Embodied Energy of Fired Bricks:
The Case of Uganda and Tanzania

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Abstract: This paper evaluates the embodied energy of fired/burned bricks as one of the major construction materials in East African countries. Production processes of bricks by artisans, and small- and medium-scale manufacturers are explained. Embodied energy of brick walls is also calculated and the key factors in the energy efficiency of brick kilns are discussed in detail. Low quality, high material waste and excessive energy waste during production and handling are highlighted as the major issues associate with traditional manufacturing processes of burned bricks in Uganda and Tanzania. The results reveal that small clamp kilns lose up to 3.5 times more energy through their cooling surfaces compared to large kilns. The results also indicate that clamp fired bricks are up to 60% more energy intensive than generic bricks and the embodied energy of artisan brick walls is 35% more than standard brick walls with comparable thicknesses. Improving kiln construction and production methods, educating artisan producers, replanting tress, providing alternative renewable energy sources, and design improvements to control fire intensity and air circulation in brick kilns are some of the recommendations to improve the energy efficiency and mitigate the environmental impacts of fired bricks in East African countries.

Keywords: Embodied Energy, Life Cycle Assessment, Fired Brick, Burned Brick, East Africa, Uganda, Tanzania.

1. INTRODUCTION

Traditional construction methods and materials have historically been a sustainable response to housing demands in developing countries. The production methods of locally manufactured materials in Uganda and Tanzania have more or less remained unchanged during the last few decades. Brick walling is a major construction method in both rural and urban areas of East African countries including Uganda (UBOS, 2010). Fired/burned brick, however has negatively affected the local environment contributing to issues such as deforestation, desertification, air pollution, excessive soil extraction and fuel crisis (Perez, 2009; CRAterre, 2005; World Bank, 1989). This is mainly due to the excessive energy and material waste and inefficient production processes of burned bricks which are mainly delivered by artisan producers (World Bank, 1989). Increased use of energy intensive materials such as concrete and burned bricks has raised concerns over the long-term environmental impacts of such trends in East Africa. The forestry cover in Uganda, for example, has reduced by 25% from 45% coverage in 1990 to around 20% in 2005. This means an annual deforestation rate of 1.7% which is increasing year by year. Considering the current situation, Uganda's forests could be vanished during the next few decades (ILO, 2010).

Environmental impacts of buildings and products are evaluated using Life Cycle Assessment (LCA) method (Figure 1). The total carbon footprint of buildings consists of the embodied carbon of building products plus the operational carbon which is the energy consumption during building lifetime. The majority of the embodied carbon of building products is linked to CO_2 emissions from fossil fuels during extraction and manufacturing processes of construction materials (Anderson & Thornback, 2012). The embodied carbon of building fabrics is becoming more important due to increasing energy efficiency requirements which reduce the operational carbon of buildings during their lifetime.

Figure 1: Building Life Cycle

Yet, considering the negligible operational energy for space heating and cooling in East African low-income housing, the embodied energy of construction materials is the main factor in evaluating the environmental impacts of the low-income housing sector. The embodied energy of construction materials such as burned brick in contrast is a major concern. Improving energy efficiency and reducing material wastes during production processes could therefore reduce the overall greenhouse gas emission rates and mitigate the environmental impacts of the construction industry. To this end, this study intends to evaluate the production processes of fired/burned bricks produced by artisan, small- and medium-scale manufacturers in order to identify the key areas for improvement.

2. METHODOLOGY

Literature review, and primary data gathered from site visits and photographic surveys in two East African countries (Uganda and Tanzania) are the main methods of data collection for this paper. Available literature is reviewed to assess the actual fuelwood consumption and brick sizes as well as production rates by artisans and small- and medium-scale manufacturers in Uganda. Energy consumption and potential saving rates during production processes are then calculated using the outcomes of the literature review. The embodied energy rates of burned bricks and brick walling are also calculated and compared with other generic bricks/ brick walls using the available data in the "Embodied Carbon: The Inventory of Carbon and Energy" developed by the University of Bath (Hammond & Jones, 2011).

3. WALLING METHODS AND MATERIALS

Figure 2 shows the main walling methods and materials during 2009/2010 in Uganda. Brick walling (either adobe or fired) is the most common construction method in Uganda. More than 80% of houses in urban areas have brick walls compared to around 50% in rural areas. Mud and poles walling is also very common particularly in rural areas where more than 40% of homes are built with mud and poles. Overall, around 84% of all houses in Uganda have brick walls compared to around 12% which are built with mud and poles (UBOS, 2010).

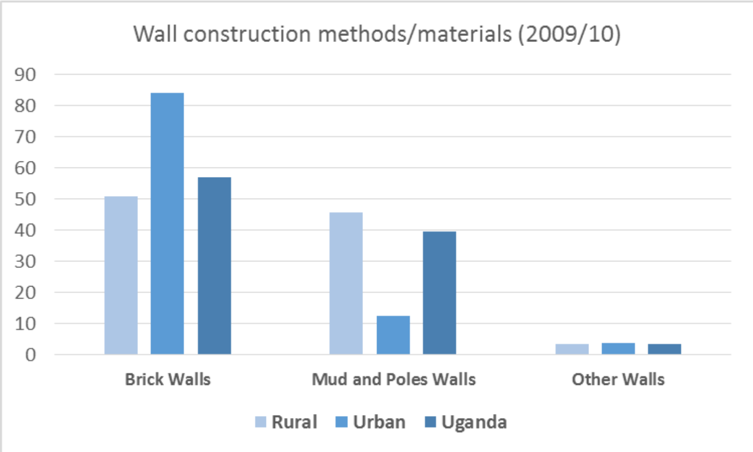

Figure 2: Main walling types during 2009-2010 (%).

Source of table: (UBOS, 2010)

Although burned brick is considered as a durable material, its high embodied energy makes it an environmentally harmful material compared to other prevailing construction materials in East African countries. The very inefficient production methods of kiln fired bricks, which mainly use local wood as their fuel, contribute to issues such as deforestation and air pollution (Perez, 2009; CRAterre, 2005; World Bank, 1989). In fact wood is the main source of energy particularly in rural Uganda. Two major reasons of deforestation in Uganda are cutting trees for firewood, and charcoal, and for creating agricultural land (ILO, 2010). Fuelwood (firewood and charcoal) and agricultural waste account for 93% of energy consumption in Uganda (The Government of the Republic of Uganda, 2001). Around 95% of supplied wood in Uganda is used for energy generation (The Government of the Republic of Uganda, 2001) including in the brick manufacturing industry (Figure 3). Around 91% of the required energy for brick production is from firewood and the rest is from agricultural waste (World Bank, 1989).

Figure 3: Inefficient production processes and use of fuelwood contribute to deforestation, air pollution and fuel crisis (Uganda).

Source: The authors

4. PRODUCTION PROCESSES OF BRICK

Low quality, energy intensive traditional methods of brick production by artisans is a major concern which has negatively affected the local environment in both Uganda and Tanzania. In the traditional production method (Figure 3), unfired moulded bricks are prepared using local clay and water and are then left to dry out before being fired in field kilns for 4-6 days using gradually intensified wood fire (Nyakairu et al., 2002; Batchelder et al., 1985; Practical Action). Energy and material wastes are the two major issues associated with traditional production methods of fired brick. One of the major issues is the lack of control over burning and fuel consumption (Batchelder et al., 1985). Considerable energy is also wasted through hot exhaust gases during production processes (World Bank, 1989).

Larger rectangular kilns and clamps can achieve better fuel efficiency thanks to lower heat losses due to the lower volume to surface ratio. Cubic kilns are assumed to have four cooling faces (on the sides) and the heat losses through the top and ground facing surfaces are considered separately (Practical Action). Table 1 shows the common brick and kiln sizes in Uganda along with the cooling ratios and average wastes of different kilns. The results of calculations reveal that a 1.5x2x2m brick kiln loses 3.5 times more energy through cooling surfaces compared with a 6x6x4.3m kiln due to much higher cooling area/volume ratio. There is also a direct relationship between the kiln sizes and the portion of under fired/ low quality bricks. According to World Bank (1989), around 46% of clamp fired bricks in a 3x3x3.1m kiln have low quality compared to 24% for a 6x6x4.3m clamp kiln. This is while, according to Batchelder et al. (1985), smaller kilns provide a more uniform distribution of fire improving the quality of final products. The latter requires more investigation to evaluate the relationships between kiln sizes and overall waste and quality of bricks.

The average size of field kilns in Uganda is 2.4-3 metres (Batchelder et al., 1985). Despite higher fuel efficiency of larger kilns, the width/length of country kilns should not be more than 4.5-6 metres mainly due to increases in total fuel consumption, labour and costs. The overall process of production from clay moulding to finished product takes around three weeks for 4,000 to 10,000 bricks. It takes an average of 5 weeks for 5 people to excavate, mould and fire up to 9,000 bricks (Emerton et al., 1998). Around 60-75 metres of 4" to 8" dry wood (in addition to woodchip and coffee/rice husks) is required to produce 20,000 bricks (Batchelder et al., 1985) and nearly 80% of the required timber for fuel is provided from locally grown trees (Naughton-Treves et al., 2007).

Table 1: Brick kiln sizes and cooling ratios

Clamp Kiln Size (W x L x H) (m)*	Brick/Block Size (mm)*	Total Surface Area (m^2)	Cooling Surface Area (m^2)	Volume (m^3)	No. of bricks	Mass of Bricks (tonne)	Ratio: Cooling Area/Volume	Relative Cooling Area/Volume energy waste	Low quality/ under fired portion*
1.5x2x2	228x111x76	20	14	6	~2100	~6.6	2.33	348%	-
3x3x3.1	290x140x90	55.2	37.2	27.9	5300	31	1.33	199%	46%
4.5x4.5x4.3	290x140x90	117.9	77.4	87.1	16860	98.6	0.89	133%	31%
6x6x4.3	290x140x90	175.2	103.2	154.8	30840	180.4	0.67	100%	24%

* Source of information: (Batchelder et al., 1985; World Bank, 1989)

Firing the bricks creates a ceramic bond in a specific temperature (900-1200° C) which increases the strength of the brick making it water resistant. Using the right amount of fuel is very important not only for fuel and cost efficiency but also to provide the right temperature for bonding. Low temperature results in poor quality/bonding while high temperature would either slump or melt the bricks. Controlling cold air flow thought the brick kiln is also a key factor to make the kiln more energy efficient. Too much air circulation will cool down the bricks and wastes the energy while too little air flow will stop the fuel from burning properly. Providing dampers and wind breaks to control/protect the fire could greatly improve the fuel efficiency of kilns (Practical Action).

5. BRICK SUPPLIERS

Artisans, small- and medium-scale manufactures are the three major types of suppliers of bricks in Uganda (Table 2). Bricks produced by artisans take a larger share of the market compared to small- and medium-scale manufactured bricks. The handmade bricks and blocks produced by artisans are suitable for single storey buildings. The length of the bricks/blocks may vary between 220-295mm; the width between 100-150mm; and the thickness between 60-130mm. The weight may also vary between 2.5 and 7.6 kg per brick/block. The final sizes/dimensions of produced bricks and blocks in a lot may also vary greatly (World Bank, 1989). This, in fact has been regarded as the major reason for extensive use of mortar (up to 30mm) in the construction of brick walls (Perez, 2009).

Table 2: Brick production scales (World Bank, 1989)

Production scale	No. of bricks (per day)	Production process	Area
Artisans	1,000	Handmade, clamp fired	Rural areas
Small-scale	10,000	Semi-mechanised	Towns
Medium-scale	40,000	Mechanised	Industrialised areas with high demand

Firewood is mainly used by artisans for brick production. The firing period and temperature are kept low to save as much wood as possible. This results in a rather poor quality bricks and blocks with compressive strengths of usually lower than 8 N/mm^2. Moreover the bricks which are within 300 mm from the external surfaces of the field kilns have a very low quality and are not completely waterproof (Figure 4). The portion of the low quality bricks produced using traditional methods varies between 25% and 45% of the entire production (World Bank, 1989).

Figure 4: Bricks within 300mm of the clamp kiln's surfaces have a very low quality (Tanzania).

Source: The authors

Moreover, around 10-17% of materials is wasted during transportation, handling and construction processes on site (Anderson & Thornback, 2012; World Bank, 1989) which has considerable impacts on the construction sites (Figure 5). Material waste is in fact one of the major concerns which has negatively affected the overall performance of the Ugandan construction industry. Improving the brick quality could, to some extent, address the abovementioned issues.

Figure 5: High material waste during production and handeling (Tanzania).

Source: The authors

6. EMBODIED ENERGY OF FIRED BRICKS

Firewood along with coffee/rice husks are the main fuels used to produce burned bricks in Uganda and Tanzania. The effective calorific value of wood is highly dependent on the water content of the wood and therefore seasonality factors are significant. On average, 0.5 m^3 of wood is required to produce a tonne of clamp fired brick (World Bank, 1989). Assuming a density of 0.56 g/cm^3 (Kumar et al., 2011) and a lower heating value of around 17 MJ/kg (Musinguzi et al., 2012) for Eucalyptus wood, as the major fuel for artisan brick production (World Bank, 1989), an average of 4760 MJ is required to produce one tonne of burned brick. According to the Inventory of Carbon and Energy ICEV2.0, the embodied energy value for "General simple backed clay products" and "General Clay Bricks" is 3.0 MJ/Kg (Hammond & Jones, 2011). This means that the energy consumptions by artisans is 1.6 times more than the required energy for the production of generic fired bricks. Table 3 summarises the fuel consumption and embodied energy of artisan bricks.

Table 3: Embodied energy of burned bricks

Product	Required equivalent fuelwood per tonne of product (m^3)	Energy consumption per tonne of product (MJ)	Energy consumption compared to "General Clay Bricks"
General Clay Bricks	Est. 0.315	3000	100%
Artisan/ Clamp Fired Bricks	0.5	4760	159%

The embodied energy values of artisan clamp fired brick walling and general clay brick walling are also calculated in Table 4. According to the information provided by the World Bank (1989), artisan-produced brick and block dimensions could vary greatly from 220 to 295 mm (length), 110 to 150 mm (width), and 65 to 130 mm (height). An average of 20mm, 1:4 cement mortar with an embodied energy of 1.1 MJ/Kg (Hammond & Jones, 2011) are assumed to calculate the embodied energy of artisan brick walling. It should be noted that mortar thicknesses of up to 30mm (Figure 5) is normally considered to compensate for uneven sizes of bricks in Uganda (Perez, 2009). According to the results, the embodied energy of 300 mm and 220 mm artisan brick walls are 1619 and 1067 MJ/m^2, respectively. Assuming the same brick density and mortar thickness of 10 mm for a "General Clay Bricks" with a dimension of 215x102.5x65 mm (UK standard brick dimensions), the embodied energy of a 215 mm solid brick wall would be 791 MJ/m^2 which is around 26% lower than the embodied of energy of a 220 mm artisan brick wall. The per square metre embodied energy of the 300 mm artisan brick wall is around 100% and 50% higher than the embodied energy of 215 mm General Clay Brick and 220 mm artisan brick walls, respectively.

The results also indicate that walls built with smaller bricks (e.g. 220x110x65 mm) have a lower embodied energy compared to walls constructed with larger bricks (e.g. 300x150x130 mm). This is mainly due to the considerably lower embodied energy of cement mortar compared to fired bricks. In other words, increased mortar to brick ratio for smaller bricks reduces the total embodied energy per square metre of walls due to the much higher embodied energy of fired bricks compared to mortar.

Figure 5: Mortar thicknesses of up to 30mm is normal for brick walling (Uganda)

Source: The authors

Table 4: Embodied energy of brick walls

Product	Brick size, (mm)	Wall thickness (mm)	Embodied energy of material (MJ/Kg)	Mass per item/littre (Kg)	Embodied energy of wall per m^2	Embodied energy of (MJ/m^3)	Relative embodied energy of walls per m^2
Artisan Clamp Fired Brick/Block	300x150x130	300	4.76	7.6	1619	5398	205%
	20mm Mortar		1.11	1.65			
	220x110x65	220	4.76	2	1067	4849	135%
	20mm Mortar		1.11	1.65			
General Clay Brick	215x102.5x65	215	3	2	791	3677	100%
	10mm Mortar		1.11	1.65			

7. CONCLUSIONS

This paper discussed the production processes of fired bricks produced by artisans and small- and medium-scale manufactures in Uganda and Tanzania. Low quality of bricks, high material wastes and excessive energy consumption were identified as the major issues associated with traditional manufacturing processes of burned bricks. The results indicate that the embodied energy of artisan clamp fired brick walling per square metre of the wall is 35% more than generic brick walls with comparable thicknesses. The embodied energy of artisan bricks is also around 60% more than the embodied energy of generic bricks. Yet, considering the high wastes and low quality (and therefore lower durability and shorter lifespan of clamp fired bricks) it could be argued that the overall environmental impacts of artisan bricks is much higher than generic bricks.

The results of this paper also reveal that small kilns can lose between 1.33 and 3.48 times more energy through their cooling surfaces compared with large clamp kilns. Up to 46% of the entire production of small kilns is also under fired, low quality bricks which increases the wastes and breakage rate during handling, transportation and construction on site. It should be noted that burned bricks are one of the major consumers of firewood in East African countries contributing to issues such as deforestation, air pollution, excessive soil extraction and other negative environmental impacts. Improving brick quality and reducing material wastes help to mitigate the negative environmental impacts of fired bricks. Improving the production methods and energy efficiency of brick kilns could also reduce the embodied energy of burned bricks. In this respect, following are recommended to mitigate the environmental impacts of bricks:

a) Encourage the use of unfired bricks/ adobe instead of burned bricks;
b) Encourage replanting trees used for fuel;
c) Provide alternative renewable energy sources as a replacement of fuelwood;
d) Educate artisans to use larger rectangular clamp kilns which are more energy efficient;
e) Provide means to control fire intensity and improve air circulation in kilns to reduce energy consumption and achieve higher quality bricks;
f) Improve the design of kilns and develop affordable heat recovery systems for field kilns to reduce heat losses through radiation and hot exhaust gases.

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