16. Ideal Living Temperature .................................................... 66
17. The Climate Change Factor .................................................. 67
18. Ideal Living Temperature ..................................................... 67
19. A Web of Issues ............................................................... 68
20. Green Roofs and Green Bubbles ........................................... 69
21. Insulation an Investment? ..................................................... 69
## List of Tables

1. Project Risk Register Part I ........................................ 33
2. Project Risk Register Part II ....................................... 34
3. Comparison of Results - Data Prior to Construction ........ 40
4. Comparison of Results - Control Data ............................ 48
5. Survey of Container Face Temperatures - September 17\textsuperscript{th} .......... 52
6. Survey of Container Face Temperatures - October 28\textsuperscript{th} ....... 52
7. Work Breakdown Structure ........................................... 60
### 5 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACC</td>
<td>Albury City Council</td>
</tr>
<tr>
<td>BASIX</td>
<td>Building Sustainability Index</td>
</tr>
<tr>
<td>BCA</td>
<td>Building Code of Australia</td>
</tr>
<tr>
<td>CBD</td>
<td>Central Business District</td>
</tr>
<tr>
<td>DC</td>
<td>Direct Current</td>
</tr>
<tr>
<td>DEWHA</td>
<td>Department of the Environment, Water, Heritage &amp; the Arts</td>
</tr>
<tr>
<td>GFC</td>
<td>Global Financial Crisis</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning System</td>
</tr>
<tr>
<td>IRA</td>
<td>Individual Risk Assessment</td>
</tr>
<tr>
<td>NEC</td>
<td>National Environmental Centre, Thurgoona, NSW 2640</td>
</tr>
<tr>
<td>NSW</td>
<td>New South Wales</td>
</tr>
<tr>
<td>NTC</td>
<td>Negative Temperature Coefficient</td>
</tr>
<tr>
<td>PVC</td>
<td>Poly Vinyl Chloride</td>
</tr>
<tr>
<td>TAFE</td>
<td>Technical and Further Education</td>
</tr>
<tr>
<td>USQ</td>
<td>University of Southern Queensland</td>
</tr>
<tr>
<td>WBS</td>
<td>Work Breakdown Structure</td>
</tr>
<tr>
<td>WSRAT</td>
<td>Work Site Risk Assessment Template</td>
</tr>
<tr>
<td>ZEB</td>
<td>Zero Energy Building</td>
</tr>
</tbody>
</table>
6 Introduction

6.1 Introduction

As I move toward the completion of my Bachelor of Engineering (Honours) Major Civil Engineer degree, via USQ, I have chosen to study and document the thermal effect that earth sheltering has on a shipping container. The effect of other environmentally conscious alterations will also be studied throughout this dissertation. This research will be the basis of my dissertation to be completed as part of the Engineering Research Project course ENG4112.

6.1.1 Project Background

Shipping containers are now readily being used as homes, emergency accommodation and storage, as well as their intended application of transportation (World News Australia (SBS Television), 11 January 2014). Despite growing popularity and public acceptance, they are still unfamiliar to the general public, making gaining approval difficult for structures using containers. An ancillary survey\(^1\) completed as a precursor to this dissertation indicated that 68.85% of those surveyed considered the temperature inside a shipping container as the most concerning factor regarding living in a shipping container. This justifies further investigation into the thermal behaviour of a shipping container.

6.1.2 The Problem

The NEC is a unique educational facility set on a 182 hectare organic farm, that teaches courses in civil construction, natural resource management, spacial information, water operations, permaculture and organic farming. The NEC possessed three shipping container in which they stored food, produce, equipment and materials. In particular, one container was used to store organic garlic and pumpkins harvested from the farm. This container was not providing the temperate environment the produce required and was causing it to spoil. Rob Fenton, the head teacher at the NEC, was interested in burying or earth sheltering this container to make it more temperate and so arose the opportunity to complete this research.

\(^1\)Questions and results outlined in Appendix B
6.2 Scope

The initial ancillary survey of public opinion regarding modified shipping container homes was undertaken to justify this topic as the basis of further dissertation research (Appendix B). The results of this survey suggested people had many inhibitions regarding shipping container homes despite their rising prevalence. Following this a GPS Survey of the proposed site was completed using Trimble equipment, a proposed design was then formed and drawing produced outlining the proposed layout in relation to the existing site.

A development application was then prepared and approved by Albury City Council. The earth sheltered container could then be constructed and monitoring of the temperature inside the earth sheltered container, as well as the temperature in a control container, could begin. Before the RC-4\textsuperscript{2} data logging thermometers\textsuperscript{3} were placed in these containers, a comparison study was undertaken against a more accurate and reliable force aspirated triple semi-conductor system. This comparison gave a point of reference for the thermal data recorded by the RC-4 units. This allowed for an analysis of the earth sheltered container to be undertaken, testing the theoretical approach published by Anselm (2008). After this initial period of comparison, the permaculture students at the NEC will begin altering the container with different insulative methods, the temperature will be monitored during this process and the effect of the insulative methods quantified.

6.2.1 Research Objectives

The objectives of this dissertation are:

1. Document and research the thermal behaviour of a 20 ft\textsuperscript{3} high cube shipping containers in an Australian climate

2. Gain an understanding of the Australian policies and procedures relating to the habitability of modified shipping containers

3. Quantify the effect of earth sheltering on a shipping containers thermal performance, and compare to theoretical estimations published by Anselm (2008)

\textsuperscript{2}Unit is further described in Section 8.16

\textsuperscript{3}International foot = 304.8 mm
4. Research the effect that green roofs and alternative insulative methods have on a shipping containers thermal performance

5. Create a temperate environment for the NEC to store organic farm produce

6.3 Justification

Estimates for the number of surplus shipping containers globally, fluctuate significantly. Unfortunately there is no reliable way to quantify this population and all numbers quoted are estimates often based purely on conjecture. The general consensus is that a combination of the 2008 GFC, strict shipping regulations and one way importing/exporting trade routes creating a surplus of containers.

In the economic stabilisation that has occurred post GFC, shipping and trading have improved and the surplus of containers has diminished. However it is well documented that these containers, whether they be new or used, can be used as emergency accommodation or as components of architecturally designed homes (World News Australia (SBS Television), 11 January 2014), the ancillary survey completed prior to this dissertation revealed a lot of people still hold reservations about the prospect of living in containers. As stated earlier 68.85% of those stated the temperature extremes in the container was the most concerning factor about living in a shipping container. 22.95% cited poor acoustics as the biggest concern, 9.84% cited humidity, while poor aesthetics, waterproofness, the size and usability of interior spaces and the previous uses of the container were other common responses.

A Department of the Environment, Water, Heritage and the Arts (2008) study revealed that, in 2007, heating and cooling accounted for 41% of all household energy consumption. The same paper projected that this percent will remain constant until and after 2020. The Australian government has assumed a target of 20% renewable energy by 2020, however Froome (2010) expressed doubt that current government policies would allow these targets to be met. As governments aim to curb the use of non-renewable energy sources, they must also consider the future energy demands of a growing global population. Regarding this, Bredenoord and van Lindert (2010) stated “For the coming decades, the developing world will witness unprecedented urban growth rates which correspond with an ongoing trend towards further urbanization of poverty ... new pro-poor housing policies are to be developed that build upon the power
of self-help efforts that both promote and support self-build initiatives institutionally, financially, technically and politically”.

The strong correlation between the high energy demands of heating and cooling the domestic environment, increased global consciousness regarding reliance on non-renewable energy sources and projected population growth demographics affirm the potential of earth sheltering and recycled shipping containers as viable housing solutions in the future.

6.3.1 Consequential Effects

The desired consequential effect of this dissertation is to increase awareness, and give merit to the use of recycled shipping containers, earth sheltering and other permaculture based insulative methods as environmentally sustainable alternatives to current building practices. Through research and experimentation this dissertation aims to quantify the validity of these methods, understand why they aren’t as popular as common methods and find ways to appease these grievances. A major derivative of this dissertation is that the creation of a temperate storage area for the NECs organic produce before it goes to market. Consequentially the project will strengthen ties between local government, education and private industry.

6.4 Conclusion

This chapter has served as an introduction to the dissertation entitled Earth Sheltered Shipping Container Thermal Performance. This research aims to examine the use of modified recycled shipping containers as habitable structures and also quantify the effectiveness of earth sheltering as method of improving the thermal performance of a shipping container. The literature review undertaken for this work, documented in the following chapter, covers four areas of this research - Shipping Containers, Policies, Procedures and Approval of Shipping Container Structures, Green Roofs and Earth Sheltered Structures. The literature review revealed thorough documentation of alternate uses for shipping containers however very little on the process of construction and approval. Conclusive experimental results exist, regarding the effect of green roofs, however only theoretical literature exists regarding earth sheltered structures. The combination of approval documentation and experimental analysis of an earth sheltered shipping container in a temperate Australian climate make this a unique body of work, adding value to the engineering body of knowledge.
7 Literature Review

7.1 Shipping Containers

Shipping containers were designed to improve the quality and efficiency of naval vehicular transport in the 1950s (Levinson, 2010). Since then, a broad range of applications have been found for these containers outside their original purpose. Chin and Lak (World News Australia (SBS Television), 11 January 2014) reported “A growing number of people are thinking outside the box and giving containers a new life as houses, spas and even restaurants. Almost indestructible, easy to move by truck, train or ship. The standard steel container is getting a new lease on life”. Innovative research undertaken by Giriunas et al. (2012) aimed to document the structural capabilities and limitations of shipping containers using finite element analysis, stating the research’s main objective as “to develop structural guidelines for International Organization for Standardization (ISO) shipping containers used for non-shipping applications”. Despite this research, Bernardo et al. (2013) stated that quantifying the structural capabilities and requirements of refurbished shipping containers is not easy, however their suitability as construction modules for buildings cannot be denied.

Gorey (National Nine News (Nine Melbourne), 16 February 2009) reported the success of earth sheltered shipping containers as fire bunkers, detailing a Clonbinane family who survived severe bushfires by taking refuge an earth sheltered shipping container on their Queensland property. Ritchie (ABC News Victoria (ABC1 Melbourne), 3 December 2013) outlined the potential for shipping containers to help counter prison over population in Victoria. Harmsen (ABC News SA (ABC1 Adelaide), 6 May 2011) echoed these sentiments, detailing the use of use of shipping containers for permanent low security prisoner accommodation in Australia, Germany and New Zealand, also noting their use for miner accommodation in Western Australia and student accommodation at Australia’s National University, Canberra. Harmsen (ABC News SA (ABC1 Adelaide), 6 May 2011) cited the cost effectiveness and speed of construction of shipping containers as the rationale for their use stating “A tradition cell block can cost half a million dollars per cell, the modular option costs just seventy thousand dollars and can be built in half the time”. Dirksen (2011) also cited the cost effectiveness and speed of construction as benefits of using shipping containers
Vijayalaxmi (2010) explored the notion that because shipping containers have a very high embodied energy they must be recycled to maintain ecological sensitivity, promoting the process of recycling more so than the use of the shipping containers themselves. In agreeance, Butera (2013) wrote “Embodied energy minimization should be an integral part of a ZEB; the day is not far when this theme will be subject to mandatory regulations”. Vijayalaxmi (2010) also researched the thermal performance of a Greentainer⁴ saying “the thermal performance of the naturally ventilated Greentainer is in no way inferior to that of the conventional building of its size”, noting a two hour lag between the conventional buildings maximum temperature and the containers.

Container structure aesthetics are often considered to be plain, industrial and undesirable. An article written by Rapley (2014) voiced critical opinions of the spacial dimensions of shipping containers and their ability to comply with the Building Code of Australia. The issue of negative public opinion is not exclusive to shipping container structures, but many eco-friendly designs. To help combat this, Benardos et al. (2014) attempted to create a paradigm for an eco-friendly earth sheltered structure that is also architecturally contemporary, bringing it to the fore of public perception by marrying practicality and innovation.

7.2 Policies, Procedures & Approval of Shipping Container Structures

Earth sheltered structures and recycled shipping container structures are uncharacteristic in Australia, causing issues with compliance from relevant government bodies. Tavares and Martins (2007) emphasised a conservative approach to predicting a buildings energy efficiency helped gain local government support in the design of a sustainable town hall in Portugal. NSW government regulation requires that all new habitable structures must comply with the BASIX and have supporting documented evidence, submitted with the development approval. The NEC shipping container was considered non-habitable negating the requirement for this standard to be met.

---

⁴Pre-clad and insulated shipping container modular building unit
Bernardo et al. (2013) outlined the issues related to receiving approval for structural alterations to shipping containers, citing the lack of data regarding the geometric properties of some materials used in shipping containers as the major factor in impeding approval. The construction works to earth shelter the shipping container at the NEC did not involve any structural alterations to the shipping container, so these issues were not encountered.

Albury City Council requires a development application to be lodged for any structure that is to be built. This document outlines the extent of work to be undertaken and the resulting short and long term implications on the environment and community. The application is assessed against, and approved or declined accordingly, a list of criteria from the Albury Local Environmental Plan 2010 (Albury City Council, 2010a), the Albury Development Control Plan 2010 (Albury City Council, 2010b) and the Environmental Planning and Assessment Act 1979 (New South Wales State Government, 1979). For habitable and non-habitable structures, the development application form asks for the structure’s location in relation to bushfire prone land, the flammability of the structure, the structures aesthetics from the street, the assessment of environmental impacts and the planning in place to minimise these impact’s along with engineering drawings showing compliance with any relevant structural building and loading codes of Australia.

### 7.3 Earth Sheltered Structures

Earth sheltered structures use massed earth against some or all of the external facades to increase the structures thermal mass and improve habitability. This ancient building method, originally born of necessity (Anselm, 2008), has seen a revival in the 21st Century in the wake of rising awareness of resource scarcity (Brown et al., 2014). Academic research into earth-sheltered structures is focused on quantifying the effect of influencing factors. A holistic paper written by Anselm (2008) was concerned with the passive annual heat storage principles in earth-sheltered housing and their historical context.

Unlike any other literature reviewed, Anselm (2008) compares the effect of varying percentages of the structures external surfaces having a thermal interface with massed soil, stating the greater the percentage of faade in contact with the earth the better

---

5Section 79C
the passive annual heating and cooling gains. Research conducted by Staniec and Nowak (2011) focused on the effect of the surrounding soils thermal diffusivity on the structures heating and cooling energy demand in winter and summer, echoing earlier research by Campbell et al. (2007) detailing the influence of air and water on the soils thermal properties.

The overwhelming motive for earth sheltering structures is to reduce their heating and cooling energy demand, van Dronkelaar et al. (2014) completed a sensitivity analysis, considering a broad range of input parameters, validating this reasoning, stating “Uncertainty analysis of the results shows that in most cases, the worst underground building performs better than the best above-ground building” noting that the effect of differing ground depths (2m, 5m and 10m) was negligible.

Martin Freney and Williamson (2013) used modelling to compare an Earthship’s thermal performance in Taos, New Mexico to Adelaide, South Australia, stating “In a Mediterranean climate such as Adelaides, the simulations give confidence that homes built according to the Earthship principles, and especially where a berm and greenhouse is employed, would provide thermal comfort conditions with, essentially, energy”. Earth sheltering is only one of the principles used by Earthships to increase thermal efficiency but this statement supports earlier research into the potential for earth sheltered housing to combat energy consumption in hot arid areas (Khair-El-Din, 1983).

In this paper, I focus on the feasibility of earth-sheltered shipping containers to be used as modular living units. The effects of the soil type, depth and properties will essentially be considered negligible (van Dronkelaar et al., 2014). However it will be appreciated that the test container would yield greater passive heating and cooling gains if all facades were earth sheltered (Anselm, 2008).

### 7.4 Green Roofs

Green roofs are those which are covered in a waterproof membrane, growing medium and vegetation, providing aesthetic and insulative improvement of the building, green roofs are a common feature of environmentally conscious structures. Research into

---

6 Registered trademark by Michael Reynolds referring to a passive solar house model
7 Graded earth mound at structures rear, immitating the effect of a cut into the earth
the benefits of green roofs has followed several paths. Hopkins and Goodwin (2012) documented the variance in insulative properties of green roofs having differing media depths. Complementing earlier research by Celik et al. (2011) which focused on green roofs thermal insulation performance, relative to the growth medium and vegetation used.

The correlation between thermal diffusivity and a soils insulative properties is summarised in research conducted by Staniec and Nowak (2011). Sun et al. (2014) published findings showing that along with an appropriate growing medium, an optimal growing medium depth must also be considered. To provide optimal thermal performance, the growing medium must thick enough to provide insulative benefit but not so thick that it holds pooled water. Completing a cost benefit analysis, their research also found that outside of extremely efficient air conditioning systems being compared to near constant irrigation “the results show higher costs associated with increased use of the air conditioning system for an un-irrigated roof, compared to the irrigation costs”.

Berardi et al. (2014) gave a broad analysis of the environmental benefits of green roofs, noting the higher potential for environmental benefits in retrofitted green roofs than green roofs being used in the construction of new energy efficient structures. Earlier research revealed that retrofitted green roofs were much more feasible in a suburban setting than in the Melbourne CBD, due to the negative impact over-shadowing large buildings have on smaller buildings in the CBD (Wilkinson and Reed, 2009). Hopkins and Goodwin (2012) and Berardi et al. (2014) both noted other environmental benefits of green roofs including reduction of the urban heat island effect, mitigation of air pollution and increased habitat for local wildlife. As stated by Lundholm et al. (2010) “green roofs do indeed add biodiversity and provide ecological value equal to that of ground gardens”. Suehrcke et al. (2008) researched the effect of the roofs solar reflectance on the buildings heat gain in a hot climate, focusing on the solar absorptance values of different roof colours in a typical Australian climate.

The container is located at the Riverina Institute of TAFE, NEC, certified organic farm site in Thurgoona. The farm teaches permaculture and a sensitive approach

---

8The retention of heat in a city’s large thermal mass, and slow release at night, increasing the natural temperature of that environment at night
9Environmentally sensitive approach of living and farming
was required during construction. I have partnered with permaculture student James Anderson throughout this project. James is interested in sustainable living and has agreed to complete the design and construction of the green roof for this dissertation. The green roof will be designed and constructed using permaculture methodology and will form the body of work for Adam’s major final project, after which he will ascertain a Certificate IV in Permaculture. The green roof is a long term project and will not be completed by the time this dissertation is written and presented. However, James has agreed to help improve the thermal performance of the container using recycled insulation and facades in-keeping with the permaculture ideology. This paper focuses on the thermal benefits of a green roof on a shipping container, however it is hoped that wide variety of benefits arise from this roof including habitat for endemic species and an environment to grow and harvest produce.

7.5 Conclusions Drawn From Literature Reviewed

From the literature reviewed it can be seen that the methods and processes that this dissertation aims to research have been verified as feasible and effective, however little numerical evidence has been published quantifying their effects, in particular earth sheltering in warm climates, and no investigations undertaken regarding the approval process for shipping container structures in Australia exist.
8 Research Design & Methodology

8.1 Resources

8.1.1 Resource Requirements

Below is a list of resources that are required, and have been obtained, for the completion of this project:

- Intermodal container (20 ft high cube shipping container)

- Appropriate location for works

- Retaining structure

- Machinery and labour

- Data logging thermometers

8.1.2 Shipping Container

The NEC had three existing shipping containers they used for storage at their organic farm. They allowed me to use one of these container for my research. The container I chose was a green 20 ft long 8 ft wide by 8 ft tall high cube container (6.096m * 2.438m * 2.438m). It was well worn and had some holes in the walls and roof.

Figure 1: Contour Map of National Environmental Centre
8.1.3 Work Site

As the container would be used in the future by the NEC, the construction and research took place on site at 94 Ettamogah Road, Thurgoona 2640. The container was cut into a mound that had initially been formed for four wheel drive driver training but was now being used as a race to get pigs off and on vehicles. A livestock run to the East side of the mound, and a marsh to the South side used to practice four wheel drive creek crossings dictated the containers final position, which was on the north side of the mound, with the long face of the container facing North.

8.1.4 Retaining Wall

According to state guideline Subdivision 15 of State Environmental Planning Policy (Exempt and Complying Development Codes) 2008, any excavation greater than a depth of 600mm requires a retaining structure. Meaning a retaining wall was required for the development application to be approved. Rocla kindly donated eleven Massbloc units, each weighing 1.8 tonnes, so the project could go ahead. These were placed in two rows, six on the bottom and five on the top to retain the earth behind the cut.

Figure 2: Rocla Massbloc Unit Retaining Wall
8.1.5 Machinery & Labour

A KOMATSU PC-200 excavator was brought to the site on a float trailer and operated by truck driver throughout construction. A bitumen emulsion flocon, with two operators was used to spray seal the container. A truck and dog configuration was used to transport the Rocla Massbloc units, this was required due to the nearly 20T load, the driver was a qualified dogman and he helped place of the Massblocs and the container. A 20T franner crane and operator was hired to lift the Massblocs from the trailer, place them in the cut and transport the container 100m to the construction site.

Figure 3: Franner Crane Unloading Massblocs from Truck and Dog

8.1.6 Data Logging Thermometers

Three RC-4 Digital USB Temperature Data Logging Thermometers were purchased to analyse the thermal performance of the earth sheltered container. These units are designed for temperature recording during storage and transport of sensitive items making them ideal for this project. These units were calibrated against a more accurate temperature recording unit so their inherent inaccuracy could be quantified, this is covered in Section 8.35. The RC-4 specifications are listed below:
8.2 Methodology

8.2.1 Planning & Construction

The major construction works were completed over five hours on the 15th of May 2014. An excavator operator brought a KOMATSU PC-200 excavator on a float trailer to the NEC and began excavation of the pre-marked site. During this early excavation a bitumen emulsion flocon truck was coordinated to spray the faades of the container that would be in contact with fill with a bitumen emulsion. The purpose of this was two fold, the emulsion helped seal and waterproof container, whilst painting the container was a requirement of the development application (Albury City Council, 2010b). Approximately 250L of bitumen emulsion were sprayed onto the container. The construction plans provided indicated that the two faces in contact with soil were to be sprayed with the bitumen emulsion, unfortunately the north facing long side was also sprayed. This resulted in the face with the most exposure to the sun being black, heavily increasing its heat absorption potential. Repainting was considered, but eventually decided against in-keeping with the permaculture philosophy of making do with what you have. The black north face will provide radiant heat in winter, helping to heat the side in cut. The container was left to dry whilst the site excavation continued. The spraying and drying of the container had to be completed in a designated area of the NEC that wasn’t organically certified, due to the chemicals being used.

When the excavation reached a suitable depth and was level the placement of 300mm
thick uncompacted base was laid in place. Millings\textsuperscript{10} from a recent runway apron upgrade at the Albury Airport were recycled for this base material. The millings were left uncompacted to aid the flow of water away from the container site. While the base was being placed and levelled by the excavator, a truck and dog picked up eleven Rocla Massbloc units, each weighing 1.8 tonnes. A franner crane was used to unload the Massblocs one by one and then placed at the back of the cut to retain the earth. The Massblocs were placed in a row of six on the bottom and a row of five on top. The Massblocs have a lip at the bottom which means a trench had to be dug in the sub-grade to allow them to sit flat, and also means that the face of the top row was set back approximately 150 mm from the face of the bottom row.

![Image of excavator and container]

Figure 5: Earth Sheltered Container from North East Face

The dry container was then moved by the franner crane and placed into position, 100 mm from the nearest edges of the cut and Massblocs. The gap around the container was then backfilled with 7 mm stone and then capped with some of the earth excavated from the site earlier.

\subsection{8.2.2 Data Collection}

Three RC-4 Digital USB Temperature Data Logging Thermometers were purchased to record temperature data throughout the length of the research project. One RC-4

\textsuperscript{10}Asphaltic millings, the fine particle bi-product of pavement milling
was placed outdoors to record an ambient temperature, it was given a weatherproof housing and placed in a tree approximately 100m from the earth sheltered container. Another RC-4 was placed in a control container that was not altered throughout the data collection period yielding a datum for shipping container internal temperature and how this relates to outdoor temperature. The final RC-4 was placed in the container which was earth sheltered giving a comparison between indoor and outdoor temperature whilst quantifying the effect earth sheltering had on the containers thermal performance. The RC-4 units were calibrated before being positioned to ensure all data being recorded was relative. A five minute recording interval was used on all RC-4 units throughout the dissertation.

8.3 Risk Assessment

8.3.1 Dissertation Risk Register

A risk register was created to quantify the initially identifiable risks associated with this project. In the Tables 1 and 2, risks are identified and then described. After this a numeric value "P" is given, rating the probability of the risk eventuating, out of five. A numeric value "I" is given, rating the impact of the risk if it eventuated, out five. The probability and impact values are multiplied to give a "R" value which represent the risk rating. These risk ratings are then order from highest to lowest, indicating their priority, which is represented by "Pr". This process allows those risks with the highest potential impact to be addressed with more detail. The four highest ranking risks were addressed with IRAs. The final column, "S" is the status of the risk in the register, "O" is indicative of an open risk, or one that is still being or still could be encounter. A "C" in this final column indicates that at the current of the project this risk is closed and will not be encountered or has been encountered and the contingency plan has been actioned.
<table>
<thead>
<tr>
<th>#</th>
<th>Risk</th>
<th>Risk Event Description</th>
<th>P</th>
<th>I</th>
<th>R</th>
<th>Pr</th>
<th>Treatment</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Slips and Trips (Construction)</td>
<td>Slips and trips caused by mud, plants, timber, rocks, uneven ground or fencing wire around site</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>10</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>Plant Causing Injury (Construction)</td>
<td>Personal injury caused by truck and dog, franner or excavator</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>15</td>
<td>Follow ACC</td>
<td>C</td>
</tr>
<tr>
<td>3</td>
<td>Pedestrian Movement (Construction)</td>
<td>Pedestrians can be expected at the site as it is a working farm, heightening the chance or risks 1 and 2</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>8</td>
<td>Follow ACC WSRAT</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>Cuts and Abrasions (Construction)</td>
<td>Cuts and abrasions caused by the uneven surface or plant and machinery in use</td>
<td>3</td>
<td>3</td>
<td>9</td>
<td>11</td>
<td>Follow ACC WSRAT</td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>Endangered Species</td>
<td>Evidence of endangered species will require site survey and recommendations from authorities, before sensitive redesign</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>19</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>6</td>
<td>Aboriginal Relics</td>
<td>Evidence of aboriginal relics will require site survey and recommendations from authorities, before sensitive redesign</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>17</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>7</td>
<td>Unapproved Development Application</td>
<td>Potential for development application not be approved due to failure to meet one of many critical criteria</td>
<td>3</td>
<td>5</td>
<td>15</td>
<td>3</td>
<td>See IRA</td>
<td>C</td>
</tr>
<tr>
<td>8</td>
<td>Failure to Secure Sponsorship</td>
<td>Failure to secure sponsorship for the container, labour and materials is detrimental to experimental aspect of this research</td>
<td>4</td>
<td>5</td>
<td>20</td>
<td>1</td>
<td>See IRA</td>
<td>C</td>
</tr>
<tr>
<td>9</td>
<td>Computer Program Faults</td>
<td>Glitches and bugs in programs leading to crashes, and frustration from designer, increasing the time to complete project</td>
<td>4</td>
<td>2</td>
<td>8</td>
<td>12</td>
<td>Accept Risk</td>
<td>O</td>
</tr>
<tr>
<td>10</td>
<td>Unlocated Services</td>
<td>Unlocated services, or incorrectly located services, may lead to a redesign</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>18</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>11</td>
<td>Falling Behind Timeline</td>
<td>May lead to failure of ENG4112, short term lags lead to increasing stress and pressure to complete work in other areas</td>
<td>4</td>
<td>3</td>
<td>12</td>
<td>5</td>
<td>Accept Risk</td>
<td>O</td>
</tr>
<tr>
<td>12</td>
<td>Inaccurate Data Loggers</td>
<td>Inaccurate data will provide false relationship between interior and exterior temperature</td>
<td>3</td>
<td>4</td>
<td>12</td>
<td>6</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>13</td>
<td>Data Logger Failure</td>
<td>Whether by battery fault or inclement weather, gaps in data will make that period ineligible for analysis</td>
<td>4</td>
<td>4</td>
<td>16</td>
<td>2</td>
<td>See IRA</td>
<td>O</td>
</tr>
<tr>
<td>14</td>
<td>Unreliable Data</td>
<td>Accuracy of data is critical for credible research to be undertaken</td>
<td>2</td>
<td>4</td>
<td>8</td>
<td>13</td>
<td>Accept Risk</td>
<td>O</td>
</tr>
</tbody>
</table>

Table 1: Project Risk Register Part I
<table>
<thead>
<tr>
<th>#</th>
<th>Risk Event Description</th>
<th>C</th>
<th>I</th>
<th>R</th>
<th>P</th>
<th>Treatment</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>Work Reliant on Others Being Delayed</td>
<td>5</td>
<td>3</td>
<td>15</td>
<td>4</td>
<td>See IRA</td>
<td>O</td>
</tr>
<tr>
<td>16</td>
<td>Construction Plans Not Being Followed</td>
<td>3</td>
<td>4</td>
<td>12</td>
<td>7</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>17</td>
<td>Insufficient Site Drainage</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td>9</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>18</td>
<td>Detrimental Massbloc Unit Faults</td>
<td>1</td>
<td>5</td>
<td>5</td>
<td>16</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>19</td>
<td>Permaculture Measures Do Not Work</td>
<td>2</td>
<td>3</td>
<td>6</td>
<td>14</td>
<td>Accept Risk</td>
<td>O</td>
</tr>
<tr>
<td>20</td>
<td>Contaminated Soil</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>20</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
<tr>
<td>21</td>
<td>Poor Sub-grade</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>21</td>
<td>Accept Risk</td>
<td>C</td>
</tr>
</tbody>
</table>

Table 2: Project Risk Register Part II

8.3.2 Individual Risk Assessments

Risk: Failure to Secure Sponsorship

Rating: 20

Description: Securing donation of the shipping container, construction plant, construction labour, appropriate land and retaining wall unit are detrimental to this project. Failure to do so will result in no experimental data and change the scope of the dissertation completely.

Response: Meet with town planners from ACC at the earliest possible time to clearly outline the scope of works required to receive approval for a development application. After this time write formal letters to appropriate managers with regards to the donation/sponsorship of this project.

Contingency Plan: If donations and/or sponsorship cannot be secured, contact project supervisor at earliest possible time to discuss the possibility of a theoretical research based dissertation on a similar topic.

Risk: Data Logger Failure
Rating : 16
Description : The possibility exist that at some point throughout the project one or all of the RC-4 units will fail. Whether by loss of power due to battery failure, overheating or water damage. This could potentially cause large gaps in the data and make comparisons for that period of time impossible.
Response : Regular checking of the data logging units will help reduce the risk of lost data. Also providing weather proof housing for the outdoor unit will reduce the reduce of storm related damage.
Contingency Plan : Calibrate a RC-4 unit against Ross Wheelers force aspirated triple semi-conductor unit so outdoor temperature data can be used from his station if failure of the outdoor unit occurs.

Risk : Unapproved Development Application
Rating : 15
Description : The stringent nature of the criteria which must be met for the development application to approved may cause issues, particularly with the time required for alterations and resubmissions to be assessed.
Response : By meeting town planners at the earliest possible time and making the scope of the project known to them, this risk should be heavily reduced. Also, prepare a thorough set of construction plans and details of the Rocla Massbloc units to be used for the retaining wall.
Contingency Plan : Some flexibility in the design is required so any point of issues that town planners may have could potentially be mitigated by design alterations.

Risk : Work Reliant on Others Being Delayed
Rating : 15
Description : Many aspects of this project require the help or input of other people, this reliance on others increases the potential for project tasks to exceed their allocated time allotments.
Response : By making deadlines known to all involved at the earliest possible time will help mitigate the risk of excessive time delays. Also reduce the reliance on others where ever possible by completing work unaccompanied.
Contingency Plan : Due to the nature of donated time and work, time delays may have to be politely dealt with, however, where possible other avenues will be explored to see late tasks completed as soon as possible.
8.3.3 Risks Associated with Planning & Approval

The ACC development approval form identified several risks inherent to the design that had to addressed before construction could begin. These were the bushfire risks associated with the structure, the public perception of the structures aesthetics, the requirement of a retaining wall and the environmental impact of the project. All of these risks were considered to be adequately addressed in the design by ACC town planners. The land on which the NEC is located is owned by the NSW State Government, and the signature of the lands owner is required on a development application. In this case, the signature must belong to the State of NSW’ Education Minister, and it was deemed the head teacher of the NEC did not have adequate authority to sign such a document. Hence the initial development application did not receive approval. After liaising with the town planning department and the Riverina Institute of TAFE, it was agreed that the institutes campus operations manager had the requisite authority to approve the works. Subsequently a second development application was lodged and approved.

8.3.4 Risks Associated with Construction

The construction work required for this research to take place involved significant excavation work. A dial before you dig request was lodged before work could begin. There were no major services located in the area and work could proceed without any further location work required. In addition to this, before any survey or construction work could begin a broad risk assessment had to be made, according to ACC policy. ACC utilises a generic risk assessment form to assess risks before work begins. This rubric is called a WSRAT,and is modified for to each individual job undertaken by council. The document identifies hazards associated with each individual aspect of the work, the risks associated with these hazards and the precautions that have been taken to nullify or reduce these hazards. The work site risk assessment template document created for, and used throughout this project, can be found in Appendix E. None of the construction risks identified in the risk register or the WSRAT were realised.

8.3.5 Risks Associated with Data Collection & Research

All analysis of the thermal performance of the shipping containers relies on data collected by RC-4 units. It is assumed that units are adequately accurate and will
give a fair indication of the temperatures of the environments they are in, however it is appreciated this may not be entirely true. To ensure that the data is all comparable the units will be recalibrated throughout the project. The containers being analysed are in constant use by NEC and the opening and closing of these containers will have adverse affects on the data obtained from the RC-4 units. To minimise the effect of temperature fluctuations due to the opening and closing of the container doors, the teachers at the NEC have been informed of the problem and have kept the doors shut at all possible times, not leaving them open for long periods. The thermometers have been placed as far away from the door as possible to minimize any small fluctuations due to the doors periodically opening and closing.

As a calibration measure, the RC-4 unit was placed next to a force aspirated logging unit, as a control comparison. From Figures 6 and 7 it can be seen there is a strong correlation between the two data logging units, with or without the fit applied to the data. The force aspirated triple semi-conductor temperature logging unit measures the voltage drop across three forward biased P-N junctions, which have a linear relationship with temperature variations, and averages their output temperatures. The semi-conductors are housed in two ventilated PVC pipes, a brushless DC motor with a tangential fan attached, slowly draws air vertically over the semi-conductors, housed inside two well ventilated white PVC pipes, to maintain constant movement of air through the unit.

The RC-4 unit has a steel sleeved probe that houses a thermistor, which measures temperature with a NTC resistor, which also has linear operating region which closely correlates to the scale that measures degrees. The results from the two loggers had a very close correlation, however when solar radiation exceeded 100 $w/m^2$ a noticeable gap between the loggers formed. This represents solar radiation warming the steel sleeve housing the thermistor of the RC-4, faster than it can in the shaded and ventilated force aspirated unit. As clouds pass between the sun and the steel sleeve its temperature quickly fluctuates accordingly, unlike the force aspirated unit which doesn’t detect these small fluctuations and only records steady changes. The noisy data recorded by the RC-4, particularly when solar radiation exceeds 100 $w/m^2$, has been fitted\textsuperscript{11} using a fifteen minute moving average and a reduction constant of .15°C at all times. The effect of solar radiation was that when solar radiation exceeded 100

\textsuperscript{11}A trial and error approach was used to fit these data sets
\( \text{w/m}^2 \), the temperature recorded was reduced by \( \text{SolarRadiation(w/m}^2) / 400 \). This calibration took place on the 9\textsuperscript{th} - 11\textsuperscript{th} of September.

**Figure 6:** \textit{RC-4 vs Force Aspirated Triple-Semi-Conductor Comparison}

**Figure 7:** \textit{Effect of Solar Radiation on Variation Between Logger}
Figure 8: Fitted RC-4 Data and Row Force Aspirated Unit Data
9 Results & Discussion

9.1 Initial Results

An initial data collection period from January through to March was used to record summer temperature data, calibrate the thermometers, experiment with the data output and computation of results. The RC-4 units came with software for data presentation, however it only offered limited data analysis options. To better analyse the data, and improve the graphing flexibility, a MATLAB\textsuperscript{12} script that would take the raw data from a .txt file, convert the date and time data and store the temperature data in corresponding matrices. This script can be found in Appendix F.

In this initial period, the container that was to be earth sheltered was positioned near the control container, orientated the same direction however with two gum trees overshadowing the container. This simple variable yielded interesting results that can be easily seen in the MATLAB output. In Figure 9, the temperatures of the two containers, along with the outdoor temperature, have been plotted for comparison. It can be seen that the shaded container had significantly lower maximum daily temperatures, however the daily minimums were very similar. Another influential factor which must be considered is the colour of the container, the shaded container, that was later buried, was a light green colour while the unshaded container was red, the effect this variable has will not be quantified in this dissertation. It must also be mentioned that containers were regularly being opened and closed during the data collection period.

The outdoor temperature data stops abruptly due to the RC-4 unit becoming dislodged from its location in a nearby tree and falling victim to rain water and frost. A replacement RC-4 unit was ordered as soon as this was realised and an effort made to find a reliable source of replacement data. As this risk was anticipated in the Risk Register, the contingency plan, outlined in the IRA Section 8.3.2, was put into motion.

\begin{table}[h]
\centering
\begin{tabular}{|l|c|c|c|}
\hline
RC-4 Unit & Average Min Temp & Average Max Temp & Average Temp \\
\hline
Shaded Container & 17.255 & 39.147 & 26.410 \\
Unshaded Container & 16.500 & 47.644 & 28.669 \\
\hline
\end{tabular}
\caption{Comparison of Results - Data Prior to Construction}
\end{table}

\textsuperscript{12}Numerical computing program and programming language
Figure 9: Temperature Comparison Prior to Works
9.2 Approval

9.2.1 Process

The main requirements that needed to be met for development consent to be given by council were:

- Signed consent for construction by the owner of the land
- That the container be painted, so as to be aesthetically pleasing
- That the container be non habitable
- That a retaining structure be placed in the cut, as it exceeded 600mm
- That container not be a fire hazard

All these requirements were easily met, except gaining the signed consent for construction by the owner of the land. Originally the head teacher at the NEC had signed the development application, however legally the land is owned by the NSW Education Department, and as such the owner of the land was deemed to be the NSW Minister of Education. After meeting with ACC and TAFE staff members an agreement was made, stating that the Riverina Institutes property manager could sign the development application allowing work to begin. A copy of the development application can be found in Appendix D.

9.2.2 Town Planners, Building Inspector and Certifiers Perspective

Due to the nature of the construction work, no further council approval was required for work to begin. However, an inquiry was made regarding the approval requirements if the works were associated with a habitable structure comprised of multiple structurally altered shipping containers. Consultation with ACC town planners and building inspectors revealed that after the conceptual approval and development consent, the structure would require the same structural engineering documentation as any other residential development to receive a construction certificate; along with an additional report with relevant supporting evidence demonstrating how performance requirements are met for each component of the building. This additional report is required to satisfy the BCA because, the reconfiguration of of shipping containers for a residential purpose is considered an alternative solution under the different pathways available to comply. According to the BCA a building can comply with
the performance requirements by either being compliant with the “Deemed-to-Satisfy Provisions; or formulating an Alternative Solution” Australian Building Codes Board (2014). This additional report would have to be prepared by a suitably qualified architect, building designer or suitably qualified building consultant. In summary to gain a construction certificate the three documents listed below are required, the third, being the additional report is the only one unique to a habitable modified shipping container structure. Under each of these three headings, the matters addressed in the document are listed:

- **Development Consent**
  - Conceptual approval
  - Zoning
  - Appearance
  - Setbacks and easements
  - Building height
  - Site cut and/or fill
  - Owners consent

- **Structural Engineers Report**
  - Wind loading and bracing design
  - Footing design to transfer anticipated loads to foundations
  - Any rectifications or additional strengthening that may be required for structural soundness after container modification for doors, windows, roof etc.
  - Details on any attached structures such as outbuildings that may be directly attached to the shipping containers
  - Details on any staircases associated with the structure
• Additional Report Addressing BCA Requirements
  - Buildings structure (covered in aforementioned structural engineers report)
  - Damp and weatherproofing
  - Fire safety
  - Health and sanitary amenities
  - Safe movement and access
  - Energy efficiency, covered by BASIX certificate

Figure 10: Approval Process for Habitable Modified Shipping Container Structures

9.2.3 Structural Engineers Perspective

From the policies and approval process, outlined in Section 9.2.2, it can be seen that a structural engineer must be employed to oversee the design and plans of alternative solutions to the BCA performance requirements. No structural alterations were made to the container during the work completed for this dissertation, meaning no input from a structural engineer was required. However, as this is a vital aspect to constructing habitable structures comprised of structurally modified shipping containers, an inquiry was made with a local structural engineer, Neil Wright (B.E (Hons) MIE Aust CPEng NPER RBPV RBPQ), as to the considerations that a structural engineer was make when dealing with shipping containers. A perception exists, in some forums, that gaining a structural engineers approval for modified containers is difficult because they are, to an extent, an unknown quantity, with some comments indicating that it is only easy in far North Western Australia, due to local structural engineers familiarity with them in the use of miner accommodation. Neil indicated that the use of shipping containers as structural elements is becoming more common, and the fact that despite their country of origin, most containers are formed from 350 - 450 MPa steel, allows them to be analysed as structural elements.
A standard exists regarding Freight Containers, AS3711 (Standards Australia, 2000), however this does not cover any loading or capacity standards, so Neil suggests the use the of Steel Structures Standard AS4100 (Standards Australia, 1998) to analyse and design modified shipping containers. As the containers become altered and the walls (or plates) structural integrity is compromised design considerations must be made to maintain the structures stability. Typically this structural analysis and design can be completed two ways. The first method and the most common is using the mathematical design of stiffening members to transfer loads from the containers top steel frame to the base, negating the need to consider the walls in the analysis. The second method is finite element analysis using computer software to analyse the shipping container as alterations are made to it, to see the effect and effect of proposed strengthening members. This is akin the method proposed and outlined by Giriunas et al. (2012). It was indicated that using the finite element method could cost up to $4000\textsuperscript{13} for the analysis of one container, in the vicinity of double what the aforementioned cheaper method would cost. The finite element analysis method would be reserved only for critical structural units in multi story residential structures or building designs that are going to be replicated and built multiple times. The depth of analysis and structural design is determined by the inherent risk in the structure and its design purpose.

It was acknowledged that new containers were preferable for habitable structures, however if a used container could be inspected by the structural engineer, be wire brushed and painted, they could potentially be used in the structure also. The two major issues noted by the structural engineer were:

- The requirement of adequate ventilation or dehumidification units to reduce problematic condensation in the container. The roof height and shape of the container make it difficult to design flashing and ventilation units for these structures

- If the container is in a coastal environment, considerations must be made to protect it from accelerated oxidisation

\textsuperscript{13}Australian dollars ($AUD)
9.3 Earth Sheltering

9.3.1 Initial Data Collection

Following the completion of the construction work, the two remaining RC-4 units were placed back in their respective containers to begin logging temperature data again. Replacement outdoor temperature data was obtained from the force aspirated unit used to calibrate the RC-4, covered in Section 8.3.5. A comparison of these three data sets is shown in Figure 11, on the following page. Upon collating the data, it was immediately obvious the data obtained from the force aspirated unit was not relatable to the container temperatures. In Figure 11 it can be seen that the containers have consistently lower minimum nightly temperatures. The difference in the temperatures must be credited to the different locations of the thermometers as they had been calibrated at the same location (the station at which the force aspirated unit is posted), and yielded closely correlated data sets. The force aspirated unit was located 4500m to the West of the NEC and at an elevation 107m greater than the RC-4 unit. Unfortunately, this was not the only data, recorded between the 2nd of August and the 11th of September that had to be disregarded.

After talking to staff at the NEC, it became apparent the control container had been left wide open for long periods to air out odours, and the earth sheltered container had also periodically been open and closed, and eventually the RC-4 unit inside had been accidentally removed. These three factors rendered this data unreliable and made it unviable to draw any major conclusions from the data sets. The straight line that is visible in the outdoor temperature dataset from the 8th to the 11th of September indicates an empty portion of the data and must be ignored. This straight joins the data retrieved from the force aspirated unit to data recorded by the replacement RC-4 unit, which was received around this time. This data was included in Figure 11 to show the difference between the two outdoor temperature recording devices, due to location, emphasising that the replacement data was invalid.
Figure 11: Temperature Comparison After Construction, Problematic Data
9.3.2 Effect on Temperature

Upon receipt of the replacement RC-4 unit, and the construction of an appropriate weather-proof housing, signs were made indicating that the doors to the two containers must be kept shut whenever possible so reliable and examinable data could be recorded. The resulting datasets are shown in Figure 12. It must be noted that, for clarity, the effect of day light savings has been omitted from the y-axis.

The control data set yielded more consistent and reliable data. The average, average twenty-four hour maximum and average twenty-four hour minimum temperatures are recorded in Table 4. The spike in outdoor temperature that can be seen on the 17th of September was caused by the probe from the RC-4 being used to conduct the survey of face temperatures which can be found in Section 9.3.3. Overall it can be seen the earth sheltered shipping container had a higher average minimum temperature than the control container but also had a much higher average maximum temperature. The reason for this is the black, unsheltered, north-facing side. To isolate the effect of earth sheltering from other influencing factors further investigation was required.

The containers thermal mass dramatically increased when it became earth sheltered, and generally this has the effect of opposing the solar radiation heat gain. The Massbloc units and stone fill at the back of the container in the cut will theoretically act as a heat bank, releasing heat when it is cold and cooling when it is warm. This theoretically should create a lag between the indoor and outdoor temperatures, relative to the amount of thermal mass. However no discernible lag is noticed between the two shipping containers. It can be concluded that any lag that does theoretically exist is countered by the high thermal conductivity of the steel and the 5 minute time recording period is too large to capture this.

<table>
<thead>
<tr>
<th>RC-4 Unit</th>
<th>Average Min Temp</th>
<th>Average Max Temp</th>
<th>Average Temp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td>5.268</td>
<td>25.259</td>
<td>13.477</td>
</tr>
<tr>
<td>Control Container</td>
<td>7.968</td>
<td>28.985</td>
<td>17.019</td>
</tr>
<tr>
<td>Earth Sheltered Container</td>
<td>8.324</td>
<td>36.000</td>
<td>19.246</td>
</tr>
</tbody>
</table>

Table 4: Comparison of Results - Control Data

Unfortunately due to the availability of solar radiation data, the data fitting method proposed in Section 8.3.5 could not be applied to the control data in Figure 12. This is not an issue due to the clear distinction between the outdoor temperatures and those with the containers as well as the already close correlation between RC-4 unit
and the force aspirated control, evident in Figure 6.
Figure 12: Temperature Comparison After Construction, Control Data
9.3.3 Weighted Arithmetic Mean Temperature

The theoretical approach proposed by Anselm was that the internal temperature of an earth sheltered structure would be equal to the weighted arithmetic mean temperature of the structures faces. The thermal properties of the structures material was considered negligible as time was not considered in his theoretical approach. This approach suits the earth sheltered shipping container as the steel faces are extremely good conductors of heat, the five minute recording period for temperature data was too large to notice any lag between the temperature of the external face and internal face.

Anselm used an equation formed by Klaus (2003) to quantify the normal heat and cooling losses due to thermal transmittance, this was not considered in the analysis for the earth sheltered container at the NEC due to availability of data, equipment limitations and the relatively small effect these losses have on the final result. Anselm used an equation formed by Labs (1979) to estimate the subsurface soil temperatures, this was also not used in the analysis of the earth sheltered container at the NEC, due to the unknown affect that the Massbloc wall would have on the subsurface temperature. The high thermal conductivity of the containers steel faces meant that during monitoring, by taking temperatures at different heights on the earth sheltered faces a thermal gradient profile could be made and a realistic estimate made as to the average temperature of buried face. The weighted arithmetic mean temperature of the containers six faces can be defined as:

\[ \bar{t} = \frac{\sum_{i=1}^{6} t_i A_i}{A_1 + A_2 + \ldots + A_6} \]

Where \( \bar{t} \) is the theoretical temperature in the centre of the earth sheltered shipping container (°C), \( A \) is the area of one of the shipping containers faces (m²) and \( t \) is the corresponding average temperature of that face (°C).

A survey of the container face temperatures, conducted on the seventeenth of September yielded the results in Table 5;
<table>
<thead>
<tr>
<th>Face</th>
<th>Dim. (mm)</th>
<th>Area (m²)</th>
<th>Weight (%)</th>
<th>Temp (°C)</th>
<th>Weighted Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buried End</td>
<td>2410 * 2410</td>
<td>5.808</td>
<td>8.32</td>
<td>20.8</td>
<td>1.7</td>
</tr>
<tr>
<td>Door End</td>
<td>2410 * 2410</td>
<td>5.808</td>
<td>8.32</td>
<td>29.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Roof</td>
<td>2410 * 6038</td>
<td>14.552</td>
<td>20.84</td>
<td>28.9</td>
<td>6</td>
</tr>
<tr>
<td>Floor</td>
<td>2410 * 6038</td>
<td>14.552</td>
<td>20.84</td>
<td>19.8</td>
<td>4.1</td>
</tr>
<tr>
<td>Buried Side</td>
<td>2410 * 6038</td>
<td>14.552</td>
<td>20.84</td>
<td>20.9</td>
<td>4.4</td>
</tr>
<tr>
<td>Open Side</td>
<td>2410 * 6038</td>
<td>14.552</td>
<td>20.84</td>
<td>31.7</td>
<td>6.6</td>
</tr>
</tbody>
</table>

Table 5: Survey of Container Face Temperatures - September 17th

From this table the weighted arithmetic mean, or the sum of weighted temperatures, is 25.2°C. For comparison the temperature at the absolute centre of the shipping container was taken and found to be 24.1°C. As normal heat and cooling losses are not considered in this simplistic approach, and the ±1 °C accuracy of the RC-4 unit, these two temperatures are encouragingly close. Another survey of the temperatures of each face of the container was conducted on the twenty-eight of October as confirmation of the accuracy of this theoretical approach, the results are shown below in Table 6:

<table>
<thead>
<tr>
<th>Face</th>
<th>Dim. (mm)</th>
<th>Area (m²)</th>
<th>Weight (%)</th>
<th>Temp (°C)</th>
<th>Weighted Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buried End</td>
<td>2410 * 2410</td>
<td>5.808</td>
<td>8.32</td>
<td>21</td>
<td>1.7</td>
</tr>
<tr>
<td>Door End</td>
<td>2410 * 2410</td>
<td>5.808</td>
<td>8.32</td>
<td>24.4</td>
<td>2</td>
</tr>
<tr>
<td>Roof</td>
<td>2410 * 6038</td>
<td>14.552</td>
<td>20.84</td>
<td>34.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Floor</td>
<td>2410 * 6038</td>
<td>14.552</td>
<td>20.84</td>
<td>22.4</td>
<td>4.6</td>
</tr>
<tr>
<td>Buried Side</td>
<td>2410 * 6038</td>
<td>14.552</td>
<td>20.84</td>
<td>21.5</td>
<td>4.4</td>
</tr>
<tr>
<td>Open Side</td>
<td>2410 * 6038</td>
<td>14.552</td>
<td>20.84</td>
<td>27.1</td>
<td>5.6</td>
</tr>
</tbody>
</table>

Table 6: Survey of Container Face Temperatures - October 28th

From this table the weighted arithmetic mean, or the sum of weighted temperatures, is 25.4°C. For comparison the temperature at the absolute centre of the shipping container was taken and found to be 24.5°C. The strong correlation between the theoretical and actual temperatures at the centre of the container allow the effect of earth sheltering and the black painted face to better quantified. It can be seen in both surveys that the earth sheltered side and end are significantly cooler than the faces in contact with the sun.

To better represent the isolated effect of earth sheltering, temperatures were recorded at different points on the earth sheltered wall and represented in Figure 13. The results show the ground temperature gradient of the cut and how the temperature can vary greatly over an earth sheltered face. The average temperature at the top of the earth sheltered face is 26.2°C, while the average temperature at the base of earth sheltered face is 17.9°C, a differential of 8.3°C.
This data was recorded at in the morning and the effect of the sun rising in the east is clearly evident in the top left portion of Figure 13. This heat was being transferred from the much warmer East end of the roof as it was getting the morning sun. The west side of the container, which is where the doors are located, was in the container’s shadow at this time and the effect is also clear in the bottom right portion of Figure 13, yielding much cooler results. It can be assumed that in the afternoon the heat map would be mirrored.

Figure 13: Heat Map of Earth Sheltered Side, October 28th, 10:00 AM
9.4 Permaculture Alterations

Since the construction of the earth sheltered shipping container James Anderson, a student studying permaculture at the NEC, has begun work on making insulative alterations to the container. This work will further mitigate the effect the unsheltered, black, north-facing side, take further advantage of the normalising effect that the earth sheltering has on the indoors temperature and improve the thermal behaviour of the shipping container. James has been collecting recycled material throughout the year in preparation for the work. Due to the disparity that exist between the USQ and TAFE curriculum scheduling this is work is currently being completed and no experimental data is available at the time this dissertation is being written. Figure 14 shows an insulative panel that will be hung on hooks welded to the container's exterior. The panel is a pallet packed with carpet underlay and capped with roofing sheet metal. The panels are designed to be easily mounted and unmounted. This will allow for the container's protection from solar radiation in summer while the panels are in place and the container's exposure to solar radiation in winter when the panels are unmounted.

The materials that James has recycled include:

- Packing pallets
- Roofing sheet metal
- Carpet underlay
- Plastic sheet packaging
- Polystyrene
Any estimates as to the insulative effect these panels and any other future measures that made would be based on conjecture, due to the experimental nature of these techniques they will be closely monitored and results recorded at a later date.
10 Conclusions

10.1 Introduction

This dissertation documented the process of gaining approval for structures comprised of, or containing shipping containers. It simultaneously experimentally quantify the effect that earth sheltering had on the thermal performance of a shipping container.

Earth sheltering has a stabilising effect on the temperature inside the sheltered structure, constantly drawing the temperature inside the structure toward the median ground temperature for the depth of the cut. The effect of earth sheltering on the internal temperature of a shipping container was difficult to isolate and quantify from the effects of other conducive factors. These external and uncontrollable factors included monetary limitation, the scale of the construction work and the working nature of the containers being monitored; resulting in unusual solutions to the research objectives. However, the permaculture ideology embraces the process of finding solutions to problems using creative, alternative and unintrusive methods. This ideology has meant the errors and issues caused by this process have been studied and accepted as part of the dissertation’s nature, rather than being seen as research faults.

The process of gaining development approval for the construction revealed which aspects of an earth sheltered structure concerned council officers, and through further discussions with council officers and a structural engineer the scope of considerations for a habitable structure comprised of modified shipping containers was compiled.

Ultimately, the bearing, colour and lack of shade on the earth sheltered shipping container meant it was more readily exposed to solar radiation heat gain than in its previous position. However this positioning was not chosen thoughtlessly. As insulative additions are made to the container by NEC students, the bearing of the container will advantageous in winter, and the effects of this increased exposure to solar radiation in summer can be negated. Any advantage to having a large solar mass and the slow release and absorption of heat was negated by the container’s high thermal conductivity and lack of insulation, this will also be improved as insulation is added to the container. These circumstances made quantifying the effect that
earth sheltering had on the container difficult, however by surveying temperatures of the containers different faces it became clear that earth sheltering was having a large cooling effect on the container with the largest through the spring and autumn months.

### 10.2 Conclusion

The five initial research objectives of the dissertation are addressed below:

1. Extensive data from a control container, an earth sheltered container and an outdoor station has been recorded and presented. Results show that a shipping containers internal temperature fluctuates greatly, with low temperatures staying close to outdoor temperatures while maximum temperatures far exceed the outdoor temperature. This is due to the heat gain caused by solar radiation. It has been shown that shade can dramatically reduce the maximum temperatures experienced inside containers and slightly increase the minimum interior temperatures.

2. Modified shipping container structures are seen as an alternative solution to comply with the BCA, therefore they require additional report to gain approval, that a deemed to satisfy structure would not. This report must address the structure, damp and weatherproofing, fire safety, health and sanitary amenities, safe movement, access and energy efficiency of the proposed structure. Structural engineers commonly design stiffening members to transfer design loads through the containers frame and ignore the containers walls in the analysis. Finite element analysis can be undertaken, it is however costly and commonly unnecessary.

3. Calculating the weighted arithmetic mean of the containers faces, to estimate the ambient indoor temperature, yielded close results to the actual ambient temperature in the container. This approach, proposed by Anselm (2008), allowed the cooling effect of the earth sheltering to be quantified and a heat map of the earth sheltered face allowed it to be visualised. To predict the effect of earth sheltering prior to construction, year round accurate ground temperature data would have to be collated.

4. A literature review indicated that green roofs can have a large impact on the ambient temperature of a structure. Unfortunately the construction of a green
roof on the earth sheltered container is a long term project that has not been undertaken as part of this dissertation. However, surveys of the container face temperatures indicated that in summer the roof would be the hottest face of the container, and therefore have the most potential to impact the ambient temperature in the container. Similarly, while the alternative insulative panels were not mounted during this study period, surveys indicate that in spring and autumn the north facing side would be the container's hottest face, and therefore have the most potential to impact the ambient temperatures of the container in those seasons. The height of the sun dictates whether the roof or the north face is exposed to more solar radiation.

5. While the NEC does not have a temperate storage environment yet, the earth sheltered container provides a great platform from which to make experimental alterations. As the insulative panels are mounted, solar radiation heat gain will reduced and the thermal conductivity of the container, as a whole unit, will be reduced, further improving the container's thermal performance and providing the NEC with a temperate storage environment.

10.3 Recommendations

10.3.1 Shipping Container Structures

- Make contact with the local council before undertaking too much preliminary work to gauge their receptivity to the project
- Make contact with a qualified structural engineer who is willing to complete the load calculations for the design
- For ease of design, ease of approval and peace of mind; construct using unused, brand new shipping container(s)

10.3.2 Earth Sheltering

- Obtain year ground temperature at the site and depth you propose cutting too, to gauge the feasibility of the project and the potential thermal affect the cut will have on the structure
- Have a preliminary quote for a suitable retaining structure before major structural design commences
10.3.3 Earth Sheltered Shipping Container at the NEC

- Observational period of one year is proposed, during which the RC-4 units will remain in place, allowing monitoring through summer and winter extremes as well as quantifying the effect any further alterations made to the container have on its thermal performance

- Complete construction of recycled insulation panels and hang

- Begin the construction of a green roof on the earth sheltered container

- Plant deciduous foliage in the containers proximity, providing natural spring summer shade and allow solar radiation exposure in autumn and winter
11 Timeline

At the projects inception, a WBS was created, outlining all works within, and outside of, the scope. The tasks identified in the WBS were then allocated durations, start dates and predecessor tasks. This data was then compiled in a Gantt chart that mapped out the dissertation over its duration. This Gantt chart was revisited throughout the project, amended and as work tasks were completed progress was documented. In both the Gantt chart and work breakdown structure, individual tasks are represented in green while collaborative tasks are represented in green.

<table>
<thead>
<tr>
<th>Project</th>
<th>Start Date</th>
<th>End Date</th>
<th>Duration</th>
<th>Progress</th>
</tr>
</thead>
<tbody>
<tr>
<td>Earth Sheltered Shipping Container Dissertation</td>
<td>23/9/13</td>
<td>31/10/14</td>
<td>403 Days</td>
<td>100 %</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task - Individual (Green), Collaborative (Blue)</th>
<th>Begin</th>
<th>End</th>
<th>Length</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Project Conference 2013</td>
<td>23/9/13</td>
<td>27/9/13</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Initial Research and Topic Negotiation</td>
<td>30/9/13</td>
<td>2/12/13</td>
<td>46</td>
<td>100</td>
</tr>
<tr>
<td>Create and Distribute Ancillary Survey</td>
<td>1/1/14</td>
<td>2/1/14</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>Analysis of Ancillary Survey Results</td>
<td>3/1/14</td>
<td>8/1/14</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Create Construction Plans</td>
<td>29/4/14</td>
<td>7/5/14</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td>Negotiations with Rocla</td>
<td>12/3/14</td>
<td>28/4/14</td>
<td>34</td>
<td>100</td>
</tr>
<tr>
<td>Negotiations with Albury City Council</td>
<td>28/1/14</td>
<td>28/1/14</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Initial Data Collection I</td>
<td>28/1/14</td>
<td>26/3/14</td>
<td>42</td>
<td>100</td>
</tr>
<tr>
<td>Negotiations with Rob Fenton</td>
<td>17/1/14</td>
<td>27/1/14</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td>Contour and Feature Survey of Site</td>
<td>9/1/14</td>
<td>9/1/14</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Create Concept Plans for Review</td>
<td>13/1/14</td>
<td>16/1/14</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Learning \LaTeX/\TeXstudio</td>
<td>17/2/14</td>
<td>6/3/14</td>
<td>14</td>
<td>100</td>
</tr>
<tr>
<td>Create Matlab Code to Interpret RC-4 Data</td>
<td>8/1/14</td>
<td>14/2/14</td>
<td>28</td>
<td>100</td>
</tr>
<tr>
<td>Literature Review</td>
<td>7/3/14</td>
<td>15/5/14</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Development Application Process</td>
<td>29/1/14</td>
<td>12/5/14</td>
<td>74</td>
<td>100</td>
</tr>
<tr>
<td>Construction</td>
<td>13/5/14</td>
<td>13/5/14</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Preparation of Preliminary Report</td>
<td>16/5/14</td>
<td>6/6/14</td>
<td>16</td>
<td>100</td>
</tr>
<tr>
<td>Adjustment of Preliminary Report</td>
<td>21/7/14</td>
<td>29/7/14</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td>Calibrating and Gauging RC-4 Accuracy</td>
<td>10/9/14</td>
<td>12/9/14</td>
<td>3</td>
<td>100</td>
</tr>
<tr>
<td>Initial Data Collection II</td>
<td>22/8/14</td>
<td>10/9/14</td>
<td>14</td>
<td>100</td>
</tr>
<tr>
<td>Partial Draft Dissertation</td>
<td>11/9/14</td>
<td>17/9/14</td>
<td>5</td>
<td>100</td>
</tr>
<tr>
<td>Initial Data Analysis</td>
<td>11/9/14</td>
<td>19/9/14</td>
<td>7</td>
<td>100</td>
</tr>
<tr>
<td>Preparation of Conference Presentation</td>
<td>22/9/14</td>
<td>22/9/14</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Engineering Project Conference 2014</td>
<td>23/9/14</td>
<td>26/9/14</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Further Study and Analysis</td>
<td>29/9/14</td>
<td>27/10/14</td>
<td>21</td>
<td>100</td>
</tr>
<tr>
<td>Finalise and Submit Dissertation</td>
<td>28/10/14</td>
<td>31/10/14</td>
<td>4</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 7: Work Breakdown Structure
Figure 15: Gantt Chart of Task Order and Duration
References


ABC News SA (ABC1 Adelaide). Inmates in box seat with sa containers plan: Shipping containers could be used to help house a growing prison population under a plan by the south australian


Appendices

A  Project Specifications

University of Southern Queensland

FACULTY OF ENGINEERING AND BUILT ENVIRONMENT

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR:  Tyler CAREY

TOPIC:  Feasibility Study of Shipping Container Habitation and Thermal Performance

SUPERVISORS:  Dr Steven Goh

PROJECT AIM:  To periodically alter factors determining the interior temperature of a shipping container, quantifying the effect different environmentally sustainable methods of improving thermal performance are having on the container. This quantitative study of green roofs, building orientation and earth sheltering will yield comparable results for these different approaches to improving the habitability of shipping containers.

SPONSORSHIP:  Albury City Council

PROGRAMME:

1. Document and research the thermal behaviour of a 20 ft high cube shipping containers in an Australian climate
2. Gain an understanding of the Australian policies and procedures relating to the habitability of modified shipping containers
3. Quantify the effect of earth sheltering on a shipping containers thermal performance, and compare to theoretical estimations published by Anselm (2008)
4. Research the effect that green roofs and alternative insulative methods have on a shipping containers thermal performance
5. Create a temperate environment for the NEC to store organic farm produce

AGREED  ____________ (Student)  ____________ (Supervisor)

Date:  21 / 10 / 2014  Date:  / / 2014
B Ancillary Survey Questions & Results

This survey was created, and results compiled, using SurveyMonkey®. At the time of publication, the results shown below were representative of 62 completed surveys. The survey can be found, and completed, at this location: https://www.surveymonkey.com/s/LGH5PRQ

Q1. If you could keep your home at a constant temperature, without fear of bills, what would that temperature be?

![Figure 16: Ideal Living Temperature](image)

Taking away the two most extreme results the average result, or the ideal temperature at which people would like their homes kept is 21.836°C.
Q2. If you were to build a new home today, would you consider potential climate change in your design?

![Figure 17: The Climate Change Factor](image)

Q3. If you were to design your dream home, which of these factors would be most important to you?

![Figure 18: Ideal Living Temperature](image)

Responses given as other options were:

- All of the above
- Size of the block
- Solar energy generation (two responses)
- Environmentally conscious (two responses)
Q4. Which of the following factors would concern you the most about living in a shipping container?

Responses given as other options were;

- Condensation
- Previous use of container, potential chemical shipping
- Airflow
- Gaining approval
- Safety issues resonating from fire and rust risk
- All of the above (two responses)
- Aesthetics and comfort (two responses)
- Size and layout of container (three responses)
- Perceived social status (three responses)
Q5. What is your opinion on green roofs (roofs that have turf or other plants on them)?

![Figure 20: Green Roofs and Green Bubbles](image)

Results indicate a 62% approval rating for green roofs.

Q6. Do you consider insulation an investment?

![Figure 21: Insulation an Investment?](image)
C  Construction Plans

The following 4 pages are scanned copies of the plans submitted for the DA, the attached drawings are as follows:

1. PLAN

2. CROSS SECTIONS CH 0.000 TO CH 4.000

3. CROSS SECTIONS CH 4.500 TO CH 6.790

4. PICTORIAL VIEWS AND MASSBLOC GUIDE
D Development Application

The following 4 pages are scanned copies of the ACC DA paperwork completed, and to be reviewed.
APPLICATION FOR
DEVELOPMENT / CONSTRUCTION / PLUMBING


This is a multi purpose form and should be used for the following applications: Development Application (DA), Construction Certificate (CC), Complying Development Certificate (CDC) and Plumbing Applications (LGA).

To complete this form, please tick the boxes and fill out the white sections as appropriate.

1. APPLICANT'S DETAILS

Name: TYLER CAREY
Company: ALBURY CITY COUNCIL
Postal address: 553 Kiewa Street
Suburb or Town: ALBURY
State and postcode: NSW, 2640
Phone No.
Mobile
Fax No.
Email
Contact person: TYLER CAREY
Contact preference: Telephone

2. OWNER'S DETAILS

Name(s): 105 Fardon St, Riverina, Albury NSW 2640
Postal address: 94 Ettamogah Rd
Suburb or Town: THURGOONA
State and postcode: NSW, 2640
Phone No.

3. TYPE OF APPLICATION

✔ Development Application (DA)
☐ Construction Certificate (CC)
☐ Complying Development Certificate (CDC)
☐ Plumbing Application (LGA)

An application for Complying Development Certificate (CDC) must be accompanied by a completed CDC fact sheet. The fact sheet is available on our website.

Pre-Lodgement Advice
Have you attended a pre-lodgement meeting with a Council officer? ☐ YES ☐ NO
Name of Officer: MATT JOHNSON

4. OTHER COUNCIL APPROVALS

To carry out your proposal you may need approval for an activity under the Local Government Act (LGA) 1993. Please attach sufficient information for Council to assess your application. Tick the type of approval(s) required.

☐ Manufactured home
☐ Domestic oil or solid fuel heating approval
☐ Driveway / gutter crossing
☐ Water connection
☐ Other

5. PROPERTY DETAILS

Unit No.
Street name: ETTAMOGAH ROAD
Suburb or Town: THURGOONA
State and postcode: NSW, 2640
Lot No. OP/SP
Area of Land: m² 62 Hectares

Office Use Only
DA/CDC No.
CC No.
LGA No.
Date Received
Property No.
Total Fees
Receipt/Invoice No.
Received by
Town Planner
Building Surveyor
Plumbing Inspector
Internal Referrals
Land Use Code:

Updated June 2011.
Please refer to Albury City’s Development Application Guidelines or the Complying Development Guidelines when completing this application. (Copies available from Customer Service or www.alburycity.nsw.gov.au)

6. DESCRIBE YOUR PROPOSAL

Please provide a detailed description of your proposal.
- EXCAVATION INTO MAN MADE MOUND
- PLACEMENT OF 11 ROCK BALES
- UNITS TO RETAIN EARTH
- 300MM CRUSHED ROCK BASE
- CONTAINER PLACED ON CRUSHED ROCK
- GAP BETWEEN BALES
- CONTAINER BACKFILLED WITH 300MM FILLING THIS GAP
- ASPHALT CRUSHED STONE WILL BE USED TO SEAL THE CONTAINER FACES THAT WILL BE IN CONTACT WITH EARTH
- A FILL

Note:
Include details of subdivisions, the use of any buildings, demolitions or tree removal.

7. PROPOSAL DETAILS

Will this involve: (Tick the relevant box)
- Erecting, altering or adding to a building structure
- Subdividing land
- Subdividing a building into strata units
- Demolition
- Changing the use of land or a building, or the classification of a building under the Building Code of Australia (without building, subdividing or demolishing)
- Other work (not including building work, subdivision or demolition).

Note:
If you do not apply for demolition on this application, and you need to demolish structures on the site, a separate Development Application will need to be submitted to, and approved by Council, prior to the removal of any structures from the property.

Total Project Value
Including cost of landscaping, car parking, etc., but excluding value of land.

$ 5000

8. REQUIRED DOCUMENTATION

Four copies of A4 or A3 size Plans (drawn to scale 1:100, 1:200) must be provided. All plans must show North Point. Larger plans may be requested.
The following plans and documentation are required dependant on the type of application being submitted. Please tick the documentation supplied.

Development Application
- Locality Plan
- Site plan (indicating all levels, existing structures and vegetation)
- Elevations
- BASIX Certificate (BASIX commitments must be identified on plans) N/A
- Floor Plan (existing and proposed works shown separately) N/A
- Statement of Environmental Effects
- Structural/Engineers design

Construction Certificate
- Locality Plan
- Site plan (indicating all levels, existing structures and vegetation)
- Elevations
- BASIX Certificate (BASIX commitments must be identified on plans)
- Floor Plan (existing and proposed works shown separately)
- Sectional Plans (indicating detailed construction)
- Specifications
- Structural/Civil Engineers design
- Complying Development
- Locality Plan
- Site plan (indicating all levels, existing structures and vegetation)
- Elevations
- BASIX Certificate (BASIX commitments must be identified on plans)
- Floor Plan (existing and proposed shown separately)
- Sectional Plans (indicating detailed construction)
- Specifications
- Structural/Civil Engineers design
- Local Government Approval (Plumbing)
- Site plan (indicating all levels, existing structures and vegetation)
- BASIX Certificate (BASIX commitments must be identified on plans)
- Floor Plan (existing and proposed shown separately)
- HA design (larger commercial projects)
- For development involving the erection of a building, demolition or other works.
- Include details of the methods of securing the site, and soil erosion and sediment control measures during the course of construction.

Applicants can generate the BASIX Certificate on the NSW Department of Planning & Infrastructure (DPI) BASIX website: www.basix.nsw.gov.au.
For commencement dates and details of the types of development for which BASIX applies, visit the BASIX website or phone DPI BASIX Help Line on 1300 650 908.
9. ENVIRONMENTAL EFFECTS OF YOUR DEVELOPMENT

To assess your proposal, the Council needs to understand the potential impacts. Depending upon the nature and scale of your proposal, you need to provide information relating to one or more of the areas listed below to fully explain the impacts of your proposal.

Is your proposal designated development?
- YES Please attach an Environmental Impact Statement (EIS)
- NO

Note: Please provide three copies.
To assist in the preparation of an SEE Council has produced a “proforma” which may be used as a guide in preparing a SEE.

Has your SEE/EIS identified and adequately addressed any of the following issues:
- Bushfire
- Heritage
- Traffic
- Flooding

Is your proposal likely to significantly impact on threatened species, populations, ecological communities or their habitats?
- YES Please attach a Species Impact Statement.
- NO

10. STAGED DEVELOPMENT

You can apply for development consent for part of your proposal now, and for the remaining part(s) at a later stage. Are you applying for development consent in stages?
- YES
- NO

If Yes, please attach:
- Information which describes the stages of your development
- A copy of any consents you already have for part of your development.

11. APPROVALS FROM STATE AGENCIES

If you need a development consent requiring one or more of the approvals listed in Council’s DA Guidelines, then your development is known as integrated development. The relevant state agency will be involved in the assessment of your proposal. Is your application for integrated development?
- YES
- NO

If YES Please list the approvals you require.

.................................................................

and attach:
- A cheque for $320.00 made out to each state agency that will assess your proposal.
- Sufficient information for the approval body(s) to assess your application.
- Additional copies of your application for each agency. The Council advise the number that will be needed.

12. CONSTRUCTION STATISTICS

This information is required by the Australian Bureau of Statistics (ABS) please complete where indicated.

Tick whether:
- New
- Alterations
- Additions

Building Construction Cost (Include labour but exclude cost of landscaping and car parking etc.)

S

Description of existing Development

.................................................................

Use the following descriptions which best describes the materials to be used for each type of construction.

Walls
- Brick Veneer
- Full Brick
- Concrete
- Metal Cladding
- Timber Cladding
- Other

Frames
- Timber
- Steel

Roof
- Steel / Colorbond
- Tiles
- Other

Floor
- Concrete
- Timber
- Other

Colour of Walls (specify)

.................................................................

 Colour of Roof (specify)

.................................................................

Floor area (under roof)

................................................................. m²

Floor area (excluded structures)

................................................................. m²

Total floor area

................................................................. m²

No. of storeys

.................................................................

No. Residential Units

.................................................................

If structure is a dwelling, state whether: separate house, kit house or transportable dwelling (excluding caravan or mobile home).

.................................................................
### 13. Builder's Details

<table>
<thead>
<tr>
<th>Builder's Name</th>
<th>Albury City</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permit No.</td>
<td></td>
</tr>
<tr>
<td>(&quot;owner builder&quot;)</td>
<td></td>
</tr>
<tr>
<td>Builder's Postal Address</td>
<td></td>
</tr>
<tr>
<td>Suburb or Town</td>
<td></td>
</tr>
<tr>
<td>State and postcode</td>
<td></td>
</tr>
<tr>
<td>Phone No.</td>
<td></td>
</tr>
</tbody>
</table>

### 14. Plumber Details

<table>
<thead>
<tr>
<th>Name / Company</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td></td>
</tr>
<tr>
<td>Phone No.</td>
<td></td>
</tr>
<tr>
<td>Mobile</td>
<td></td>
</tr>
<tr>
<td>Fax No.</td>
<td></td>
</tr>
</tbody>
</table>

### 15. Applicant's Declaration

I hereby apply for approval of the development proposal described above and in the plans, specifications and documents accompanying the application.

The applicant, or the applicant's agent, must sign the application.

Signature: [Signature]

Name (print): Tyler Carey

Method of payment:
- [ ] Cash
- [ ] Account

Account No/details: [Account No/details]

Privacy Statement
The information you provide in this application will enable your application to be assessed by Council as the consent authority under the Environmental Planning and Assessment Act 1979. Members of the public can potentially view the application. Please contact Council if the information you have provided in your application changes or is incorrect.

Disclaimer
Use of third party documents or plans

The signatory to this Development Application warrants, for and on behalf of the owners of the land, that they own all documents and plans submitted with this Application or have the consent of the copyright owner to submit the documents and plans with this Application. The signatory, for and on behalf of the owners of the land, jointly and severally, indemnify Council against any claim or action in respect of breach of copyright in accordance with Regulation 57 of the Environmental Planning and Assessment Regulation 2000 during the assessment of the Application and also for any subsequent disclosure, production or publication of the documents or plans (whether in hard copy or online) for any other legal purpose following determination of the Application.
E Work Site Risk Assessment Template
F RC-4 Data Analysis Script

```matlab
%***Comparison of Outdoor, Control and Modified Container Temperature***%

% This script has been written to convert, store and plot data generated by
% an RC-4 temperature data logger using MATLAB. Written by Tyler
% Carey, for the purpose of creating functional data arrays to be
% used in the dissertation:

% The Thermal Performance of an Earth Sheltered Shipping Container %

clear all; clc;
formatin='yyyy-mm-dd HH:MM:SS'; % Output date format from RC-4 being read
dateFormat=2; % Plot style mm-dd-yyyy
%.txt file format - 4 columns {#}{date}{time}{temp}
% called in script as C*****{1} {2} {3} {4}
% refer lines 10, 25 & 41

% Control Container - Unaltered %
fileIDnormal=fopen('control.txt'); % RC-4 .txt output
Cnormal=textscan(fileIDnormal, '%s %s %s %s'); % Scan 1st 4 columns of .txt file
% Time
datetimedatanormal=strcat((Cnormal{2}),(Cnormal{3})); % Joins date & time data
XYnormal=datenum(datetimedatanormal,formatin); % Convert date style to MATLAB

timenormal=[rot90(XYnormal)]; % Rotate from row to column and place in array
% Temperature
tempnormal=[rot90([Cnormal{4}])]; % Rotate from row to column and place in array
tempnormal=[str2double(tempnormal)]; % Convert from string data to double precision;
% Plot
zeromatrix1=[zeros(1,numel(timenormal))]; % Creates matrix of zeros the same size as the data recorded
threeedline1=plot3(zeromatrix1, timenormal, tempnormal, 'Color', [0.117647, 0.564706, 1], 'LineWidth', .45);
% Plots data blue
```

81
hold on;

%% Earth Sheltered Container – Altered %%
fileIDshelter=fopen('alter.txt'); % RC-4 .txt output
Cshelter=textscan(fileIDshelter, '%s %s %s %s'); % Scan 1st 4 columns of .
  % txt file
% Time
datetimedatashelter=strcat((Cshelter{2}),(Cshelter{3})); % Joins date &
  % time data
XYshelter=datenum(datetimedatashelter,formatin); % Convert date style to
  % MATLAB
timeshelter=[rot90(XYshelter)]; % Rotate from row to column and place in
  % array
% Temperature
vshelter=rot90([Cshelter{4}]); % Rotate from row to column and place in
  % array
tempshelter=[str2double(vshelter)]; % Convert from string data to double
  % prec.
% Plot
zeromatrix2=[zeros(1,numel(timeshelter))]; % Creates matrix of zeros the
  % same size
% as the data recorded
threeedline2=plot3(zeromatrix2, timeshelter, tempshelter, 'Color',[1 0.54902 0], 'LineWidth',.5);
% Plots data orange
hold on;

%% Outdoor Temperature %%
fileIDoutside=fopen('outside.txt'); % RC-4 .txt output
Coutside=textscan(fileIDoutside, '%s %s %s %s'); % Scan 1st 4 columns of .
  % txt file
% Time
datetimedataoutside=strcat((Coutside{2}),(Coutside{3})); % Joins date &
  % time data
XYoutside=datenum(datetimedataoutside,formatin); % Convert date style to
  % MATLAB
timeoutside=[rot90(XYoutside)]; % Rotate from row to column and place in
  % array
% Temperature
voutside=rot90([Coutside{4}])); % Rotate from row to column and place in
  % array
tempoutside = str2double(voutside); %Convert from string data to double
prec.
zeromatrix3 = zeros(1, numel(timeoutside)); %Creates matrix of zeros the
same size
% as the data recorded
threellipse3 = plot3(zeromatrix3, timeoutside, tempoutside, 'Color', [0.196078
  0.803922 0.196078], 'LineWidth', .35);

% Plots data green

%% Plot Control
uistack(threellipse2, 'top'); %Brings earth sheltered data to top of plot
uistack(threellipse3, 'bottom'); %Take outdoor data to bottom of plot
date tick('y', dateFormat); %Changes plot tick to format specified in
  %foreword
daspect('manual'); daspect([1 1 2.2]); %Manually control plot output
hFig = figure(1); set(hFig, 'Position', [100 100 2500 1250]) %Manually
  %set location and size of plot
view(90, 0); %Rotates to 2d view, so x appears as y and so on ...
h=legend('Outdoor Temperature', 'Unaltered Container', 'Earth Sheltered
  %Container'); %Control the data displayed in the legend
set(h, 'Position', [.5, 0.81, 0.001, 0.001]); %Set location and size of
  %legend
ylim([min(timenormal) max(timenormal)]); %Set date limits on data for
  %plot
zlim([0 45]); %Set temperature limits on data for plot
ylabel('Time (weeks)');
zlabel('Temperature (degrees celcius)'); \%cric function unavailable, due
to .eps conversion issue
print -depsc third_temp.eps %Plot .eps file, for use in MATLAB