

SHIPPING CONTAINER HOUSES:

IN A HOT CLIMATE, THE CASE OF SAUDI
ARABIA

Abdulaziz Aljahdali

P132783

Terms of Reference

The purpose of this report was to fulfill the requirements for (M6X01851),
Faculty of Architectural Technology, University Wales Trinity St David
(UWTSD)

Table of Content

1. Executive Summary	5
2. Introduction	6
3. Material and Method	
3.1. Background of Modern Shipping Container	7
3.2. Structure and Sizes of Shipping Container	7-9
4. Findings	
4.1. Benefits and Drawbacks of Shipping Container as a Home in Hot Climate Countries	10
4.1.1. Strengths and Durability	10-11
4.1.2. Modularity	12
4.1.3. Transportability	13
4.1.4. Costs	14-16
4.1.5. Availability of SC in Saudi Arabia	17
4.1.6. Construction Work of SCH	18
4.1.7. Sustainable building & Indoor comfort	18
4.1.8. Eco-friendly	19
4.2. Design Plan	20
4.3. Design Strategies	20-21
4.4. Compatibility of Thermal Insulation	21-22
4.5. Thermal Performance Assessment	23-26
5. Discussion of Results	
5.1. Hourly Temperature Profile (HTP)	
5.1.1. Model A	27
5.1.2. Model B	28
5.1.3. Model C	28
5.1.4. Model D	28

Table of Content cont.

5.1.5. Model E	28
5.1.6. Model F	28-29
5.2. Discomfort Load Hours	30-31
5.3. Thermal Lag and U-value	32-33
6. Conclusion	34
7. Recommendations	35
8. References	36-39
9. Appendix	40-42

1. Executive Summary

According to Islam et al. (2016) the current trend in construction industry reflect that shipping container housing appears as one of the simple yet practical options to meet the needs for instant houses, site offices or even for leisure centre. This is because it offers not one but many benefits such as spacious along with small building footprint, affordable construction costs and many more which will be discussed further in the report. During this project, student (P132783) had performed research on the use of shipping containers in hot climate country, Saudi Arabia. In this research, the focus scope is on how to convert shipping containers (SC) as a living space with ultimate indoor comfort in Saudi Arabia by looking closely at the suitability on the climate. Many factors have been considered in this research, such as insulation, cost, materials, availability of shipping containers, its strengths and weaknesses, and many more. The aim of this report is to convert SC into a living space and as a result, student created an affordable and eco-friendly living area for Saudis community in which could help in housing shortage issue in the country. Besides, most houses in Saudi Arabia are extremely expensive to the point where a traditional house could cost up to £190,000-£570,000 (Zaahib, n.d.). Issue on housing shortage in Saudi Arabia needs to be tackled and it appears that ISO (International Organisation for Standardization) SC is one of the best alternatives that could help the citizens to buy affordable houses. Besides, this research had helped the student to gain valuable experience in problem solving and in pursuing green architecture.

2. Introduction

One of the biggest nightmares in current housing is that there is an irrelevant access to buying a house, as buyers are required to pay more money than the actual value of the house. Under some circumstances, this could be worse because for some people, they will have to pay mortgage because not everyone can afford to buy a house. The climate change has brought several effects to the housing industry. A study by the National Oceanic and Atmospheric has shown that there is a sharp increase in temperature of the planet's surface due to greenhouse gases, (Mafi, 2017). The study predicts that this climate change will leave continual destructive outcome, which in this case, will influence home values.

One of the aims of this report is to explore an alternative in housing industry in Saudi Arabia due to the housing shortage and over-priced houses by converting ISO containers into homes precisely in a hot climate country. The reason why the geographical scope of this report is Saudi Arabia is because there is a high demand of affordable houses. Besides, there is a high value in construction industry in Saudi Arabia, (MarketLine, 2017). According to MarketLine (2017), in 2021, the market value of construction industry in Saudi Arabia is predicted to reach \$31,123.6 million (approx. £ 23,165.3 million), a growth of 13.5% from 2016. This research will highlight the typical structure of shipping containers. This report will also discuss about the benefits and pitfalls of converting SC into houses. The ultimate expectations when building a house is comfort, which include the temperate, A container house needs to be properly insulated otherwise it would feel like living in a green house.

3. Materials and Method

3.1. Background of Modern Shipping Container

Back in 1955, a trucking entrepreneur, Malcom McLean bought a steamship company. McLean bought the company with a brilliant idea of transporting entire truck trailers together with their cargo still inside, (World Shipping Council, 2017). McLean thought that this idea wouldn't just create simplicity but also a much quicker logistical process when unloading its contents would be unnecessary if a vehicle can lift a container directly on to a ship. Furthermore, there has been lots of changes and developments of shipping containers in the matter of size and functions ever since the first container vessel sailed from Port Newark, New Jersey to Port Houston, Texas.

3.2. Structure and Sizes of Shipping Container

About 15 years after the invention, the International Standards Organisation, also known as ISO has standardised the size of shipping containers to the most common sizes used worldwide. These typical sizes of shipping container are 20', 40', 20' High Cube (HC), 40' HC and not to forget 45' HC. Moreover, to date, these exact sizes are still widely used across the globe. Table 1 shows the most common dimensions and capacities of some types of ISO containers.

Model	Length (m)		Width (m)		Height (m)		Volume (m3)	Empty Weight (kg)	Max Gross Mass (kg)	Net Load (kg)
	Internal	External	Internal	External	Internal	External				
20'	5.898	6.058	2.352	2.438	2.385	2.591	33.1	2400	30480	28080
40'	12.032	12.192	2.352	2.438	2.385	2.591	67.5	4000	30480	26480
40' HC	12.032	12.192	2.352	2.438	2.698	2.896	76.2	4200	30480	26280
45' HC	13.556	13.716	2.352	2.438	2.698	2.896	86.1	4800	30480	25680

Table 1: Size & Dimensions of ISO Shipping Containers
Source: *Evergreen Marine Corp (2017)*

As illustrated in Table 1 (page 7), it is clear that although the 40' container is to some extent light compared to the combination of two units of 20' containers, its strength is slightly weaker compared to the latter. This probably one of the factors why most businesses prefer to go with 20' containers. According to Olivares (2010), the cost of 20' container is cheaper compared to 40' container, which is a bargain choice for many architectural projects. As of the height, most of the industry experts endorsed that a container with 8'9" height (1' higher than normal container height) which also known as high cube (HC) is a better fit to be used as buildings because the space between the ceiling and the roof can be used to cover up the ductwork. Note that this also compiles with most of the global national building by law regulations, where it also offers minimum clear ceiling height of 2.40m, (Bernardo et al., 2013).

'Cor-ten' steel which is an weathering steel that is used in the construction of shipping containers to increased resistance to rust. Moreover, the steel panels, which include walls and roof are both 2mm thick, said Urban Space Management (2010). Bernardo et al., (2013) said that, as of the formation of the walls, ceiling, the edges of the container and a grid to support the wooden floor, construction typically require the use of trapezoid sheets. As of the ceiling and walls, the thickness of trapezoidal normally about 2mm, according to Bernardo et al., (2013). The corners are purposely designed as rigid fundamental to support the container to ensure connection between ISO containers. Average lifespan of a shipping container is about 15 years, Bernardo et al., (2013). However, some experts believe that if consistent maintenance and repair are in place, there is no doubt that it can last for about 30 to 50 years, (Urban Space Management, 2010). Figure 1 illustrates the most common 20' ISO shipping container.

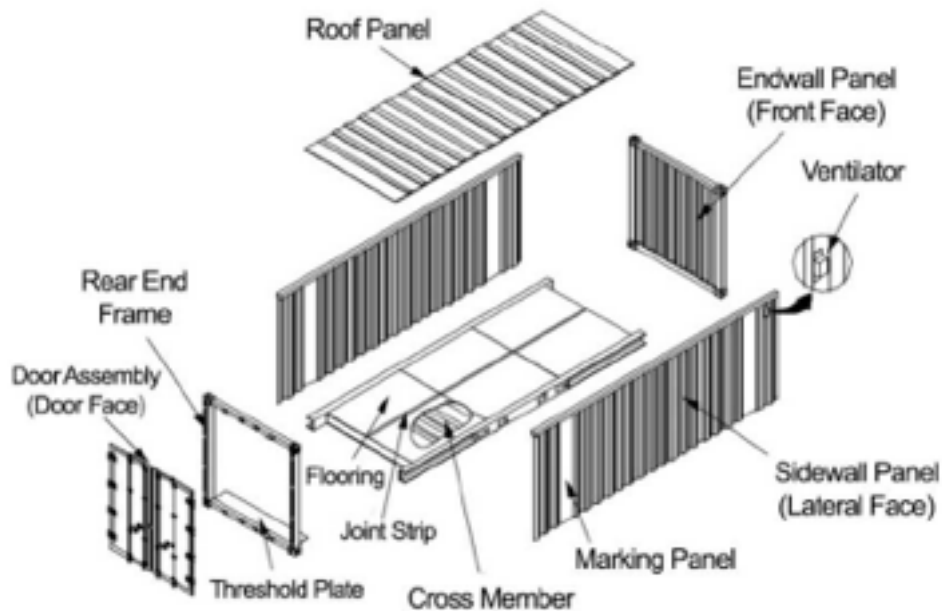


Figure 1: Formation of 20' ISO shipping container
 Source: *(Residential Shipping Container Primer, 2017)*

Undoubtedly in this modern era, many contemporary buildings across the globe are refurbished from used ISO containers for many different reasons, especially in creating creative architectural spaces. However, used shipping container is not the only option. Intermodal Steel Building Unit (ISBU) or better known as GreenCube is specifically built for the purposes such as storage and mainly construction work (ISBU, 2009). Note that despite the fact that ISBU is not made for shipping, the standard is similar to ISO containers whereby with a little bit of fabrications, it will be suitable to be a home (Robinson and Swindells, 2012). For this reason, the container is typically modified, as it needs to be combined with the other units, perhaps with partial removal of sidewall panels. As for this, it will require a certain values of insulation layers to be installed either internal, external or both depending on the climate situation, mainly because of indoor comfort and safety purpose (protection from fire).

4.Findings

4.1. Benefits and Drawbacks of Shipping Container as a Home in Hot Climate Countries

In general, SCH is chosen as the core of this research because it is almost indestructible, which is good for hot climate country like Saudi Arabia. Interestingly, many aspects have been closely considered to be beneficial as it supports why SCH is one of the best fit for construction industry in Saudi Arabia. These aspects include strengths, modularity, transportability, cost, SC availability in Saudi Arabia as well as its construction work, its sustainability and eco-friendly. On the other hand, these aspects also have its downsides.

4.1.1. Strengths and Durability

As of from structural perspective, Garrido (2015) stated that it should be noted that SC are intended to resist a heavy load that can substitute most buildings structure without any problem. For instance, a 40' ISO container weighs 3750kg with a construction overload 30,00kg and stacked up to 15 containers will not encounter any complications. Tropical countries like Malaysia and Indonesia would be the closest example that can relate to Saudi Arabia climate. In Malaysia, there is an iconic container building called 'Container Home' located in Bukit Tinggi, Pahang that used six stacked 40' used containers. Meanwhile in Indonesia, 'The Contertainer' is made up of eight SCs stacked together, which operates polyclinic and library in East Java, Indonesia for the local community. Both examples are built for different purposes as can be seen in Figure 2.



Figure 2:
Top: Malaysian multi-story bungalows
Bottom: Indonesian public building

Nonetheless, despite being known for its firm structure, SCH like many others also has its own limitation concerning the freedom of design. In the case of wind loads, it is advised that, if these containers are stacked in vertical form, it should be placed alongside the same axis, which in certain ways has narrowed the essences of innovation and creativity in building design to retain its strength and avoid torsion (Pagnotta, 2011). Botes (2013) says one of the things that will weaken the strength of container buildings is when there is a need to cut the sidewalls (typically for the purpose of combining one unit with another) to fulfill particular needs of interior spaces. Another disadvantage of SCH is its lifespan. Another negative side of SCH is its lifespan where it has been predicted that it can only last for 15-50 years. This means it can only stand half of the existence of most traditional houses (Olivares, 2010).

4.1.2. Modularity

One of the best and creative techniques to form SC architecture is to attach it to one another. A study by Garcia (2014) has shown that the trend of SCH will continue to develop momentum because it brings number of advantages in construction industry, particularly in term of cost and time saving. Sawyers (2008) describes SCH in the simplest form where Sawyers pictured ISO container as gigantic 'Lego' which it can be built and also pull to pieces to fit the architectural requirements of the particular area. As a matter of fact, Islam et al. (2016) argued that the modularity of building SCH boost the construction time, which is roughly around 40-60% a lot quicker. Furthermore, it helps in dropping the number of waste production about 70% if compared to traditional construction approaches (Islam et al., 2016). In addition, when several units of SH are stacked together and creatively composed as a structure, it is likely to have unique attractions as an architectural piece. In a hot-humid country like Malaysia, Container City in Miri is a perfect example of how the essence of modularity has been positively applied by its architect. Nevertheless, modular construction of SCH also has its own downside where it includes its facade tend to be less appealing. This eight-sided rigid box is often noticeable if it stands solo due to low aesthetic value and dull appearance of SC architecture.

4.1.3. Transportability

Another benefit that ISO SC brings to construction industry is concerning transportability. Due to its structure and compatibility in terms of transportation, SC is known to be a convenient and swift option as it can ease the relocation process from one place to another (Levinson, 2016). As a matter of fact, SC physical distribution ultimate goal is to move goods quickly and efficiently. SC has always been useful building alternative because apart from affordable housing, it has also been used as many other architectural creative constructions. These include emergency shelters (Brodaski, Campanelli and Zabinski, 2010), school buildings such as Waldorf School of Orange County in California (Grozdanic, 2014), office buildings, abstract art and more.

Although SC has a good point in terms of transportability and can be developed in precarious area, there are also numbers of reports that argued its suitability to be constructed in certain area. The reason behind this argument is because of its geography aspect of that particular site, where the 'sloping' area is apparently not the best fit to place the SC building.

4.1.4. Cost

The cost of building a SCH is undoubtedly cheaper than building traditional houses due to up-cycle reason. According to Brandt (2011), although transforming a SC into a house costs less than constructing a conventional building, beware of the luxurious interior finishes as could easily influence the increase in cost to the same amount as constructing an old-fashioned building. Building a SCH can easily allow cost reduction in construction work approximately around 20% compared to conventional building if they stick to the initial budget plan.

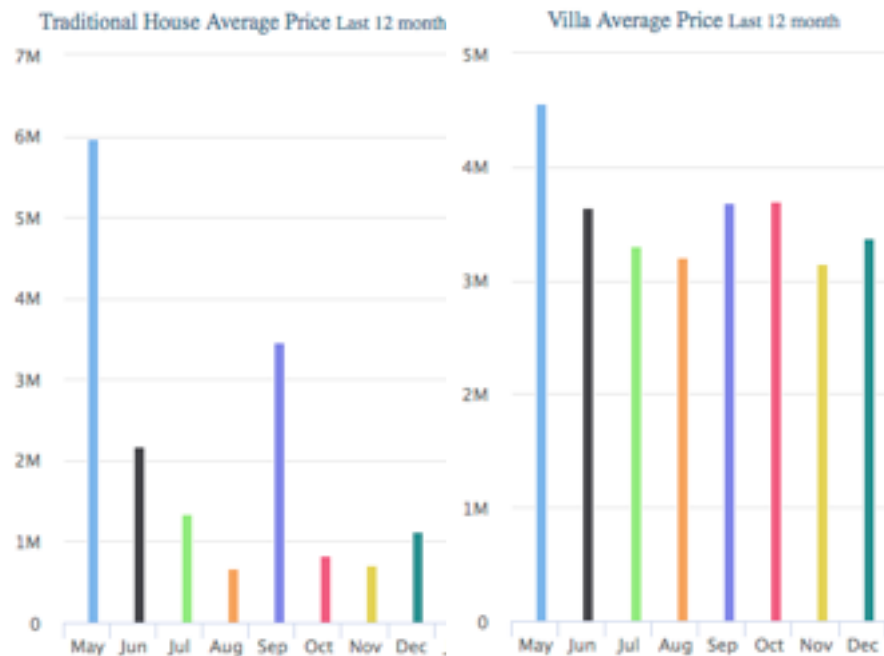


Table 2. Traditional House Average Price in Saudi Arabia

Table 3. Villa Average Price in Saudi Arabia

Although it helps in cost reduction, it also differs on the various human habitation preferences in the matter of thermal and acoustic performance, (Garrido, 2015). There are number of drawbacks behind this low-cost housing alternative. In brief, low price constructions of SCH will likely lead to poor living conditions as it typically eliminates numbers of core construction necessities. These include proper insulation, thermal inertia, acoustic insulation and coating (Garrido, 2015). Another factors that might influence the construction cost of SCH include things such as insulations materials, transportation and also installation.

ISO container is a reasonable option because it is one of the cheapest home options to build or rent, precisely in Saudi Arabia. In comparison, traditional house price in Saudi Arabia will range from one million to three millions Saudi Riyal (SAR) that is equivalent to £190,000-£570,000 (Zaahib, n.d.). These prices, of course will be hugely depend on the location and the size of the house. Table 2.1 and Table 2.2 below illustrate the average prices of traditional house and villa in Saudi Arabia.

Shipping container on the other hand, can cost as low as 10,000 SAR (£2,000) for used container and it can go as high as 15,000 SAR (£3,000). In addition, some people only buy the container and hire a contractor to do all the construction work to covert it to living home with door, windows and insulation for safety reason and indoor comfort. Construction and any technical work can cost on average 250 SAR (£50) an hour and it add up to around 10,000SAR (£2000). Conversely, buying a pre-built container fitted with windows, doors, etc., can cost roughly 34,000 SAR (£6,600), which include delivery to anywhere in Jeddah city from Barsh Container Solutions FZE (see Figure 3 page 16).

Item	Description	Unit	Qty	Unit Price	Amount
1	<u>Modification of container</u> <u>Scope of Work</u> ✓ 1X20' CONTAINER NEAT & CLEAN ✓ 2X2 STEEL FRAME INSIDE THE CONTAINER ✓ 50 MM ROCKWOOL INSULATON TO PROTECT HEAT FROM OUTSIDE ✓ CORNER DECORES ✓ 15MM FIRE RATED GYPSUM BOARD FOR WALLS ✓ 12MM FIRE RATED GYPSUM BOARD FOR CEILING ✓ WATER PAINT INSIDE ✓ ELECTRICAL FITTINGS ✓ WATER PROOFING CIRCUIT BREAKER ✓ DISTRIBUTION PANEL ✓ STANDARD WIRING ✓ SWITCHES ✓ 3 TUBELIGHT SETS ✓ 1 PARTITION WITH ALUMINIUM DOOR (1X2 METER) INFRONT OF THE CONTAINER DOOR TO PROTECT FROM OUTSIDE HEAT ✓ 1 A/C CUT- WELDED FRAME & PAINTED ✓ PAINT OUTSIDE ✓ VINYLE CARPET ✓ 1X1 METER ALUMINIUM WINDOW - 1 ✓ 1X2 METER ALUMINIUM DOOR ✓ TRANSPORTATION UPTO JEDDAH	1	1	SR 34,000/-	SR 34,000/-

Figure 3. : Price Quotation of SCH from Barsh Container Solutions FZE

4.1.5. Availability of SC in Saudi Arabia

As a matter of fact, all empty containers must be moved to avoid surplus container blocking plots along any port network all around the world after each container has been unloaded. According to Rodrigue (2017), it is a must for every SC that carries imports to leave the port, especially those major port across the globe despite loaded or empty. However, nothing is free in trading world, so does moving an empty SC. Country that has massive amount of imports, in this case, Saudi Arabia tends to face a problem such as holding excessive amount of SC and vice versa. For instance, China is Saudi Arabia biggest importer. As the main importer, China often has a shortage of empty containers and conversely Saudi Arabia has a surplus of empty containers (Epstein, Neely and Weintraub, 2012). Note that repositioning these massive amount of containers will not just require both trade parties to commit regarding the shifting process, but also costly (Rodrigue, 2017). Furthermore, it is almost irrelevant to ship back empty containers back to its origin specifically in Asia as the cost of SC is much cheaper compared to the cost of relocation of SC.

In contrast, this allows great opportunity for construction industry in Saudi Arabia. This is because it will be a great help in decreasing the cost of transporting SC from one country to another, mainly countries that do import the most. There will be no need to deal with the hustle of importing SC from other countries like China and Netherlands as Saudi Arabia itself has a great access to used SC to develop shipping container homes. This indirectly verifies the reason why ISO containers offer a reasonable low construction cost compared to traditional construction, because most SCH involve recycling of the used material.

4.1.6. Construction Work of SCH

A study by Botes (2013) shows that although the idea of SCH construction may sound simple, however it also has many challenges. Building SCH not just requires construction experts but also requires purpose-built machinery to perform extensive modification work, says Botes (2013). In addition, Botes (2013) also mentioned that there would be a fundamental need for crane in order to do the lifting and assemble works.

Despite these limitations, utilizing SCH likewise inherent many advantages. Aadhan (2016) claims that in comparison to brick-wall construction, building a housing structure out of ISO containers consume less time, which is a very efficient option. Instead of taking months, it only takes approximately two-to-three weeks to construct. Typically, most SCH structure takes only one day or so to be assembled. However, this also means all containers must be in a ready form to be stacked to one another, which must be based heavily on the desired design.

4.1.7. Sustainable building & Indoor comfort

Shipping containers are intentionally designed to be strong. The term strong here are defined as the ability to abide weighty goods, resist extreme weather conditions and able to be attached to one another to create multi-story homes, says Aadhan (2016). Structural steadiness of ISO containers makes SCH exceptionally safe for natural disaster-prone areas as it have the ability to resist earthquake and hurricane (Aadhan, 2016).

4.1.8. Eco-friendly

The construction of SCH can be described as an eco-friendly architectural piece. By re-using ISO containers, it relatively helps in reducing the impact of using conventional construction materials that somehow could harm the nature. According to The International Firm (n.d.), these materials may include bricks, cement, and wood. Not to forget, re-purposing SC into living spaces also means less energy will be needed, as there will be no need to melt down metal containers when doing scrap works (The International Firm, n.d.). For a fact, a 40' container up-cycles contains roughly 3500kg of steel and if re-use, it will prevent around 8000 kWh from getting melt down. What makes it more interesting is that reusing SC will only consume around 400 kWh, which obviously make a huge difference. As mentioned above, building a SCH also helps in preventing the use material such as cements. Here, the use of cements seems to be main concern because the cement industry is one of the major producers of CO₂.

4.2. Design Plan

The structure of SCH can be classified in many different forms such as hybrid, on-site manufactured

4.3. Design Strategy

When building a SCH, it is significant to ensure the design is complied with the concept of green architecture and sustainability. With most days are hot in Saudi Arabia, living roofs would be one of the alternatives to be considered as it reduces indoor temperatures by up to 8% during warm days (Tom 1, 2015). When constructing a SCH, particularly in hot climate country like Saudi Arabia, we need to be environmentally conscious about its design, safety and indoor comfort. As of the roofing systems, double roofing is one of the many options that can be functioned as a thermal insulation. Other roofing systems include hip and gable roofing. In addition, reflective paints can be used on roof as it reflects the sunlight on the roof and disperse the heat from the roof (Paints, 2016). However, it will be depend on the budget and design requirements, Islam et al., (2016).



Figure 4



Figure 5

According to Tom 2, (2015), the building cares involve external shading and small windows with low-E glass and/or blinds on the inside (Figure 4.). A photovoltaic (PV) rooftop in Figure 5 will be the source of the essential energy that have the control over the heating, cooling and lighting systems inside

the SCH, (Green, 2008). See figure 5. One of the most essential steps is to inertly ventilate the SCH is by crawl space ventilation, this is to guarantees the air flow under the SC. Nevertheless, only several sorts of foundations are well matched with these airing systems, for instance, raised foundations or concrete piers. This is because it offers protection mold and rots and stops moisture from leaking to the flooring. However, this type does not suite tropical climates, as the external is wetter. A dehumidifier as mechanical ventilation tool is a better fit, says Tom 3 (2015).

4.4. Compatibility of Thermal Insulation

There are many types of insulation but in this case, spray foam, insulation board and blanket insulation will be taken into account as it best fit the construction requirement based on the climate. In order to avoid the possibility of rust and mold on the surface of ISO container, spray foam would be the answer as it gives a smooth and flawless barrier as an outcome. Considering its speed and flexibility as well as a high R-value, it indicates resistance against heat flow. The only pitfall from this type of insulation is that it is very costly. Its flexibility here is referring to how it can both be useful to both internal and external wall of the SCH to evade dampness. It is very easy to apply as it can be painted directly and give you the finished look right away. An insulation board requires the installation of studs. Insulation board offers an instant installation but note that it is more costly than blanket insulation. Conversely, blanket rolls come in a lower price in the market compare to its insulation rival mentioned above that are spray foam and insulation board. The most popular and leading form of blanket insulation is Rockwool. However, the nature of Rockwool requires more care in handling. Rockwool is fireproof, with a melting point of approximately 1093 °C. One of the benefits of Rockwool is it dries up the moisture thus help to prevent rust to occur. In addition, it is also soundproof, (Rockwool International, 2016).

As stated by Alemdağ & Aydin (2015), external insulation is more beneficial to the construction of SCH compared to internal insulation. This is because when the installation of internal insulation takes place, it will reduce the

size of the SCH, (Smith, 2015). In addition, with external insulation, architects will get to maximize the benefit of the ISO container's thermal inertia. Also, Alemdağ & Aydin (2015) argues that no insulation should be installed with metal or wood studs, as these materials will reduce the thermal insulation. However, internal insulation can be considered if it has a slim depth, as with several layers of aluminum foil covering the insulation. There will be no need for waterproofing work as ISO containers are water resistant and the only thing that will change is the cost if the waterproofing work is required. Smith (2015) stated that by stacking the ISO containers, it would minimize the need for thermal insulation. Table 4 demonstrates several types of thermal insulations that are commonly applied to SCs.

Insulator Type	Specifications
• Glass fiber mat. • EPS.	Botes has compared ISBU housing and conventional housing in a test case using a 100 mm glass fiber mat, a 35mm EPS internal insulation and plaster coat finish for the ceiling, and a 35 mm EPS internal insulation for the walls.
• Foil board. • Ceramic coating.	A 25 mm layer of foil board attached to the SC's metal walls works as a thermal breaker, and A ceramic coating as thermal insulation for steel surfaces can achieve tremendous energy savings by preventing heat transfer. It can be used as paint, an adhesive, a thermal insulator, and a noise barrier, and it is fire resistant. Polyurethane foam works well as an internal insulator alongside the ceramic coating as an external insulator, as that combination further reduces the carbon footprint.
• ccSPF	Closed-cell spray polyurethane foam is best suited to CBBs as it is strong and durable. It provides an extra sealing for openings and has waterproof resistance, high durability, a high R-value (15.75), and renewability
• Prodex Total Insulation (PTI).	Prodex Total Insulation (PTI) is designed specifically for metal structures because it operates as a thermal breaker, radiant heat barrier, and vapor barrier at the same time. This insulation consists of aluminum foil with a polyethylene backing and a surrounding closed-cell polyethylene foam. The R-value for PTI is 7 for walls and 15.67 for ceilings, with 5mm thickness.

Table 4.

4.5. Thermal Performance Assessment

This part aims to analyse the construction of SCH in Saudi Arabia, a hot-climate country. The software used are Ecotect and Revit. Since a weather file on Riyadh and Jeddah are unavailable in both Autodesk Ecotect Analysis and Autodesk Revit library, the weather and the location of site in Saudi Arabia as a whole has been used to proceed with the software. In order to make a comparison on two different situations between a traditional building and a SCH along with analysing how well the thermal installed perform on the SCH, this study has explored four different models, all of them are common single story and single zone buildings comes with two windows faces one faces north and the second one faces south to make sure the container have a natural ventilation and lastly a door on the door face. All The dimensions of the models are exactly the same and mentioned in the 20'HC containers (See appendix 2; page 40).

The insulation materials to be examined in the assessment section are as follows:

- i. Spray foam insulation:
 - High R-value
 - Moist-resistant
 - Replaceable for maintenance work
- ii. Rockwool
 - Soundproof
 - Fireproof
- iii. Wool
 - Eco-friendly materials
- iv. Straw
 - Sustainable materials

In this case, these materials are for external application on insulation work. All material will be examined with standardised widths of 100 mm. Refer Table 5 on page 24 for further detailed descriptions.

Table 5. Six different models to be analysed

	Model A	Model B	Model C	Model D	Model E	Model F
Type of Model + Insulation	Traditional Masonry	20'HC ISO Container (Non-Insulated)	20'HC ISO Container (Rockwool insulation)	20'HC ISO Container (Wool insulation)	20'HC ISO Container (Spray-Foam insulation)	20'HC ISO Container (Straw-board insulation)
Door	Hollow Core Plywood Door (2.2 A~ 1 m)					
Floor	28 mm plywood floating floor on 10cm concrete slab	28mm marine-grade plywood floor on steel cross members & 127 mm height on a sand bedding				
Roof	10 cm reinforced concrete, 2 cm waterproofing (Bitumen Impregnated Paper), 3 cm cement mortar	2mm ridged Cor-Ten Weathering steel sheets	2mm ridged Cor-Ten weathering steel sheets, Insulated externally with 100mm Rockwool /Wool and layered with a 10mm water-resistant layer	2mm ridged Cor-Ten weathering steel sheets, External insulation with 100mm insulation (depend on model) finished with 30 mm cement mortar	2mm ridged Cor-Ten Weathering steel sheets, external insulated with 100mm medium-density Spray-foam, layered with 30mm cementations screed (cement mortar)	2mm ridged Cor-Ten Weathering steel sheets, external insulated with 100mm straw board, finished with 30 mm cement mortar
Walls	4.8" brick masonry medium, 2cm cement mortar for both internal and external finishing		2mm ridged Cor-Ten Weathering steel sheets, External insulated with 100mm Rockwool/Wool and layered with a 10mm water-resistant layer			
Windows	Single glazed timber frame (1.2 A~ 1.2 / 0.6 A~ 1.2)					

Table 6. Description of Cor-Ten weathering steel (a) & Spray Foam

	Cor-Ten weathering steel (a)	Spray-Foam
Thermal conductivity (W/m.K)	16 (at 100°C)	0.024 (at 50°C)
Density (kg/m ³)	8,000	33
Specific heat (J/kg.K)	500	1,674 a

5. Discussion of Results

5.1. Hourly Temperature Profile (HTP) for the Warmest and Coldest Period (average). [See figure BB]

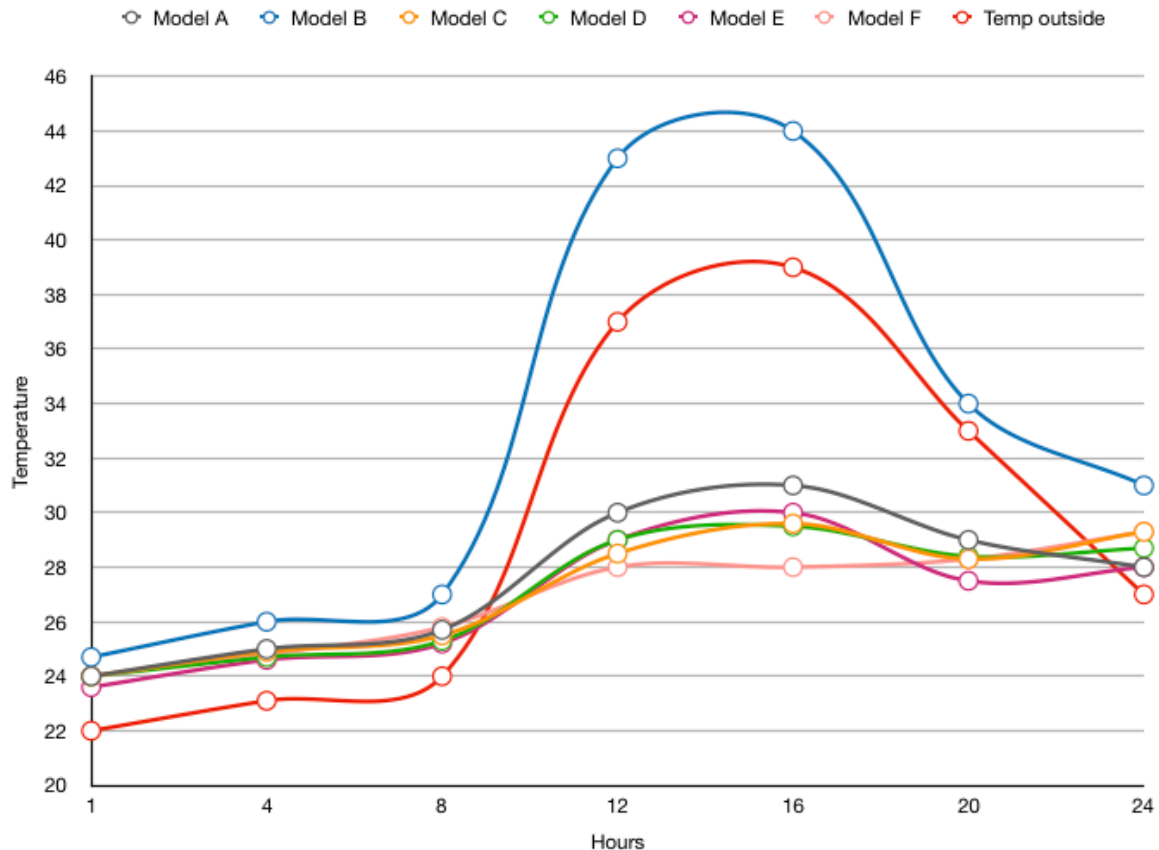


Figure 6. Hourly Temperature Profile for the Warmest Day

5.1.1. Model A

Based on the HTP result for the warmest day (average), May 1 (Figure 6), Model A warmed the interior space for almost 12 hours from 10.00p.m. until 9.00a.m.,. At the same time, the internal temperature went up within a range of 0.5 to 5.4 degrees. In the early evening, the internal space cooled down and the gap temperature from internal and external temperature stretched between 9 and 2.2 degrees

5.1.2. Model B

As mentioned in the table, Model B was not insulated. It appeared to heat the interior of SC the whole day. The distinction between indoor and outdoor temperatures was ranging around 6.5 degrees at noon and 0.7 degrees at 7 at night.

5.1.3. Model C

Model C was insulated with Rockwool. Just like Model A and Model B, Model C also heat up the space. However, Rockwool insulation helped to cool down much better than Model A and Model B. The cooling process was way better than a traditional house.

5.1.4. Model D

As of Model D, wool was installed to insulate the container. The result of its thermal performance was equivalent to Model C.

5.1.5. Model E

Spray Foam was installed in Model E. It started to heat up the space right before midnight until 5a.m. Nevertheless, this is the weakest insulation method in terms of heating. Compared to traditional houses, the cooling phase for Model E lasts for almost 12 hours from morning and ends at 9 at night. However, when compared to Model C and Model D, it appeared that spray-foam is not the best alternative.

5.1.6. Model F

Straw insulation turns out to be the best insulation method in cooling the SC, which would be ideal to fit Saudi Arabia climate. The cooling starts from morning approximately around 10a.m. until 6 in the evening, which usually the hottest period of hours in the country. The temperature of the internal and external varies hugely, which is 11.4 degrees at 4 p.m. and reduces about 9.2 degree to 2.2 degrees at night (9p.m. to be exact). As of the heating, it starts warming at 10am

until 9pm.

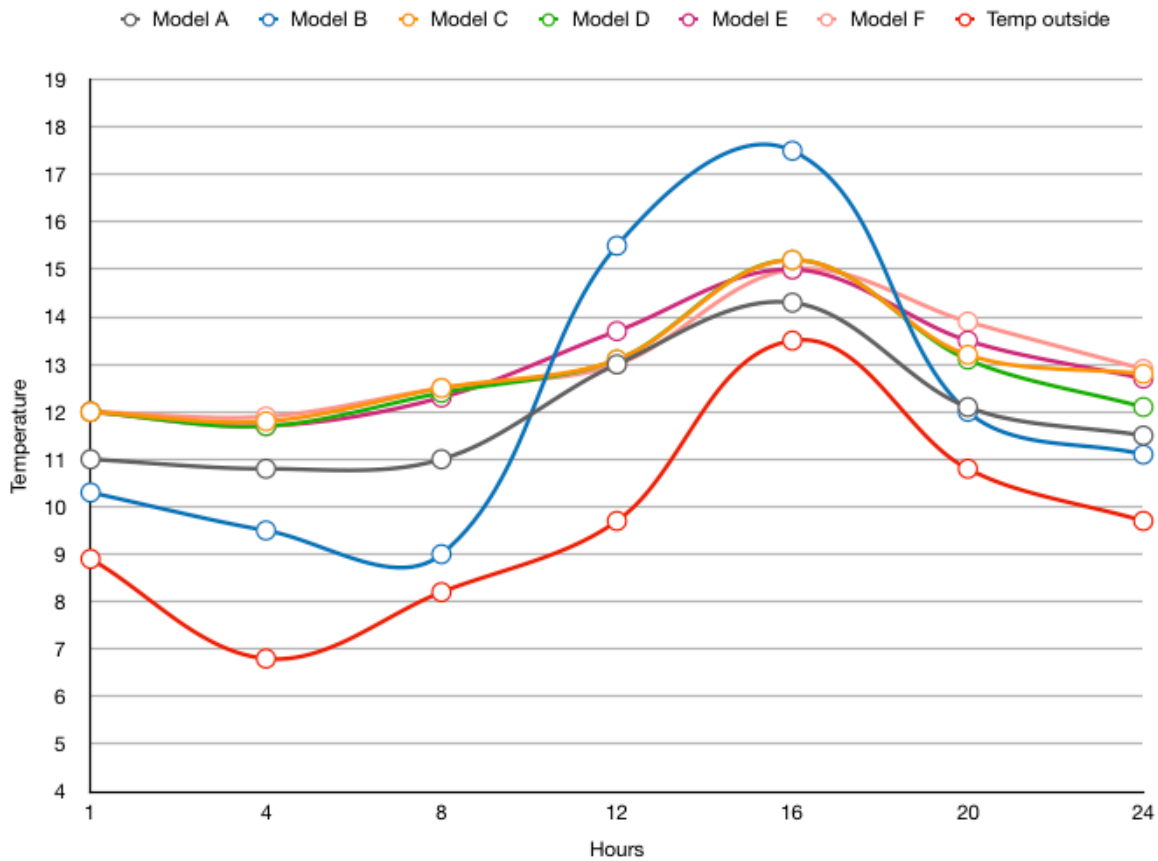


Figure 7. Hourly Temperature Profile for the Coldest Day (January 15)

After analysing the result thoroughly, it shows that Model F is the best fit for insulation method in building SCH in Saudi Arabia. Based on the research, the highest external temperature noted was less than 40°C. As there was no insulation material installed in Model B, it breaks the highest temperature record for internal spaces. Overall result ranking are as follows: Model E, Model C and followed by Model D.

5.2. Discomfort Load Hours (DLH)

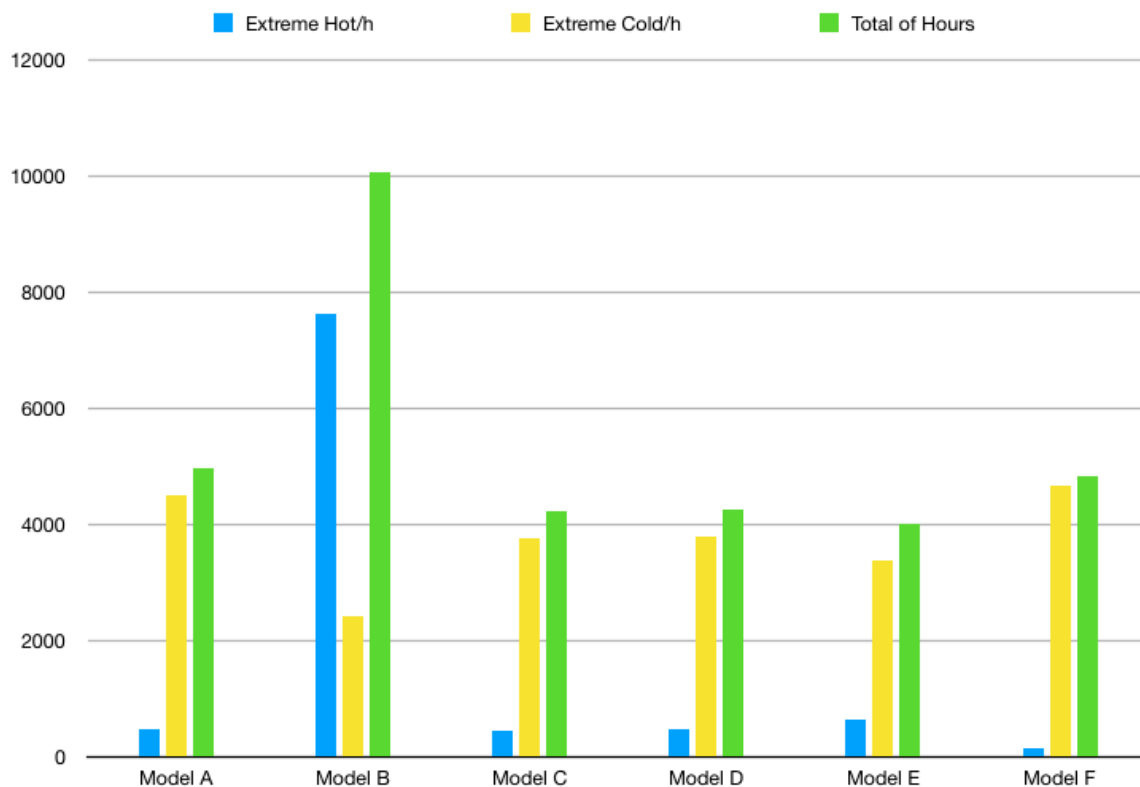


Figure 8. Hours of Discomfort

Based on the result of discomfort hours shows in Figure 8, Model B followed by Model A, appeared to be extremely hot and extremely cold thus lead to rank the highest discomfort hours. In this case, the finest model is the one that ranked the lowest extreme-hot along with lowest extreme-cold hours of discomfort. Figure 8 also shows that with straw insulation, Model F produces the lowest extreme-hot discomfort hours. However, it also generates the highest hours of discomfort on extreme-cold. This is an obvious result that this could be one of the best insulation materials that can be used in the construction of SCH in hot-climate country, Saudi Arabia. It is claimed to be the potential insulation materials because the result shows that this is the most effective insulation in cooling, as most days in Saudi are extremely hot. Model C and Model D may also be taken into consideration as alternatives because both models have the

lowest extreme-hot discomfort hours. Arguably, Model E that was insulated with spray foam could be the best fit for SCH in Saudi. This is because the result shows that Model E has the lowest extreme-cold and extreme-cold, which definitely is showing a balance between both. When compared to Model F, despite the fact that it works efficiently on hot days to lower down the space temperature, straw insulation lift up the need for heating system on cold days, which will not be the case of green architecture and will be the oppose to on of SCH advantages as the use of heating system will prove that the construction of SCH is not sustainable.

5.3. Thermal Lag and U-value

- Thermal lag is defined as the postponement on heat transmission through the wall, (Belden Brick, 2018).
- U-values are described as a tool to measure the effectiveness of the material as an insulator, (BBC UK, 2014).

Thermal Lag (Table SS)

Formula of thermal lag is as follow:

$$t \text{ (hrs)} = 0.53 * \frac{T}{2} * e * \sqrt{\frac{ro * c}{\lambda * \pi * T}}$$

T stands for the exterior differences hourly taken for 24 hours

E stands for the width in meter (m)

Ro reflects the density calculated based on (kg/m³)

C reflects the precise heat (kJ/kg K)

Lambda is the conductivity/response (W/m K)

The **pi** is 3.14

Table SS. Thermal Lag (hour)

	Model A	Model B	Model C	Model D	Model E	Model F
Door	0.332					
Floor	5.688	2.92				
Roof	6.97	0.023	5.745	5.1	4.523	7.2
Walls	0.67					
Window	0.189					

Table 7. Thermal Lag results

Table 7 illustrates the results of thermal lag calculations based on each body parts of the SCH such as door, floor, roof, walls and also window on each model discussed earlier. As of the roof and walls, it proves that non-insulated SCH (Model B) will result in a poor thermal performance, as it generates the lowest thermal lag but also highest U value. Model F followed by Model A reflects the highest thermal lag. However, its U-value ranked the third after Model B followed by Model A, see Table 8. With regard to the roof and walls, U-value of Model E appears to be at the bottommost. The second lowest U-value is at 0.3 W/m K, that is Model C insulated with Rockwool. As of the floor, all models except Model A shows a consistent thermal lag, that is at 1.74 W/m K.

	Model A	Model B	Model C	Model D	Model E	Model F
Door	2.5					
Floor	1.48	1.74				
Roof	0.97	5.61	0.3	0.43	0.23	0.51
Walls	2.49		0.43			
Window	5.44					

Table 8. U-Value Results for six models

6. Conclusion

As shipping containers come in standardised dimension that can definitely accommodate human scale, shipping containers are valid for projecting as human-living spaces. SCH has a lot to offer such as its durability, reasonable price and sustainable. Besides, with the availability of used SC in Saudi Arabia, construction period will take less time to transform ISO shipping containers to a SCH. Building a SCH brings huge potential to restore the housing shortage not just in Saudi Arabia but also to any countries, if properly fitted. Nevertheless, in Saudi Arabia the development of SCH is still not widely spread. Undoubtedly, there are still some uncertainties that could influence the capital costs for this construction. These include the construction method and procedure that can be different and unfamiliar with available local skills. However, with its advantages such as strengths and modularity, along with a proper installation and construction works trade for a comfortable place to live in, these limitations won't be the barrier for ISO containers to be one of the architectural options in Saudi Arabia.

7. Recommendations

1. Sometimes building on-site is not always a good idea due to topography reasons. Individual can get the SCH constructed off-site at a local workshop and then when it is done, it can be transported to the plot of land, ready to move in.
2. Maximise the ecological level of SCH.
3. Make use of usable waste for interior finishes to avoid over-budgeted.
4. Ensure insulation and ventilation are properly designed and installed to fit the climate condition.
5. In hot climates, the main concern is on ventilation, not on insulation. Balancing the temperature is significant.

8. Bibliography

- Aadhan. (2016). *The Pros and Cons of Building with Shipping Containers*.
[online] Available at: <http://www.aadhan.org/blog/2016/7/2/pro-and-cons-container-architecture> [Accessed 8 Jan. 2018].
- Alemdağ, E., & Aydin, Ö. (2015). A study of Shipping Containers as a Living Space in Context of Sustainability. *Atrium*, 3(2147-6683), 17-29.
- BBC UK. (2014). GCSE Bitesize: U-values. Retrieved from
<http://www.bbc.co.uk/schools/gcsebitesize/science/aqa/heatingandcooling/buildingsrev1.shtml>
- Belden Brick. (2018). What is 'Thermal Lag'?. Retrieved from
<http://www.beldenbricksales.com/products/faqs/what-thermal-lag>
- Bernardo, L., Oliveira, L., Nepomuceno, M. and Andrade, J. (2013). Use of Refurbished Shipping Containers for The Construction of Housing Buildings: Details for The Structural Project. *Journal of Civil Engineering and Management*, 19(5), pp.628-646.
- Botes, A. (2013). *A Feasibility Study of Utilising Shipping Containers to Address the Housing Backlog in South Africa*. Master of Engineering (Construction Management). Stellenbosch University.
- Brandt, K. (2011). *Plugging In: Reinterpreting the Traditional Housing Archetype Within a Community Using Shipping Containers*. Master of Science. University of North Carolina.
- Brodaski, M., Campanelli, R. and Zabinski, K. (2010). *Shipping Container Emergency Shelters*. Degree of Bachelor of Science. Worcester Polytechnic Institute.
- Epstein, R., Neely, A. and Weintraub, A. (2012). *A Strategic Empty Container Logistics Optimization in a Major Shipping Company*. Department of Industrial Engineering. University of Chile, Santiago.
- Evergreen Marine Corp. (2017). *Container Specifications*. [online] Available at: https://www.evergreen-marine.com/tei1/jsp/TEI1_Containers.jsp [Accessed 21 Dec. 2017].

- Green, J. (2008). Greentainer Project in Gandino Italy. Retrieved from <http://www.jetsongreen.com/2008/11/greentainer-pro.html>
- Grozdanic, L. (2014). *Costa Mesa Waldorf School is Made From 32 Recycled Shipping Containers*. [online] Inhabitat. Available at: <https://inhabitat.com/costa-mesa-waldorf-school-is-made-from-32-recycled-shipping-containers/> [Accessed 8 Jan. 2018].
- Intermodal Steel Building Units and Containers Homes (ISBU) (2009) *ISO shipping container specifications/ materials*. Cheyenne, WY: ISBU Association.
- Islam, H., Zhang, G., Setunge, S. and Bhuiyan, M. (2016). Life cycle assessment of shipping container home: A sustainable construction. *Energy and Buildings*, 128, pp.673-685.
- Garcia, M. (2014). *Alternative Housing: The Shipping Container Home*. [online] Crt.blogs.realtor.org. Available at: <https://crt.blogs.realtor.org/files/2014/12/shipping-container-homes-white-paper-2014-12-10.pdf> [Accessed 4 Jan. 2018].
- Garrido, L. (2015). *Green container architecture*. 3rd ed. Sant Adrià de Besòs: Monsa.
- Levinson, M. (2016). *The Box. How the Shipping Container Made the World Smaller and World Economy Bigger*. 2nd ed. New Jersey: Princeton University Press.
- Mafi, N. (2017). *How climate change affects your home value*. [online] Architectural Digest. Available at: <https://www.architecturaldigest.com/story/how-climate-change-affects-your-home-value> [Accessed 8 Jan. 2018].
- MarketLine. (2017). Construction in Saudi Arabia. Retrieved from <http://advantage.marketline.com/Product?ptype=Industries&pid=MLIP2565-0042>
- Olivares, A. (2010). *A comparative life cycle analysis of container architecture for residential structures*. Master in Architecture. Victoria University of Wellington.
- Pagnotta, B. (2011). *The Pros and Cons of Cargo Container Architecture*. [online] ArchDaily. Available at: <https://www.archdaily.com/160892/the-pros-and-cons-of-cargo-container-architecture> [Accessed 2 Jan. 2018].

- Paints, R. (2016). The Benefits of Heat Reflective Roof Paints | Rawlins Paints Blog. Retrieved from <https://www.rawlinspaints.com/blog/the-benefits-of-heat-reflective-roof-paints/>
- Residential Shipping Container Primer. (2017). *Shipping container structural components and terminology*. [online] Available at: <http://www.residentialshippingcontainerprimer.com/CONTAINER%20COMPONENTS%20AND%20TERMINOLOGY> [Accessed 21 Dec. 2017].
- Robinson, A. and Swindells, T. (2012). Customize Container Architecture. In: *ACSA Fall Conference*. pp.64-69.
- Rockwool International. (2016). ROCKWOOL Sound insulation slab. Retrieved from <http://www.rockwool.co.uk/products/rockwool-sound-insulation-slab/>
- Rodrigue, J. (2017). *The Geography of Transport Systems*. 4th ed. New york: Routledge.
- Smith, J.D., (2015). *Shipping containers as building components* (Department of the Built Environment). University of Brighton.
- The International Firm. (n.d.). *Fidus International*. [online] Available at: <http://www.the-international-firm.com/fidus/fidus-profile.html> [Accessed 8 Jan. 2018].
- Tom 1. (2015). 5 Methods to Insulate Your Shipping Container Home | Container Home Plans. Retrieved from <https://www.containerhomeplans.org/2015/03/5-methods-to-insulate-your-shipping-container-home/>
- Tom 2. (2015). How Do I Keep My Container Home Cool?. Retrieved from <http://www.containerhomeplans.org/2015/02/how-do-i-keep-mycontainer-home-cool/>
- Tom 3. (2015). How Should You Ventilate Your Shipping Container Home? | Container Home Plans. Retrieved from <https://www.containerhomeplans.org/2015/04/how-should-you-ventilate-your-shipping-container-home/>

- Urban Space Management. (2010). *Container City*. [online] Available at: <http://www.zen17279.zen.co.uk/images/CCFREQUENTLY%20ASKED%20QUESTIONS.pdf> [Accessed 21 Dec. 2017].
- World Shipping Council. (2017). *History of Containerization | World Shipping Council*. [online] Available at: <http://www.worldshipping.org/about-the-industry/history-of-containerization> [Accessed 11 Dec. 2017].
- Zaahib. (n.d.). *Prices Index for properties For Sale in Makkah Province - Saudi Arabia*. [online] Available at: https://www.zaahib.com/property_index/en/for-sale/makkah-province/ [Accessed 9 Jan. 2017].

9. Appendix

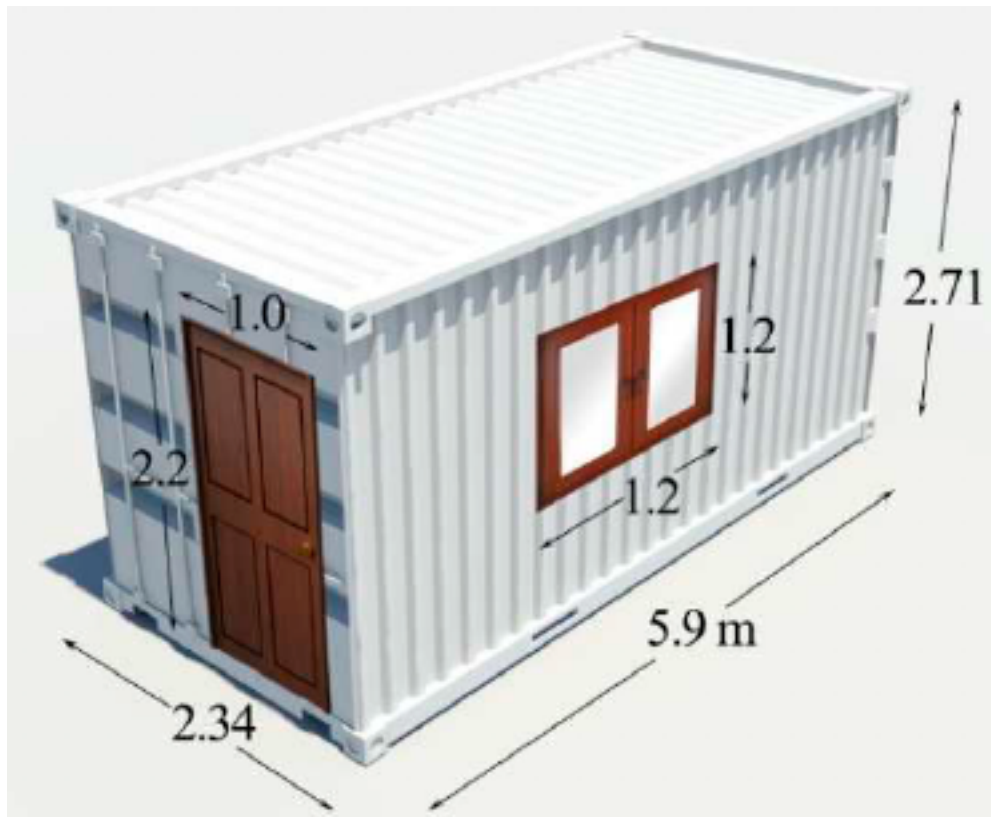
Appendix 1

The screenshot displays the MarketLine ADVANTAGE website interface. The top navigation bar includes the MarketLine logo, the word 'ADVANTAGE', and a user login status: 'You are signed in with Shibboleth' with a 'Sign out' link. Below the navigation bar, there are tabs for 'Home', 'Browse', 'Databases', and 'Ask Analyst'. A search bar is located on the right side of the navigation bar, with the text 'Search' and 'All research' and a magnifying glass icon.

The main content area is titled 'Saudi Arabia - Construction'. Below the title, it says 'INDUSTRIES | Industry Profile published by MarketLine on 21 December 2017'. The page is divided into several sections:

- Classifications:** This section shows two industry paths. The first path is 'INDUSTRY > Construction and Real Estate > Building Construction > Home Construction', which is highlighted with a blue checkmark. The second path is 'INDUSTRY > Construction and Real Estate > Building Construction > Hospital Construction'.
- Downloads:** This section contains a button labeled 'Download full Report' with a red arrow icon.
- Table of contents:** This section is currently empty.
- Related research:** This section is currently empty.
- Executive Summary:** This section contains three sub-sections:
 - Market value:** The text states: 'The Saudi Arabian construction industry grew by 1.2% in 2016 to reach a value of \$27,414.4 million.'
 - Market value forecast:** The text states: 'In 2021, the Saudi Arabian construction industry is forecast to have a value of \$31,123.6 million, an increase of 13.5% since 2016.'
 - Category segmentation:** The text states: 'Residential is the largest segment of the construction industry in Saudi Arabia, accounting for 65.9% of the industry's total value.'
 - Geography segmentation:** The text states: 'Saudi Arabia accounts for 36.8% of the MEA construction industry value.'

Appendix 2.



Appendix 3.

Case study on container architecture

Title: Customized Container Architecture

https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=9&ved=0ahUKEwj6i8eH4p7bAhWIK8AKHVbYDwoQFgg9MAg&url=http%3A%2F%2Fapps.arch.org%2Fresources%2Fproceedings%2Fuploads%2Fstreamfile.aspx%3Fpath%3DACSA.FALL.12%26name%3DACSA.FALL.12.12.pdf&usg=AOvVaw1A_9GVXqYVCXQYPmaDpxyd