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# Disaster Relief Shelter Design

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*Hexayurt Shelter Design through Material  
Selection and Thermal Testing – 9770 Words*

This dissertation focuses on correct material selection of the hexayurt in order to make it suitable for use in Dadaab as a transitional refugee relief shelter. Physical laboratory testing and computer software modelling has been implemented to assess the thermal comfort of the shelter when exposed to the Kenyan climate.

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*March 2012*

# Disaster Relief Shelter Design

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# Disaster Relief Shelter Design

## Executive Summary

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This dissertation looks at developing a Hexayurt for people in need of relief in hot climates, following natural disasters such as drought. My focus will be towards designing such a Hexayurt, focussing on correct material selection so that it is suited to the Kenyan climate and environment. My final design will be composed after exhaustive testing and analysis of materials.

To this day there are no comprehensive procedures which tackle the problem of homelessness in the surrounding areas of the refugee camp of Dadaab, with the use of emergency relief shelters.

My hypothesis is therefore that *emergency relief shelters could be a simple yet quick and effective way of responding to the temporary shelter needs of thousands of people who have been affected by hot climate catastrophes.*

The aim of this dissertation is *to improve the Hexayurt shelter so that is suitable for the Kenyan climate, by focussing on material selection.*

The brief outline for this dissertation follows as thus:

1. The rationale for this project addressing the aim and objectives that have been set out, which will outline the physical environment which this project is aimed at.
2. The methodology for the development of the Hexayurt, focussing on material selection, testing and modelling.
3. Development of the Hexayurt including analysis of results from testing, which will be used to finalise a list of suitable materials with regard to the environmental conditions that it will be subjected to.
4. And finally the conclusion, based on comparisons of the improved Hexayurt shelter against the refugee counterpart.

# Disaster Relief Shelter Design

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# Disaster Relief Shelter Design

## Chapter One – Introduction

### 1.1 Introduction:

“Humanitarian aid is material or logistical assistance provided for humanitarian purposes, typically in response to humanitarian crises including natural disaster and man-made disaster. The primary objective of humanitarian aid is to save lives, alleviate suffering, and maintain human dignity.” (Wikipedia, 2011) A disaster relief shelter is a type of material humanitarian aid which is used in response to various crises. The main purpose of the shelter is to provide cover at all times, whether it being long term or short term, without compromising on quality or durability. This chapter will explain the reasoning and provide argumentation to the material selection, in addition to the justifications. Also, a more in depth dissertation outline will be included.

### 1.2 Project Rationale:

After life threatening disasters in hot climates, such as earthquakes, bush fires and drought, there have been several concerns raised with regards to the provision of aid to the people affected. These include:

- Cost of manufacturing and logistics associated with the shelters. (UNHCR, 2009)
- Period of time that these shelters take to build and the period thereafter which they’ll be used.
- Damage to the natural environment. (Gibert, 2008) (Delrue and Sexton, 2009)
- Corruption which sees aid given to only the rich and sometimes, used for other purposes discounting the needs of the ones affected. (Lipton, 1989) (Transparency, 2011)
- And lastly, the technology which may prove to be ineffective if there are no ways of repair in the instance of damage.



Some of these factors are apparent today with the increasing crisis that troubles the largest refugee camp in the world (Al Jazeera, 2011) (MSF, 2011), which is located in Dadaab, Kenya.

Figure 1. Map of Kenya, Africa. (Google Maps, 2011)  
The map to the left shows the location of Kenya, Africa. Kenya is formally known as the Republic of Kenya, situated in eastern Africa. The equatorial line passes through the centre of Kenya, with the Indian Ocean to its south-east.

The refugee camp, Dadaab, is sited in north-eastern Kenya. This is shown on the map below.

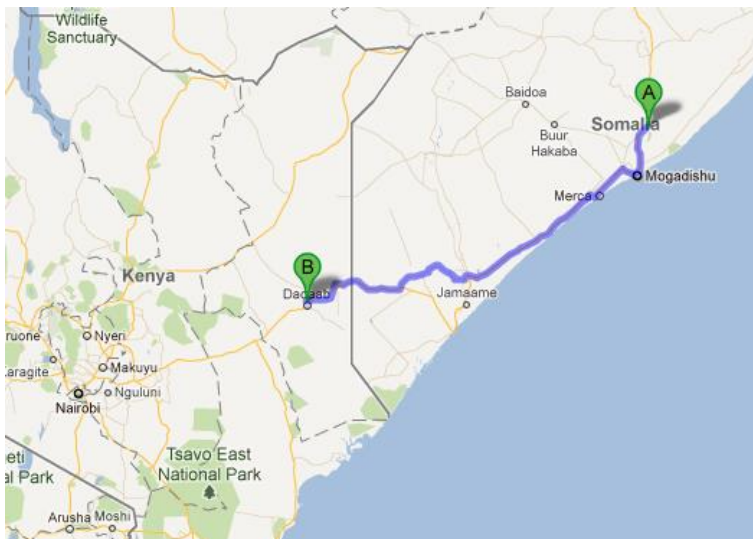


Figure 2. Map of Dadaab, Kenya. (Google Maps, 2011) The map to the left shows the location of Dadaab (marker B), which is situated in the north-eastern province of Kenya, around 900km from bordering Somalia (marker A).

The north-eastern province is classed as being semi-arid and hot. Semi-arid conditions are characterised by low annual rainfall, typically in the region of 250mm–500mm/annum, with scrubby vegetation (short, coarse grasses). Given the extension of the arid regions, the biggest part of Kenya's land consists of deserts or semi-deserted steppes. Rainfall is infrequent for this region, falling mostly during April or October. The region is suited to nomadic pastoralism due to its hot temperatures and extreme evaporation. There are no significant rivers, only tributaries (which rarely have water) of the Jubba River near the border of Somalia. Therefore, irrigation based development is not possible, whilst the nomadic pastoralists have to rely on wells for water. Dadaab itself is classed as having one of the roughest climates, with annual rainfalls around 350mm, temperatures reaching 37°C in the day and not falling below 21°C at night. (Kenyalogy, 2011)

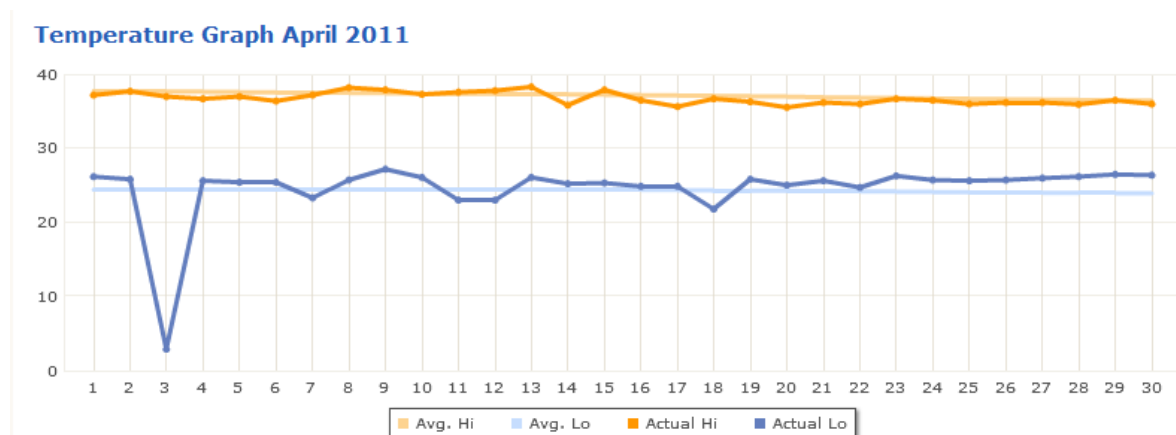


Figure 3. Weather chart for Dadaab, April 2011. (AccuWeather, 2011)

From the graph above, we can see that temperatures are as high as 39°C with an average low of 23°C. Temperature charts from January 2011 – December 2011 are located in Appendix 1. According to Dr.Kulbhusa Juneja and Dr.Manish Bhatia, “in hot environments, profuse sweating can result in heat exhaustion/stroke. Heat stroke can prove to be a life-threatening emergency. Heat exhaustion and heat stroke most commonly occur at around 40°C. Left untreated, heat stroke may progress to coma. Death may result due



to kidney failure, acute heart failure, or direct heat induced damage to the brain." (Juneja and Bhatia, 2006) This has been evident in Dadaab where refugees are found dead/close to death due to the extreme heat. (Actionaid, 2011) (Huffingtonpost, 2011) Therefore, it is critical to protect against these conditions by using opaque boards, whilst assessing the thermal comfortability of the shelter.

The lack of rain and the soaring temperatures have further induced a drought crisis in Dadaab. The Humanitarian Coalition, a network of Canadian NGOs, is responding to the crisis which is seeing 13million people affected. With the population of the Dadaab camp overflowing, in addition to the worsening situation, the humanitarian crisis is the largest in the world. Communities have collapsed, livelihoods have been damaged beyond repair and families are facing severe malnutrition. The United Nations has raised its food security alert level to its maximum, whilst the Humanitarian Coalition is concentrating on providing food, drinking water and basic sanitation. (Humanitarian Coalition, 2011) Therefore there is a specific need for humanitarian aid.

Dadaab consists of three UNHCR camps (Dagahaley, Hagadera and Ifo) spread over an area of 50km<sup>2</sup>. The influx of new refugees from Somalia and neighbouring towns and villages were significantly diminished during the December of 2006 when the Kenyan government decided to close its borders. With a total capacity of around 90,000, the severe droughts of 2011 saw the arrival of as much as 1000 people per day, who were in excessive need of food, water and most importantly shelter. Maalim Bahigow, a 50-year old new arrival into Dadaab in May 2011 says, "I have no tent yet, so I'm making do with pieces of cloth and sticks. All that matters is that my family gets some form of shelter." (Oxfam, 2012) This has placed extreme strain on the camp with it having to support 450,000 refugees by the end of July 2011, and will create further stresses as this figure is set to rise by the end of 2011. (MSF, 2011)

Around two thirds of new arrivals are provided with a tent by the UNHCR within a month of arrival, but as resources and funds dwindle, this has been reduced to a sheet of polythene or a thin rag. (MSF Somalia, 2011) Neither provides adequate protection from the unrelenting sun, pushing temperatures up to and over 50°C during the day. And at night, fear lies with attack from animals such as wild hyenas. Taking up to 12 days to receive the first food rations, 34 days to receive cooking utensils and blankets, the refugees find themselves fending for their lives without sufficient or sometimes no aid whatsoever in an environment that is best described as hostile and desert like.. (MSF, 2011) Makeshift shelters are constructed by families that reside outside the overflowing camps. These shelters are made from cardboard, polythene, sticks and anything else that can be salvaged. (MSF, 2011)

Shelter wouldn't have been such a problem if it weren't for the halted construction of an extension to the Ifo camp in January 2011, which would've housed a further 40,000 refugees. (MSF, 2011) This would have been a short term solution to house new arrivals and help ease congestion in the overflowing camps. But even with this extension, the other 300,000 odd people living in their makeshift shelters wouldn't have been accounted for. Therefore a great presence lies with providing a sufficient transitional shelter to those situated outside the camps that are subject to intolerable conditions.

### 1.3 Hypothesis:

Following the project rationale, my hypothesis for this dissertation is that:

*Under specific conditions, a transitional shelter would be an effective and apposite response to the needs of refugees in hot climates.*

### 1.4 Aims and Objectives:

I will start by highlighting the main aim of this dissertation, which is as follows:

*To improve the Hexayurt shelter (standard design) so that is suitable for the Kenyan climate, by focusing on material selection.*

The objectives for this project are therefore:

- *To verify the feasibility of the Hexayurt as a shelter for use in the surrounding areas of the Dadaab camp.*
- *To test materials in order to judge which will fair best in the north-eastern Kenyan environment.*
- *To finalise a list of materials which are most suitable for use in a Hexayurt.*

### 1.5 Scope:

This dissertation looks at the shelter needs of refugees in hot climates due to natural disasters, focussing mainly on drought. The shelter will not protect refugees from conflict, but will only act as a source of protection from sunlight and high temperatures.

### 1.6 Detailed Outline of Dissertation:

#### Chapter Two – Shelter

This chapter explains the problems involved with providing the correct types of shelters during emergencies. The current UNHCR tent that is used within the Dadaab camp will be analysed, as well as the Hexayurt and its refugee-built counterpart. The UK humanitarian policy and the humanitarian shelter needs will also be explained, which will act as background information for explaining the viability of the Hexayurt as a shelter solution for the refugees.

#### Chapter Three– Material Selection

This chapter looks at material selection, highlighting the pros and cons of each. The focus will be on narrowing down the best materials which provide shelter and cooling in hot environments. The materials will then be put under testing.

#### Chapter Four – Methodology

Generally speaking, a methodology is “a documented process for management of projects that contains procedures, definitions and explanations of techniques used to collect, store, analyse and present information as part of a research process in a given discipline.” (IPRR, 2011) This chapter provides further research into procedures of correctly selecting the materials, the different methods of lab testing that will be involved, and also field testing. This will therefore support the Hexayurt that will be designed.

#### Chapter Five – Results and Analysis

This chapter will publish and analyse the results of the tests that will be performed on the materials. Tests in a “real environment” will not be performed due to time pressures and therefore only laboratory tests will be undertaken. From the analysis of these results, the best performing materials will be suggested for Hexayurts for use in hot climates.

#### Chapter Six – Conclusion

This chapter explains the limitations that were encountered during the project, whilst outlining means of addressing them in future projects. Most importantly this chapter will sum up the successfulness of the project by comparing it against the specific aim, objectives and the hypothesis that have been formed.

# Disaster Relief Shelter Design

## Chapter Two – Shelter

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### 2.1 Introduction:

This chapter will provide an analysis of the shelter used in the Dadaab camp till this day, and an analysis of the Hexayurt. It also discusses the policies involved with shelter provision and the problems associated with them. The aim of this chapter is to provide background information on shelter as a whole, which will be used as background information for explaining the viability of the Hexayurt as a shelter solution for the refugees.

### 2.2 What Is Shelter? :

A simple definition is “a structure that provides privacy and protection from danger.” (Definitions, 2011) A shelter is defined as a structure (mainly man-made), but it can also be a natural habitable feature e.g. caves, rocky crevices, clumps of bushes, small depressions, large rocks on leeward sides of hills, large trees with low-hanging limbs, and fallen trees with thick branches. (Wilderness Survival, 2011)

There are two different types of shelter, long term and short term.

Short term – Short term shelter mainly comes in the form of tents, made from tarpaulin, wooden planks and plastic sheeting. But it also includes buildings, such as sports stadiums, school halls etc. This is designed to last up until the recovery stage when the refugees can return back to their homes. The natural features listed above also fall into this category.

Long Term – Long term shelter includes building permanent housing with all the necessary amenities, and its purpose is to rebuild the livelihoods of those that have been affected. This improves the quality of living over time through self-sustaining programs.

As with all shelters, they have to be carefully chosen and are mainly dependent upon the following:

- The level of protection needed against the natural climate and cases of extreme weather
- The materials that are readily available for use during construction and repair
- Their specific use.

### 2.3 UK Humanitarian Policy:

The delivery of shelter aid is subject to different policies. The UK policy responds to the needs of victims following conflict and natural disaster related emergencies, but still follows the codes of conduct that have been set by DG ECHO. These are solidarity, respect for human dignity, equality and tolerance. (ECHO, 2011) The DFID, Department for International Development have explained how the UK will administer its aid to refugee countries and the main aims of the new UK Humanitarian Policy 2011, as shown in Appendix 2. The

UK will act to administer and provide aid for those in need whilst following the principles that DG ECHO have set. In addition to this, the UK aims to work with partners multilaterally to expand its donor base, thus reducing the burden on each member. (DFID, 2011) (Branczik, 2004)

There are many problems associated with delivering and administering humanitarian aid, e.g. efficiency issues, political problems, humanitarian organisation failures etc. But, this dissertation focuses on material selection for the Hexayurt; therefore these problems will not be assessed and linked with the Hexayurt that will be developed. They are usually seen to by relief agencies and governments.

2.4 Humanitarian Need for Shelter:

Shelters are needed for protection during crises and to retain one’s dignity whilst doing so. As our case study shows in chapter one, there is a specific need for shelter in the surroundings of the Dadaab camp. The refugee-built makeshift shelters provide inadequate protection from the environment, therefore other solutions are needed.

Potential solutions include:

- Resettlement
- Return to Somalia
- Provide other shelter

Resettlement – This process involves finding refugees a place to stay, which may be in bordering towns or camps. With the fear of death from conflict, resettlement proves to be a difficult option. The process itself is administratively onerous and protracted; time frames through the Nairobi office are the worlds slowest. CIC, Citizen and Immigration Canada, has published statistics showing processing times of more than 42 months, with a fifth of all families having to wait over 52 months. (Toronto News, 2011) The processing time for a private sponsorship is shown in the table below.

Time (months)	Date	Details
0	November 2007	Application submitted
6	May 2008	Application received at Nairobi visa office
14	January 2009	Nairobi office send letter to refugee stating “You can expect to hear from us in the next 36 months. We will not reply to any correspondence or case enquiries during this period.”
50	January 2012	Refugee should receive a pre-decision letter by this time.
50+	January 2012	Refugee undergoes interviews, medicals, security checks and receives final decision.

Figure 4. Table showing the processing time for private sponsorship. (Greenstone, 2011)

As we can see from the table above, resettlement to westernised countries (UK, Canada, North America, France, Germany etc.) is the only credible option for the handful that are willing to be relocated. From the agonisingly long process times to the number that actually are relocated, resettlement seems to be an ambiguous dream.

Return to Somalia – From the constant influx of refugees from Somalia into Dadaab, returning to Somalia can be easily ruled out. Somalia is experiencing widespread conflict, leaving only a small number of citizens unaffected. Those who have tried to avoid the fighting, innocent civilians in particular, have been swept up by a virtual dragnet, resulting in at least 88% of Somalis experiencing conflict in their area due to clan warfare. One paramilitary member (FG, militiamen, Kismayo) has quoted, “ten years in constant fighting created a situation in which every person has participated in war, be it practically or intentionally.” (Greenstone, 2011)

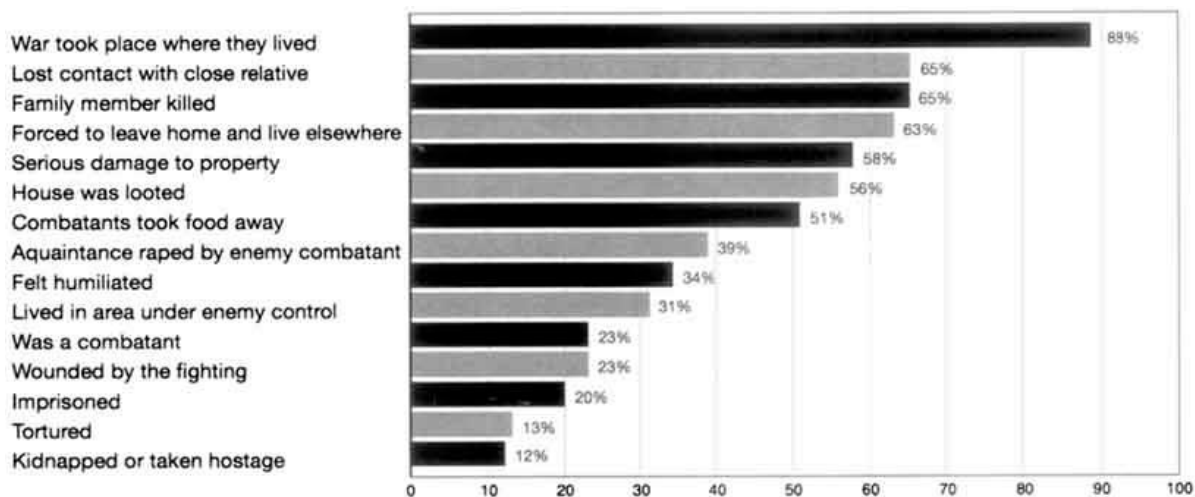


Figure 5. Bar chart showing how Somali refugees have been affected. (Greenstone, 2011)

The chart above shows the percentage of the population affected and specifically the way in which they were affected. The situation is worsened by the fact that Somalia is experiencing an economic crisis; high food prices, devalued currency, and a drop in remittance received. Therefore, the only viable option is to provide shelter.

### 2.5 Disaster Recovery.

The International Strategy for Disaster Reduction, ISDR, defines recovery as the “decisions and actions taken after a disaster with a view to restoring or improving the pre-disaster living conditions of the stricken community, while encouraging and facilitating necessary adjustments to reduce disaster risk.” (UNDR, 2005) Recovery following disasters focuses on restoring livelihoods of those who have been affected. In effect, it harnesses conditions for future development. Therefore, before looking at the Hexayurt in detail, it is imperative to define the recovery phase that Dadaab is in. This is to ensure that the right type of shelter is used in the right phase of the disaster, for the reason that selecting the wrong phase could lead to money and time wastage, worsening the current situation.

As with the shelter types, that were defined at the start of this chapter, disasters are also classed as being short or long term. Short term disasters are mainly unexpected weather, whereas long term disasters are droughts

and floods. The recovery phases associated with both types of disaster, as defined in the BRGov Basic Plan, is shown below:

**Initial Response (1-7 days)**

- Debris removal and clean-up
- Emergency, short-term repair of lifeline utilities
- Emergency, short-term repair of transportation systems and provision of interim transit services
- Building safety inspections
- Coordination of State/Federal damage assessments
- Re-occupancy of buildings

**Mid-Term Planning (7-30 days)**

- Provision of interim housing
- Restoration of lifeline utilities (power, water, sewers)
- Restoration of social and health services
- Restoration of normal City services
- Establishment of new ordinances governing location and nature of rebuilding
- Examination of building standards
- Economic recovery measures, including interim sites for business restoration

**Long-Term Reconstruction (Several Years)**

- Rebuilding
- Restoration of transportation systems
- Hazard Mitigation
- Reconstruction of permanent housing
- Reconstruction of commercial facilities
- Development and implementations of long-term economic recovery targeting impacted and critical industries"

Figure 6. Recovery phases as outlined in the B.R.Gov. Basic Plan. (B.R.Gov, 2009)

With the refugees making their way from Somalia into the surrounding areas of the Dadaab camps, preliminary thoughts may lie with placing the disaster within the first phase - initial response. But, from the case study and explicitly from the humanitarian need for shelter section, expatriates have been known to stay for years. Therefore, the recovery phase would be long-term construction. This also offers a problem; refugees are actively seeking to be relocated to regions

which have higher living standards and greater amenities. Given the shortage of resources, placing the surrounding areas of Dadaab into this stage would be unfitting.

Therefore, the most suitable recovery phase would be mid-term planning. Quarantelli has identified housing options which are appropriate to each disaster recovery stage. This is shown below.

- ▲ **Emergency shelter** is the first stage. Emergency shelter is an unplanned location that is intended only to provide protection from ordinary weather conditions of temperature, wind, and rain. For example, some families sleep in their cars after earthquakes (Bolin and Stanford, 1991, 1998).
- ▲ **Temporary shelter** is the second stage. This includes food preparation and sleeping facilities that are sought from friends and relatives or are found in hotels or motels. Mass care facilities in school gymnasiums or church auditoriums are a last resort.
- ▲ **Temporary housing** is the third stage. Temporary housing allows victims to reestablish household routines in nonpreferred locations.
- ▲ **Permanent housing** is the last stage. Permanent housing reestablishes household routines in preferred locations.

Figure 7. Appropriate housing options at each recovery stage. (Lindell, 2006:349)

For the refugees situated in the surrounding areas of Dadaab, the types of shelter that they'd benefit from would be temporary shelter or temporary housing. But from the reasons explained above, with the addition of material shortage in the area, temporary/transitional shelter is the most prominent solution.

Following BR Gov's Basic Plan and the work of Quarantelli, the flow chart below has been developed to ensure the correct selection of housing type during different recovery phases. The route to pin-pointing the suitable housing type for the refugees in the surrounding areas of Dadaab has been highlighted in red.

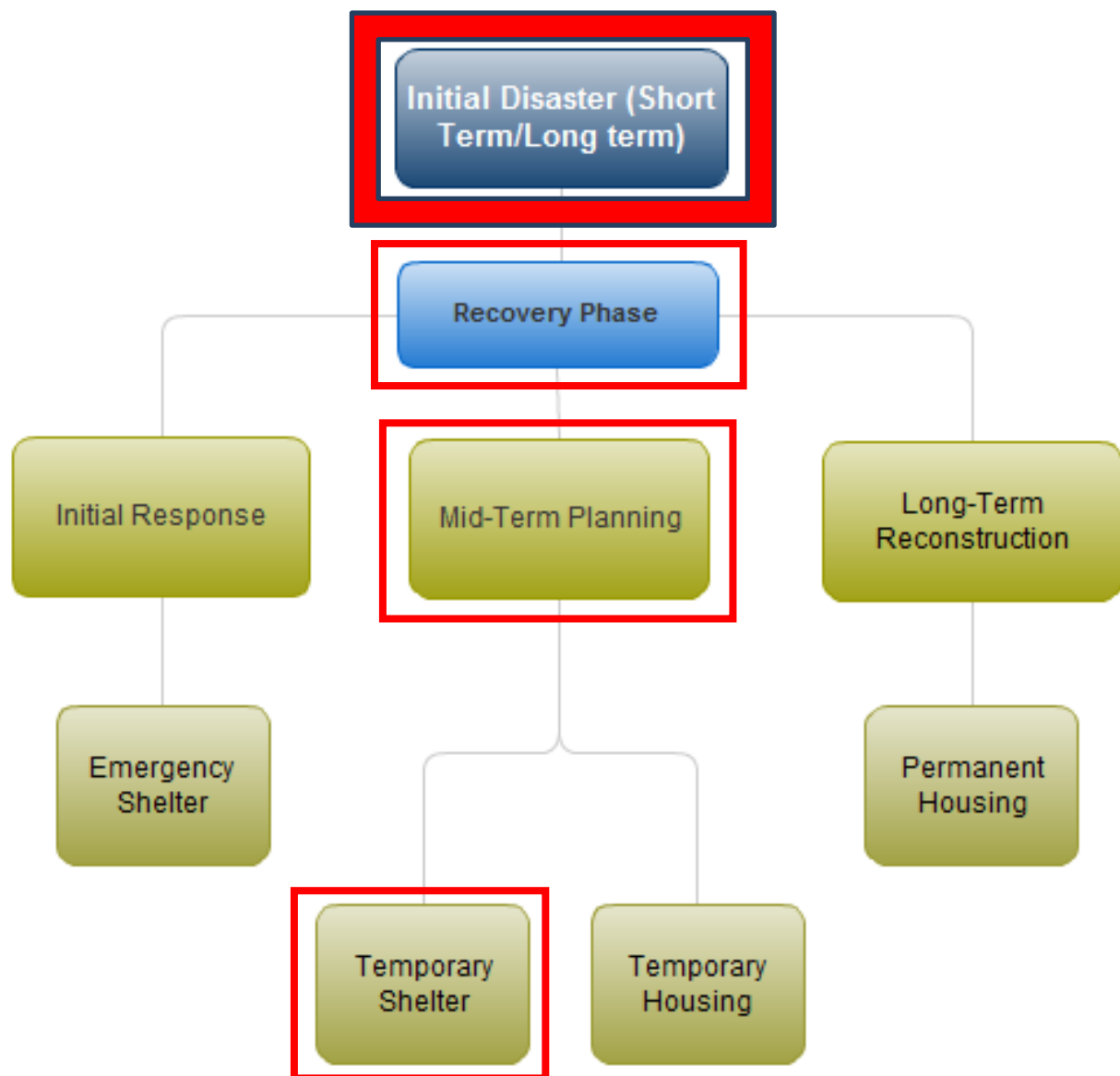


Figure 8. Flow chart showing appropriate housing options at different recovery stages.

The flow chart above shows the main stages following a major disaster – starting with the disaster itself; which leads to the recovery phase; which in turn calls for planning; which then finally follows with the correct shelter solution. Below is a case study which explains the importance of providing transitional (temporary) shelter.



## 2.6 Case Study – Aceh Province, 26<sup>th</sup> December 2004.

A major earthquake, which measured 9.0 Richter occurred in the Indian Ocean off the coast of Sumatra, Indonesia at 7.58am on the 26<sup>th</sup> December 2004. Due to the quake occurring in the ocean, a large amount of water was displaced which resulted in a tsunami. The hardest hit was the coastal areas, mainly Indonesia, Sri Lanka, India and Thailand. (Samek, Skole and Chomentowski, 2004:2)

Around 226,000 people were reported dead, including 166,000 in Indonesia; 38,000 in Sri Lanka; 16,000 in India; 5300 in Thailand; and 5000 foreign tourists. In addition to this, over 500,000 were injured, and a staggering 5 million lost their homes or access to food and water. (Pickrell, 2005) There was an obvious need for shelter.

Whilst the government provided Beurangong Barracks (BRR, 2005:60), which were timber buildings that accommodated 12–20 families in 20m<sup>2</sup> rooms. They comprised of a porch area under which meals were cooked. (Eye on Aceh, 2005) By the end of March, 686 barracks had been completed, providing accommodation to over 8400 families. (UNHIC, 2005) But by the end of 2007, only 5200 families remained. (EC, 2007) The barracks were used in accordance with tents as means of emergency shelter till permanent housing was built. BRR's target of 127,000 permanent houses was reached in December 2008, with the IFRC building 20,000 of them. (da Silva, 2010) (IFRC, 2008) Around 290,000 people chose to stay with host families, which included relatives and friends. (Oxfam International, 2005) With the time needed to build permanent housing, the TSPA –Temporary Shelter Plan of Action was launched in September 2005. All 19,920 shelters were erected by December 2007. (van Dijk and van Leersum, 2009)

Although families did not receive transitional shelters until 18 months after the tsunami, they did make a significant impact upon recovery. They enabled the refugees to return to their villages from the barracks and tents, which helped rebuild a neighbourhood. When the building of permanent housing was completed, families reused the shelter as extra living space or sold the materials for cash. Some even set up businesses. Dijk and Leersum quote, “this demonstrates that transitional shelters are not just a temporary post-disaster housing solution, but are a valuable asset which can be used by beneficiaries to further improve their lives.” (van Dijk and van Leersum, 2009) ACARP, Dercon and Kusumawijaya, and, van Dijk and van Leersum quote:

“Those communities that received temporary housing allowing them to move out of barracks and back to their village have fared better than those that did not receive similar assistance. All aspects of recovery have advanced more successfully in these villages.” (ACARP, 2007:152)

“If IFRC transitional shelters were provided earlier within the original villages of the survivors, all the permanent houses would have been completed earlier. Transitional shelters in original villages would have given some time for proper planning and would have facilitated the participatory process.” (Dercon and Kusumawijaya, 2007:2)

“Ms. Isrijal. Living in a tent made life really hard for the entire family. There was no privacy and it caused a lot of stress. Receiving a transitional shelter has helped to get me and my family started again. It gave the

family more comfort and relieved some pressure. My husband was more relaxed and more capable of taking care of the family again.” (van Dijk and van Leersum, 2009)

As the construction of permanent housing in Aceh was slow, transitional shelters had a major impact on recovery. They enabled the refugees that were living in tents and the barracks to stay in their shelters till they returned home. Also, some set up these shelters outside their destroyed homes so they could be closer to their families. It is possible that the Indonesian homes that were worst hit would have benefitted further from the building of transitional than those that weren't. This is due to the reconstruction of their homes taking longer due to the greater damage. Therefore, the use of transitional shelters would have bridged the gap between emergency shelter and permanent housing, maintaining the refugee's dignity and providing safety.

From this case study, it can be learnt the transitional shelters could play a significant role during post-disaster recovery by providing secure accommodation for displaced families. In Dadaab, tents (emergency shelters) have already been pitched but with the shortage of space within the three camps, the refugees on the outskirts of the camp are most at risk. As the refugee's stay is indefinite, it is viable to provide transitional shelter whilst aid agencies concentrate on building permanent homes. Therefore, the Hexayurt will be developed, focusing on correct material selection, as it is a temporary (transitional) shelter.

### 2.7 Hexayurt.

“Hexayurt is a simplified disaster relief shelter design. It is based on a geodesic geometry adapted to construction from standard 4x8 foot sheets of factory made construction material. It resembles a panel yurt, hence the name.” (Appropedia 1, 2011) They are constructed from 4x8ft sheets of foam or hexacomb cardboard and duct tape, and costing wise it has been calculated to around £100 each. (Wired, 2011) This provides shelter for 2 individuals at the most, but larger yurts can be constructed but will obviously cost more. Construction wise, typical Hexayurts will use tape to attach the cardboard pieces. The Hexayurt has no internal frame as the walls itself provides the structural rigidity needed for it to stand and resist forces from wind.



Figure 9. Image of a cardboard Hexayurt. (Yurt, 2011) The image on the left shows typical Hexayurts which are used by desert-camping enthusiasts during the “Burning Man” festivals, which are based in the USA. The Hexayurt was invented by Vinay Gupta in 2002 in response to the Sustainable Settlements charrette hosted by the Rocky Mountain Institute. The name Hexayurt comes from the word yurt, which is a portable, bent wood-framed dwelling structure traditionally used by Turkic nomads in the

steppes of Central Asia. (Woodlandyurts, 2011) Yurts have been in use at least since the 13th century, and there are indications that the design is much older. (Appropedia 2, 2011) This dissertation does not focus on

the design of the Hexayurt, only the material selection; therefore a standard Hexayurt (height of 12ft) will be used. But, for material testing, it is essential that the structure of the Hexayurt is detailed – in particular the joints. Appendix 3 shows how a cardboard (hexacomb) Hexayurt is built. The structure is the same for wooden Hexayurts, but obviously tape joints are replaced by blocks and screws.

Having outlined the Hexayurt structure itself in Appendix 3, it is necessary to highlight the comparisons between the Hexayurt and the refugee built counterpart in relation to the humanitarian needs that have been explained earlier in this chapter. This will provide further supporting evidence as to why the Hexayurt would be the ideal shelter type to use in Dadaab.



Figure 10. Image of a refugee built shelter 1. (International Business Times, 2011) The photo to the right shows women building a makeshift shelter, while the photo below shows the end product.



Figure 11. Image of a refugee built shelter 2. (Frankel Family Association, 2011) As our case study shows in addition to the humanitarian need section, there is a specific need for shelter in the surroundings of the Dadaab camp. The makeshift shelters that

are built by the refugees provide inadequate protection from the environment. This can be seen in the images above.

Therefore during drought, a Hexayurt would be an appropriate response to the problem by tackling the needs of the refugees by addressing the following:

- Privacy
- Health
- Security

The table below shows how both structures relate to these needs.

	Refugee built structure	Hexayurt
Privacy	A low level of privacy as it is not an enclosed structure and is only covered with a sheet of tarpaulin; therefore there isn't much that can be done to maintain refugee dignity.	A high level of security due to it being a fully enclosed structure, covered with a roof which is made from the same material as the walls. Refugee dignity is well maintained as they can carry out tasks such as changing clothes without anyone seeing.
Health	A low level of protection from wind, sunlight, temperature etc. The single sheet of tarpaulin over the structure provides nominal protection from the elements; therefore survival rates are still likely to increase, but only marginally.	A high level of protection from the elements and also from animals (hyenas) due to thick walls which are sufficiently sealed, therefore survival rates are likely to increase adequately.
Security	It is not an enclosed structure with solid walls; therefore there is a low level of security and hardly a feeling of security. Refugees are less likely to keep children unsupervised in the shelter, and will not act as an area where they can carry out essential activities. Therefore it barely acts as a support for livelihood.	Fully enclosed structure with solid walls, therefore there is a high level of security. Refugees are more likely to keep children unsupervised in the Hexayurt, enabling them to gather food and fuel. It will also act as an area in which essential activities can be carried out, therefore the Hexayurt will act as a substantial support for livelihood.

Figure 12. Table showing comparisons between the refugee shelter and the hexayurt.

2.8 Conclusion:

As we can see from the table above, the Maltby has obvious benefits over the refugee built shelter when equated with important humanitarian needs that shelter must provide. From the project rationale, it is vital for the Maltby to provide protection against soaring temperatures by assessing the thermal comfortability of the shelter.

# Disaster Relief Shelter Design

## Chapter Three – Material Selection

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### 3.1 Introduction:

Having provided evidence for using the Maltby as a viable solution to the shelter problem in Dadaab, this chapter will focus on determining the materials that will be put through testing. Maltby states “We think that the most likely material is plywood, Maltby or a similar engineered wood product. This is based on two factors: cost and strength. The polyiso insulation boards commonly used to make Maltby in the US are vulnerable to wind and not suitable for long term use. Honeycomb panels are too expensive and are not available in large enough quantities. This leaves one of the myriad of wood products. We suspect that plywood will handle humidity better than Maltby, but there are a wide variety of possible candidate materials out there, and this is an area we are actively seeking expert advice in.” (Maltby, 2010)

From Maltby, the two main candidates that will be subject to testing will be plywood and Maltby, but he also highlights that similar engineered wood products will also be appropriate. Having negated the usage of hexacomb (honeycomb) panels for Maltby construction, and as hexacomb is not suitable to be used with block joints, they will not be analysed in this dissertation.

### 3.2 Materials:

Providing protection against the sun is vital to survival in hot climates, therefore opaque boards should be used which minimise light transfer. Therefore the materials that will be analysed in this dissertation will be:

- Chipboard
- Maltby (high density fibreboard)
- Maltby (medium density fibreboard)
- Maltby (oriented strand board)
- Plywood

These man-made boards are available from local DIY stores and will need to be shipped to Dadaab by aid agencies. To see the main advantages of each board, the analyses are spread into three subsections – working, fixing and finishing. These are related to Dadaab and are shown in detail in Appendix 4. It is difficult to choose the correct board type from this analysis as each board has its fair share of advantages as well as disadvantages. Therefore, testing will be carried out on each board type in order to gauge which will be most suitable for use in Dadaab.

As with all shelters, the materials have to be tested structurally. The Maltby project in Haiti, written by Benjamin Maltby, can be used to prove that the Maltby is structurally sound. Maltby quotes, “the Maltby can be made structurally adequate, using only screwed timber block joints, for use as a transitional disaster relief

shelter Haiti." (Maltby, 2011:89) This conclusion has been made following structural testing which determined the structural adequacy of the Maltby using only screwed timber block joints, without glue or strapping. Code based joint design and tension tests were used to endorse the statement above. Shear testing was also used but produced inconsistent results. As the climate and temperatures in Haiti are similar to those in Maltby, excluding the possibility and effect of seismic activity in Dadaab, it is assumed for this dissertation that the Maltby will be structurally adequate for use in Dadaab. If further analysis of the Maltby's strength through joints testing wishes to be undertaken, a full testing procedure has been produced to Maltby specifications, and is shown in Appendix 5.

### 3.3 Conclusion:

Due to all five boards being similar in regard to workability, fixability and finishability, it is difficult to select the most suited board at this stage. As some boards have already been tested structurally by Maltby, in this dissertation each board will be tested thermally to determine which will produce the most comfortable indoor conditions for the refugees in the Maltby. These are shown in the succeeding chapter.

# Disaster Relief Shelter Design

## Chapter Four – Methodology

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### 4.1 Introduction:

The types of boards and their respective fixings have been determined in the previous chapter and Appendix 3 and 4. This chapter will provide procedures and explanations of techniques that will be implemented to test the boards that will be used for the Maltby. A thorough explanation will also be provided for the computer software test.

As the Maltby is a semi-permanent shelter, refugees are not expected to return to their place of origin in the short term. Therefore, the Maltby will have to be made durable as the time the shelter is used by a person/family cannot be quantified; hence it will be required to resist short-long term use and should be adapted for use by aid agencies. The thermal comfortability plays a significant role in ensuring the conditions in the shelter are habitable. According to UNHCR shelter needs, staff accommodation may also be required where accommodation isn't readily available. (UNHCR, 2006) This is a logistical problem and an issue which should be resolved by agencies. Therefore in this dissertation, the focus will remain on material selection, not logistics.

From the Transitional Shelter Quality, Standards and Upgrading Guidelines that has also been published by the UNHCR, they have noted a list of criteria that should be associated with short term shelters if upgrading works are not needed. Upgrading works are, fundamentally, remedial fixing works on existing shelters in a certain location. As with the surrounding areas of the Dadaab camps, the shelters that have been made by the refugees are not in a salvageable condition, therefore remedial upgrading works will be of no use. Thus, the following list of criteria for shelters is identified and should be used.

- Around 200sq ft. of enclosed space
- Shelter 6ft-8ft high
- Adequate ventilation
- Acceptable internal temperature
- Durable roof and wall materials
- Secure shelter
- Adequate privacy and partitioning (UNHCR, 2005)

Due to time and testing facility restrictions, it is not possible to test the Maltby on all of the key criterions identified, therefore only the highlighted condition will be analysed. This dissertation focuses on material selection alone, with the roof and wall materials being constructed from the same board type. This testing will be done through the thermal testing of the boards, and using computer software to gauge the internal temperatures of the Maltby.

#### 4.2 Testing Categories:

There are two categories of testing, which are shown below:

1. Environmental
  - Laboratory tests which includes structural and thermal performance testing.
  - Environmental chamber tests which include testing of thermal performance and condensation.
  - Modelling tests which includes logistical criteria comparisons.
2. Field
  - Real environment shelter testing using several groups in a chosen area over a substantial time period. These tests give results for buildability, usage patterns and material degradation.

In this dissertation, the thermal performance of the materials will be tested in the laboratory and is highlighted above. Since this dissertation focuses on testing materials for their thermal properties, logistical modelling will not be undertaken. Also, due to the lack of testing equipment, environmental chamber testing cannot be undertaken, but instead computer software will be used to assess the internal temperatures (thermal comfortability.)

Shelters are customarily tested in the real environment (field) with the aid of a relief agency programme. This is done so that all assumptions and rationale associated with them hold true in reality. This type of testing is carried out using several receipt groups so that averages can be evaluated and any changes can be seen to, both of the shelter and the aid programme. But due to time pressures and the inability to travel to Dadaab to test the Maltby materials, field testing will not be embarked upon in this dissertation.

#### 4.3 IES – Apache Simulation:

Apache simulator will be used as the computer program to test how the different wooden boards affect the internal temperatures inside the Maltby. Apache qualifies as a dynamic model in the CIBSE system of model classification, and is based on the first principles of mathematical modelling of the heat transfer processes occurring within and around a building. According to IES, "The program provides an environment for the detailed evaluation of building and system designs, allowing them to be optimised with regard to comfort criteria and energy use." (Apache, 2011) For every element of the building, the processes of conduction, convection and radiation heat transfer are modelled individually and integrated with models of room heat gains, air exchanges and plant. Real weather data is used and covers periods of up to one year. The buildings thermal conditions can be recorded in 60 second intervals also.

Apache will model the Maltby in a Kenyan climate, using the weather data present on the system. The Maltby will be imported into Apache in an AutoCad drawing format to ensure the dimensions of the shelter remain exact, therefore ensuring a more accurate analysis. The main aim of this test is to model the thermal climate of Maltby to see how the internal temperatures of the shelter will fair in response to the changes in weather. This will show if the shelter is habitable for refugees. The main aim of this dissertation is to improve the



Maltby so that it is suitable for the Kenyan climate by focussing on material selection. The objectives stated in chapter one were:

- *To verify the feasibility of the Maltby as a shelter for use in the surrounding areas of the Dadaab camp.*
- *To test materials in order to judge which will fair best in the north-eastern Kenyan environment.*

Through performing the computer thermal analysis of the Maltby using the materials highlighted in the previous chapter, it will be easier to gauge which of those materials are best suited to Dadaab and should be used in transitional shelters. To model the Maltby on Apache accurately, the thermal conductivities (k-values) of each material will have to be inputted into the program. The program will calculate the U-values of each material which will then be used to calculate the thermal gains of the materials and the internal temperatures due to solar gain and wind. Maltby recommends “18mm thick board” (Maltby, 2011:89) which will be used in the model. To calculate the k-values of each material, each board will have to be testing separately in a laboratory. The information on laboratory testing is shown below.

#### 4.4 Laboratory Testing:

Thermal conductivity  $\lambda$  is the intrinsic property of a material which relates its ability to conduct heat. Its value is defined as the quantity of heat  $Q$  transmitted through a unit thickness  $\delta$  in a direction normal to a surface of unit area  $A$  due to a unit temperature gradient  $\Delta t$  under steady state conditions and when the heat transfer is dependent only on the temperature gradient.

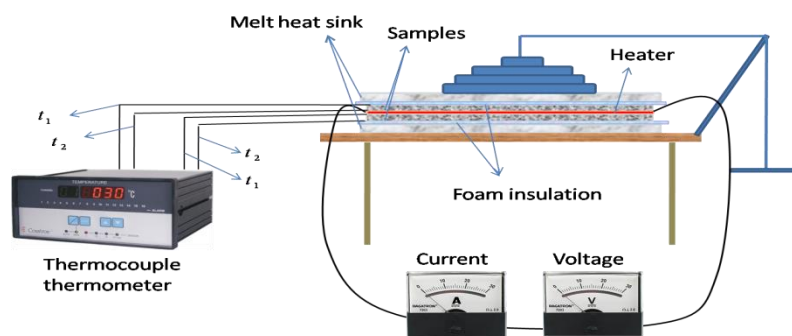


Figure 13. Image showing the apparatus setup for thermal conductivity analysis.

The apparatus consists of two identical samples of the material to be tested sandwiched between two metal heat sinks as shown above. An electrically conducting sheet is placed between the samples thus acting as a heater. Thermocouples are placed on either side of each sample. Thin sheets of foam are used to take up small irregularities in the surfaces of the samples, and to ensure good thermal contact between the thermocouples and surfaces. Electrical power is supplied to the heater, causing the inner faces of samples to rise in temperature. The rise in temperature is measured by the voltage output of the thermocouples, and this voltage is plotted on a chart recorder. The moisture content will also be calculated after oven-drying of each board.

The thermal conductivity will be calculated using the Fourier heat conduction equation shown below.

$$Q = \lambda A \Delta t / \delta, \text{ where thermal conductivity is expressed as } \lambda = \frac{Q \delta}{A \Delta t}.$$

#### 4.5 Conclusion:

The results from these two tests are shown in the following chapter, with appropriate analyses carried out for each test and using applicable literature to draw conclusions.

# Disaster Relief Shelter Design

## Chapter Five – Results and Analysis

### 5.1 Introduction:

This chapter will describe the results and analysis of the five boards that were tested through the methods shown in the methodology. Where possible, the results will be analysed against the climatic conditions of Dadaab.

### 5.2 Laboratory Testing:

The thermal rig was used to gauge the temperature differences on the hot and cold faces of the boards. This information, along with the board dimensions were inputted into the Fourier equation and the thermal conductivity was calculated. The graphs from the tests are shown in Appendix 8.

Results:

Wood Type	Bottom Voltage (mV)	Top Voltage (mV)	Average Voltage (mV)	Temperature Difference (°C)	Area (m <sup>2</sup> )	Depth (m)
Plywood	1.040	1.160	1.100	5.500	0.250	0.010
Chipboard	2.140	2.800	2.470	12.350	0.250	0.015
OSB	1.320	1.680	1.500	7.500	0.212	0.010
MDF	0.800	0.960	0.880	4.400	0.250	0.006
HDF	2.080	2.580	2.330	11.650	0.250	0.018

Wood Type	Wet Weight (g)			Dry Weight (g)		
	1	2	Average Wet (g)	1	2	Average Dry (g)
Plywood	1506.400	1212.900	1359.650	1425.200	1132.300	1278.750
Chipboard	2713.600	2755.500	2734.550	2587.300	2630.700	2609.000
OSB	1301.600	1534.200	1417.900	1233.400	1467.400	1350.400
MDF	1285.200	1268.000	1276.600	1231.700	1215.000	1223.350
HDF	3033.300	2985.900	3009.600	2918.900	2867.400	2893.150

Wood Type	Average Moisture Content (%)	Thermal Conductivity $\lambda$ (W/mK)
Plywood	6.326	0.039
Chipboard	4.812	0.026
OSB	4.999	0.034
MDF	4.353	0.029
HDF	4.025	0.033

Figure 14. Table showing the results from the laboratory tests.

#### Analysis:

The thermal conductivity of structural woods is much less than that of metals, e.g. the conductivity of structural softwood lumber at 12% moisture content is in the range of 0.1 to 1.4 W/mK compared to steel at 45 and aluminium at 216. (Simpson & TenWolde, 1999:15) These values will change dramatically due to moisture content, density and temperature, with thermal conductivity increasing as these factors increase. (Simpson & TenWolde, 1999:16) From the results, the moisture contents are far less than 12%, so the thermal conductivities are less than that of structural lumber. While temperatures hit nearly 40 degrees in Dadaab, the humidity is likely to be greater than that in the laboratory. Therefore the conductivities are expected to be greater than from the test. But due to difficulty in predicting the expected conductivities, the values from the test will be used in the IES model.

Thermal conductivity determines the rate of heat transfer across a material due to a temperature gradient; heat transfer occurs at a higher rate for materials which have greater conductivities. For the Hexayurt to be 'liveable' (thermally comfortable) the heat transfer from the outer face, which is influenced by solar radiation, to the inner face of the board should be kept to a minimum. Low thermal conductivities are analogous to high insulating capabilities, which results in reduced heat flow to the inner part of the Hexayurt; thus maintaining a temperature gradient and producing a more comfortable occupant environment when outside temperatures are extremely hot.

From the research carried out by Loughnan-et-al, "in Mawson Lakes, the thermally comfortable range of temperatures is from 25°C and 30.6°C." (Loughnan-et-al, 2012:2) Since temperatures in Mawson Lakes are similar to that of Dadaab, with temperatures reaching highs of around 42°C (MLA, 2012), it can be assumed that the thermally comfortable zone within the Hexayurt should be between 25°C and 30.6°C. This can be backed up by the psychometric chart shown in Appendix 7. As thorough weather data for Dadaab was not available, the data for Garissa (only 199km from Dadaab) was used. The chart was produced using Climate Consultant 5.1 which conforms to the adaptive approach to thermal comfort. It is a behavioural approach whereby occupants tend to make themselves comfortable by adjusting clothing and activity in relation to their thermal environment. (Humphreys and Nicol 1998:991-1004)

Many buildings in temperate climates during the summer months are not heated or cooled i.e. they are free running. Thus the indoor temperatures change relatively to the outdoor weather. The type of clothing is likely to change given certain weather conditions, i.e. cool clothing in the summertime and warm clothing during winter months. According to deDear and Brager, "clothing changes due to weather even in buildings which are air-conditioned." (deDear and Brager, 2002:549-561) Humphreys argues that "as a result, the temperature indoors which people find comfortable also changes with the weather." (Humphreys, 1981) Therefore, a comfortable climate will vary considerably with climate.

Field studies or climatic chambers are used on subjects that are tested and required to quote their thermal sensations based on the ASHRAE or Bedford scale, shown below.

ASHRAE	Bedford
Hot	+3 Much too warm
Warm	+2 Too warm
Slightly warm	+1 Comfortably warm
Neutral	0 Comfortable neither warm nor cool
Slightly cool	-1 Comfortably cool
Cool	-2 Too cool
Cold	-3 Much too cool

Figure 15. Table showing the comparison between the ASHRAE and Bedford scale. (Greenlux, 2005)

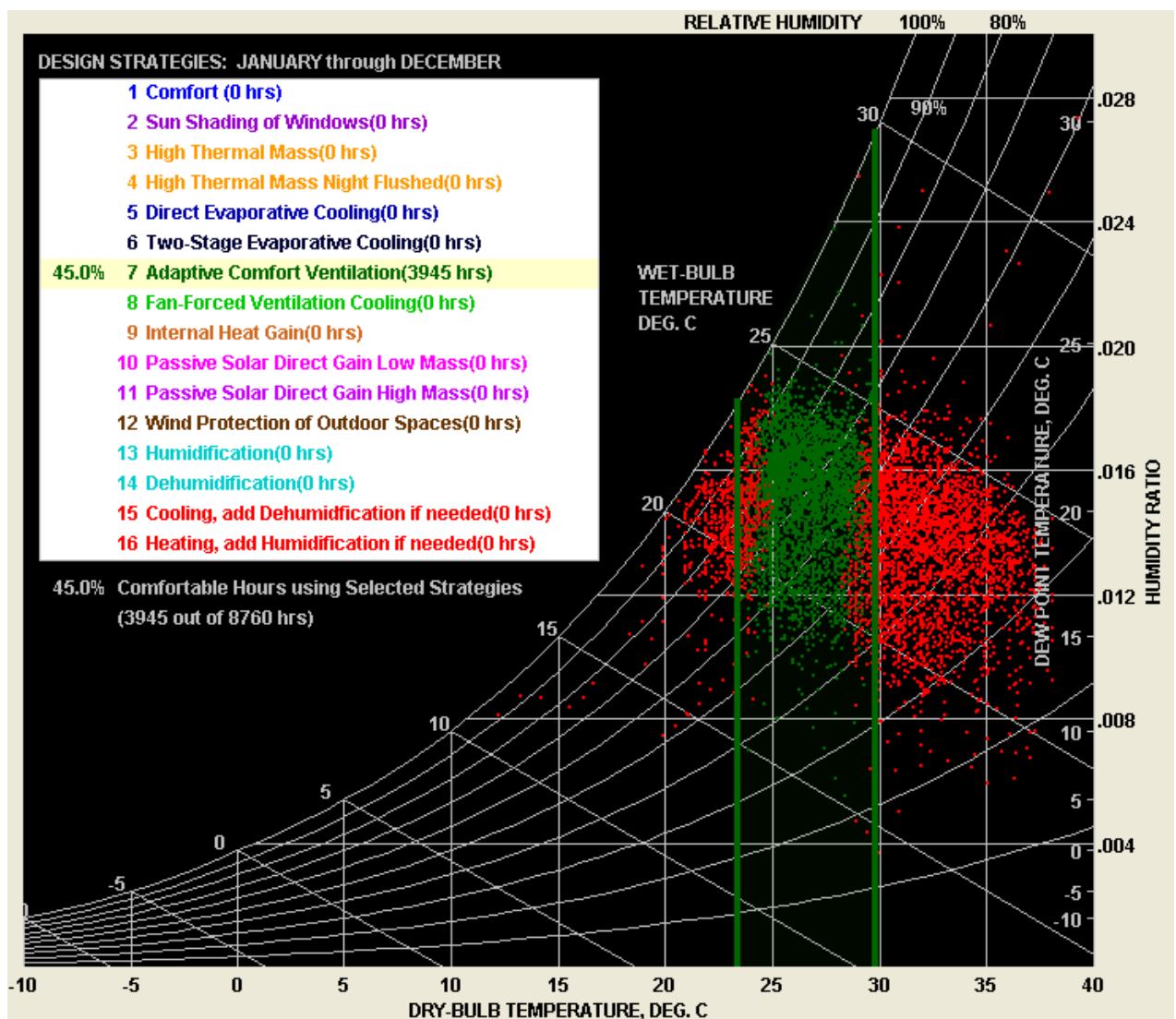


Figure 16. Psychrometric graph showing the thermally comfortable zone in Dadaab.

For this dissertation, the ASHRAE scale was used. From the psychometric chart shown above and in Appendix 7, it can be observed that the thermally comfortable zone is in the range of 23°C to 30°C. For the Hexayurt in Dadaab, the boards with the lowest thermal conductivities should result in indoor temperatures which are within the range shown above. From the results, chipboard and MDF have the lowest thermal conductivities of 0.026 W/mK and 0.029 W/mK respectively; thus when the values are inputted into the IES model, theoretically they should produce the most comfortable internal conditions.

5.3 IES – Apache Simulation:

The Apache simulator was used to determine the theoretical indoor temperatures for each board type, with 10 people inhabiting the available space. The results from the simulation for all wood types are shown in Appendix 6.

Results:

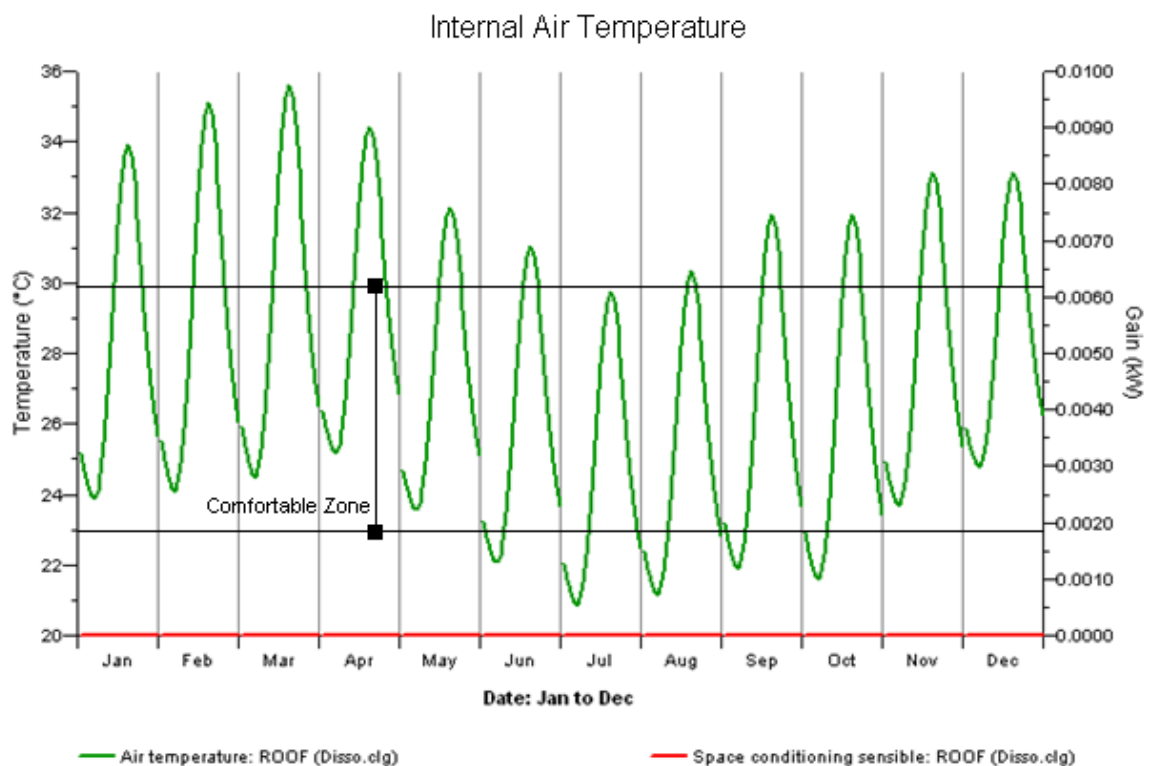


Figure 17. Graph showing the air temperature change over 12 months within the hexayurt, when built with Plywood.

Analysis:

The Apache simulation produced extremely similar results for all five board types, showing that the majority of internal temperatures lie within the comfortable zone. This may be due to the thermal conductivities of the boards. As the conductivities do not vary considerably, the U-values are also similar, which in turn provides similar thermal masses. The thermal mass of a material is a variable which depends on multiplying its mass, its

specific heat capacity, and the increase in temperature. The thermal properties related to thermal mass are its U-value and their thermal admittance parameters. According to Thomas, “the heat loss from any building element is related to its U-value.” (Thomas, 1999)

The U-value is the heat flow rate per unit area from the air on warm side of the material to the air on the cold side. The admittance, Y, is the amount of energy entering the material’s surface for each degree of temperature change occurring just outside the surface. It also has the same units as the U-value ( $W/m^2K$ ). A material’s admittance depends on its thickness, thermal conductivity, density, specific heat and the frequency at which heat is put into it.

The graph above shows the internal temperatures for Plywood over a period of 12 months. It can be seen that the majority of the air temperatures are within the comfortable zone, as defined by the adaptive comfort chart shown in Appendix 7. The results produced for Chipboard, HDF, MDF and OSB are near identical; the majority of temperatures are also within the comfortable zone, and therefore the same analysis will apply.

As explained previously, the thermal properties of materials depend on their K-values, U-values and thermal admittance parameters. The thermal admittance parameters change due to the position of the sun, which alters the frequency at which heat hits the surface of the board of the Hexayurt. The specific heat depends on the thermal conductivity and density, with the board thickness constant at 18mm. The admittance parameters are controlled by the IES software.

The thermal conductivities (K-values) are similar, ranging from 0.026W/mK to 0.039W/mK, thus the U-values which are dependent on them and are calculated by the program are also very similar. According to RIBA, “U-values are a measure of heat loss and are used to show how well building elements transfer heat.” (RIBA, 2012) Instead of relying on individual material properties, they can be used to predict the composite behaviour of an entire building element. Thus it can be assumed that the material’s ability store and release heat depends on its U-value. With similar K-values, the U-values are also similar meaning the materials heat storage capacities are presumed to be similar also. As heat storage is undesirable in hot climates such as in Kenya, according to Greenlux the building materials should have “high U-values and low heat capacities.” (Greenlux, 2012)

From the graph it is apparent that the indoor temperature is controlled effectively during the cooler months, from May to September. But for the rest of the year when the climatic temperatures are much warmer, indoor temperatures can reach 35°C. This is 5 degrees above the comfort zone which in the sweltering heat could prove to be fatal, especially for young children. But, as not every member will be present in the shelter or the actual number of habitants may be much less – around 5 members, the actual indoor temperatures may be less. But the tests were executed using the extreme case scenario by using the maximum number of habitants that the Hexayurt can hold, and no cooling or heating profiles, to determine whether the Hexayurt is suitable for the Kenyan climate for use in Dadaab. As the refugees are likely to adapt the Hexayurt to their surroundings, by cutting out windows for passive cooling or using mist sprays (provided by the relief agencies) for active cooling, the 5 degrees can be accounted for. Furthermore, the refugee-made shelters that are used now utilise rags, old clothes and tarpaulin for protection against the sun. This provides shade, which

cools the inside of the shelter by limiting and slowing heat transfer through the structure. Judging from this, it is likely that the same techniques will be implemented on the Hexayurt, which supports the views of Humphreys and Nicol. If the refugees are to provide shading, the internal temperatures will fall to a more comfortable level.

If shading materials are not available, insulation could be provided by pre-fixing it to the wooden panels during manufacture. Insulation slows the transfer of energy, whilst materials with high thermal mass store the energy. According to Graves and Wysocki, "the amplitude of the indoor air temperature oscillation during the diurnal temperature cycle is reduced when the building envelope has mass inside and insulation outside." (Graves and Wysocki, 1991:314) This should dampen out daily temperature fluctuations within the building, assuming the thermal mass of the material is great enough. (House, 2012) According to NZWood, "mass is most effective when it is thermally connected to the building space. Thus for maximum effectiveness, the insulation must be located on the external surface of the thermal mass material. Furthermore, by increasing thermal mass by using wood, temperature fluctuations within a building space are also reduced." (NZWood, 2012) This agrees with the research carried out by Graves and Wysocki. "The insulation isolates the internal thermal mass (wooden boards) from external temperature variations as the mass becomes a thermal sink for summer heat gain, consequently lowering indoor temperatures during the summer." (Graves and Wysocki, 1991:314)

As external insulation reduces the heat transmission for the outside, the thermal lag of the building will increase. This will allow the diffusion of heat from the external surfaces to the outdoor environment before the heat is transmitted to the internal space. From the experiments carried out by the U.S. National Bureau of Standards, where the high thermal mass is not utilised in the roof, "rooms with external insulation consumed the lowest energy for cooling." (Graves and Wysocki, 1991:314) It is also quoted that "in hot-arid climates, insulation when coupled with thermal mass, there is a significant effect upon a room's thermal behaviour due to the higher angle of the sun in equatorial regions." (Graves and Wysocki, 1991:314)

Thus in Dadaab where the climate is also hot-arid and the temperature oscillation is very high, external insulation would theoretically reduce the temperature oscillation inside the Hexayurt by shielding against and diffusing the solar heat before transmitting it into the living space. IsoSpray recommends using polyurethane foam as insulation, which can be easily sprayed onto the external face of the Hexayurt's wooden panels during manufacture. IsoSpray explains that "under real world conditions, polyurethane foam is at least 5 times more effective as an insulator than mineral wool. Also its insulating properties are largely unaffected due to air movement and moist air, whereas mineral wool assumes the thermal conductivity of water and thus has no thermal insulation qualities." (IsoSpray, 2012) As a spray, it can be applied uniformly over the wooden boards, whilst being lightweight, waterproof, weather resistant, and fire rated to BS476 Part 20. (Sitebox, 2012) Thus, polyurethane foam is a likely choice for insulating the Hexayurt to make it suitable for use in Dadaab.



#### 5.4 Conclusion:

As each material produced the same result with regards to internal temperature, it is difficult to select a board which can be stated as the best performing and thus the best suited. As the material's ability store and release heat depends on its U-value, which in turn depends on the K-value; whereby  $U=K/L$ , thus larger values of K will give higher values of U when  $L=18\text{mm}$ . As aforementioned, the building materials should have high U-values, so the board with the highest K-value will give the highest U-value, which is plywood at  $0.039\text{W/mK}$ . Gupta states "We think that the most likely material is plywood, OSB or a similar engineered wood product. This is based on two factors: cost and strength." (Gupta, 2010) Based on the thermal properties that have been analysed, it can be confirmed that plywood is the best performing wood board.

# Disaster Relief Shelter Design

## Chapter Six – Conclusion

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### 6.1 Introduction:

This dissertation began with the following hypothesis:

*Under specific conditions, a transitional shelter would be an effective and apposite response to the needs of refugees in hot climates.*

The aim:

*To improve the Hexayurt shelter (standard design) so that is suitable for the Kenyan climate, by focusing on material selection.*

And the objectives:

- *To verify the feasibility of the Hexayurt as a shelter for use in the surrounding areas of the Dadaab camp.*
- *To test materials in order to judge which will fair best in the north-eastern Kenyan environment.*
- *To finalise a list of materials which are most suitable for use in a Hexayurt.*

### 6.2 Conclusions:

The Hexayurt was chosen as a transitional shelter as it had obvious benefits over the refugee built shelter when equated with important humanitarian needs that shelters must provide. From the project rationale, it was vital that the Hexayurt provided protection against soaring temperatures through assessment of the thermal comfortability.

From the material selection chapter and using Appendix 4 for material analysis, all five boards were deemed similar in regard to workability, fixability and finishability; therefore it was difficult to select the most suited board at that stage. As some boards were already tested structurally by Maltby, other methods of testing were implemented.

It was researched that thermal comfortability plays a significant role in ensuring the conditions in the shelter are habitable, so the different boards were tested thermally to see which would produce the most comfortable internal conditions, making it easier to select the best suited materials for the Hexayurt for use in Dadaab. The IES Apache simulation was used to model the Hexayurt using weather data closest to Dadaab, whilst the thermal conductivities and other parameters that were needed for each board were gained through laboratory testing. Appropriate analyses were carried out for each test whilst using applicable literature to draw conclusions.

Thus, by focusing on material selection only, the Hexayurt has been proven suitable for the Kenyan climate by selecting the material with the highest thermal conductivity value, which translates to having the highest U-value, thus the greatest ability to store heat during the day and release it at night when temperatures drop. Although the Apache simulation gave conclusive results to an extent, as the majority of temperatures for the year were between the thermal comfort temperature range, it showed that all five boards produced similar indoor temperatures within the Hexayurt. But from the analysis shown in the previous chapter, the most suitable material is plywood. Through extensive literature review and testing, the hypothesis and objectives have been satisfied by this dissertation.

With direct comparison to the aim of this dissertation, the Hexayurt is suitable as a shelter in Dadaab, Kenya and has been improved through material selection.

However, this statement is based on the parameters shown below for it to stand true:

- The structure of the shelter must follow the design that has been set by Gupta of the 12ft high Hexayurt,
- The boards are 18mm thick, with the roof and wall boards made of the same material.
- Appropriate cooling, insulating or shading techniques are implemented to allow for the internal temperatures of the Hexayurt to always stay within the comfort zone.

In order to reach the conclusions in this dissertation, the environmental conditions of Dadaab were investigated. As discussed throughout the dissertation, the discovery of hard data with which to carry out thermal analysis, in relation to accurate weather data for the region, proved difficult as no accurate and reliable readings existed. Also, due to the lack of testing equipment and time, an environmental chamber test was not performed. It is therefore anticipated that with the collaboration of further data that is necessary for a full thermal analysis, this project will provide a useful reference for similar investigations in the future.

### 6.3 Recommendations:

The process of conducting the research included in this report has resulted in the identification of the following recommendations for further research:

- Investigate the effects of cooling, insulating and shading on the thermal comfortability of the hexayurt in Dadaab.
- Investigate how the change in thickness of the boards relates to its ability to store heat.
- Take multiple readings of weather in Dadaab, including accurate temperature readings.
- Perform environmental chamber tests to show how the internal temperatures are affected for different climatic conditions.
- Carry out field testing in order to see how the hexayurt is affected in 'real' conditions.

# Disaster Relief Shelter Design

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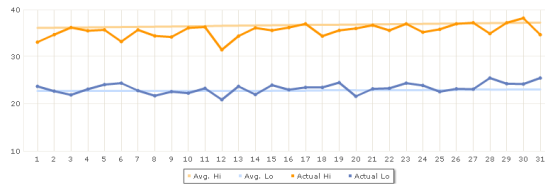
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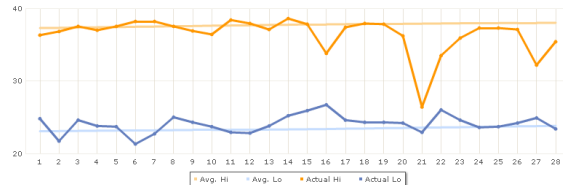
# Disaster Relief Shelter Design

## Appendix 1 – Temperature Graphs

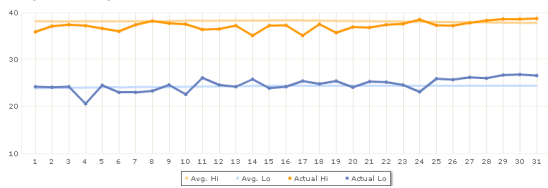
Temperature Graph January 2011



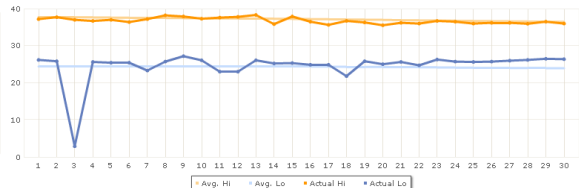
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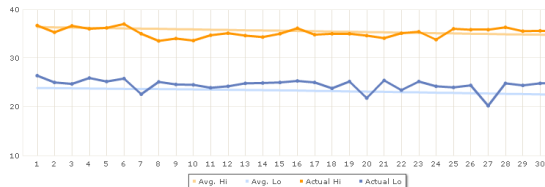
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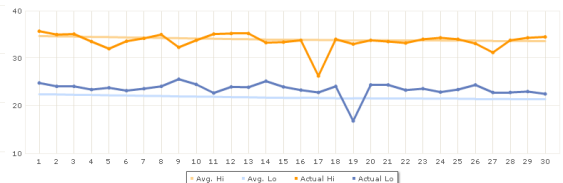
Temperature Graph April 2011



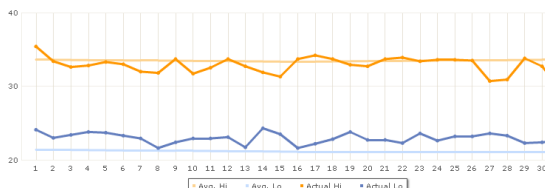
Temperature Graph May 2011



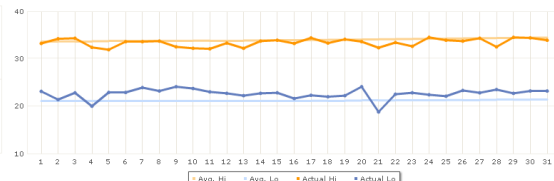
Temperature Graph June 2011



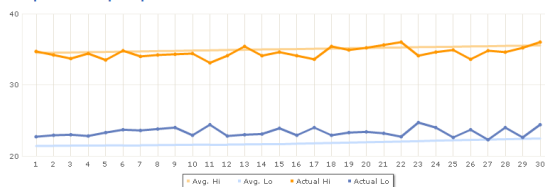
Temperature Graph July 2011



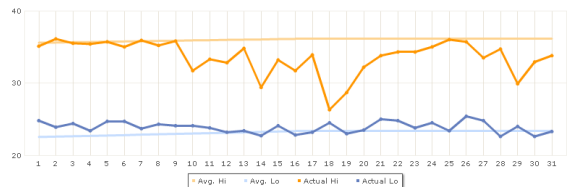
Temperature Graph August 2011



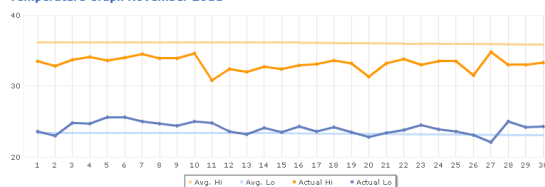
Temperature Graph September 2011



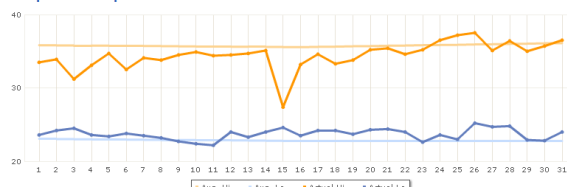
Temperature Graph October 2011



Temperature Graph November 2011



Temperature Graph December 2011



# Disaster Relief Shelter Design

## Appendix 2 – Humanitarian Policy

### How we will work

13. The UK is firmly committed to a multilateral and UN-led and coordinated international humanitarian system. To this end, the UK will attach priority to working with others to support the UN Emergency Relief Coordinator to lead the system and the UN Office for the Coordination of Humanitarian Affairs to fulfil its demanding mandate.
14. The UK will make disaster resilience a core part of its operations in all country programmes, and show international leadership on this important area of work. This will require a significant change in the way we work.
15. The UK approach to humanitarian assistance has four elements:
  - **Multilateral** – The multilateral system has the mandate and experience to be the first line of response to humanitarian emergencies when international assistance is required. The UK has committed to significantly increase its core contributions to those multilateral agencies that have demonstrated they can deliver swiftly and appropriately to emergencies.
  - **Country-specific** – When emergencies are beyond the resource capacity of the multilateral system to respond, we will provide additional support to multilateral partners and where appropriate governments, local civil society and international NGOs.
  - **Directly** – Where needs are overwhelming and the UK can add value, we will directly deploy expertise, goods and assets; and
  - **Diplomatically** – We will share information and advocate to secure humanitarian access and to protect civilians.
16. The UK will allocate more resources to building resilience at national, institutional and community levels, and to delivering humanitarian results. We will also expand our range of financing mechanisms to improve the predictability and timeliness of our support to the Red Cross, NGOs and the private sector.
17. A small number of donors currently fund most of the international response to humanitarian crises. As more countries become prosperous, the number of donors providing humanitarian support needs to increase. The UK will channel its diplomatic efforts to encourage a broader range of countries to provide responsible humanitarian financing and more equitable burden sharing amongst donors. We will build alliances and coalitions for change with national governments, regional organisations, the UN, NGOs, the Red Cross and diaspora communities. We will encourage the use of private sector resources and expertise.
18. We will continue to champion accountability and transparency in aid, including to beneficiaries. Our focus on identifying results, evaluation and lesson-learning will ensure that UK humanitarian aid provides value for money and delivers high quality, rapid support.

**The UK will honour its commitment to transparency and accountability to beneficiaries, and to the UK taxpayer**

19. We need to strike a balance between ensuring accountability to taxpayers and beneficiaries and respecting the independence of implementing

Value for money in DFID programmes means maximising the impact of each pound spent to improve poor people's lives

partners. We will support our partners to strengthen their monitoring, evaluation and accountability systems and will seek to avoid imposing additional bureaucracy on them. DFID will coordinate the UK Government's humanitarian responses. Standard Operating Procedures will be developed in line with internationally agreed frameworks such as the Oslo Guidelines on Use of Foreign Military and Civil Defence Assets in Disaster Relief, and Guidelines on the Use of Military and Civil Defence Assets to Support UN Humanitarian Activities in Complex Emergencies.

- We will:**
1. Provide aid according to need and need alone, in line with the humanitarian principles of humanity, impartiality, neutrality and independence.
  2. Follow Good Humanitarian Donorship principles and best practice, and encourage others to do likewise.
  3. Work multilaterally and with other partners to expand the donor base for humanitarian action and greater burden sharing.
  4. Strengthen our commitments to be transparent and accountable to beneficiaries, and encourage our partners to do likewise.

**The Humanitarian Emergency Response Review**

The Humanitarian Emergency Response Review (HERR) was chaired by Lord Paddy Ashdown and presented its independent report in March 2011.

The HERR recommended how the UK could better deliver a response fit to deal with the challenges of the 21st century, based around seven key themes:


- Anticipation** • the need to better anticipate crises using a combination of science and on the ground experience;
- Resilience** • the need to work with nations to make them more resilient to disaster and conflict, in part through better linkages with the UK's development programme;
- Leadership** • the need for better, more consistent international leadership when nations are not able to cope alone;
- Innovation** • the need to bring new techniques and technologies to bear on humanitarian challenges;
- Accountability** • the need for aid providers to be accountable to those they serve, and those whose funds they use;
- Partnership** • the need to build networks and alliances to find solutions to humanitarian challenges; and
- Humanitarian space** • the need to preserve the fragile space that allows agencies to work in contested areas, helping those most in need regardless of who they are.

The full report is available online: [www.dfid.gov.uk/Documents/publications/HERR.pdf](http://www.dfid.gov.uk/Documents/publications/HERR.pdf)

# Disaster Relief Shelter Design

## Appendix 3 – Standard Hexayurt Design

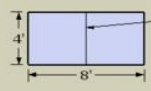
**How to build a 6' Hexayurt (page one of two)**




- Go to Home Depot or an equivalent building supply place and buy 5 4' x 8' sheets of 1" Super Tuff R and two 60' rolls of 3" wide tape.
 

Super Tuff R is an insulation board. It has reflective foil on one side and is bright blue on the other. STR can be incredibly moopy to cut, so do ALL your cutting at home.

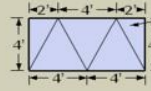
Most tape is rated to work at 200F these days, but check carefully: lower temperature rated tape may melt off in hot conditions. 3" wide tape can be hard to find, but this design works better with it.
- Cut your wall panels. You can use either a craft knife or a saw. The pattern is below:
 



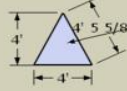
Take three of your panels and cut them in two to form 4' x 4' squares. Make sure the edges are straight!



You now have six of these.

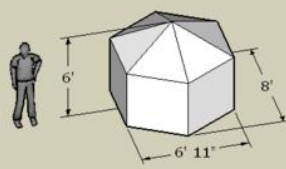



Cut these two panels into six isosceles triangles 4' high and 4' wide. There is a little scrap left over.




You now have six of these.
- Tape your edges. Stick tape along the full length of every side to make sure the panels do not ever moop, and to make the edges stronger. This will take approximately 60 yards (180 ft) of tape.
- Cut a door and any windows you may want. The door should leave at least 1' clearance from the top and side edges so as not to weaken the material. Windows should be small and spaced on opposite sides of the unit. Tape the door and window edges! Use tape as a hinge for the doors and windows. They should be hinged at the top edge so that when they are open they still provide shade. Ideally the door and windows should be pressed flush back into the wall of the unit when closed making a tight seal.
- See page two for how to assemble a unit on the Playa

hexayurt@gmail.com





You have six of these roof panels



You have six of these wall panels

- Tape all six of the roof triangles into a cone. The cone is two feet high. You should tape all the way down each seam so that the seams are completely covered and waterproof. The easiest way to do this is to use a 2' prop under the point of the cone and work around taping each panel in place. It is a good idea to run additional tape from the center of each panel to the center of its neighbors.
- Tape the six wall panels into a hexagon. For maximum strength, have one piece of tape which runs all the way around the top edge as a single piece, across all six boards. That is the "tension ring" like on a regular yurt.
- Tape the roof cone on to the wall and you are done. You now have 41 sq. feet of high quality shade.
 

There are two ways to guy down the unit. If you are using filament tape (has glass or polyester strands in it) run tape down the roof seams and tape it around a bit of scrap wood to make a ball. Tie rope round those balls and run it down to rebar stakes.

If you are using a duct-type tape which will tear in that application, make a ring of rope around 12 feet long and drape it over the cone. Then tie the rope ring down to the stakes with additional ropes. The ring of rope reduces the load at any individual point of the structure while still keeping it secure. Remember to cover all your stakes with tennis balls or bubble wrap to protect feet, and make sure the guy lines are visible at night.
- Now the good part. Sit inside your newly completed hexayurt. Close the door. Take a mist bottle and spray it into the air so the mist falls freely. The evaporation of the water into the 0% humidity playa air will drop the interior temperature far enough that, if you keep spraying, you will begin to shiver in the cold.

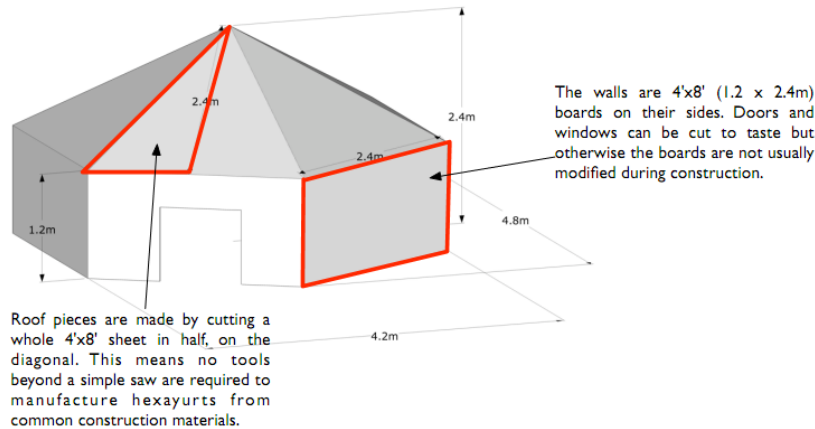
hexayurt@gmail.com

(Appropedia, 2011)

The main parts of the Hexayurt, as can be seen from the schematic above, are the walls and roof, and their joints. The materials that will be used in the final yurt are specified in Chapter Three – Material Selection.

Walls and Roof:

Gupta quotes “common construction materials” (Gupta, 2011) are to be used for the manufacture of the Hexayurt. For the purpose of explaining the diagrams, they will simply be referred to as boards. The total number of boards for a 6ft Hexayurt is 12, typically 4’x8’ (1.2m x 2.4m) – 6 boards are used for the walls and the remaining 6 for the roof.

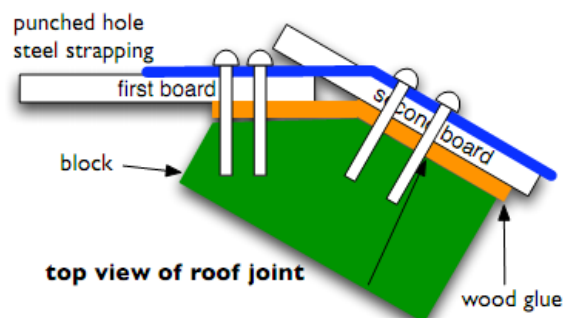
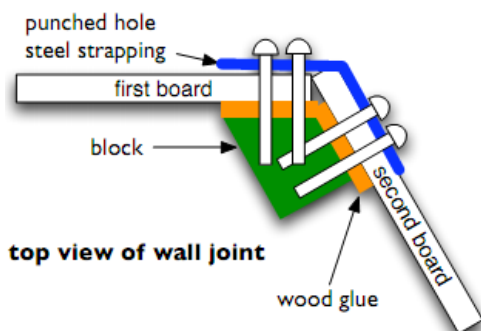
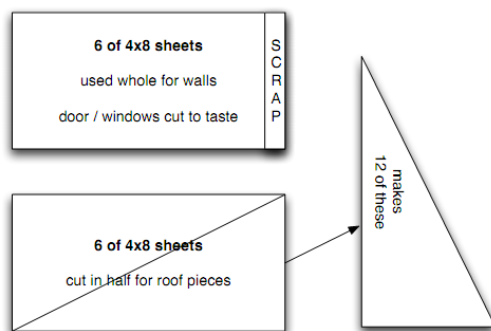


(Gupta, 2011)

(Gupta, 2011) The diagram above shows the placement of each board to form a Hexayurt, while the diagram to the left shows how each board will be utilised to form the walls and roof. The boards for the walls will have 6 inches cut off and used as scrap. This is so that the walls fall inside the diameter of the roof causing a roof overhang, resulting in better water run-off properties (essential for use in rainy periods).

Joints:

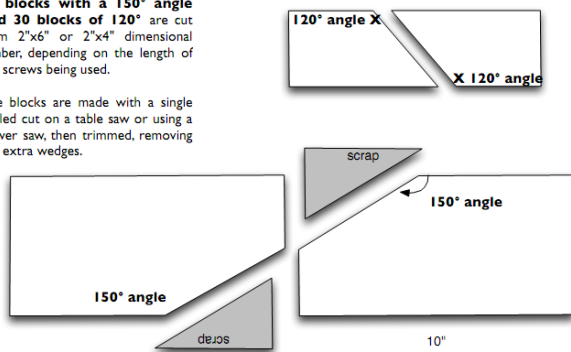
(Gupta, 2011)



The figure above shows the top view of the wall joint and roof joint. The blocks themselves are shown below.

**12 blocks with a 150° angle and 30 blocks of 120°** are cut from 2"x6" or 2"x4" dimensional lumber, depending on the length of the screws being used.

The blocks are made with a single angled cut on a table saw or using a power saw, then trimmed, removing the extra wedges.



(Gupta, 2011)

The blocks are cut from dimensional lumber, 2"x4" CLS (Canadian Lumber Standard). A 150° angle is cut into the block which is used for joining the roofing together, whereas the 120° angle cut blocks are used for joining the walls. The angles are to be cut using a table saw or power saw, with one clean cut. Prefabricating these blocks before

shipping the Hexayurt materials to Kenya will save time. Also as power tools may not be available in the surrounding areas of Dadaab, it will be beneficial to fabricate as much of the Hexayurt as possible, leaving the refugees and aid workers to simply glue and screw the boards together. Also, as the refugees may have limited knowledge in joinery and construction, pre-cut blocks (and boards) will negate material wastage as cutting of any sort will not be required.

For the walls, the boards are glued onto blocks – slightly asymmetrically. The first board is glued slightly behind the block edge, whilst the second board is positioned so it's touching the edge of the first board and then glued into place. The positioning of the boards is so to produce a more airtight seal. A steel strap is placed over the two boards and screwed into place – screwing through the boards and into the blocks to provide a substantively stronger joint.

Or the roof, the boards follow a similar procedure with only minor changes. Firstly, the second board is placed so that it extends more over the first board. Secondly, a small hole is cut into the second board to allow the steel strap to remain flush against both boards.

As with wall and roof joints, the same wood glue, steel strapping and screws are used. When different board materials are tested, these things will remain the same. Therefore it is essential to highlight the wood glue type, steel strapping type and screw type that is normally used and which type will be used for testing for the purposes of this dissertation.

Glue:

There are thousands of glues available, but Gupta specifies using gorilla glue. Gorilla glue is polyurethane glue. When exposed to moisture the adhesive reacts and creates a foaming action that fills while it sticks. From the Gorilla Glue website, the following properties have been stated.

- Versatile – ideal for most household fixes, building repairs and creative projects. (Ideal for joining wood therefore suitable for the Hexayurt)
- 100% waterproof – does not break down when exposed to outdoor elements. Easily passes ANSI/HPVA hp-1-2000 types 1 and 2. (Waterproof capabilities mean the glue can be used for the Hexayurt which may be subjected to heavy rains from time to time)

- Temperature resistant – once it's dry, gorilla glue is unaffected by extreme heat or cold. (Can be used from 4.5°C to 55°C therefore suitable for use in the Kenyan climate)
- Sandable, paintable, stainable – the invisible glue line makes finishing easy. (For refugees which may use the shelter for longer than transitional periods, the glue can be painted and protected for a longer shelf life) (Gorilla, 2011)

Original gorilla glue is recommended when constructing the Hexayurt.

Steel strapping:

Gupta has not provided any guidance as which type of steel strapping should be used, but does suggest Signode produced strapping which are pre-drilled. There are a variety of steel strapping that could be used, in all sizes and grades. But it is not appropriate to carry out research into which should be used at this stage. Strapping with high tensile capacities is the likely option, but medium tensile steel would save on cost. But for this dissertation and due to the constructability factor, a pre-drilled solution would be of most benefit. The same type of strapping should be used to make each joint.

Screws:

Gupta states "Wood is easy to fasten. Nailing a Hexayurt together is inconvenient and nails pull out under load, so the natural fastener is deck screws." (Gupta, 2011) Typically, wood screws are used to fasten wood to materials such as steel, board and also other woods, e.g. timber to timber. Screws perform better than nails in tension, which is predominantly the case in most joints. This is because the aggressive screw thread itself grips the fibres in the wood, giving them a higher holding strength than smooth nails. The gripping of the fibres provides a pulling action, which forces the two pieces together, providing a stronger joint. This would be of advantage in Dadaab where unexpected weather, such as high winds, may arise. Winds generate lift, which may pry the roof off the walls on the Hexayurt if not attached with screws.

Another reason to use screws in place of nails is removal. If the yurt needs to be transported to a more ideal location, the refugees must be able to disassemble the structure with ease. Glues joints will be damaged as they have to be forced apart, in addition to more glue being needed to reassemble to yurt again. But with screws, they can literally be 'screwed out' using a screwdriver, meaning less hassle and less damage. Following from the topic of damage, during construction of the different joints, the wood is less likely to split when using screws. This would increase bond strength, in turn making the whole structure more able to withstand higher forces.

Gupta expresses the use of deck screws, which are available as a 2½" long option in sizes 7, 8 or 10. "Screws for use on outdoor structures are most often driven with a square (or Robertson) head, a Phillips head or a Torx head. Each of these has advantages over the other with regards to commonly used tools, less wear or stripping and speed of installation." (Fastenertips, 2011)



# Disaster Relief Shelter Design

## Appendix 4 – Material Analysis

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### Chipboard:

Chipboard is composed of wood chips and ureumformaldehyde–glue. The chipboards are of the three–layer type, compressed, and obtained through the separate gluing of coarse and fine fractions. (Linopan, 2011) The layered effect is obtained by bonding wood particles with glue, under heat and pressure. Chipboard tends to soak up water, swell and disintegrate, but higher density boards perform better. While standard chipboard is not suitable for exterior use, high density chipboard is suitable. It is normally used within kitchens as the material for table tops. It is extremely hard wearing when coated with specialist materials, which could be suitable for the Hexayurt, but will cost more.

Working – Chipboard is made of wood chips, therefore when cutting, these wooden chips will tend to break and rip off fragments surrounding the cut. This will result in a poor quality cut, and workability wise is not very advantageous. With the Hexayurt, clean cuts will be needed, with straight edges so that the structure is symmetrical and each part will bear equal weight. From personal experience, clean cuts are difficult to achieve with chipboard, even when using a saw blade for increased accuracy. One way of reducing damage will be to tape along the cut–line and then cut through the tape. But this could be a problem when manufacturing these boards to fit the Hexayurt as it is very time and cost consuming. In Dadaab, cutting each board to the relevant size may not be an option as there will be limited supplies of electricity and hardly any power tools, in addition to the lack of carpentry skills.

Fixing – The use of nails, pins and screws is permitted on chipboard, but when fixed to a support (in the case of the Hexayurt – the block joint) the fixing are found to pull out easily when loaded. The refugees in Dadaab would benefit from a transitional shelter, so the Hexayurt should be built to last. If during high winds or accidental knocks within or from outside the shelter, the screws may be pulled through and will be exposed. This is not safe, and will cause the joint to lose strength and the whole shelter will be made structurally unstable. The lifespan of the Hexayurt may be significantly reduced, and immediate repair may not be available. Double–threaded or chipboard screws can be used, but the board may tend to split. Adhesive (gorilla glue) can be used, but only in addition to screws, as outer wood chips will separate from the board during failure.

Finishing – As chipboard is prone to swelling due to moisture, water based paints cannot be used for protection. Providing it is kept dry, chipboard has an excellent resistance to warping and shrinkage, a bonus in hot climates and today's centrally heated homes. (DIYinfo, 2011) Laminating the surface and edges provide extra protection against the elements. The climate in Dadaab is normally dry–humid, with random bursts of rain at the start of the year and towards the end, therefore this board will have to be carefully manufactured with high protection if it is to be used in Kenya.

#### HDF:

High density fibreboard or hardboard is a type of fibreboard which is formed using wood chips (inter-felted ligno-cellulosic fibres) (PBMDf, 2011) and resin. During the production process, the wood chips are softened using pressurised steam and then refined into wood fibres. These are then mixed with resin, whilst forming them into mats and pressing them to form panels. FIG quotes "Other materials may be added during manufacture to improve certain properties such as stiffness, hardness, finishing properties, resistance to abrasion and moisture, as well as to increase strength, durability and utility." (FIG, 2005) With such properties, HDF would be an appropriate material to use for the Hexayurt.

Working – As a resistant board is needed for Dadaab, a tempered-treated HDF should be used. This is usually treated with oil to give extra strength and water resistance, and it is particularly suitable for exterior use. From the manufacturing process, HDF has no grain and therefore looks uniform. Table saws should be used to produce a clean cut, which is easy with HDF as wood chips that are cut do not cause surrounding chips to lift or break apart. Therefore it is very workable, meaning any shapes and designs can be produced by the manufacturer. When cutting the material for the Hexayurt, the boards can be clean-cut to the right dimensions without fear of the boards disintegrating along the line of cutting. Unlike chipboard, no additional tape is required when cutting, saving time and cost.

Fixing – All types of fixings are permitted with HDF, including screws which will be used with the block joints outlined in the previous chapter. Headboard pins could also be used, but they are a permanent solution whereas screws can be removed when disassembly is needed for transport. This is useful when the refugees may need to move their shelter to a different location, or when they repair damaged panels. Gorilla glue can be used, as well as woodworking PVA and resin, but screws will have to be used. This is because at failure, the top sheet of the board may separate from the underlying board, exposing the formed fibres. Therefore screws are needed to avoid separation. The top sheet acts as the protecting layer, which gives the hardboard its moisture resistant properties.

Finishing – Strips of softwood should be fitting around the edges of the board to protect from damage, as with any board the corners and edges are most prone to damage. Aluminium strips can also be fitted to provide increased protection, which could be of advantage in Dadaab. They will mean the sheets can last longer, and can withstand more wear and tear. In addition to fitting strips, the board can be primed then painted. But this will increase costs. As the shelter will be for transitional use, aluminium strips may not be needed.

#### MDF:

Similar to HDF, MDF is also made from wood fibres which are bonded together under heat and pressure, with the aid of a resin (urea-formaldehyde-glue or phenol-formaldehyde-glue). Unlike hardboard, the process through which it is created takes place at a lower temperature, additional resins are needed. Made up of fine wood fibres, it does not have an easily recognisable surface grain, along with it being "dense, flat, stiff, and contains no knots." (Premier, 2011)

Working – Bailie writes that, “the International Agency for Research on Cancer (IARC), part of the World Health Organisation (WHO), quoted evidence that even short term exposure to formaldehyde, at far below the legal limit allowable in Britain, could cause irritation to the eyes, nose and throat.” (CF, 2011) Therefore, when cutting MDF, dust masks or professional respirators should be worn, as well as safety goggles. As the resin used in MDF can be harmful, it is best that the cutting is done during the manufacturing stage. And that spares should be shipped out to agencies in Dadaab to avoid risking the health of the refugees. Just like hardboard, MDF can be drilled, machined and tapped, resulting in a smooth edge along the cut-line. This is advantageous to the manufacture of the Hexayurt as the boards can be cut to exact lengths without the fear of the edges or the area surrounding the cut being damaged whilst cutting. The cuts will result in high quality edges which are smooth, and can be tapered or rounded so that it is more user-friendly.

Fixing – MDF is prone to splitting, if the fixing is less than 25mm from the edge. Therefore pilot holes, that are around 85% of the screw diameter, should be drilled first ensuring that the length of the pilot hole coincides with the length of the screw that will be used. Screws which have a “straight shank” (WWT, 2011) are also preferred. If the Hexayurt is to be constructed in Dadaab, this information may not be known to the refugees or even the relief agency workers. Therefore pilot holes must be pre-drilled into the boards and also the block joints prior to shipping to avoid damage to the wood. Splitting of the wood makes it weaker, and therefore, with one failed joint it will be a liability to the whole shelter as each joint and board work in unison with each other to provide stability and strength in a Hexayurt. Improving and maintaining the safety of the refugees is crucial to humanitarian relief success, therefore this precaution must be taken. MDF can also be glued without the fear of the top layer detaching itself, because the whole board is comprised of just one layer. Gap-filling (gorilla glue), PVA, epoxy, or hot melt glues are suitable, meaning MDF will be suitable for the Hexayurt as the block joint can be made to the same specifications as outlined by Gupta.

Finishing – “MDF can be used not only in dry conditions, but also in humid, high humid and even exterior conditions,” (Towood, 2011) but the resin used in MDF releases harmful emissions gradually over a long period; therefore suitable finishes should be applied to all exposed surfaces to minimise these emissions. Finishes include laminates, vinyl and wooden veneers, but wax and oil could also be used. MDF can also be primed and painted. With a variety of finishes that could be used, it is vital to choose one which will give the highest level of protection in the Kenyan climate. An alternative is to use moisture resistant MDF panels which are “designed for use in humid conditions in accordance with MDF.H1 as defined in EN 622 Part 5 so is ideal for applications such as kitchen and bathroom furniture, window and skirting boards and architectural mouldings.” (PBPLY, 2011)

OSB:

OSB is manufactured using softwood strands/wafers which are bonded using exterior-type water resistant binders/resins (phenolic resin/isocyanate binder) (SBA, 2007) under heat and pressure. The strands have uniform thickness and their dimensions are predetermined, with mill members of the SBA (Structural Board Association) using strands that are up to “6inches (150mm) long and 1inch (25mm) wide.” (OSBGuide, 2011)

OSB's strength comes from the uninterrupted, interweaving wood strands, while the resins and binders provide internal strength, as well as rigidity and moisture resistance.

Working – From personal experience, the strands on the reverse side of the cut will always lift no matter how carefully the board is cut. This is known as delamination, and will occur even when using a power saw. Therefore this will not be suitable when cutting these boards to size for the Hexayurt. With poor quality cuts, the edges are more prone to swelling in the presence of moisture (Kenyan climate), and will disintegrate, therefore decreasing its strength and rigidity. Boards like MDF or HDF are more preferable.

Fixing – Nails and screws can be used with OSB, while no countersinking of holes is needed, drilling pilot holes is. As the screw is tightened, the strands in contact with the screw will compress, giving it a greater holding strength. This would be useful for the Hexayurt as the strength of the joints will be increased, but if the board is pried away from the joint using an external force such as an accidental push, then the screw will crack the board or even pull through it. This causes permanent damage which would require the board to be replaced. If the board is not screwed in properly, the same process is likely to take place. Glue alone is not suitable for use with OSB as the layers of wood attached to the glue will separate at failure; therefore screws have to be used. The OSB user guide quotes, "parallel core screws should be used because they have greater holding power than conventional tapered wood screws." (EPF, 2002)

Finishing – The untouched surface of OSB is unsuitable as a finished board as the strands are prone to lifting and the edges are easily damaged. This surface is okay for use where aesthetics aren't important, but there are safety issues with the exposed strands as they can cause cuts to the refugees. Factory sanded boards are available which can be primed and painted using oil-based timber paint. Water-based paints are not permitted to be used on OSB as the moisture will cause swelling and the surface strands will peel away from the rest of the board. If this board is to be used in Dadaab, it will have to be manufactured so that it is factory sanded or wire-brushed to remove any loose strands or resin deposits, and will have to have a layer of oil paint on all surfaces for protection against moisture.

Plywood:

Unlike the previous boards, plywood is made of thin timber veneers, which are free from knots, bark and other defects. The veneers are dried so the moisture content falls to below 10%. This allows the bonding glue to be absorbed into the wood, aiding strength and rigidity. Bonding glue is spread on both sides of the veneer, and is usually in the form of phenol-phormaldehyde. (Mutharathod, 2011) After the veneers are glued, they pass through a hot press to form slabs, which are then cut to size.

Working – If plywood sheets are subjected to heat, they have a tendency to shrink, therefore it is best to use sheets that have been placed in rooms with similar temperatures and conditions as found in Dadaab before they are to be shipped. Power saws should be used to produce an accurate cut, but it will still damage the outer layer of the board. This is unavoidable but cutting the sheets in bulk together may induce less damage to inner sheets. The outer layer is known to splinter, and this is a safety hazard, not only for the relief workers who will be handling the boards but also the refugees who will live in the finished Hexayurt. Therefore it is

vital that the plywood boards are sanded down to avoid any future mishaps. As with all sheet material, swelling due to moisture should be avoided at all costs, therefore it is best that the pre-cut sheets are stored in a low-moisture chamber before they are shipped.

Fixing – Screws, nail and adhesive can be used with plywood, but only small screws grip well in thicker sheets. As plywood is made of several veneers, it is best to use bolts with washers and nuts, which will compress the sheet thus improving the strength of that joint. But with the Hexayurt block joints, Gupta advises to use screws as they provide a higher fixing strength, whilst being easily removed if needed. Trada quotes, “The main types of screws used with wood based panels are conventional woodscrews, parallel shank woodscrews and double threaded parallel shank woodscrews. For fixings into panels the parallel shank type screw is generally preferable. When screws are used for panel to panel fixings, a slightly oversize hole should be drilled in the uppermost panel.” (Trada, 2008:24) Therefore, parallel shank screws should be used when attaching the plywood boards to the block joints. Gluing is permitted for plywood, but the surface should be roughened using coarse abrasive paper before applying the glue. Mechanical fasteners (screws) should be used in addition to glue to give a stronger hold, as “the mechanical fastener holds panels in position and provides bonding pressure while the adhesive cures.” (Trada, 2008:24)

Finishing – Plywood is usually manufactured with a veneer which can be varnished or painted using oil-based paint, although pre-painted sheets are available. For Dadaab, moisture resistant sheets are beneficial, therefore exterior grade plywood (WBP – weather and boil proof) should be used. WBP is suitable for outdoor construction and can withstand certain amounts of moisture. The veneer on the top and underside protects against moisture, but for durability, it is advised that additional varnish or paint is needed. Panels that are CE marked should be used which comply with “EN13986 governing panels for use in construction.” (Wickes, 2011)

#### Screw Type:

In addition to the board types, the screw type has to be established. Gupta quotes, “the screws should not be countersunk screws; they should have a flat head against the washer.” (Gupta, 2010) From the analysis of the materials, parallel core screws with a flat head should be used. The flat head prevents it from being pulled through the board, whilst the parallel core prevents the board from splitting. The screw should also be turned into the joint, not hammered as the load bearing capacity will decrease significantly if hammered. BS 1210 1963 Standard should be used for the screws. Trada states that, “the main type of screw used in engineered timber structures is the coach screw...which is generally produced in accordance with the German Standard DIN 571.” (Trada, 2002:52) Coach screws are available in lengths of 25mm to 300mm and diameters of 6mm to 20mm, which require a washer. Trada also states that, “screws with a diameter greater than 5mm should be turned into pre-drilled holes to prevent splitting of the wood.” (Trada, 2002:52) Thus for Hexayurt construction, coach screws (M6 x 90mm) should be used with washers under the head.

# Disaster Relief Shelter Design

## Appendix 5 – Joint Testing Methodology

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### Testing Conditions:

Bolts (screws) can be loaded in three ways:

- Shear
- Tension
- Combination of shear and tension

Screws are designed to hold components together whilst withstanding tensile loading, but they can also take the shear load in a joint. The boards that have been highlighted in the previous section can be tested by bending, but as they will be attached to block joints in the Hexayurt, it is vital that they are tested as part of the joint to reflect real life situations. The boards will be attached to the block joint as explained in Appendix 3 using screws. The strength of the joint rests on the holding strength of the screw, which predominantly rests on the strength of the board. As the screws can be loaded in shear and tension, it is best to examine the whole joint using shear and tensile testing. Therefore, my prediction is that the boards with higher shear and tensile strengths will produce a stronger joint, thus making them the suitable material for Dadaab.

The tests are designed in accordance with Chapters 7 and 8 of EN 26891:1991, whilst prioritising overall joint strength instead of deformation. To aid analysis of these tests, the failure of each joint will be assessed using Eurocode 5 Clause 8.7.2.

Therefore, the failure modes whilst assessing the load-carrying capacity of connections with axially loaded screws are:

- The withdrawal of the screwed-in part of the screw
- The head of the screw being pulled through the board
- The tensile failure of the screw

As timber blocks are to be used, shear failure of the block can also occur, thus this should be added to the failure mode list.

In addition to this, the conditioning, fabrication and preparation of the test pieces are shown below.

Conditioning – As specified in Eurocode 5 and BS 5756, the test pieces should be kiln dried or of Class 2. Class 2 is, “characterised by a moisture content in the materials corresponding to a temperature of 20°C and the relative humidity of the surround air only exceeding 85% for a few weeks each year. In such conditions, most timber will attain an average moisture content not exceeding 20%.” (BS 5268 Part 2) The test boards will not be kiln dried due to the lack of kiln drying equipment being unavailable. The Hexayurt should be tested using

the worst case scenario, using Service Class 3. This would mean the boards are externally, exposed boards with an average moisture content of 20% or more. But as the manufacture of these board joints will be inside a lab, which is a covered and heated space, the UK national product standard of 15% (NBS, 2012) should be used. According to Taylor, Baradan and Widehammar, "The strength of clear timber rises approximately linearly as moisture content decreases from the fibre saturation point and may increase 3-fold when the oven-dry state is reached. However, toughness decreases with drying. At moisture contents of around 15%, the strength would be approximately 40% higher than that of the saturated state, depending on the type of wood. The mechanism of the strength increase is similar to that of shrinkage in concrete; the contraction results in decreased inter-fibre spacing and, therefore, stronger bonding between fibres." (Taylor, 2001) (Baradan, 2003) (Widehammar, 2004) So when analysing the results, a reduction factor should be applied.

Fabrication – There are no special requirements for the production of the test joints, only that the boards should be planed and each board should be of the same dimensions. The screws should be drilled in perpendicular to the boards and the timber block. The timber blocks should be identical for each joint, along with the screws to ensure a fair test with only one variable which is the board type for the roof and wall joints. The boards should be cut using a table saw ensuring a clean and accurate cut, whilst using M6 90mm coach screws and 4x2" sawn and kiln dried timber blocks throughout.

Preparation – Using Eurocode 5 Table 8.6, a minimum spacing and edge distance for the screws of 4d will be used for every joint that is made and tested. This is to conform testing to the Eurocodes so that a viable analysis can be made, whilst referring to the modes of failure. Due to this, steel strapping will not be used. This will show how the boards react when they're under force as there is room for lateral movement because the fasteners aren't restricted. According to Grahn, "the width of the wood-based plate should be chosen not less than 200 mm in order to reduce bending of the plate member." (Grahn, 2007) As only shear and tension will be tested, the boards that will be tested will be 300mm x 300mm. This provides a 50% increase in width over what Grahn recommends, and will make it easier to highlight the specific modes of failure.

#### Testing Methods:

There are three tests that can be used, which have been developed by B.Maltby, to test the joints of a Hexayurt in shear and tension. These are:

- Pure shear test
- Hydraulic jack tension test
- JJ Lloyd tension test

It is difficult to test the joints through a combination of both shear and tensile testing on a Hexayurt whilst conforming to the Eurocodes. Therefore separate tests will be performed.

#### Pure Shear Test:

To test the boards in shear, two identical 300mm x 300mm boards will be screwed to the 120° and 150° block joints as outlined by Gupta. For clamping purposes, an additional length of 4x2" timber is to be attached

to one of the boards. This additional clamping block will be clamped to a hollow steel section for added clearance. The whole joint will then be clamped to an I-beam frame, whilst loading the unclamped board using a hydraulic jack. Wandel explains that, “because wood is relatively weak perpendicular to its grain, screws don't hold that well when screwed into the end grain. This is because the thread has a harder time cutting into the grain from the side, and also because what it does grab shears out more easily, as the shear is cross-grain.” (WG, 2012) So, for this test, the weakest part of the joint will be the joint at the board which is screwed into the partial end grain of the timber block. This is where failure is likely to occur, therefore that board will become the ‘free-board’ and will be loaded.

Maltby expresses that use of a load cell, which is “attached to a computer through a RDP modular interface under the hydraulic jack. The load reading from the cell is logged at 1 second intervals using a Microsoft Excel macro program.” (Maltby, 2011) Following Maltby’s test, the readings from the shear test for this dissertation will be from an RDP modular interface and a load cell. As the hydraulic jack is will be placed over the loading cell, it is necessitous to omit the weight of the jack when calculating the final readings.

EN 26891 Clause 8.2 explains that the loading rate on a test piece must be constant. Due to the lack of computerised jacks, the load will be applied manually at regular intervals. This results in Clause 8.2 being unattainable, although Clause 8.4 is attained as the load measuring equipment is to the needed accuracy.

From the tests carried out by Feio, Lourenço, and Machado to analyse the capacity of timber joints, LVDTs (linear variable differential transducers) were used to measure any displacements. In their tests, “displacements were measured using linear variable differential transducers, continuously recorded until failure occurred. The measurements of the vertical and horizontal displacements in the specimens were done by two pairs of LVDTs placed on opposite faces of the specimens to eliminate the effect of bending, if any.” (Feio, Lourenço and Machado, 2002) However, with no suitable method of attaching them to the test joint, linear movements cannot be measured in this shear test so will have to be “observed visually.” (Maltby, 2011:69)

#### Hydraulic Jack Tension Test.

As explained above, the ‘free-board’ is left unclamped and will be loaded from the side using the same hydraulic jack. This is due to the joint on the free-board being the weakest theoretically. Therefore, for the same reasons as above, this board is loaded to failure. The hydraulic jack will be attached to the I-beam frame, but instead of resting on the bottom edge, it will be placed on the side to recreate a lateral force. For added accuracy, a load cell and an RDP interface will be placed under the jack to measure the loading that will be applied. The clamped board will have to be securely clamped without damaging the board itself; otherwise failure could occur at the point where the clamp touches the board. So, a temporary 4x2” timber block will be attached to the board which will clamp the whole board into place. To load the free-board, an additional timber block will be screwed through the board directly above the block joint. This is so pressure can be placed as close to the joint as possible whilst minimalising bending. This is important as the joint will be tested in tension, so any other variables affecting this will be seen to.



As with the shear test, EN 26891 Clause 8.2 explains that the loading rate on a test piece must be constant. Due to the lack of computerised jacks, the load will be applied manually at regular intervals. This results in Clause 8.2 being unattainable, although Clause 8.4 is attained as the load measuring equipment is to the needed accuracy. For the same reasons stated in the shear test, LVDTs will not be used in this test.

JJ Lloyd Tension Test.

This is the final test, which will use a JJ Lloyd computer controlled tension machine, which has built in extension measuring capabilities. Therefore, there will be no need for the use of LVDTs. The whole joint will be tested, not just the weakest point, thus showing failures on both boards and the behaviour of the joint. For attachment, both boards must be drilled with a 20mm hole in the upper part of the board. Maltby recommends drilling the holes "40mm from the top edge and 150mm from the side." (Maltby, 2011) This ensures the board is attached at its central point without creating problems with attachment to the machine. Steel pins will be used to secure the boards to the machine.

The JJ Lloyd machine was used as it complies with EN 26891 1991 Clause 7. The machine has a tensile loading capacity of 100kN, in addition to loading speeds ranging from 0.001mm/min–101.6mm/min and a data sampling rate of 8 kHz. (Lloyd, 2012) The loading rate for this test will be controlled at 5mm/min so that the modes of failure can be visually analysed more easily.

Additional Notes:

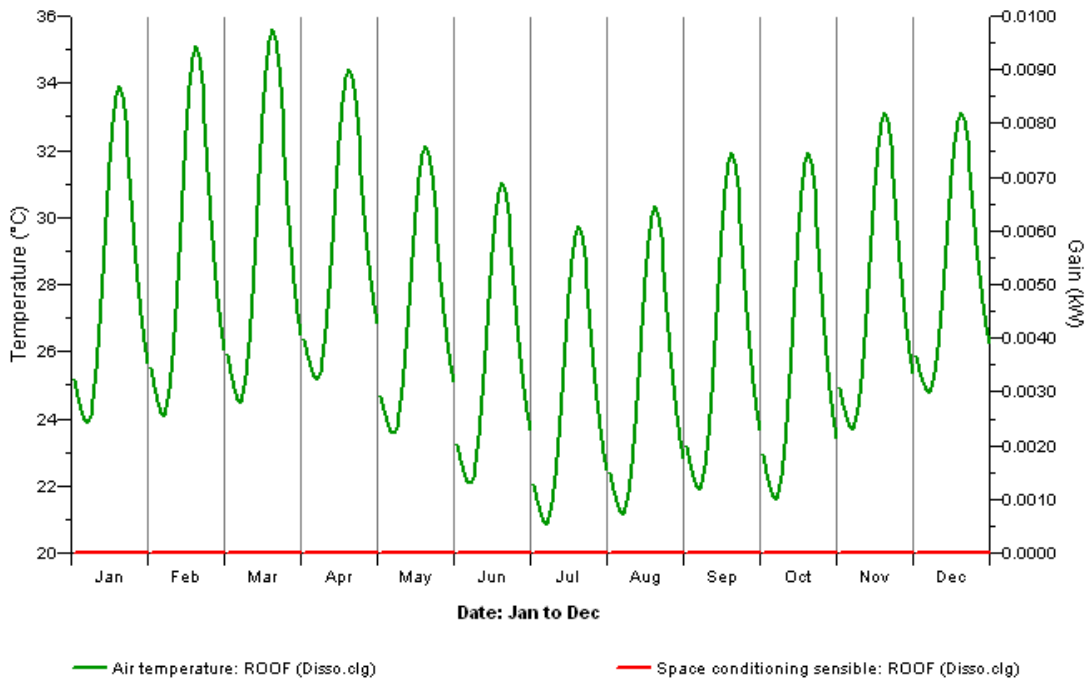
As this dissertation focuses on material selection, specifically the material of the roof and wall boards, other variables which could affect the testing of the boards will be minimalised. The main aim of these tests is to analyse how the joint as a whole reacts to loading, but also how the board fails. To ensure board failure before the timber block joint failure, a higher strength timber block joint should be used, such as C24. But, C16 timber is the most common and cheapest available source in the UK. (BSW, 2012) According to BSW Timber, "softwoods are the most frequently used timbers for loadbearing situations. In order to comply with the Building Regulations they must always be strength graded: they are then usually put into a Strength Class. In the UK, softwoods are graded visually, in accordance with BS 4978 2007, or by machine to EN 14081 2005. BSW Timber grade all load bearing construction timbers by a machine to achieve C16 strength Class and the timber is stamped accordingly. BSW use BM TRADA as the independent body who audit and check the strength grading machine to ensure that all C16 strength graded timber complies with current legislation and guidelines." (BSW, 2012) Therefore, the block joints will use C16 timber for testing.

Furthermore, no glue, strapping or washers will be used. This is so the tests can comply as closely with the regulations set by the Eurocodes. The boards will be attached to the joints using only one fastener – the coach screws. The failure modes will be more apparent as the screw is not restricted and has the ability to pull through.

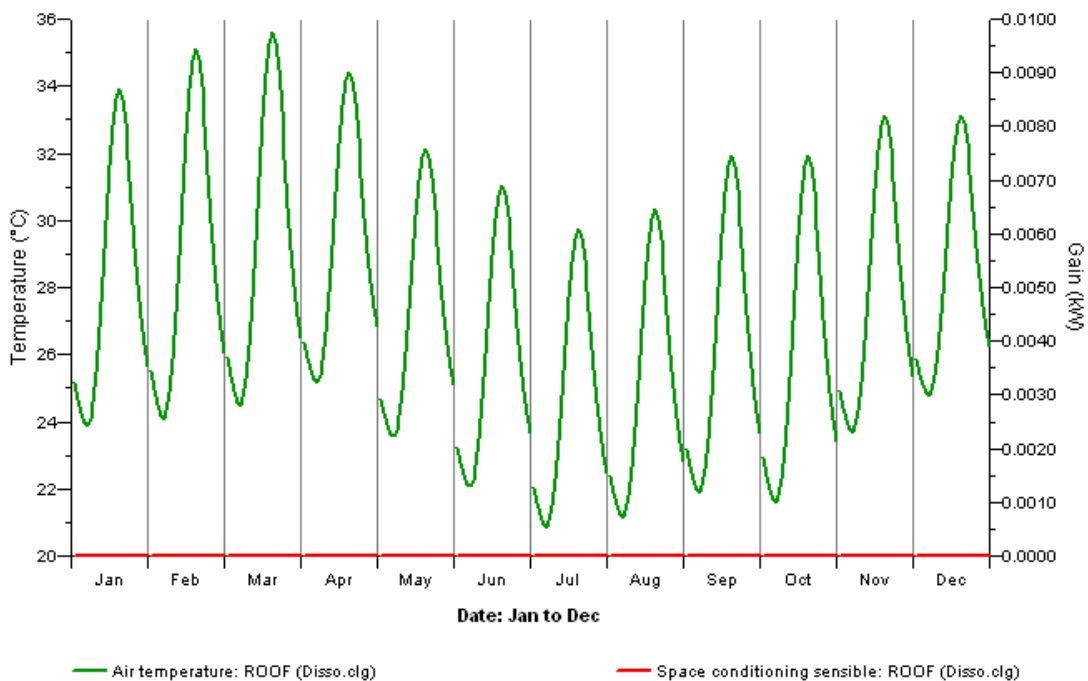
# Disaster Relief Shelter Design

## Appendix 6 – IES Apache Graphs

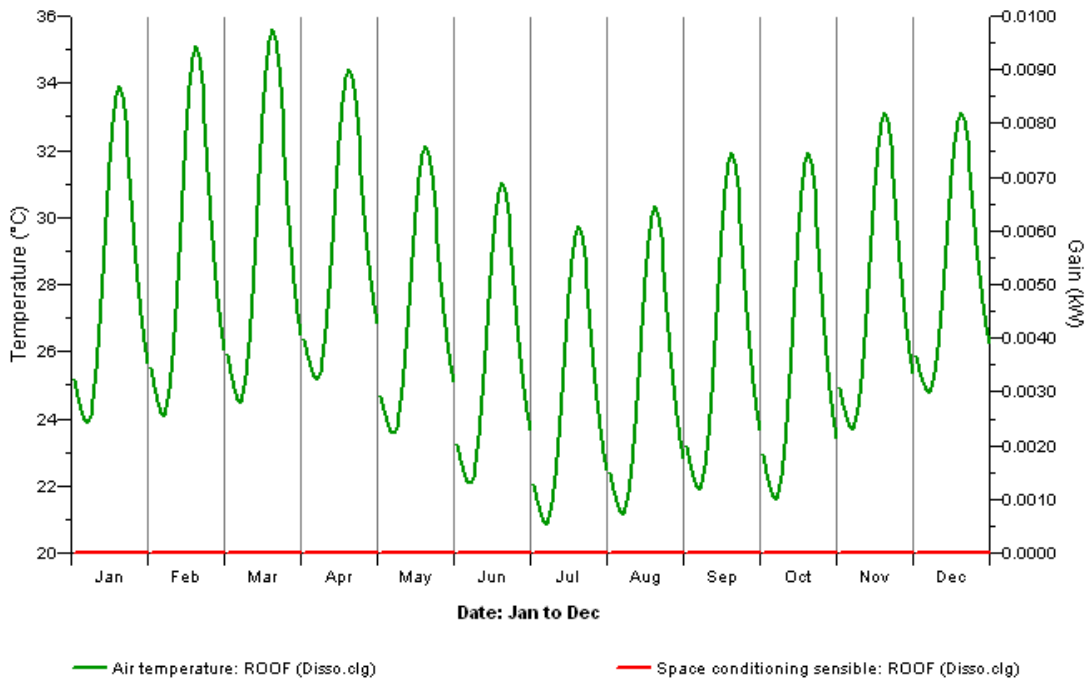
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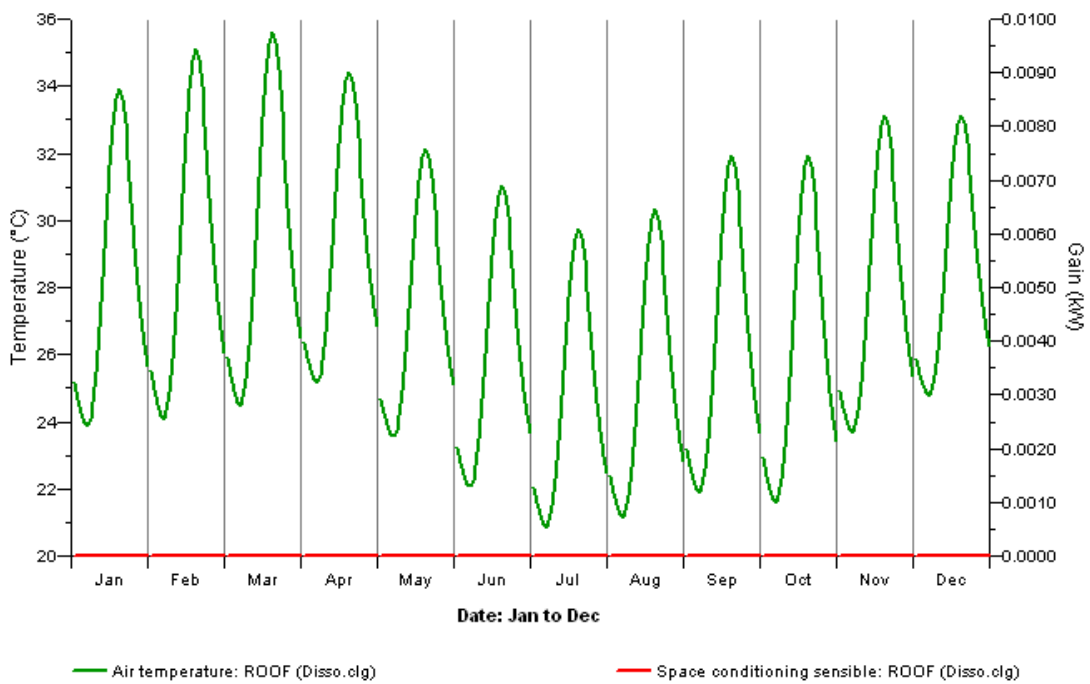
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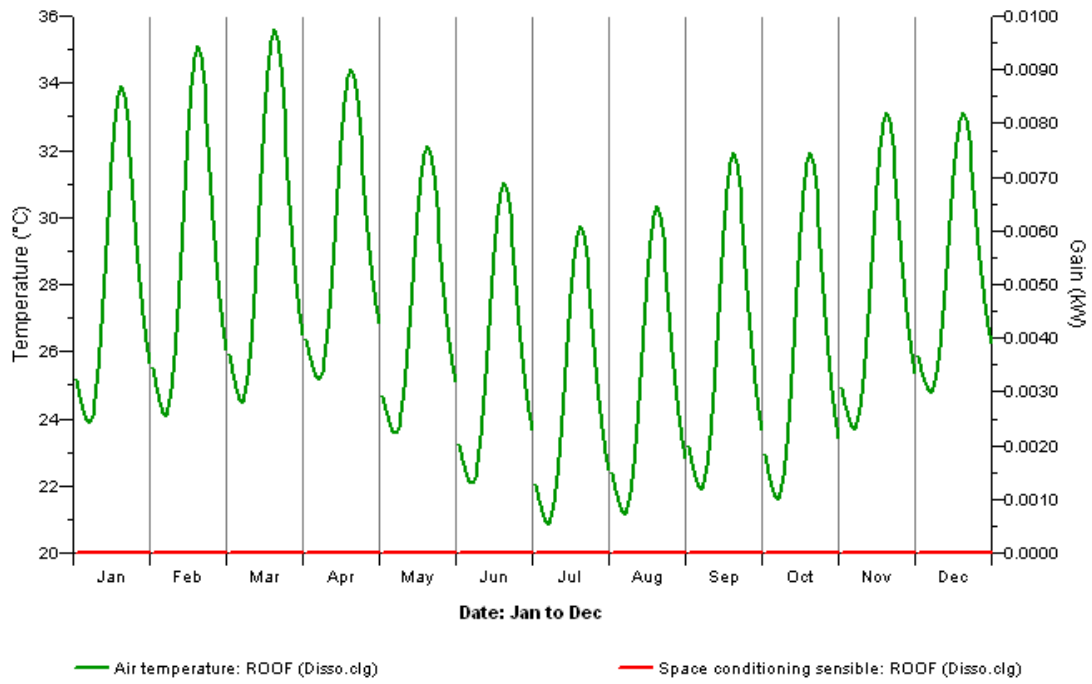
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OSB:

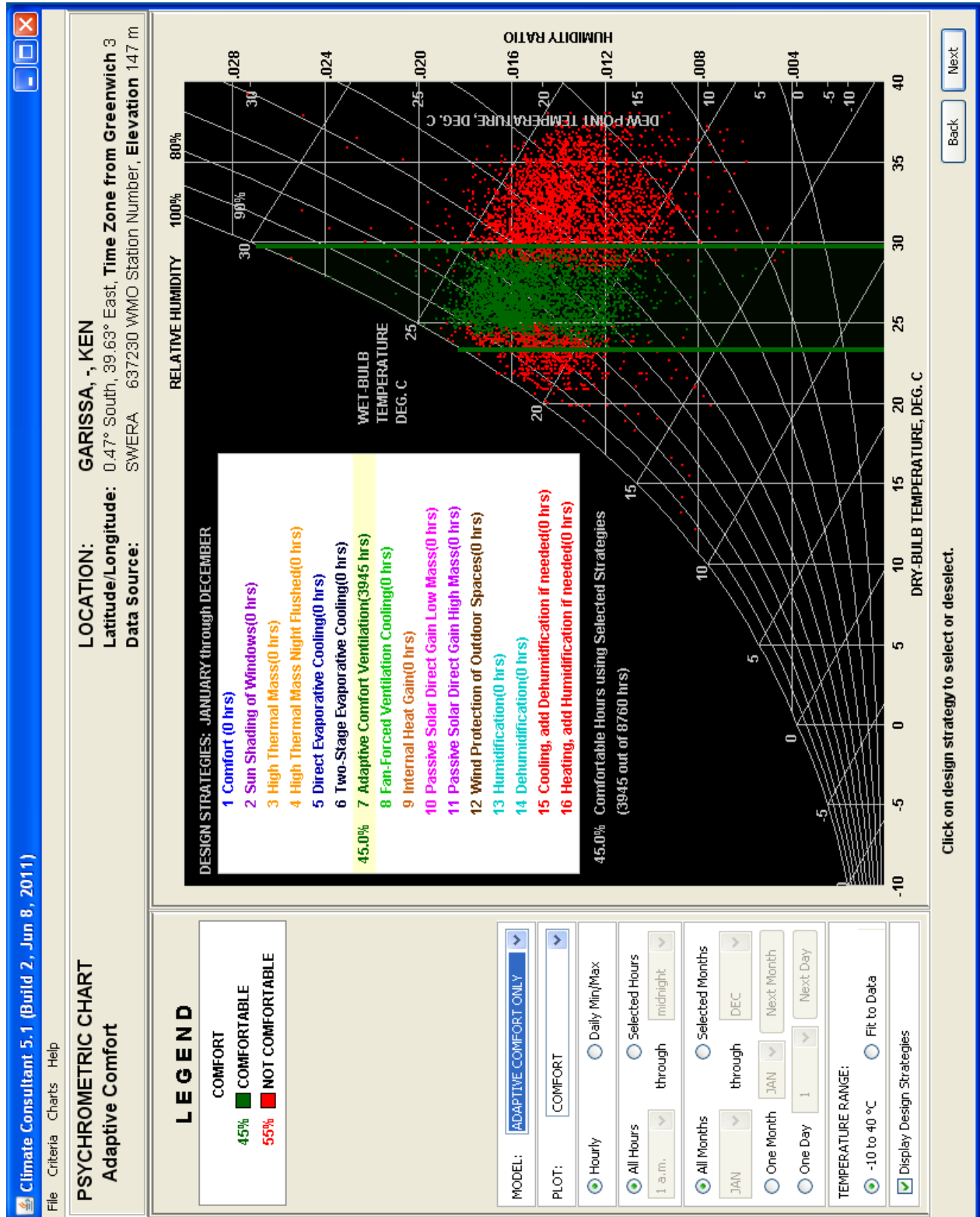


Plywood.



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## Appendix 7 – Psychrometric Chart

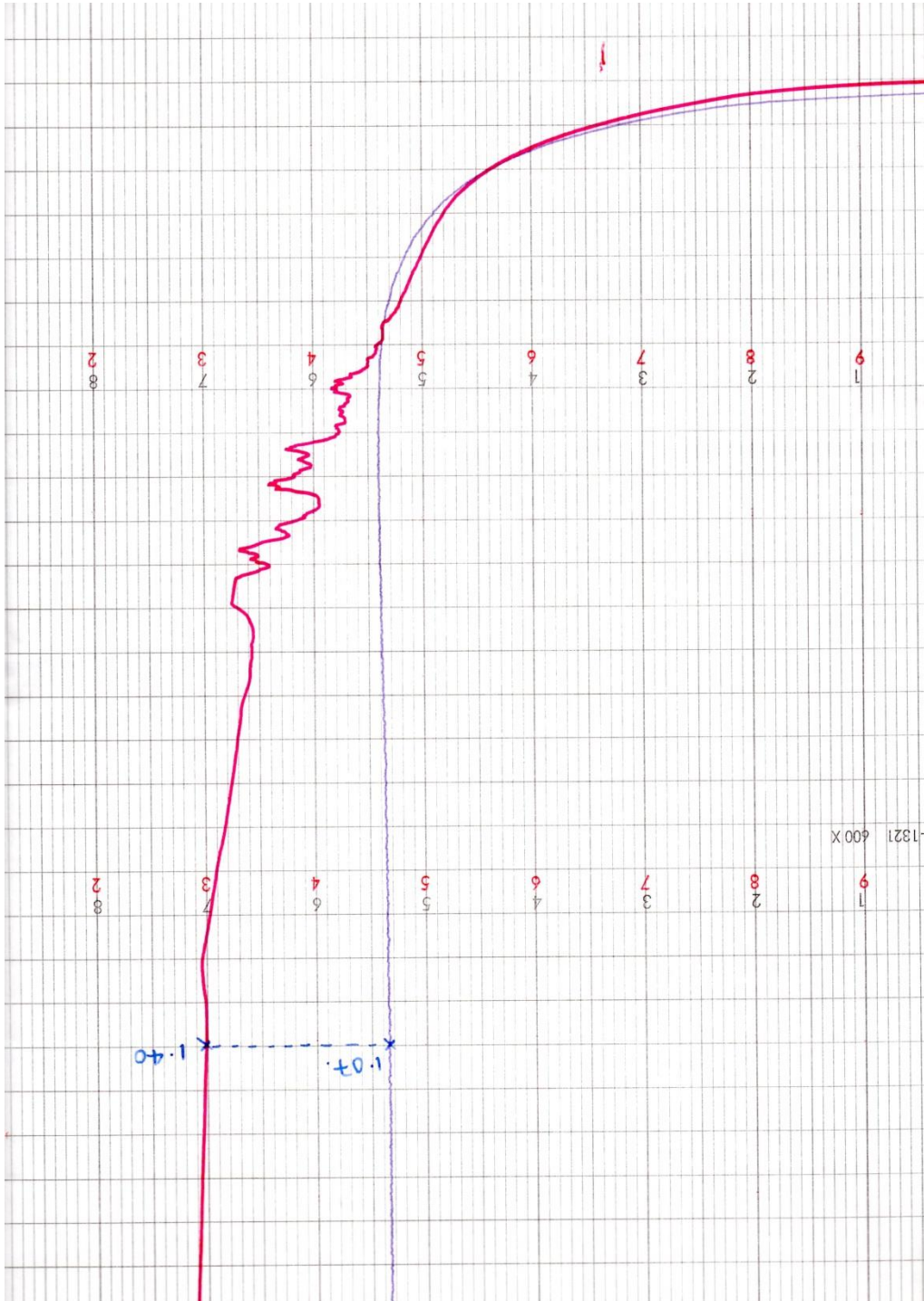


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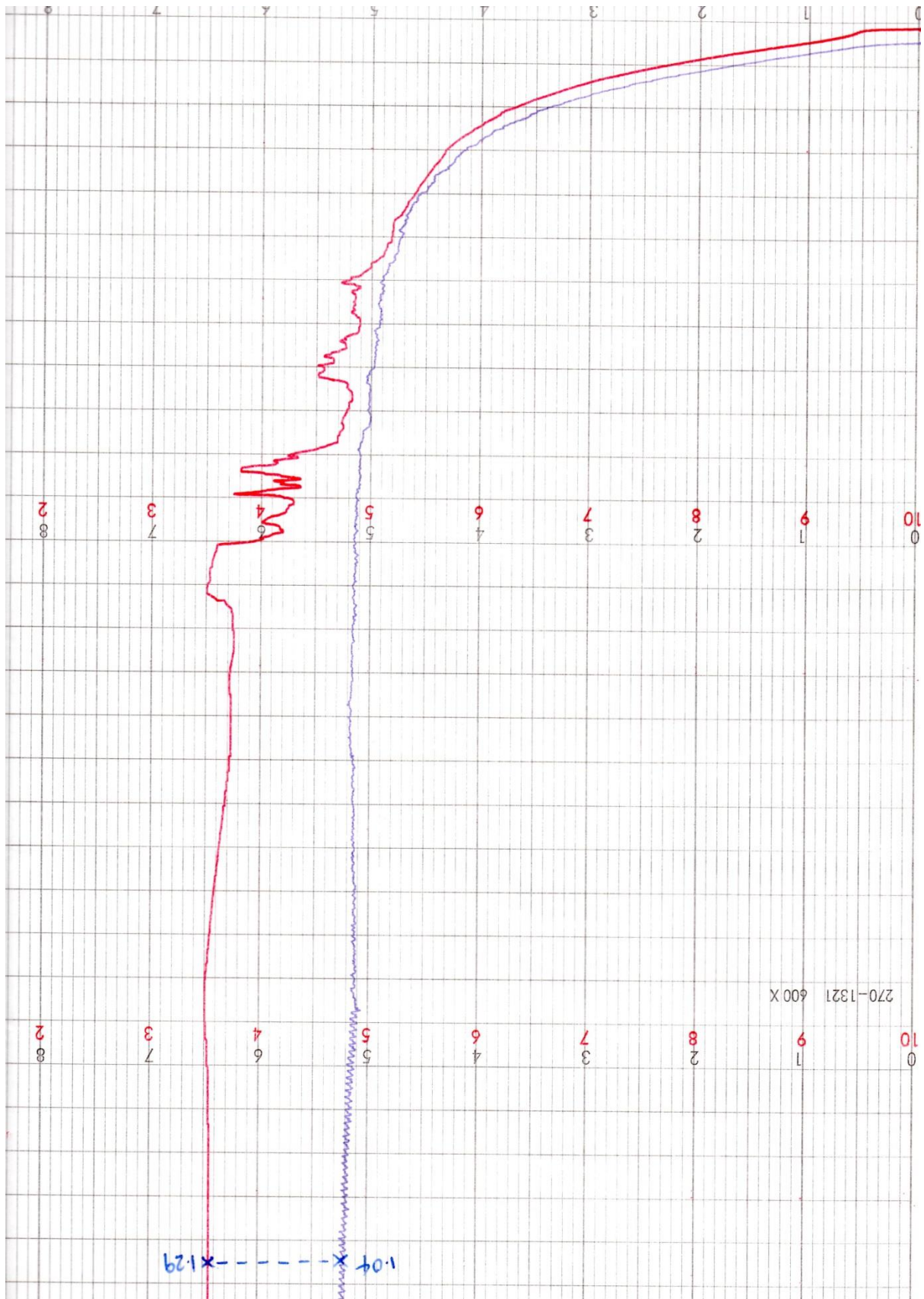
## Appendix 8 – Laboratory Test Graphs

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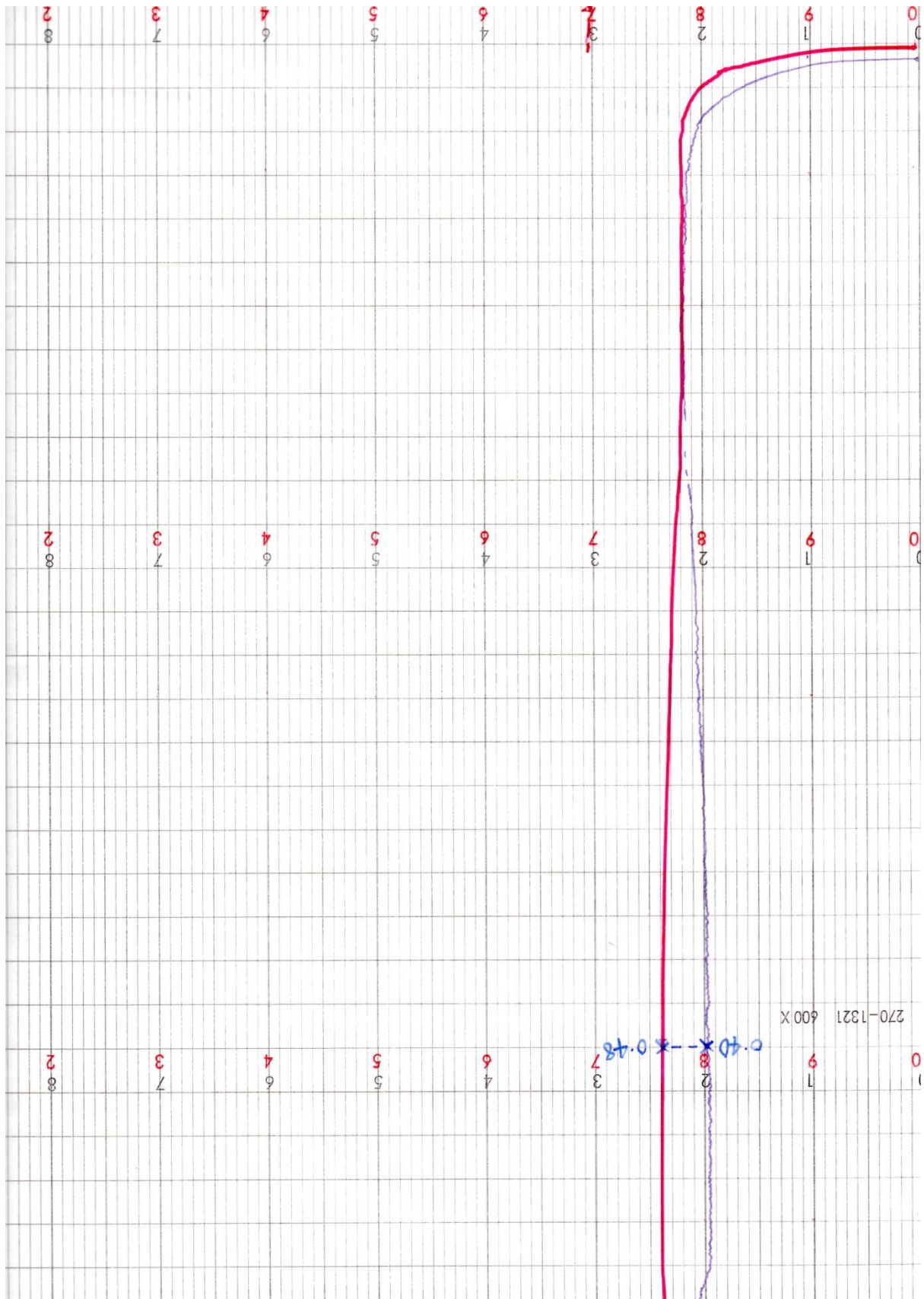
Chipboard:



HDF:

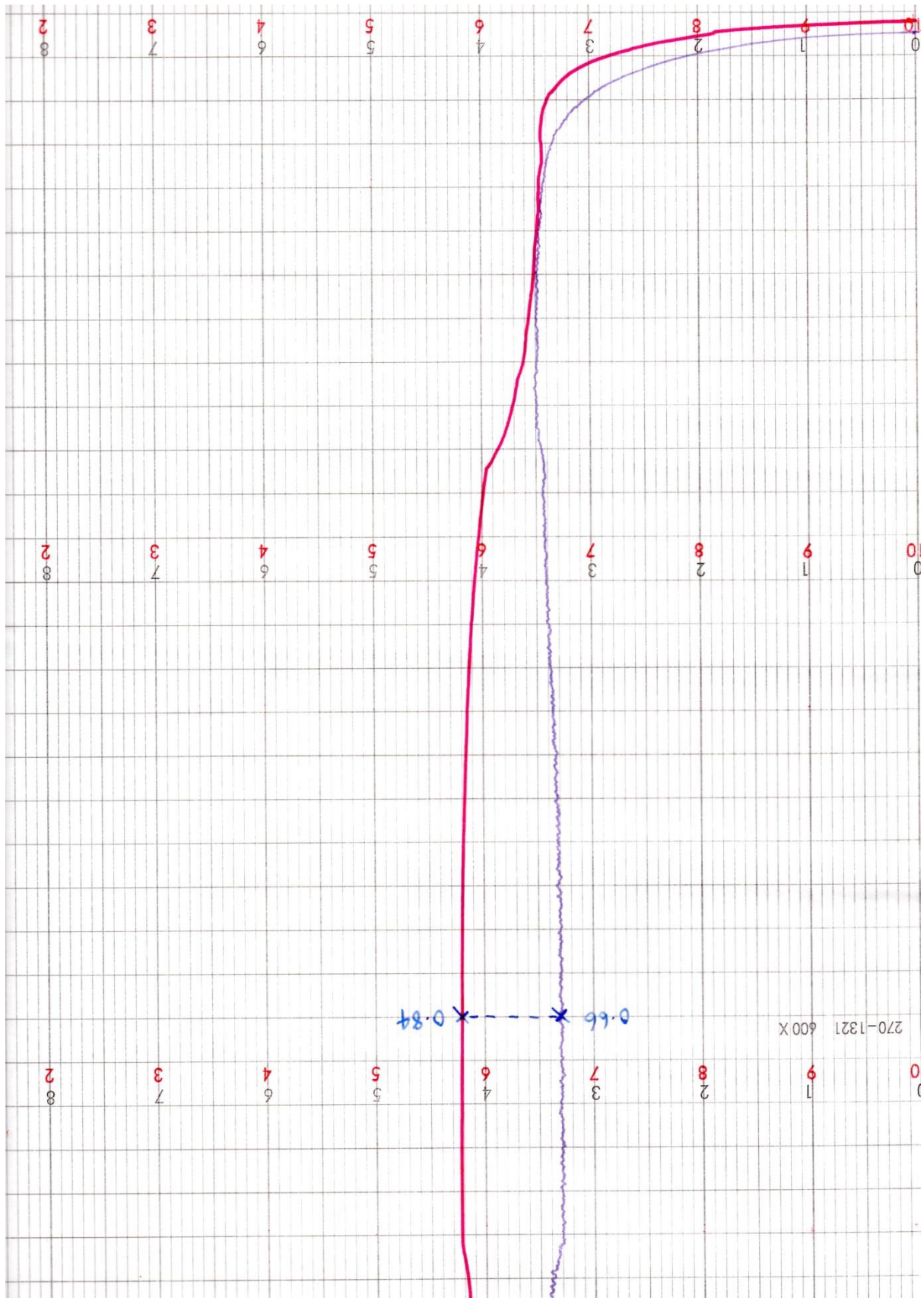


MDF:





OSB:



Plywood:

