ENERGY AND LOW-INCOME TROPICAL HOUSING IN TANZANIA

Bryony Coombs[1], Arman Hashemi[2] & Heather Cruickshank[3]

[1] Department of Engineering, University of Cambridge, UK & Balfour Beatty, London, UK, coombsbryony@gmail.com
[2] School of Environment and Technology, University of Brighton, UK, A.Hashemi@brighton.ac.uk
[3] Smart Villages, Cambridge, UK, heather@es4v.org

Abstract: Low-income housing in Tanzania is traditionally made from mud and thatch. With thatch having a typical life span of 2-7 years and mangrove poles 5-15 years, low durability is identified as the key issue with the traditional low-income house design. This paper studies the financial and social implications, embodied energy (EE) and human energy (HE) of a variety of materials in a bid to identify both the positive and negative impacts of each material substitution on the overall design, the environment and the local community. Using primary data collected from houses in the Mbweni district of Dar es Salaam and The Inventory of Carbon and Energy to calculate EE, a qualitative and quantitative assessment of each material is made. 47% of residents questioned in Tanzania, identified low durability to be the key issue with their mud house, with design changes which address this issue therefore affecting the largest share of the population. Stabilised bricks are identified as the key material substitution that should be adopted by local people, they perform well in terms of improved durability, financial and environmental considerations, and have the potential to be socially beneficial as well. This research identifies the social considerations to be key to understanding how local people will respond to the suggested material substitutions and whether they are likely to be adopted in the future. Whilst the environmental considerations are important, this is not a concept local people can relate to and does not affect their day-to-day lives as much as financial and social implications. It is extremely difficult and ethically questionable, especially in communities with people living close to poverty, to expect someone to adopt a design which requires more effort/money on their part, just because it is better for the environment.

Keywords: Low-income, Housing, Embodied Energy, Building Materials, Tanzania

1 Introduction

Tanzania is one of the least developed countries in the world, with a Human Development Index ranking of 159/187. It has a land area of 945,203 km², a population of 49.6 million with an average life expectancy of 61 years (World Fact Book 2014). Dar es Salaam is Tanzania's largest city, located in the tropical region on the east coast, with a population of 3.6 million. 70% of the population of Tanzania live in rural areas (National Bureau of Statistics 2013). 78% of houses in Tanzania are built with mud walls (Tanzania National Bureau of Statistics 2011), indicating that projects addressing problems associated with the mud house designs carry the potential to impact a large portion of the country's population.

There are a range of problems associated with the use of mud and thatch in house construction, as they fail to meet the needs of residents. The availability of photos and house dimensions for mud house designs is limited. There is no clear identification of the key issue surrounding the traditional design and much of the previous research does not discuss the social considerations of low-income housing or provide sufficient focus on the needs of the residents these problems affect daily. Hence there is a clear need to obtain primary data focusing on obtaining information about a large range of mud houses and the views and opinions of the residents, whilst looking into material substitutions to be made to the traditional design. Studying the Embodied Energy (EE) of building materials used in low-income housing allows comparisons of the environmental impact of certain designs/materials to be drawn (Hashemi et al. 2015). The level of development in a country or area affects the efficiency of industry, efficiency of material transportation and the processing techniques used for materials and hence careful consideration is needed to select adoptable values of EE for materials in Tanzania. Whilst The Inventory of Carbon and Energy (ICE) Version.2.0. details the EE of construction materials in the UK (Hammond 2011) no such database is available for Tanzania. To this end, this paper assesses the environmental, financial and social impact of making material changes to a traditional low-income house design in Tanzania, with particular focus on the direct effect on the local community. Considering these aspects side by side is what makes this project unique.

1.1 Low-income house design

Low-income housing in Tanzania has many forms. Traditionally, mud and thatch were used for house construction as the materials could be sourced locally for little or no monetary cost. In recent years, especially in semi-rural areas of Tanzania, there has been a move away from the traditional design outlined in Figure.1. This is due in part to the increased difficulty associated with sourcing traditional materials, paired with increased availability of and desire for modern materials, with concrete becoming a 'wealth status indicator,' as evidenced by the field work.

Figure 1: Photo and layout of traditional mud house, House 6

Almost all of the observed low-income houses were made from mud and pole walls covered with a thatch roof. The dimensions of the houses that were surveyed by the author during the field work were noted and the average dimensions computed. 'House 6' (Figure.1.) from the survey matches, almost exactly, the dimensions of the average house calculated. This two room house has therefore been taken for this research as the typical traditional house design, on which design modifications are based.

The walls are made from mangrove poles dug vertically into the ground, strung together with bamboo poles and the frame (Figure.2.) filled with mud. The roof is made from coconut palm fronds, woven together and built into a pitch, supported by mangrove poles (Wells 1998). Iron sheeting is commonly placed at the ridge of the roof, as it is difficult to get a perfect seal between the two slopes. Salvaged material is often used to patch up sections of the house, in a bid to improve the overall durability. Traditionally the houses are built by the local community, using free collected materials or materials bought from local traders, keeping money exchange within the community. The house is constructed in a collaborative effort by local people for convenience, ease of repair and to reduce labour costs.

Figure 2: Detail of timber support to a mud house, House 7

Theoretically, thatch lasts 2-7 years and mangrove poles 5-15 years (Wells 1998), with thatch therefore limiting the durability of the traditional design. Table.1. outlines the properties of traditional construction materials:

Table 1: Traditional low-income housing material properties (Wells 1998 and field surveys)

Material	Positive	Negative
Mangrove Poles	Strong for weight-bearing and naturally resistant to rot and termite attack	Expensive to buy and becoming increasingly difficult to source locally, due to environmental regulations
Bamboo Poles	Lightweight and strong for linking vertical poles together	
Mud	Readily available and cheap	Easily worn away during the rainy season
	Ideal phase shift filter properties – keeps the inside of the house cool during the day	
Coconut Palm Fronds (Thatch)	Highly insulating with a low thermal capacity	Low durability during the rainy season
	Compliments thermal properties of mud	Difficult to obtain a strong seal between the two slopes of the roof

2 Methodology

Site visits and surveys were carried out in collaboration with The National Housing and Building Research Agency (NHBRA) collecting data from houses in small villages in the Mbweni district, north of Dar es Salaam.

- Housing physical surveys: identified typical dimensions (including floor plan, elevation dimensions and photos) of traditional mud houses in Tanzania. This was necessary due to limited availability of data to show the variations between different mud house designs. Each house was numbered and the collected information is summarised in Table.3.
- Householder questionnaire survey: identified how people use their houses and what they identify as the main issues with their current house design. Information was obtained through non-intrusive semi-structured interviews with extra information being obtained through more casual conversations with locals. The findings are summarised in Table.3.
- Strength and porosity tests: were completed on a range of construction blocks, using methodology identical to that used by The NHBRA to complete continuous testing on the stabilised mud bricks that they produce.

2.1 Embodied Energy (EE)

Papers which support the idea that no database is 100% accurate show that even countries with extensive research into EE do not have highly accurate or reliable values for all materials (Dixit 2010). If reliable information for developed countries is difficult to obtain, this reduces the likelihood of finding usable values for Tanzania, due to significantly less research in this field in developing countries. The following resources detail EE values in different countries:

- UK – The Inventory of Carbon and Energy, Version.2.0 (Hammond 2011)
- New Zealand – Alcorn and Baird (Alcorn 1996)
- Canada – (Canadian Architect 2015)
- India – Various Reports (Reddy 2003; Shukla 2008)

'Embodied Energy and CO_2 Analyses of Mud-brick and Cement-block Houses' (Abanda 2014:18-40) looks at the EE of a mud-brick and concrete house in Cameroon, using values for EE taken from the ICE. The use of this database in Cameroon would suggest these values are also accurate estimates of EE values in Tanzania. 'Embodied Energy Analysis of Adobe House' (Shukla 2008:755-761) shows the EE of constituent parts of an adobe house in India. The analysis assumes that the EE of mud is zero, because it is dug out of the ground on site with zero transportation or commercial excavation costs. Shukla identified that 12% of the total EE of an adobe house is consumed making repairs. The paper therefore supports the need to consider 'human energy' (HE) alongside EE as well as assessing the energy input for repairs and not just the initial construction, turning the focus back to the durability of designs.

The concepts identified above, combined with independent research, confirm that using the ICE v.2.0 for values of EE in Tanzania will not produce large errors. Table.2. shows the ICE v2.0 EE values of the common construction materials used in low-income housing in Tanzania. The relatively large ranges and standard deviations for each material show the huge variation between EE of the same material within a single country, highlighting the difficulty in pinpointing a single value of EE for materials in a country where data it readily available. It is likely that the value of EE for a material in Tanzania will fall somewhere inside the range of values documented in the ICE. Therefore, the average EE values given in the ICE are used in this study for materials in Tanzania. Whilst it is important that the EE values used are as accurate as possible, because the focus is on comparisons between different materials studied, as long as information from the same source is used for each material, a reliable comparison can be drawn.

Table 2: Embodied energy values of raw materials taken from ICE (Hammond, 2011)

	Average EE (MJ/kg)	No of Samples	Standard Deviation	Minimum	Maximum	Range
Cement	5.32	94	2.05	1.42	11.73	10.31
Sand	0.21	18	0.23	0.02	0.63	0.61
Iron	24.62	21	7.5	11.7	36.3	24.6
Concrete (General)	3.01	112	9.07	0.07	92.5	92.43
Steel*	21.6	-	-	-	-	-
Timber	7.11	55	4.8	0.72	21.3	20.58

*Uses World Typical Value (39% recycled)

It is noted that 'the single most important factor in reducing the impact of EE is to design long life, durable and adaptable buildings. Buildings should aim to use materials that have lower EE' (Strine Environments 2015). So whilst this project doesn't focus on the full life cycle energy analysis of houses, there are key long-term implications of material choice which should be considered. Although the initial mud house contains less energy than a more durable design, if it needs to be repaired every 2 years then the energy (especially human energy) required to make these repairs must be considered as well.

3 Results

3.1 Field Work Results

Table.3. summaries the information recorded in the field from the housing surveys and questionnaires. These results summarise key information about house construction and maintenance, house use, house dimensions and the key problems with mud house designs. The results clearly show that low durability is the key problem with low-income housing, this forms the basis of the research presented in this paper.

Table 3: Summary of primary research

Detail (n=Number of houses surveyed)		Number	Percentage
Source of material (n=16)	Bought	11	68.8%
	Found	5	31.3%
How often are repairs made?		1.8years	-
Where do you cook? (n=17)	Inside	7	41.2%
	Outside	10	58.8%
What fuel do you use? (n=12)	Wood	7	58.3%
	Charcoal	3	25.0%
	Both	2	16.7%
Average number of people living in the house		3.8 ppl	-
Biggest problem with the house (n=19)	Low durability	9	47.4%
	High internal temperature	6	31.6%
	Poor ventilation	2	10.5%
	Low lighting	2	10.5%

	Not enough space	0	0.0%
Average house dimensions (m)	Length	6.41	
	Width	3.67	
	Outside wall height	1.77	
	Roof pitch height	2.66	

3.2 Calculation Results

Using previous research combined with primary data from the field, calculations of the cost and EE of constituent elements for each house design were calculated, based on the house outlined in Figure.1. Table.4. provides a summary of the values associated with each material for each element of the house, allowing comparisons of durability and social and environmental impacts to be drawn.

Table 4: Summary of housing material calculations

Element	Material	Material Cost (£)[1]	Embodied Energy of Material	Embodied Energy for whole house (GJ)
Walls	Mud	0.00		0.00
	Stabilised Mud Brick	206.58	6.67 MJ/Block	10.44
	Concrete Block	506.52	14.8 MJ/Block	18.59
Roof[2]	Thatch	0.00		0.00
	Iron	129.74	279.59 MJ/sheet	6.08
	Sisal Reinforced Tiles	200.22	3.44 MJ/tile	10.59
Floor	Mud	0.00		0.00
	Concrete	1,222.10	7.22 MJ/m^3	78.38

4 Findings

4.1 Durability

From the housing survey, the mud and thatch houses required repair every 1.8 years, on average, with the main cause for repair being problems with the thatch roof. Theoretically, thatch lasts 2-7 years and mangrove poles 5-15 years (Wells 1998). Common variations on the traditional design aim to improve durability, requiring less continuous repair, but come with other issues.

- Concrete blocks have a cement to sand ratio of 1:16 and an ultimate compressive strength (UCS) of 1.1MN/m2
- Stabilised mud bricks have a cement to soil ratio of 1:12 and an UCS of 6.5MN/m2, almost 6 times that of the concrete blocks

Whilst these figures do not directly measure durability, they indicate the block's ability to withstand loading/erosion. During the hydration of cement tobermorite gel is formed (Brunauer 1962), giving cement-containing elements their strength. Hence blocks with a higher cement content should be more durable. Quality control is recognised as a key influence over durability of buildings worldwide (Gjørv 2015). In Tanzania many construction materials are made using a variety of techniques in a largely unregulated

[1] 1000 Tzs = £0.33. Exchange rate taken on 11th May 2015 at 13:06. (XE 2015)
[2] Timber beams used for roof designs have an EE=61.9MJ/m

manner, like the concrete blocks studied for this research. The NHBRA tiles and bricks are either built in the lab or made on site by trained locals.

Considering all these points the stabilised mud bricks are expected to be the most durable wall material, followed by concrete blocks and then mud. It is difficult to compare the roof materials quantitatively, due to limited strength data.

- Thatch is the key element that reduces the durability of traditional designs. It is readily attacked by termites, it also rots and leaks in high rain and thus offers little protection to the elements.
- Iron sheeting is susceptible to rust, but is easy to assemble to form a sturdy, protective roof and easily adaptable for houses with a variety of wall materials. Yet, it should be noted that unlike thatch, iron sheeting may have negative effects on thermal comfort inside low-income houses (Hashemi 2016).
- Stabilised roof tiles are only compatible with blockwork walls that have the strength to support them.
- Both the iron and tile roof materials are waterproof and therefore have the capability to improve the durability of both the walls and foundations by directing rainwater away from these elements.

4.2 Financial Implications

Mud and thatch houses traditionally have zero material costs. With the recent implementation of conservation projects, however, the availability of these ‘free’ building materials has been reduced. Considering that it may become necessary to pay for these low durability materials, investments in the development of higher durability, similar function materials may prove worthwhile and should be investigated.

- The materials required to build concrete walls cost approximately 2.5 times that of the stabilised block design, with 62% of the cost of the concrete walls due to the reinforced concrete beam, a feature which is not required for the stabilised brick wall due to the bricks’ interlocking nature.
- The sisal tile roof design is 1.6 times more expensive than the iron roof design, due to the large quantity of timber needed.
- Installing an iron roof is the single cheapest design change, as all other designs require the installation of a concrete foundation first, for safety reasons, and for this reason iron sheeting is seen as the preferred roof material substitution.

4.3 Embodied Energy

The EE of the different elements of each design can be used to assess their relative environmental impacts, as summarised in Table.4. and discussed below:

- The EE of the concrete wall design is approximately 1.8 times that of the stabilised brick wall design, with the concrete beam contributing to 64% of the total EE of the concrete design.
- The sisal tile roof design contains almost twice the EE of the iron roof but the sisal tiles contain 1.7GJ EE whereas the iron sheets contain 3.9GJ EE in total. The key difference is the nature of the timber support structure which requires significantly more timber.
- The design improvement with the highest EE is the concrete foundation containing 78.4GJ EE, but is also expected to be the most durable design change. This raises the issue of whether this financial and EE investment in a concrete foundation is worthwhile in terms of return in improved durability.

The EE of a concrete foundation is 13 times the EE of an iron roof. It is unlikely that installing a concrete foundation rather than an iron roof improves the durability of the house 13 fold, as this still leaves thatch as the key determiner of durability. Hence a concrete foundation is not an environmentally beneficial investment.

4.4 Social Considerations

Social considerations are quantified by Human Energy (HE) calculations. HE comes from:

- Extraction, processing and transportation of materials;
- Construction of house elements;
- Repair and maintenance.

HE inputs have two key considerations in this study:

1) The HE input, whilst significantly lower than the EE, contributes to the overall energy required for house construction. Due to the low EE values of traditional materials, the HE contribution forms a larger proportion of the overall energy than it would for more EE intense materials.
2) The main problem identified with low-income housing in Tanzania is low durability. Residents resent having to repair and rebuild their houses. The relatively high HE input needed to maintain a mud house makes it less desirable than more durable designs, despite their higher EE and financial cost.

According to CIBSE (2015), a human produces 233 Watts/m^2, when lifting 50 kg bags (activity taken as closest to that of mud house construction). Multiplying this by 1.8 gives the energy output for a standard human body as 419.4 Watts. Using these figures it is calculated that a human produces 12.1MJ of energy during an 8 hour working day during the house construction. Using simplified assumptions of the human working hours (Kwanama 2015) put in to the mud and thatch house construction, the HE input can be calculated (Table.5.).

Table 5: Outline of mud house building timescales and the associated human energy

No of Days	Number of People	Activity	Human Energy (MJ)	Design Element	Stage
2	3	Collect poles and stripes	72.6	Walls	Material Extraction and Transportation
2	3	Dig holes in the ground	72.6	Walls	Construction
1	3	Erect poles	36.3	Walls	Construction
2	3	Fix stripes	72.6	Walls	Construction
2	3	Look for rafters for roof	72.6	Roof	Material Extraction and Transportation
2	3	Collect and prepare thatch	72.6	Roof	Material Extraction and Transportation
2	3	Fix stripes on roofing poles	72.6	Roof	Construction
4	12	Digging mud from ground & putting on the walls	580.8	Walls	Construction & Material Extraction and Transportation
3	12	Construct roof from thatch	435.6	Roof	Construction
1/2	12	Gather all the materials and move them to house location	72.6	Walls/Roof	Material Extraction and Transportation
	Total		**1560.9**		

This shows that:

- 580.8MJ of HE is used to extract and transport the raw materials used for the house design, assuming half of the energy for putting the mud onto the walls is used for digging the mud from the ground.
- The HE of extracting and transporting the materials constitutes 37% of the total HE of the entire house design – 399.3MJ in the wall materials and 181.5MJ in the roof
- 212.9MJ of HE is required for repairs (17.6 human working days), using Shukla's (2008:755-761) principle that 12% of the total EE is for repair work, as all energy input is from HE.

The HE for the mud and thatch house is 1.5% of the EE of a concrete and iron house which, whilst small, is significant when you consider that all of this energy is from human exertion. HE is a value that quantifies the efforts of local people. Doubling the HE of a design has more direct impact on local people than doubling the EE. Low durability was identified as the key issue with mud houses in Tanzania, because of the inconvenience that house repairs pose to the residents. Overall, considering materials and construction the thatch roof has 689.7MJ HE and the mud walls 871.2MJ HE. The average lifetime of thatch is 4.5 years and of mud walls is 10 years. Therefore thatch roofs have a higher HE input (153.3MJ HE per year) than mud walls (87.1MJ HE per year) relative to their durability. This confirms why iron roofs are commonly installed in Tanzania. An iron roof design takes equal or less time to construct, compared with a thatch roof, but requires fewer repairs and is significantly more durable.

4.5 Discussion

The use of concrete blocks, stabilised bricks and sisal fibre roof tiles all require the installation of a concrete foundation, for safety reasons. Installing a concrete foundation has huge durability benefits as shown by House 20 (Figure.3.) which was built 40-50 years ago and since then has required little repair expect for "sometimes filling in the gaps in the walls with more mud". As this design change needs to be installed first, the traditional design cannot be gradually improved using the methods studied, highlighting the need for other small-scale modifications, which do not require concrete foundations. Protective measures, such as covering mud walls with plaster or paint and using baked mud bricks should therefore be considered. When a mud house is sold, the buyer pays for the cost of the plot of land the house sits on, so investments made to make small scale improvements to the design using plaster and paint, are not recovered upon sale. If there is a concrete foundation or brick/block walls, extra revenue is obtained in the sale, recovering some of the initial investment. Therefore, there is a point at which small-scale improvements to mud houses become economically unviable in the long-term compared with block/brick designs. In order to save enough money to make substantial design improvements families stop making repairs to their current houses and save up money to invest in more durable designs, causing families to live in extremely poor conditions with all their hope pinned on a better house in the future.

Figure 3: Mud house with concrete foundation (Author)

The key concepts outlined in Ethics in Engineering Practice and Research (Whitbeck 1998) highlight the moral obligations researchers and engineers carry. In the context of this research this book raises a key question. Ethically, is it right to expect someone to adopt a design which requires more effort/money on their part, just because it is better for the environment, especially in communities with people living close to poverty? Whilst environmental considerations are important, and in terms of global sustainability environmental considerations should form part of the basis of all engineering decisions this should not be the key driver in these communities in Tanzania. The EE of low-income, single-storey houses is insignificant compared to the EE of the materials used for buildings in developing countries. Tanzania will be better equipped to address environmental issues, once the majority of people in the country have acceptable living conditions and are no longer living in poverty. What is most important is that the new designs bring benefits to the local people, fix the key issue (low durability) they have with the current design whilst reducing the negative social and financial impacts as much as possible. These are also key drivers for a design being accepted by the local community as they have a direct impact on their lives. Ultimately homeowners will form their own opinions about a material or design based on the return in improved durability obtained for a given financial or HE input and this will determine its success.

5 Conclusions

Following the comparison of a range of material substitutions made from the traditional mud and thatch house design, the following conclusions can be drawn:

- Low durability is the key problem with low-income housing in Tanzania (confirmed by 47% of residents surveyed).
- Whilst no material substitution is perfect, The NHBRA stabilised bricks perform well in terms of improved durability compared to mud walls with lower financial and environmental costs than concrete walls. This is identified as the key material substitution which should be adopted, for its financial, environmental and social benefits over mud and concrete walls.
- The installation of an iron roof, whilst having huge positive impacts on the durability of a mud walled house, is both the cheapest and most environmentally friendly material substitution studied. As thatch is the least durable material this highlights why iron is commonly substituted for thatch in mud houses.
- Whilst the environmental impact of a design change is not something to which local people can easily relate, the social considerations are particularly important. The

opinions that local people have about a material decides whether that design will be accepted and adopted, which ultimately determines the 'success' of a design change.
- It is extremely difficult and ethically questionable to expect someone to adopt a design which requires more effort/money on their part, just because it is better for the environment, especially in communities with people living close to poverty.

This work does not focus solely on one single aspect of a design, but incorporates social, environmental and financial considerations, showing that future research should give heightened consideration to priorities of local people. Continuing on from this work, the following is suggested:
- Precise calculation of the HE input for each material substitution suggested;
- Establish precise maintenance regimes for each of the materials and designs suggested, providing a better understanding of the durability of each material, allowing durability comparisons to be more accurate;
- Further interviewing of local people to obtain opinions on the material substitutions suggested in this project, to establish whether people are willing to invest money in the suggested material changes.
- Identification of any other material substitutions which should be analysed using the above framework.

Acknowledgements

This document is an output from a research project "Energy and Low-Income Tropical Housing" co-funded by UK aid from the UK Department for International Development (DFID), the Engineering and Physical Science Research Council (EPSRC) and the Department for Energy and Climate Change (DECC), for the benefit of developing countries. The views expressed are not necessarily those of DFID, EPSRC or DECC. The authors would like to thank The National Housing and Building Research Agency (NHBRA), Tanzania for supplying essential data, Emmanuel College, Cambridge and The Cambridge University Engineering Society for the funding of the research trip to Tanzania. The authors would also like to thanks the Institute of Civil Engineers for providing funding for the conference and conference paper submission.

References

ABANDA,H. ET AL, 2014, 'Embodied Energy and CO_2 Analyses of Mud-brick and Cement-block Houses', Aims's Energy,2(1),pp.18–40.

ALCORN,J. & BAIRD, G., 1996, 'Use of a Hybrid Energy Analysis Method for Evaluating the Embodied Energy of Building Materials', Center for Building Performance and Research, Victoria University of Wellington, New Zealand.

BRUNAUER,S., 1962, 'Tobermorite Gel — The Heart of Concrete', American Scientist,50(1),pp.210-229.

CANADIAN ARCHITECT, 'Measures of Sustainability', [online] retrieved from: http://www.canadianarchitect.com/asf/perspectives_sustainibility/measures_of_sustainablity/measures_of_sustainablity_embodied.htm [Accessed: 22nd May 2015].

CIBSE, 2008, 'CIBSE Concise Handbook', CIBSE, pp.2.

DIXIT,M. ET AL., 2010, 'Identification of parameters for embodied energy measurement: A literature review', Energy and Buildings,42,pp.1238–1247.

GJØRV,E., 2011, 'Durability of Concrete Structures', Arabian journal for science and engineering, 36(2),pp.151-172.

HAMMOND,G. & JONES,C., 2011, 'Inventory of Carbon & Energy (ICE) Version 2.0. UK', Department of Mechanical Engineering, University of Bath.

HASHEMI, A., CRUICKSHANK, H., CHESHMEHZANGI, A., 2015, 'Environmental impacts and embodied energy of construction methods and materials in low-income tropical housing', Sustainability,7(6),pp.7866-7883.

HASHEMI, A., 2016, 'Climate Resilient Low-Income Tropical Housing', Energies,9(6),pp.468.

KWANAMA, E., 2015, Email to E.Kawanama, 21st May 2015.

NATIONAL BUREAU OF STATISTICS, MINISTRY OF FINANCE, 2013, 'Tanzania in Figures', [online] retrieved from: http://www.nbs.go.tz/takwimu/references/Tanzania_in_figures2012.pdf [Accessed: 19th May 2015].

REDDY,V. & JAGADISH,K., 2003, 'Embodied energy of common and alternative building materials and technologies', Energy and Buildings,35(2),pp.129-137.

SHUKLA,A. ET AL., 2008, 'Embodied energy analysis of adobe house', Renewable Energy,34,pp.755–761.

STRINE ENVIRONMENTS, 2015, 'Concrete and Embodied Energy – Can using concrete be carbon neutral?', [online] retrieved from: http://strineenvironments.com.au/factsheets/concrete-and-embodied-energy-can-using-concrete-be-carbon-neutral/ [Accessed: 27th January 2015].

TANZANIAN NATIONAL BUREAU OF STATISTICS, 2011, 'Tanzania Demographic and Health Survey 2010', Dar es Salaam, Tanzania: NBS and ICF Macro.

WELLS,J. ET AL., 1998, 'Housing and Building Materials in Low-income Settlements in Dar es Salaam', London: Elsevier Science Ltd.

WHITBECK,C., 1998, 'Ethics in Engineering Practice and Research', Cambridge University Press.

WORLD FACT BOOK, 2014, 'Tanzania', [online] retrieved from: https://www.cia.gov/library/publications/the-world-factbook/geos/tz.html [Accessed: 1st November 2014].

XE. TZS., 'Tanzanian Shilling', [online] retrieved from: http://www.xe.com/currency/tzs-tanzanian-shilling [Accessed: 11th May 2015].