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Embodied Energy of the Common Wood Fired Brick

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Abstract: With calls for environmentally conscious building design and construction on the increase across East Africa, the need to better appreciate the environmental credentials of commonly used materials has become a priority.Lack of in-depth studies of Embodied Energy (EE) and Green House Gas (GHG) emissions related to the construction industry can be attributed to a variety of factors, most notably, the ad hoc nature of the industry in the region. Of interest for this study is the EE of the most commonly used material for domestic construction, the wood fired brick.Manufactured close to sources of heavy clays or laterite soils, these bricks are fired on site in traditional scove kilns, making use of wood fuel to bake the bricks.Regarded as a cheap material and used in virtually all construction, little is known of their structural integrity, embodied energy values or the emissions stemming from the manufacturing process.Through an investigation of a selection of kilns in the central region of Uganda, the manufacturing process of the bricks was tracked and documented, making use of the inputs-outputs method to determine the EE of the final brick product. The findings of this study suggest relatively high Embodied Energy value for these bricks with a value of 4.26MJ/kg.While burning wood in this case could be considered carbon neutral, the broader impact from Green House Gas emissions as a result of this method of brick manufacture still needs to be explored.This also raises concerns for the potential growth in materials to support the growing demand for housing over the next few decades.

Keywords: East Africa; embodied energy; scove kilns; wood fired brick

1. Introduction

The analysis of embodied energy in buildings has been investigated in different parts of the world over the past three decades, acknowledging that use of low energy inputs in building construction is a key strategy in energy efficiency (Irurah and Holm, 1999). Embodied energy has been revealed as a major element in life-cycle energy demand, with literature suggesting that energy associated with building construction may constitute a significant proportion of life time energy, and in some cases, may be greater than use energy, where energy use for space heating and cooling is negligible (Hashemi *et al*., 2015). Little is known of how life-cycle energy is proportioned in the context of buildings across sub-Saharan Africa (Mpakati-Gama *et al*., 2011), more so as much of the material used comes from informal artisans, as is the case across Uganda. While progress has been made to gain an appreciation of operational or use energy, largely related to the shortfall between energy generation and exiting demand (See Drazu *et al.*, 2015 andKazoora, *et al.*, 2015), only limited efforts have been made to investigate embodied energy and its contribution to the energy footprint of buildings, with a few studies in South Africa, such as Irurah (1997) and in Ghana (Eshun *et al*., 2010). Consequently, more needs to be done to ascertain the embodied energy of buildings across the continent, in a push to lower energy consumption in the construction industry, where substantial growth in demand for housing is expected, to accommodate rapidly growing populationsacross the region.

In Uganda, wood fired bricks are the dominant material for new domestic construction, despite only being introduced to the region early in the twentieth century by Christian missionaries seeking to build in the style of their home countries. Lacking building stone, they, found a solution in the firing of bricks; with early kilns built to provide bricks for the construction of the grand cathedrals that grace the skyline of Kampala; St Paul's Cathedral, Namirembe (1919) and St. Mary's Cathedral, Lubaga (1925).While these buildings have weathered the decades, the quality and value provided by wood fired bricks has recently been brought into question, more so bricks produced in the numerous informal scove kilns that have cropped up over the years to meet the growing demand for housing.The quality of these bricks have only recently come to light, with a study of the structural properties of these bricks revealing they were largely sub-standard (Okello, 2010), confirming anecdotal evidence that already showed this to be the case, thus increased use of concrete frame construction for even simple building projects.Regardless, the availability and low monetary cost of these bricks have made them a dominant feature in the landscape (literally), but with increasing interest in environmentally conscious design and construction, attention to their environmental credentials have been thrust into the spot light in the context of life cycle energy assessment.A key task of the project Energy and Low Income Tropical Housing (ELITH) was to investigate embodied energy for building materials in sub-Saharan Africa, where only limited information is available, hampering investigations into life cycle energy related to construction, more so with much of the material and labour linked to the informal economy.This investigation would be a small step to map out embodied energy values for different materials across the region.

Studies by Hashemi *et al.*(2015) and Niwamara *et al.*(2016)had been directed at ascertaining the embodied energy of the whole building, and made extensive use of The ICE Database (Circular Ecology Ltd.: 2017).While attemptshad been made to quantify embodied energy of wood fired bricks, this had excluded some aspects such as transport and labour. The current study seeks to rectify this shortfall, through a detailed monitoring process, undertaken in conjunction with the artisanswho worked the kilns. This paper presents the initial findings of the study, which assessed embodied energy of wood fired bricks, looking at the manufacturing process of scove fired bricks within Mpigi District in Central Uganda, based around the township of Nkozi, situated 84km southwest of Uganda's capital Kampala.

2. Embodied Energy and Wood Fired Bricks

Life cycle assessment is a key part of energy related research, seeking to evaluate the total environmental impact of a building across its life.This process takes in the four key stages of a building: Material production; Construction; Occupation and Use, and End of Life.Embodied energy taken as "… the quantity of energy required to process, and supply to the construction site, the material under consideration" (Hammond and Jones, 2008).It includes three components: Extraction and raw material supply, processing, and transportation. The importance of Embodied Energy studies in the context of East Africa, lies in the fact that virtually no energy is expended on heating or cooling of buildings, making the contribution of embodied energy in the construction and maintenance of buildings proportionally larger in terms of energy expenditure. While there has been a move globally toward more centralised methods for manufacturing building materials, this is not the case for sub-Saharan Africa, where material production; from concrete aggregate, to scaffolding and brick and block production is still part of the informal sector and highly labour intensive.Significant work on brick kilns has been undertaken in India over the years, tackling elements such as kiln performance, brick properties, emissions and embodied energy, including: Mishra and Usmani (2013) and Weyant *et al.* (2014). In contrast no studies of environmental performance of materials have been conducted in sub-Saharan Africa apart from a few general studies in South Africa, such as Irurah and Holm (1999) and Mpakati-Gama *et al.* (2011). Gathering data for embodied energy analysis is difficult and time consumingat the best of times, with many companies not having this information readily available, while some claim it is confidential(Hammond and Jones, 2008).This is more challenging in the context of East Africa, where there is little interest in research and organisations are reluctant to share information, fearing it would end up in the hands of competitors or used against them. A bigger concern is thatbrick producers in the informal sector may not keep accurate records of their activities.

Scove kilns are a common method of firing bricks across the globe, and still dominate brick production across sub-Saharan Africa and some parts of Asia.This method of brick production is responsible for a substantial proportion of bricks used in Uganda.Compared to traditional methods of building construction that made use of wattle and daub, grass thatch, or other materials, bricks are generally considered durable and this a big step in upward mobility. A downside of this form of brick manufacture has been its contribution to deforestation, desertification, air pollution and soil erosion (Deboucha and Hashim, 2011), with wood fuel for brick making accounting for more than 50% of commercial firewood use (Tabutia*et al.*, 2003). More recently, there has been increased attention to the embodied energy of these bricks, as the firing process makes use of firewood as the main, if not only source of fuel to fire the bricks, adding to an ever increasing demand on the dwindling reserves of old growth forests, due to the preference for denser wood which burns longer and hotter (Tabutia *et al.*, 2003). The size of kilns in Uganda, are relatively small, ranging in size from 2,000to 20,000 bricks, compared to some of the larger scove kilns in South Africa, that accommodate well over seven million bricks.This method of firing bricks is known to be inefficient, with significant energy lost through the outer surface of the kilns, not to mention their contribution to air pollution and other severe negative environmental effects (Akinshipe and Kornelius, 2015). In much of sub-Saharan Africa, the brick making industry is largely uncontrolled and unregulated, with kilns found virtually anywhere there is the raw material, and labour to make the bricks.A challenge in this production environment, which largely congregate close to centre of construction – i.e. urban centres, is that the lack of pollution controls means these kilns contribute immensely to pollution and particulate in the urban environment (Weyant *et al.*, 2014).

Across Uganda, the abundance of laterite soils and heavy clays mean that these kilns are found everywhere, largely close to the road for easy access for trucks to deliver the firing material, and to carry out the finished product. Scove kilns in the central region of Uganda are largely an informal enterprise carried out by landowners, or young entrepreneurial men making the most of the building boom in the country.The bricks which are all hand made, using wooden moulds, and do not benefit from any quality control or consistency criteria; varying considerably in size, shape and density. The kilns generally incorporate the firing chamber at the bottom, with one two or three chambers depending on the size of the kiln.Crucially, no allowance is made for heat transfer through the kiln, save for conduction, with bricks stacked adjacent to each other.The external surface of the kiln is plastered with a mud slurry, presumably to prevent external lateral heat loss.

3. Assessment Methodology

The study makes use of Life Cycle Assessment (LCA), defined by Menzies *et al.*(2007), 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. In this study, the focus was on the former stages: extraction, processing and manufacture of the bricks. Lack of available data would make the use of an Input-Output approach difficult, giving added weight to the use of Process Analysis to determine embodied energy values. Manufactures in this case are largely informal sector artisans, thus process analysis which accounts for both direct and indirect energy inputs was deemed most appropriate, and able to generate information to aid comparison with other materials in terms of energy per unit; in this case per kilogram (MJ/Kg), and per unit (MJ/Unit).This approach is regarded as the simplest, and most accurate when dealing with a single material, and based on primary data (Mpakati-Gama *et al.*, 2011).This approach in itself is labour intensive, requiring significant commitment of time to track and document activities, which could only be achieved through mutual trust with the artisans, many of whom were working sites illegally, and therefore were suspicious of any outsiders asking questions.Assured of our intentions, activities could be monitored unimpeded, providing the first assessment of the embodied energy of fired clay bricks in the region. Each stage of the process was meticulously documented, tracking the process of brick manufacture through primary documentation, investigating the source of the raw materials, time taken to mould the bricks, source of wood fuel for the firing process, and the quality of the final product. A key factor was the need to engage the artisansin the local language as a means of building trust, and ensuring they were comfortable in discussing the nature of their activities.Gaining trust was critical in ensuring the validity of collected data. Reviewing the brick manufacturing process, we can break these down into six stages, as presented in Table 1 below for a kiln of about 13,000 bricks.

Table 2: Stages of Brick Manufacture

Stage	Required Material
Forming	26 cubic metres of Clay
Sun Drying	100 kilogrammes Elephant Grass
Stacking for Air Drying	20 kilogrammes Elephant Grass
Sourcing of Firewood	35 Litres of Diesel
Scove Kiln Assembly	0.5 Cubic Metres of Clay
Firing	6,100 kilogrammes of Wood

Data was collected from three sites and seven kilns in the area, monitoring brick manufacturing from small producers, with scove kiln sizes ranging from 7,000 to 20,000 bricks.Brick manufacturing is largely undertaken in wetlands, close to the source of the raw material, as virtually all the work is undertaken using human labour.Bricks are hand made, and sun dried before being stacked on a scove kiln to be fired, making use of wood off-cuts for fuel. Finished products are transported direct from the kilns to site by the buyer, and thus are not included in manufacturing embodied energy calculations.

4. Production Process

The following subsections describe the manufacturing process, and provide an evaluation of the associated embodied energy for each step of production. In this case labour is treated separately to make it easier to calculate. The assessment is made based on an average size scove kiln of 13,400 bricks, arrived at after a study of seven different kilns in the area.

4.1. BrickMaking

The process starts by identifying a good location with available raw materials; preferably clay based soils (found around wetlands) or in some cases heavy laterite soils, common across the region, andlocally known as Murrum; use of the latter brings brick manufacturers into competition with farmers. Three types of clays (*alumino-silicates*) were identified within the study area: Grey clays; Yellow clays, and; Red clays (Laterite soils with high iron content). The colour variations depended on the location, and affected the pH levels of the soils (Mukasa-Tebandeke*et al.*, 2015). For the current study, bricks made from Grey clays are the focus of this investigation. The location for brick production was always close to the source of materials, eliminating the need to transport raw materials, understandable as virtually all work is by hand.Material is excavated or dug out using a hoe, and mixed both by hand, and using hoes; water is added to the laterite soils to make them malleable. Each brick maker works with a single wooden mould, and is able to make approximately 250 - 300 bricks per day, working seven hours per day. The moulded bricks, which are fairly moist, are tipped out onto grass covered ground to dry in the sun, and left to dry for one or two weeks, depending on the season. Bricks are then stacking for further are assisted curing for another two to four weeks. Curing times were largely determined by experience, and not on any measurable moisture content value.The length of time taken depended on weather conditions (largely related to the rains), which can greatly prolong the drying process(Figures 1 and 2). Thus, for a kiln of approximately 13,400 bricks, approximately 630 hours would be needed just to make the bricks, going through over 26 cubic metres of clay.In terms of embodied energy, there is no direct contribution from the raw material, with the major energy input from labour, which is discussed separately.

Figure 1: Brick making in a wetland (source: Author)Figure 2: Air drying of bricks (source: Author)

4.2. Transport

While there are no associated transportation inputs as part of the brick making process, with bricks made close to the source of raw materials, and workers walking to work, it becomes critical for the sourcing of fuel to fire the bricks. Wood used generally comes from old growth forests. On average, three trips are required to ferry wood for the kiln, making use of a two tonne truck.Wood came from a number of different sites, ranging from 6km, to 124km, largely depending on the availability of felled wood; on average wood was ferried from 56km from the kilns. Based on data obtained through the project Supporting African Municipalities in Sustainable energy Transitions (SAMSET), vehicle transport energy for western Uganda was calculated to be 1.9MJ/t/km for petrol, or 2.5MJ/t/km for diesel (McCall *et al.*, 2017).Most trucks make use of diesel, and are often overloaded, however for the purpose of this study the standard haulage value of the trucks is used.Based on a need for 6.0 tonnes of fuel wood, and an average 56km, the contribution of transport was calculated tobe 840MJ, adding an additional 0.079MJ per useable brick, or 0.025MJ/kg.

4.3. Firing Process

Unlike kilns in Asia that often make use of waste material such as old tyres, low quality coal, and used-oil, brick manufacturers in Uganda use wood fuel as the only fuel source; largely off-cuts from trees that had been felled for timber. Trees were predominantly hardwood, such as *Milicia excelsa* (Mvule), as brick makers believe they 'burn longer'. *Milicia excelsa* has a density of 0.58g/cm^3 (580kg/m^3), with a measured heating value of 22.8MJ/Kg (Adekiigbe, 2012). Use of Mvule wood is contrary to what has been reported in the literature, which suggests scove kilns are fired with eucalyptus wood, with a density of 0.56g/cm^3 (560kg/m^3) and a heating value of 17.0MJ/Kg(Hashemi and Cruickshank, 2015). While Eucalyptus wood may be in use in Kenya and Tanzania, it is generally not used in Uganda, with a visual inspection of most kilns indicating no evidence of use of eucalyptus wood. Use of Mvule wood however puts brick makers in direct competition with charcoal producers, and those seeking firewood.

Figure 3: Kiln with unfired bricks (source: Authors)Figure 4: Kiln after firing (source: Authors)

Assembly of scove kilns is done by two to three people, who stack the kiln within a day, plastering the outer layer with a clay slurry in order to reduce conductive heat loss (Figures 3 and 4). The average kiln size was about 2.4 x 3.0 metres at the base, with a height of about three metres, and contained about

13,500 bricks. Bricks in the scove kilns investigated were stacked close together, with the heat source at the bottom of the kiln, making conductive heat transfer the only real means of heating the bricks. The firing process generally started in the evenings, with two people working to keep the fire blazing for 20 to 24 hours, depending on weather conditions and the nature of the clays used to make the bricks. Artisans reporting that bricks derived from grey clays require the most fuel wood, and red clay soils the least. Kilns are left to cool after the firing process, and disassembled when a buyer is found, with most kilns generally fired as and when bricks are needed (fired to order), and not as a speculative endeavour.

The amount of wood required to fire one tonne of bricks was found to be about 0.25m^3, which gives an energy input of about 3,3MJ per tonne of bricks.Given an average brick weight of 3.1kg, on average 139GJ of energy are used to fire a scove kiln of 13,400 bricks (about 26 cubic metres), or 10.4MJ/Brick, or 3.37MJ/kg, before factoring brick losses. Brick makers reported manufacturing losses of about 20% of fired bricks; the high temperature near the source of the fire contributing to a substantial proportion of bricks fusing together, while bricks near the outer surfaces are not fired completely,remaining brittle and of dubious strength (Okello,2010). Taking a 20% loss, a brick kiln of 13,400 bricks will yield about 10,700 useable bricks; this revised figure giving embodied energy values per useable brick as 13.1MJ/Brick, or 4.21MJ/kg.

4.4. Labour

Energy inputs from labour, or eco-energetics, has been a controversial area in embodied energy studies, as it is often unclear how to relate human energy to manufacturing processes, more so in the context of industrialised societies where labour forms a minor component of production (Mpakati-Gama *et al.*, 2011). For sub-Saharan Africa, where human inputs form a substantial component of the construction process, as is the case for burnt bricks production, where no mechanical equipment is used, labour forms a major energy component,along with the sourcing of wood and the firing process;thus, marginalising human energy inputs would significantly skew the data. Calculating the value of energy from labour is based on the calorific value of food consumed, as derived from the FAO (2010), which estimates that the calorific value of food consumed each day by an average adult in Uganda to be 2020kcal., or 8,448kJ. For this project, the full value of energy was used, which we acknowledge does not take into account Net Metabolised Energy, or Basal metabolism, nevertheless, it does provide a good indication of the energy expended by workers, given this is their full time activity, and the values are calculated based on the combined work hours, rather than for individual workers. The workers generally worked full time, and thus all their energy went into the brick manufacturing, and engaged at all stages of the low-tech process, including; sourcing of the wood (loading onto the truck), digging up the clays, making of the bricks, stacking of the bricks for drying, building the scove kilns, and feeding the furnace. For this study, felling of trees is excluded, as this activity could be attributed to the timber industry, more so as the wood used were a by-product. Work hours for each of the respective stages are presented in Table 2 below. In total, for an average brick kiln of 13,400 bricks, a total of 645 hours of labour goes into the production process. Based on these labour inputs, an energy input of 778.42GJ of energy was expended for the manufacturing process, translating to an additional embodied energy value of approximately 0.073MJ per useable brick or 0.023MJ/kg.

Table 2: Labour Requirements for Stages of Brick Manufacture

Stage	Labour (Person Hours)
Forming	629.0
Sun Drying	0.0
Air Drying	14.0
Sourcing of Firewood	6.5
Scove Kiln Assembly	39.0
Firing	16.0

5. Discussion

Taking the various components of the process and putting them together forms a composite picture of the embodied energy for scove-fired bricks, up to the completion of the firing process. The study found that the total embodied energy for the bricks was 13.25MJ/brick (per useable brick), or 4.26MJ/kg (See Table 3 below).

Table 3: Embodied Energy per Component

Stage	MJ/Brick	MJ/kg
Transportation	0.079	0.025
Firing Process	13.1	4.21
Labour Process	0.073	0.023
Total	13.252	4.258

Menzies *et al.*(2007) provided a range for clay products, from 0MJ/kg to 30MJ/kg, a range that reflects the range of clay products available, and the different levels of processing put into the different products. Hammond and Jones (2008) give a value of 3.0MJ/kg for bricks, likely made through industrial processes. More specific for burnt clay bricks, Esteban and Buccellato (2012)give an embodied energy value of 4.25MJ/brick (Although this seems an error, and should be per kg); they however do not provide the basis for this value, nor do they give the weight or densityor source of the bricks in question. Hashemi and Cruickshank (2015) give a value of 4.76MJ/kg, slightly above that cited by Esteban and Buccellato, largely based on the firing process. A study by Mishra and Usmani (2013) suggests that the embodied energy of Burnt Clay bricks to be about 5.0MJ/brick with average size 100mm x 50mm x 50mm, typically used in India, while Mithra *et al.*(2015), give a value of 0.8MJ/kg, which is at the lower end of the values, although as with Esteban and Buccellato (2012), they do not specify what product was investigated, or how they were manufactured. By comparison, the embodied energy of fired clay bricks as presented in the current study, through Process Analysis could be seen to provide a fairly accurate picture of the embodied energy of wood fired scove kiln bricks. The established figure of 4.26MJ/kg is close to what Mishra and Usmani (2013)and Hashemi and Cruickshank (2015) suggested as the embodied energy value. The difference largely relates to the fuel used to fire the bricks, given that the firing process accounts for over 99% of the embodied energy of wood fired scove kiln bricks. Incorporation of energy from labour is certainly not mainstream (Dixit, 2017), thus incorporating this element into the current study, while useful still needs to be further refined, and build a case for comparison with different processes in the industry. Clay fired bricks thus emerge as having an embodied energy value substantially higher that that of the benchmark of 3.0MJ/kg, making them a significant contributor to energy use in the building construction industry in Uganda, albeit an unseen cost, which makes it that much more difficult to effect change in an industry which is largely unregulated, and where designers rarely specify the type of material to be used for construction.

6. Conclusion

The findings of this study are part of a process to unpack the embodied energy values of construction materials available in Uganda. It is however the case that such energy analysis is not embedded in the design and construction practices of the industry, where capital cost is still the basis for decisions. Transmitting such information to manufacturers, builders and designers becomes a key challenge, more so as there currently are no rules and regulations that are directed at materials used in the building construction industry, beyond basic strength and integrity. Nevertheless, seeking to quantify the environmental impact of various materialsmay provide the impetus for the change, and a catalyst for responsible materials management as the most viable means of reducing environmental impact of existing practices. There is a need to widen the study, looking at different regions, and clay types in order to build a more accurate picture of the embodied energy of wood fired brick produced in scove kilns. An added interest would be to assess emissions from the scove kilns, given anecdotal evidence that suggests they are also a large contributor to airborne pollution, in addition to the other environmental impacts already associated with this method of brick production. By placing a value on activities related to the manufacture of these products, it may be possible to influence the process, leading to more efficient firing practices.

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