Embodied Energy of Low Income Rural Housing in Uganda

THOMAS NIWAMARA[1], MARK OLWENY[1], ALEX NDIBWAMI[1]

[1]Faculty of the Built Environment, Uganda Martyrs University, Kampala, Uganda

ABSTRACT: Embodied energy is an important consideration in discussions related to the sustainability of the construction sector. As part of this dialogue, this paper presents a developing country context of how these can serve to enable a transition in energy related discourse. In East Africa, the energy related discourse is largely concerned with the reduction in the use of wood fuel, which is the predominant energy source for cooking, with little attention to the current and future impact of the buildings themselves, that is, life-time energy consumption. The primary goal of this study was to determine the embodied energy (EE) of low-income tropical housing to better appreciate the relative values of energy for construction. The study investigated different housing sizes and typologies. Data collected from various embodied energy databases was the basis of an initial investigation, followed by an in depth exploration of values for specific building materials used in a typical rural building, with two materials, fired clay bricks, and cement standing out. The investigation of the fired clay bricks suggested slightly lower embodied energy values that found in the literature, although it is evident that the sources of energy used for the processing of the bricks is of concern for embodied carbon.
Keywords: embodied energy, rural housing, Uganda, low-income housing

INTRODUCTION

Embodied energy of buildings has been investigated in different parts of the world over the past three decades. This has provided a holistic appreciation of energy consumed as part of building construction, ultimately giving a better understanding of total energy demanded for the building over its life time. Embodied energy has been revealed as a major element in life-cycle energy demand, and particularly significant in relation to a need to reduce overall energy use. The literature suggests that the energy associated with the construction elements of a building may constitute a significant proportion of the life time energy associated with buildings, and in some cases, may be greater than use energy. While this is true for buildings constructed with modern building materials, little is known of how life-cycle energy is proportioned in the context of buildings in many tropical countries in sub-Saharan Africa, more so for low-income housing, where use energy is relatively small compared with housing in cooler or warmer climates.

In the context of Uganda, few studies have been undertaken to appreciate the nature of embodied energy, or embodied carbon within buildings. Progress has however been made in gaining an appreciation of energy use within dwellings (See Drazu et al 2015). With regard to low-income dwellings, studies have focussed on use energy, and a need to transition from biomass, to modern fuel sources. However as energy consumption in low-income households was negligible (in the context of global energy consumption), this led to a belief that further attention was not really warranted. At a broader level, a current UN-Habitat project - *Promoting Energy Efficient Buildings in East Africa* (UN-Habitat, n.d.), looked to address energy in buildings, although it too has largely been concerned with energy-in-use.

While interest in embodied energy grows, there has been a lack of studies in the context of sub-Saharan Africa, save from a few studies in South Africa, such as Irurah (1997). This could be attributed to a variety of factors; primary amongst these has been the difficulty in gaining access to reliable data on which to base analysis. Increased interest in overall energy consumption, linked to concerns for global climate change, have sparked recent interest in embodied energy studies in the region, acknowledging the contribution building materials and construction make to energy demand, and green house gas emissions. This paper seeks to contribute to this ongoing discourse through a study of embodied energy in Uganda.

Of wider concern is the potential upswing in demand for housing across sub-Saharan Africa, with a rapidly growing population, resulting in an unprecedented demand for dwellings over the next 40 – 50 years and projections estimating the number of buildings that need to be built to satisfy this demand, are in excess of the existing building stock. This suggests a significant increase in demand for energy for construction, which could add significantly to embodied energy and embodied carbon for sub-Saharan Africa. Consequently, an appreciation of the nature of this demand is critical for the region, if it is to ensure growth targets can be met.

Seeking to fill the evident gap in knowledge, this study investigated the embodied energy of rural dwellings within Mpigi District in Central Uganda. The study made use of the Life Cycle Energy Assessment approach, which considered energy as the single criteria for analysis, thus giving a manageable tool for simple analysis. This paper presents the initial findings of the study, which assessed the overall embodied energy of a typical rural residential building to provide an initial data set on which future detailed analysis could be undertaken. The study considered a cradle to site approach, taking into account energy expended for extraction, processing, manufacture and transportation of building materials and components to site for construction. The ultimate goal of this study is to develop a comprehensive database of materials that could be used as part of future life cycle assessments.

LIFE-CYCLE ASSESSMENT METHODOLOGY

Life Cycle Assessment (LCA) is a technique for assessing the environmental impact associated with a product, by; compiling an inventory of relevant inputs and outputs; evaluating the potential impacts associated with those inputs and outputs; interpreting the results of the inventory analysis and impact assessment phases in relation of the objectives of the study (ISO, 1997). This definition of LCA is expounded upon by Menzies et al. (2007), who define LCA as a means of investigating the environmental impact of products, buildings or other services throughout their lifetime. LCA encompasses: extraction, raw material processing, manufacturing, transportation and distribution, use, maintenance, recycling and final disposal; giving an idea of the expansive nature of this assessment approach. For the purpose of this study, we made use of a component of LCA, Life Cycle Energy Assessment (LCEA), which considers energy as the single criteria for analysis, thus providing a manageable data set.

The study made use of Process Analysis, involving a survey of existing buildings to document materials uses, as well as to ascertain (as far as was possible) the source of these materials. This provided a basic starting point for the LCEA, particularly given the challenge in accessing data, as is the case in much of sub-Saharan Africa (Mpakati-Gama et al., 2011). This lack of available data would make the use of an Input-Output approach difficult at best, giving added weight to the use of Process Analysis to determine the embodied energy for the purpose of this study. The lack of data did present another challenge, related to which existing data sets would be most appropriate to use. The use of data from elsewhere in embodied energy analysis is not new, with research indicating that where data is not always available, coefficients from alternative sources could be utilised (Mpakati-Gama et al., 2011). Use of material coefficients from different parts of the world however remains controversial due to the fact that resultant values are not always a true representation of the materials' embodied energy in the different context. A key sticking point arises from the contextual differences: in production technologies; sources of energy; as well as efficiency in production and material use. Although these variations are possible to anticipate, their extent is what needs to be seriously considered (Hammond and Jones, 2008). Nevertheless, use of this data can form part of initial assessment of embodied energy, and as a basis for benchmarking locally available data when it eventually becomes available. For the purpose of the current study, a comparative database of materials was found in the embodied energy inventories by Venkatarama et al. (2003), who had based their work on the construction in India.

STUDY LOCATION

The study was undertaken in a semi rural setting, based around the township of Nkozi, situated 84km southwest of Uganda's capital Kampala (Fig. 1). The choice of study location was based on previous engagement with the community in the area, an important factor to enable access to dwellings, and to ensure the validity of collected data.

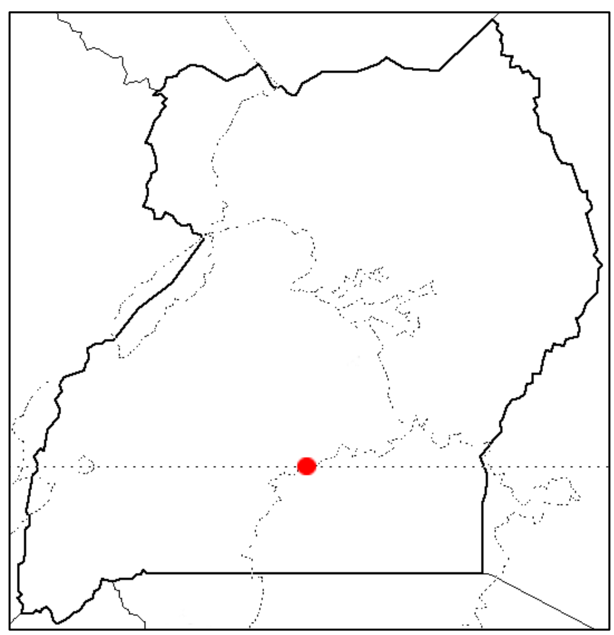

Figure 1: Map of Uganda and study location

Figure 2: Typical rural dwelling

Figure 3: Contemporary rural dwelling

The wider study took in a variety of housing typologies as part of an assessment of construction materials used in typical rural dwellings. Data was collected from 64 housing units, which ranged in size from a modest 6sq.m. for a single room dwelling, to 90sq.m. for a six-room detached house. The survey gathered information on materials commonly utilised in the construction of various elements in the building. The most dominant typology was found to be a four (4) room dwelling with an area of between 45 and 60sq.m., built of fired clay bricks and roofed predominantly with corrugated steel sheets (Fig. 2 and Fig. 3). This typology represented a typical dwelling across the rural environment of Uganda, and what many rural (and urban) dwellers aspire to as they seek their own housing. This housing type thus typifies not only the most dominant dwelling type today, but also potentially the most dominant typology into the near future.

CONSTRUCTION MATERIALS

To better appreciate the nature of the buildings included in the study, the following sub-sections give an overview of the different building components, and the materials used for the substructure, superstructure (walls and roof), and the doors, windows, ceiling, and any other fixtures.

Sub-Structure and Super Structure

The substructure of the buildings generally comprised of mass concrete strip footings with fire clay bricks forming the plinth walls. In many cases, floors were built after the walls had been completed - built room by room, with buildings that made use of trained builders the only ones to make use of an over-site-slab on top of the plinth wall, onto which the superstructure was built. The floor was generally mass concrete, with the occasional building making use of brick or compacted earth. The predominant floor finish was cement screed overlaid on the mass concrete or brickwork.

Walls were constructed of fired clay bricks, which were largely produced, and procured locally, usually within a 10 km radius of a construction site in order to reduce the cost of transportation. Brick manufacturing is undertaken in wetlands, with make shift kilns built close to the source of the raw material. Bricks were all hand made and sundried for at least two months before being placed on a stack kiln to be fired, with timber off-cuts used as fuel (Fig. 4). The process involved firing continuously for one to two days, with constant addition of wood fuel. For the final day, residual heat in the kiln completes the process. Off-cuts were generally branches of trees that had been felled for timber, and were predominantly hardwood, as brick makers believe they 'burn hotter'. The nature of the kilns and the firing process was such that there was inconsistency in the final product, with bricks on the outer edges of the kiln not being adequately fired, and thus of dubious strength, while those close to the fire source were burnt, as was found by Okello (2010). With regard to embodied energy, key factors to take into account included: the person hours required to make the bricks (all done by hand); the stacking and preparation of the kiln; and the fuel used to fire the bricks, and the source of this fuel.

Figure 4: Wood fuel, with bricks drying in the sun

Sand for construction was also mined locally, from old riverbeds within a 10 to 20 km radius of the site. As sand is generally not processed, and used in its extracted state, thus the associated energy cost relate to labour and transportation. Aggregate is generally hand crushed, also making it a labour intensive process, with energy again largely tied to labour and transportation. Concrete was generally mixed on site, making use of locally manufactured cement, from either Hima Cement based in Western Uganda (260km), or Tororo Cement from Eastern Uganda (320km). Both factories use similar processes in the manufacture of cement. Both brands are sold in local hardware shops in individual 50kg bags, with cost as the main determining factor in the choice of which cement to use. Mortar was either sand cement based or clay based, although clay based mortars, were not as common as they were in the past, highlighting a change in material preferences across the rural landscape. This was also linked to the increased use of fired clay bricks rather than sun dried bricks. Mortar joints larger than 40mm were commonplace, a result of the use of irregularly shaped bricks. The survey of different dwellings revealed average mortar joints of 30mm, a major source of waste. Walls were generally plastered with sand-cement render, although for many dwellings, this was only for interior walls, with exterior walls left bare as a cost saving measure.

Doors

Both external and internal doors were largely timber panel doors, with hollow core doors rarely used, perceived as being inferior, and easily damaged. In all cases doors were manufactured within the vicinity by local carpenters, making use of timber purchased from timber markets in Kampala. Wood used for the doors was largely sourced from within Uganda, and to a lesser extent the Democratic Republic of Congo (DRC). These were hardwood species such as Muvule (*Milicia excelsa*) and Mahogany (*Khaya anthotheca*), and occasionally Gum trees *(Eucalyptus grandis)*. Hardwood is desired as these are long lasting and generally resistant to termites. Most timber mills were small-scale operations, making use of mains electricity or diesel generators to cut the logs. All timber is air-dried, although the exact length of time for this is not available as this varied considerably between dealers, but in most cases this was for less than six months. Planing was generally done by hand, as was joinery and carpentry work. For the most part, the timber industry in Uganda is unregulated, therefore getting a true picture of processing of timber from source to the timber dealers is difficult (Smith, 2004).

Windows and Window Frames

Windows were predominantly steel framed, although there were still a large number of dwellings with traditional timber shutters. Rooms generally had a single window, with an average area of about one square metre. This was similar for buildings with timber shutters and those with glazed windows, suggesting a direct substitution of timber shutters for steel windows. Timber again was sourced from local carpentry shops, however glass and steel used for windows - generally 25mm steel angles – were sourced either locally, or in Kampala depending on whether they were bought piecemeal or in bulk (Fig. 5). Although steel is manufactured in Uganda, products are generally of poor quality, largely produced from recycled scrap, and due to the lack of quality control is not recommended for structural purposes - although the major outputs of these plants is re-bar. Steel products are largely imported from Kenya, or further afield; from South Africa India, or China. It was however difficult to trace the origin of the steel being used, thus a key assumption was that steel used was generally imported from Kenya, given much of what was used were steel angle bars.

Figure 5: On site construction of steel window frames

Glass was 3mm clear glass, and sourced from Kampala. As there isn't any glass manufacturing plant in Uganda, all glass used is imported primarily from Kenya, or from India or the United Arab Emirates (UAE). Individual panes were usually cut to size by the glass dealers and transported to site ready for installation. This was a consequence of the lack of transportation for large panes of glass. Glass was generally ferried to the site piecemeal; by taxi bus from Kampala, then by motorcycle taxi to the site.

Ceiling and Roof

All roofs on the surveyed buildings were galvanised steel on timber supports. The roof structure on the majority of houses was composed of cut timber sections, although a large proportion of buildings made use of timber poles (largely eucalyptus) as the structural elements, all joined using nails. In most cases houses did not have ceilings, and where these were installed, they were made of dried papyrus reeds or palm leaves.

Fixtures and Finishes

Most dwellings did have plastered internal wall, and where there was a wet area, or internal kitchen, part of the wall was tiled, and in some cases so was the floor. For the most part however, floors were generally cement screed.

Based on the preliminary assessment of materials used for construction of the different dwelling, a summary of these is presented in Table 1 below, presenting the location of manufacture and where the material is procured.

Table 1: Sources of key building materials

Item	Material	Manufacture	Procurement
1	Cement	Local	Local
2	Fired clay bricks	Local	Local
3	Sand	Local	Local
4	Steel sheet	Imported	Local
5	Steel	Imported	Regional
6	Timber	Local	Regional
7	Glass	Imported	Regional
8	Ceramics	Imported	Regional
9	Stone / Aggregate	Local	Local

EMBODIED ENERGY ASSESSMENT

This initial investigation looked to ascertain a ballpark figure for embodied energy for the construction of a typical rural dwelling, which is the predominant typology across the rural landscape of Uganda. From the survey, the embodied energy of the commonly used building materials for a typical 55m^2 dwelling was determined using the Life Cycle Energy Assessment approach. This considered energy as the single criteria for analysis, thus providing a manageable tool for simple analysis. The study presents the initial findings of the study, which concentrated on assessing overall embodied energy. It will subsequently move into a more detailed assessment of life-cycle energy including more detailed assessment of the embodied energy of materials. The study considers a cradle to site approach, taking into account energy expended for extraction, processing, manufacture and the transportation of building materials in rural Uganda.

The quantity of materials used in a dwelling, were determined based on computations from the typical dwelling as previously described, and presented in Table 2 below. Making use of data from previous studies, it was possible to ascertain the embodied energy of the various material components, as well as that for the entire building. Quantities for Embodied Energy were initially derived from the literature. This was to gain an appreciation of the overall embodied energy for the building. Making use of two data sets in particular: the ICE dataset; and Venkatarama et al. (2003), it was determined that the total embodied energy for a typical building would be approximately 294.4GJ, or 5.3GJ/m^2. This compares to a range of between 2.72 and 2.91 GJ/m^2 for housing in Canada (Timber construction) as estimated by Cole (1994), or 5.0 GJ/m^2 for Australia (Brick-veneer construction) as reported by Pullen (1995). This indication that rural dwellings may not be too different from typical housing in other parts of the world, brings home the challenge faced in getting out the message that buildings may have similar carbon footprints if using similar materials. It should be noted that transportation was not factored into this initial calculation, but will be with further investigation.

Table 2: Embodied energy for the manufacturing of key building materials for typical rural four roomed house

Item	*Material*	*Unit*	*Quantity*	*Density (kg/m^3)*	*Embodied Energy (MJ/kg)*	*Reference*	*Total Embodied Energy (MJ)*
1	Cement	m^3	13.933	1,500	5.85	Venkatarama & Jagadish (2003)	122,262
2	Aggregate	m^3	7.100	1670	0		0
3	Fired clay bricks	m^3	14.920	2,000	4.25	Venkatarama & Jagadish (2003)	126,820
4	Sand	m^3	21.800	1500	0		0
5	Steel sheet	m^3	0.200	900	42.00	Venkatarama & Jagadish (2003)	7,560
6	Steel	m^3	0.002	7,850	42.00	Venkatarama & Jagadish (2003)	659
7	Timber	m^3	0.795	500	10.00	ICE V2.1	3,975
8	Glass	m^3	0.004	2,500	15.00	ICE V2.1	150
9	Ceramics	m^3	0.315	2,780	12.00	ICE V2.1	10,508

To further explore the specificity of embodied energy in the context of Uganda, the study looked at the largest component of building construction, fired clay bricks, seeking to determine the embodied energy of this key element in the local context. This began with reviewing the various stages of the brick manufacturing process, which could be broken down into four stages, as presented in Table 3, and taking account of the associated materials used for these stages, as well as the labour inputs for each. On average, a single brick maker creates 250 – 300 bricks per day. Thus, taking a medium size kiln of 12,000 bricks, this suggests approximately 200 person hours to make the bricks, or close to two weeks with four people, going through over 16 cubic metres of clay. The bricks are left to dry in the sun for 5 to 7 days, placed directly on the ground, or on dried grass, before being dry stacked for a further two weeks in order to reduce their moisture content before they are placed on the kiln for firing. An outer layer of clay is added to outer layer of the kiln in order to reduce conductive heat loss (Table 3).

Table 3: Stages of Brick Manufacture

Item	Stage	Required Material (Kg)	Labour (Person Hours)
1	Forming	16 cu.m. clay	192
2	Drying	0	0
3	Kiln Stacking	0.5 cu.m. clay	12
4	Firing	5 tons wood	24

The firing process generally starts in the evening, with a two people working to keep the fire blazing through the night, and for 24 to 48 hours. After the firing process, the kilns are left to cool, and disassembled when a buyer is found. In most cases, kilns are generally fired as and when bricks are needed (fired to order), rather than as a speculative endeavour. The high temperature near the source of the fire contributes to a substantial proportion of bricks being lost as they are fused together due to the heat, while a number of bricks close to the surface are not fired completely, remaining brittle. In all, brick makers reported manufacturing losses of between 12% and 20% at the firing stage. Taking these losses into account, the average amount of energy used to for the brick kilns was found to be 77GJ, for a typical 12,000 brick kiln (equivalent to about 26 cubic metres), yielding 10,000 useable bricks. This gives an embodied energy value of approximately 3.0GJ per cubic metre (exclusive of labour or transport of wood for firing the brocks). This compares with 2.1GJ per cubic metre as was found by Venkatarama Reddy, and Jagadish (2003) in India. Taking into account manufacturing losses, this translates to 3.5GJ per cubic metre, representing the embodied energy of the bricks at the point of manufacture. This represents an embodied energy value of 2.5MJ/kg, given an average brick weight of 3.1kg, and at the lower end of range provided by Menzies et al. (2007). It is also in line with values provided by Hammond and Jones (2008), who give a value of 3.0MJ/kg, but higher than what was reported by Mithra et al. (2015), who give it at 0.8MJ/kg.

It is acknowledged that variations do exist in the embodied energy calculations, as such the quest to derive data in the local context is significantly important. Given the low tech processing employed across the low-income building sector, it is clear that labour would form a significant portion of inputs into the manufacturing process, however, seeking to quantify this in terms of embodied energy has not been carried out as part of the current study, a consequence of there being many unknowns in this area. A further area of interest is transportation, which for many rural housing projects varies widely, depending on the location of the site, and the method by which materials are procured. As was indicated earlier in this paper, most materials are purchased within the immediate surroundings of the site – within a 10km radius. This reduces the amount of energy expended on transportation, but nevertheless, it is still an energy component that must be taken into account. Unlike cement, which can be purchased by the bag, and transported to site using bicycles, motorcycle taxies or wheelbarrows, this is not the case for aggregate, sand and bricks, which have to be transported to site in larger batches, generally using small pick-up trucks load capacity (2-3 tons), with five to six loads required for the standard building. Embodied energy for the bricks alone is estimated at 326MJ, compared with a total transport related embodied energy of 5.3GJ, much of which was tied to the transportation of cement.

Table 4: Transport related Embodied Energy

Item	Stage	Weight (Tonnes)	Transport Embodied Energy (MJ)
1	Cement	13.9	4,761
2	Aggregate	7.1	155
3	Fired clay bricks	14.9	326
4	Sand	21.8	477
5	Steel	0.2	23

Transportation adds an additional 5.7GJ, or 0.05GJ/m^2 to the cost of the building, taking the total embodied energy for the typical rural house to 300GJ, or 5.46GJ/m^2. For the fired clay bricks, embodied energy increases to 2.55MJ/kg (Table 4).

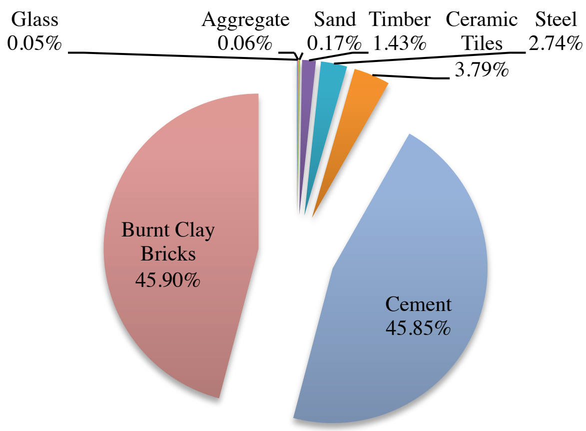

Figure 6: Embodied Energy of building components

Using published data, Cement and Burt Clay Bricks emerge as the two largest contributors to embodied energy in typical rural residential buildings across Uganda (Fig. 6). The high value of cement is linked to increased use of concrete in buildings, while the value for bricks is linked to the artisan processes used for their production, which are energy intensive, and making use of primary energy, which is inefficient. The investigation of embodied energy of clay bricks in the context, revealed this as being marginally lower than was found in the literature. As the study is on going, it is unclear how this will affect the total embodied energy of the building.

CONCLUSION

This study provided a benchmark from which further studies of embodied energy in Uganda can be investigated and refined. A key challenge of course is the lack of available and reliable data, and where available, is largely out-of-date, incomplete and in some cases lacking in credibility. Making use of international databases, it is evident that the embodied energy of the low cost buildings is comparable with that found internationally, and largely as a consequence of the use of a similar pallet of materials. Nevertheless, it is essential that more work be undertaken to determine the embodied energy of locally manufactured materials, in both the formal and informal sectors. The on-going investigation of fired clay bricks, which are largely an informal activity was an important starting point. It is envisioned that working with manufacturers and transporters who largely operate in the informal sector, it will be possible enrich this study, and provide a better picture of the state of embodied energy in East Africa.

The investigation of the embodied energy of a typical rural building, as well as for specific building component, represent only limited efforts to appreciate sustainability in building materials in Uganda. The study is significant in light of the potential growth in demand for housing across the country, with a housing shortage of at least half a million housing units over the next 40 years. Given the major role of the construction industry in the future of energy consumption across sub-Saharan Africa, it is critical that a better appreciation of the contribution this can have to global energy requirements, and to Green House Gas emissions. Consequently, while embodied energy has been investigated in this paper, this represents an initial staring point, with the ultimate goal is to investigate embodied energy and embodied carbon of different materials across East Africa, enabling more detailed comparative analysis.

ACKNOWLEDGEMENTS

This study was undertaken with support from the project: Energy and Low Income Tropical Housing (ELITH), funded by EPSRC/DFID/DECC as part of the energy and international development programme.

REFERENCES

Carnegie Mellon University Green Design Institute. (2008). *Economic Input-Output Life Cycle Assessment (EIO-LCA), US 1997 Industry Benchmark model* [Online], Available from:< http://www.eiolca.net> Accessed 29 February 2016.

Circular Ecology Ltd. (2015). *Embodied energy and carbon - The ICE database*. [online] Available from: <http://www.circularecology.com/embodied-energy-and-carbon-footprint-database.html> Accessed 29 February 2016.

Cole, R.J. (1994). Embodied Energy and Residential Building Construction, *Proceedings: Innovative Housing: a world conference on advanced housing for energy-efficiency and environmental responsibility*, Volume 1: Technology Innovations, Vancouver, B.C. June 21-5, p. 49-59.

Dixit, M.K., Fernández-Solís, J.L., Lavy, S. and Culp, C.H. (2010). Identification of parameters for embodied energy measurement: A literature review. *Energy and Buildings*, 42(8), p. 1238-1247.

Drazu, C., Olweny, M.R.O. and Kazoora, G. (2015). Household energy use in Uganda: Existing sources, consumption, and future challenges, Crawford, R.H. and Stephan, A. (eds.), *Living and Learning: Research for a Better Built Environment: 49th International Conference of the Architectural Science Association*, Melbourne, The Architectural Science Association (ANZAScA), p. 352–361.

Fay, R., Treloar, G. and Iyer-Raniga, U. (2000). Life-cycle energy analysis of buildings: a case study. *Building Research & Information*, 28(1), p. 31-41.

Hammond, G.P. and Jones, C.I. (2008). Embodied energy and carbon in construction materials. *Proceedings of the Institution of Civil Engineers - Energy,* 161**,** p. 87-98.

Hashemi, H. and Cruickshank, H. (2015) Embodied Energy of Fired Bricks: The Case of Uganda and Tanzania. Paper presented at the *14th International Conference on Sustainable Energy Technologies*, SET 2015, Nottingham, 25-27 August.

International Standards Organisation (ISO). (1997). ISO 1404: Environmental management, life cycle assessment - Principles and framework. Geneva: International Standards Organisation.

Irurah, D.K. (1997). *An embodied-energy algorithm for energy conservation in building construction as applied to South Africa*, Ph.D. University of Pretoria.

Menzies, G.F., Turan, S. and Banfill, P.F.G. (2007). Life-cycle assessment and embodied energy: a review, *Proceedings of the Institution of Civil Engineers - Construction Materials*, 160. p. 135-143.

Mithra, P., Kuriakose, L.T. and Unnithan, A. (2015). Embodied energy assessment for building materials, International Journal of Research in Engineering and Technology, 4(3), p. 27-28.

Mpakati-Gama, E.C., Wamuziri, S. and Sloan, B. (2011). Applicability of inventory methods for embodied energy assessment of buildings in sub-Saharan Africa. *The Built & Human Environment Review*, 4(2), p. 41-55.

Okello, P.A. (2010). *Studying key attributes of the common clay brick from selected locations in Uganda*, Master of Architecture. Uganda Martyrs University.

Pullen, S. (1995). *Embodied Energy of Building Materials in Houses*. Masters Thesis, University of Adelaide, Adelaide.

Reddy, V.B.V. (2004) Sustainable building technologies, Current Science, 87(7), p. 899-907.

Senfuka, C., Kirabira, J.B. and Byaruhanga, J.K. (2011). Options for improvement of the Ugandan iron and steel industry. Mwakali, J.A. and Alimaitwe, H.M. (eds.) *Advances in Engineering and Technology, Proceedings of the second international conference*, Entebbe, Makerere University, p. 228-243.

Smith, A. (2004). *Sourcing timber in Uganda: King of the jungle*. [Online], <http://www.building.co.uk/sourcing-timber-in-uganda-king-of-the-jungle/3033493.article> Accessed 29 February 2016.

Sturgis, S. and Roberts, G. (2010). Redefining Zero: Carbon profiling as a solution to whole life carbon emission measurement in buildings. RICS, London.

Treloar, G.J. (1998). A comprehensive embodied energy analysis framework. *PhD Thesis*. Deakin University.

UN-Habitat (n.d.). Promoting Energy Efficiency in Buildings in East Africa. [Online], Available from: <http://eebea.org> Accessed 29 February 2016.

UN-Habitat. (2010). Uganda urban housing sector profile. Nairobi: UN-Habitat

Venkatarama Reddy, B.V. and Jagadish, K.S. (2003). Embodied energy of common alternative building materials and technologies. *Energy and Buildings*, 35(2), p. 129-137.