Demystifying Fired Clay Brick:
Comparative analysis of different materials for walls, with fired clay brick.

ACHILLES AHIMBISIBWE[1], ALEX NDIBWAMI[2]

Uganda Martyrs University, Kampala, Uganda

ABSTRACT: *Low-income tropical housing in Uganda today is a complex issue that extends beyond the physical dwelling and encapsulates psychological notions, i.e. human ideals, needs, wants, aspirations, and economic ability. Rural construction continues to expend significant quantities of energy and environmental resources in production of fired clay brick, the locally favoured choice. Regrettably, the notion that this material is cheap escalates negligent handling during production, transportation and construction, which then generate large quantities of waste.*

This paper presents a study that seeks to evaluate people's perceptions of the production and usage of fired Clay Bricks, then to propose viable alternatives. People are a crucial entity in the struggle to: improve fuel efficiency at local Kilns, increase reuse/repurposing of construction waste, then raise awareness about material embodied energy and subsequent energy demand on communities. Despite evidence of associated negative impacts of brick production like deforestation, excessive soil extraction, energy intensive production, and high waste, there is still rampant unregulated production. Cost, being a primary consideration for many construction stakeholders, is interrogated as part of this search for a viable alternative. The alternative shall endeavour to minimize production energy and construction waste, and possibly save up to 20% on the building cost. This study culminates in a student lead design-build project. The Display Space at Uganda Martyrs University is a built attempt to investigate alternative wall materials as well as building cost. The Space was designed and shall be built by students of the Faculty of the Built Environment. The building structure is a combination of rammed earth walls and site produced stabilized soil blocks to replace the commonly used brick. Since precedent success stories reveal that a creative force emerges when all the residents, stakeholders and consultants come together as a collaborative community. It is envisaged that a creative force shall emerge from community involvement in this project with the hope of disseminating concerns that shall propel the community residents towards shaping more regenerative environments.

***Keywords**: Fired Clay Brick, embodied energy, Self-build model, regenerative design*

INTRODUCTION

This paper reports on a study that sought to evaluate people's perceptions of the production and usage of fired Clay Bricks in construction in Uganda. The investigation was under a multi-partner research project on Energy and Low income Tropical Housing (ELITH) which was conceived as a concerted effort towards documenting low-income housing in the tropics and identifying possible areas of intervention to overcome the perceived challenges, especially pollution rooted in embodied energy and carbon.

The Energy and Low-Income Tropical Housing Project ELITH is co-funded by the UK Department for International Development (DFID), the Engineering & Physical Science Research Council (EPSRC) and the Department for Energy & Climate Change (DECC), for the benefit of developing countries. Views expressed are not necessarily those of DFID, EPSRC or DECC. Grant number: EPSRC EP/L002604/1.

The objective of the on going project is to reduce energy use and carbon emission in low and medium income households while improving the quality of interior environment and the quality of life for the residents. This specific study sought to respond to common perceptions about the fired bricks, run a comparative analysis for walling materials and then to propose viable alternative materials for wall construction the rural context. The envisaged option considered to replace fired brick wall, is a combination of revised earth technologies, which make use of locally available resources more favourably. This option is rooted in the fact that Earth technologies have been a reliable and consistent walling choice in Africa for centuries. Surprisingly, today Earth has taken a back seat since Cement blocks and fired clay bricks are regarded as symbols of modernity and progress even in the most remote communities (Perez, 2009).

Homeowners and their local artisans in Uganda often seek feasible opportunities to reduce construction cost. However, when unit cost remains the sole consideration, it is noticed that the fired clay brick emerges as the popular wall-material choice. Fired brick, though considered a durable material; is environmentally harmful due to its low quality, very inefficient production processes and over dependence on local wood fuel in brick kilns, which contribute to deforestation and air pollution (Perez, 2009). According to the Second Volume of Inventory of Carbon (partially shown in *appendix 1*), the embodied energy of "General Clay Bricks" in the UK is 3000 MJ/tonne (Hammond, 2011). Here we should consider that kilns in the United Kingdom adhere to strict production regulations and restrictions. However, the average energy consumptions by artisans and small-scale brick producers in third world countries are up to 5 times more than the average energy required for brick production in developed countries. Rural artisans rarely seek sustainable fuel sources like coffee husks or sawdust that have been adapted to fuel larger commercial kilns. Small-scale producers by comparison target naturally occurring indigenous species in the absence of replacement and this disrupts flora and fauna patterns in the environment. Further, artisans keep the firing period and temperature low to save on fuel (which is increasingly harder to come by), this in turn results in low quality bricks up to 45% of the entire production.

Further, any variation is weather like unexpected gusts of wind or rains can severely diminish the output of a local kiln. Despite this low production efficiency, bricks are then recklessly handled during transportation, storage and construction. It is a common occurrence to notice, heaps of unused bricks strewn around building sites long after the construction process as shown in *image 1*.

Image 1: A heap of used bricks abandoned near a plantation.

This negligence is commonplace because the brunt of rural construction is relegated to unskilled homeowners or low-skill level artisans since most rural developers cannot afford more competent contractors.

In spite of their inclination to adhere to traditional construction methods, this study found that if given a cost saving alternative, local artisans and self-build homeowners in Uganda might quickly adopt a new strategy. Particularly one that further reduces labour costs, by accommodating the do-it-yourself strategy that is already prevalent in most rural construction. However, in either case an additional case needs to be made so that all construction stakeholders begin to deal with wastage and ecological footprints. This intervention is timely since according to Uganda Human Settlements Network (2014), materials made from clay are gradually becoming scarce in Uganda due to the limited availability of appropriate clay in the country coupled with high demand associated with an enhanced construction sector. It should be noted that new technologies such as interlocking stabilized soil blocks (ISSB) have not been integrated into the educational curricula of secondary vocational institutions and tertiary engineering and architectural institutions and thus their adoption remains slow. Therefore, integrating these technologies into the educational system is another effective way to ensure their use in the future.

As such, this study shall culminate in the construction of an actual **105 Sq.m**. Display Space. The Display space construction seeks to engage local artisans and students to interrogate prevailing perceptual concerns like cost and durability of earth walling, create new job opportunities through skilled local artisan and empower social entrepreneurs. The finished building shall provide comparative data about the materials thermal performance against predicted estimates from software simulations. Further, the embodied energy and material saving analysis will further assess the merits of this selected walling strategy.

METHODOLOGY

Undergraduate students at the Faculty of the Built Environment of Uganda Martyrs University explored the design of a Display Space that sought to reduce cost, consider alternative low Embodied Energy materials and to reduce construction duration even with a low-skill labour force. Costs and procedure are documented at each stage and these shall provide actual data to compare to other estimates from different local sources. A team of local artisans shall participate in the construction to set off a transfer of skills and knowledge about the Stabilised Soil Technologies and any achievable cost benefits.

Embodied energy is a reliable indicator for efforts to improve energy efficiency of low-income houses in tropical climate. When one considers the nature of low-income tropical housing in Uganda: there is little or no heating or cooling energy load because of the relatively mild climatic conditions; the relative poverty of low-income households implies low prevalence of heating, ventilation and air conditioning systems (HVAC); it is therefore clear that embodied energy of building materials and associated impacts should be a major concern.

The 105m^2 space is intended as a functional student display space for the faculty, however the Form considerations adhere to the commonly favoured row house seen in many rural communities in Uganda. Soil for the rammed earth wall as well as the stabilised soil blocks is for the most part obtained from a pit adjacent to the site. With consultation and assistance from *Hydraform*, a local Interlocking Stabilised Soil Block machine vendor, the 3200 Blocks for this project shall be made in two days. The blocks shall then cure for 10 days. When the blocks are ready the walls shall be erected in two days (from foundation to wall plate). In order to maintain the argument of low-skill level, students from the faculty shall make the blocks alongside a select team of local artisans who have not participated in such a project before. These local artisans shall be living testament to the rest of their community that the project outcomes were achievable.

Also these same artisans might opt to open local businesses to produce these blocks for sale to local projects. The *Hydraform* Company has offered to send a team of trainers to engage the students and selected residents and to ensure the process goes as smoothly as possible. The finished building shall later be simulated using appropriate computer codes for energy performance for more energy analysis during use.

Literature review, and primary data gathered from local artisan brick makers, vocational schools and construction site visits, and photographic surveys are the main methods of data collection for this paper. Relevant documents published by individual researchers, Ugandan Government, UN-Habitat and other research organisations were reviewed. Site visits and photographic surveys were also carried out in five districts (in different regions) in Uganda to collect relevant information on prevailing construction methods and materials and on their environmental impacts in rural areas. The outcomes of the literature review along with the surveys are used to evaluate the current conditions of low-income housing in rural areas. The embodied energy values of walling methods and materials are compared with standard construction methods using the available data in the "Environmental Impacts and Embodied Energy of Construction Methods and Materials on Low-Income Tropical Housing." (Hashemi, Cruickshank & Cheshmehzangi, 2009).

The key factors for improving energy efficiency and reducing the environmental impacts of the low-income housing sector are highlighted and recommendations are provided as the conclusion of this paper.

RESEARCH OBJECTIVES

Objective of the work is to verify that it is possible to build a high quality building at a lower cost than with the prevailing clay brick construction. It is envisaged that adopting Interlocking Stabilised Soil Blocks even while using inexperienced local labour for the construction can achieve this. The construction duration should be considerably shorter with no requirement for special equipment *(except for the block press)* or tools to further the uptake of this strategy.

Theoretical and survey experience:

Excessive energy waste during the production processes of fired burned bricks, with impacts such as deforestation; air pollution and other environmental issues are the major concern, which should be addressed. Owing to the general consensus that it is apparently the cheapest option, the fired clay brick has not left much room for consideration or evaluation of other possible alternatives. We acknowledge people's taste and preference for the fired clay brick; however, suggest that this walling material has become a victim of its own success. Therefore, alternative-walling options that challenge this position would have a significant impact on construction attitudes and practices in general. Preliminary field evidence shows that contractors, even on large-scale projects, generally opt for rural artisan made fired clay bricks instead of the more sustainable factory-manufactured options in a bid to save money. The danger associated with this decision is two fold: on one hand, the inefficient production process continues to strain local wood fuel sources, which contributes to deforestation, air pollution and environmental degradation. According to (NEMA 2002: 122), Uganda is experiencing rapid deforestation as up to 3% of forest cover is lost per year due to unsustainable harvesting.

A look at fuel wood usage reveals that three quarters of households in Uganda use firewood for cooking while one in every five households, 21% use charcoal. Combined, biomass fuels constitute the main fuel for cooking for 96% of households (UBOS 2014). Of major concern is the source of the wood; according to UBOS (2014), 72% of households that used firewood for cooking got it from the Bush/Forest, and 16% got it from own plantations, while 13% bought from the market. The high percentage that that get firewood from the bush/forest has implications on environment protection. Worse still, excessive quantities of mortar as shown in *image 2* are used during brick construction due to rapid construction timelines, inconsistent brick sizes, negligence, and low mason skill levels. As a result, vast quantities of plaster are required to deliver a smooth finish to these uneven walls. Cement wastage in mortar and plaster cannot be ignored since cement production causes further pollution and accumulation of waste.

Image 2: Excessive mortar joints contribute to waste associated with brick construction in Uganda.

This discussion does not claim to provide a comprehensive solution on material selection since as Sanya (2007) attests; the global discussion embodies the difficult to reconcile aims of safeguarding human wellbeing (including alleviation of poverty) and preservation of the environment. Our discussion here merely posits that there are actual viable alternatives to the brick wall. Often times, the argument against alternative construction methods has limited information on cost and performance as compared to conventional methods. Yet we, in the education for construction industry need to respond to the **S**ustainable **D**evelopment **G**oals particularly; **E**nsure healthy lives and promote well-being for all at all ages, **M**ake cities and human settlements inclusive, safe resilient and sustainable, as well as **T**ake urgent action to combat Climate change and its impacts.

Fortunately, when more practitioners get involved in this endeavour toward better buildings, irrefutable evidence of overall gains associated with alternative construction shall emerge. This evidence could then inform local communities to devise even more efficient site-specific alternatives and subsequently mitigate the latent cost impacts to our environment. It should be noted that fired brick production depletes the same wood fuel, which is the primary source for cooking energy in these rural communities.

Brick masonry with EE at 580.2 GJ (Mishra & Usmani, 2013) consumes highest of the masonry options. Hollow concrete masonry at 508.8 GJ, consume less than brick masonry. Stabilised Soil Blocks consume a significantly lower 370.0GJ. This data is comparable to the following calculated Embodied Energy comparison for three walling types around the Nkozi village.

Taking sections through three (3) walling options from around our local context, we used descriptive terms:- **O**ld, **P**opular and **A**lternative. Embodied Energy for these options was compared to facilitate a discussion to propose future walling options. These samples were considered for an area of one square meter (**1m^2**) of walling. The tables based in a given section indicate materials, layer thickness and levels that exist between the exterior and the interior. The tables presented for this discussion consider three basic wall types

Old: Wattle, Daub render
Popular A: Plaster, Fire Clay Brick, Plaster
Popular B: Plaster, Concrete Block, Plaster
Alternative: Plaster, Stabilized Soil Block

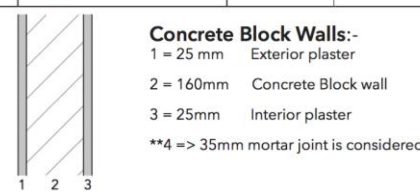
1. Old Construction

Layer	Element	t (m)	Volume	EE - MJ
1	Daub	0.025	0.025	
2	Wattle Wall	0.250	0.216	
3	Mud-Dung mortar *(35mm)*	0.250	0.103	

This walling option does not record any Embodied Energy since raw materials are sourced locally from around the construction site with no transportation or manufacturing costs. It should be noted that human labour through expended during construction, values are not reflected for any of the walling options.

2. Popular Construction

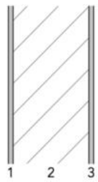
Layer	Element	t (m)	Volume	EE - MJ
1	Plaster	0.025	0.025	97.2
2	Fired Clay Brick	0.120	0.105	1,620.36
3	Plaster	0.025	0.025	97.2
4	Cement Mortar	0.120	0.070	167.61



Layer	Element	t (m)	Volume	EE - MJ
1	Plaster	0.025	0.025	97.2
2	Concrete Block 10MPa	0.160	0.138	194.30
3	Plaster	0.025	0.025	97.2
4	Cement Mortar	0.160	0.066	158.73

These calculations reveal that brick walls among these three selected options consume the most significant amounts of energy. Moreover, since brick production is localized to swampy areas, there are additional energy costs at 1.5MJ/ tonne for Wood fuel transportation over each Kilometer.

3. Alternative Construction



Stabilised Soil Block Walls:-

1 = 210 mm ISSB Wall

2 = 13 mm Lean Plaster finish

Plaster is optional for this wall type, although interiors are usually plastered

Layer	Element	t (m)	Volume	EE - MJ
1	ISSB	0.210	0.200	249
2	Plaster	0.013	0.013	50.4
3	Mortar	-	-	-

Besides, with brick and concrete options, there are no guarantees on quality, strength, size or configuration. Limited consistency of these bricks/block types is attributed to production at roadside block yards and makeshift kilns by different skill-level artisans. Yet the production process of ISSBs guarantees consistency in shape and size. Despite the advantages rendered by ISSB in construction, the general perception is that the blocks are not durable and are unable to withstand harsh weather conditions (Nambatya, 2015). Further, these ISSBs are not as readily available for sale on the commercial market as are the other two walling materials.

THE DISPLAY SPACE

In order to interrogate alternatives to fired brick construction, students in their second year at the Faculty of the built environment were tasked to design an Architecture Display space for the local context, with significant passive features, to be built in as short a period as possible. A single story was considered in order to conform to typical rural housing typologies. The area of 105m^2 took the intended function as a Studio Display Space into consideration, however the design intentionally conforms to the typical row house design that is observed in local communities within Uganda. The building is a single space with an entrance door and a window on the north facing wall, two windows facing south and another door facing east that leads to the shaded model making space. The cost of the foundation and walling elements has been calculated and compared to estimates from other building contractors. This construction is funded under the Joint Development of Courses for Energy Efficient and Sustainable Housing in Africa (JENGA) project. The energy behaviour of the building has been simulated using Ecotect to estimate its performance. The model shall be monitored to test the actual performances during occupancy and to compare the simulated results with the measured values of inner air temperature and humidity.

Building Structure

The Display Space design includes a naturally cross-ventilated interior space and employs a locally fabricated ceiling to mitigate the heat gained through the steel sheet roof. The building structure is made of one rammed earth wall and three other stabilised soil block walls. The building is opened to the north and south for passive cooling through cross ventilation. Openings to the west are inset in the 600mm thick earth walls, where as the roof of the model making space shades the opening to the east as shown in *appendix 1*. A stone plinth option shall replace the traditionally used brick plinth.

Energy features

The building was designed with large windows to maximize natural day lighting. The operable windows are positioned to enable cross ventilation. 300mm thick walls are estimated to have U-values between 1.9 - 2.0 W/m^{2}K. All the openings are shaded with an exception of the south facing windows. Deciduous creepers shall be used as horizontal shading device to limit overheating from the south facing widows

RESULTS AND DESIGN POTENTIAL

The computed results from the walling material comparison shown in *image 3* below indicate the significant energy demand for Brick walls. Further, an additional energy cost is incurred for transporting on average 9 tonnes of wood fuel as shown in *image 4* to each kiln from over a 30Km distance.

Brick Wall	=	1,982.37 MJ
Concrete Wall	=	547.43 MJ
ISSB Wall	=	299.40 MJ

Image 3: Computed results from the three walling type comparison, Brick wall exhibiting significant energy demand.

Image 4: Wood fuel at kilns at an average of 9 tonnes per burning, where 45% of the bricks might not bake in case of Rain or unexpected Night breeze.

The Display Space project seeks to demonstrate that earth technologies do not reduce the architectural quality of a building, yet could significantly reduce its energy behaviour. The project shall engage its participants in the construction of two earth walling options Rammed Earth as well as Interlocking Stabilised Soil blocks. The final building shall be studied and the expected performances should be tested and validated. Ideally the space should maintain low interior temperatures; the lack of infiltration and air change rates data leaves the Ecotect simulated data inconclusive at this stage. However, after construction, actual energy behaviour of the Display space shall be compared with simulated data. The original building simulation was performed using Ecotect energy simulation codes. The modelled conditions obtained using the codes are quite similar, but for such a small building we expect that measured data could be quite different from simulated ones. Construction errors have an effect in small buildings compared to larger ones. Simulations for daylight conditions though performed using Ecotect software are not admissible. Lighting data shall not be collected because the changing in lighting conditions are considered of little interest in terms of energy reduction.

FUTURE IMPLEMENTATION

The Display Space shall provide much needed information on the benefit of ISSBs on associated embodied energy and energy efficiency. The construction logs shall also provide the information about efficiency and ease of setting up walls with interlocking blocks. Preliminary cost estimates reveal that ISSBs for this project shall cost USD 15.65 per Square meter, which is lower than the average quote of USD 17.29 given by the contractors who were interviewed. Working with artisans on the actual project shall provide a more reliable first hand account on the cost related information. The artisans can gain ISSB and rammed earth wall construction experience that they can then take back and share with the community. The students and faculty on the other hand shall benefit from the feedback loop with the artisans as they share other construction related concerns. The objective of this process is to create an experimental building (a life size model) on which to test different, alternative solutions for building and systems.

It should be noted that though machine pressed blocks shall be used on this project, hand pressed blocks are adequate for most rural construction requirements.

CONCLUSION

This paper discussed the limitations of the common fired brick production and construction methods in Uganda. This paper then presented the ISSBs as an alternative to reduce the embodied energy of locally produced materials, in an effort to mitigate the environmental damages of low-income housing. Preliminary estimates based on local contractors demonstrate that it is possible to reduce building costs with this site-specific material option. The embodied energy of brick walls compared with ISSB walls of similar thicknesses are in order 5 to 7 times more. With the benefit of lean construction, Interlocking Stabilised Soil Blocks becomes a more environmentally and socially friendly material/method that further adheres to the do-it-yourself approach common for simple local housing in Uganda. The display space examines and interrogates the cost barrier more thoroughly as this shall present a better case for broader uptake of earth alternatives for local communities. Notwithstanding, the local construction industry provides employment to many people. This is why local artisan shall be trained on this project, with the hope that they shall continue as social entrepreneurs to propagate the project outcomes to the broader community. In this respect, providing rural communities with dependable evidence that there are alternatives that reduce reliance on wood fuel during production is a necessary result. It shall then be prudent to acquaint more stakeholders with the uncomplicated construction process, which eliminates material transportation costs and wastages due to over-production. Additionally, engaging vocational schools as well as other institutions starting at the lowest levels to change the negative public attitude towards sustainable materials such as revised earth technologies would increase the market share and stimulate commercial production of such materials for the housing industry.

It is envisaged that when more communities embrace these solutions, alternative innovative methods borne of further interrogation of earth technologies in rural communities shall be introduced to the construction industry.

ACKNOWLEDGEMENTS

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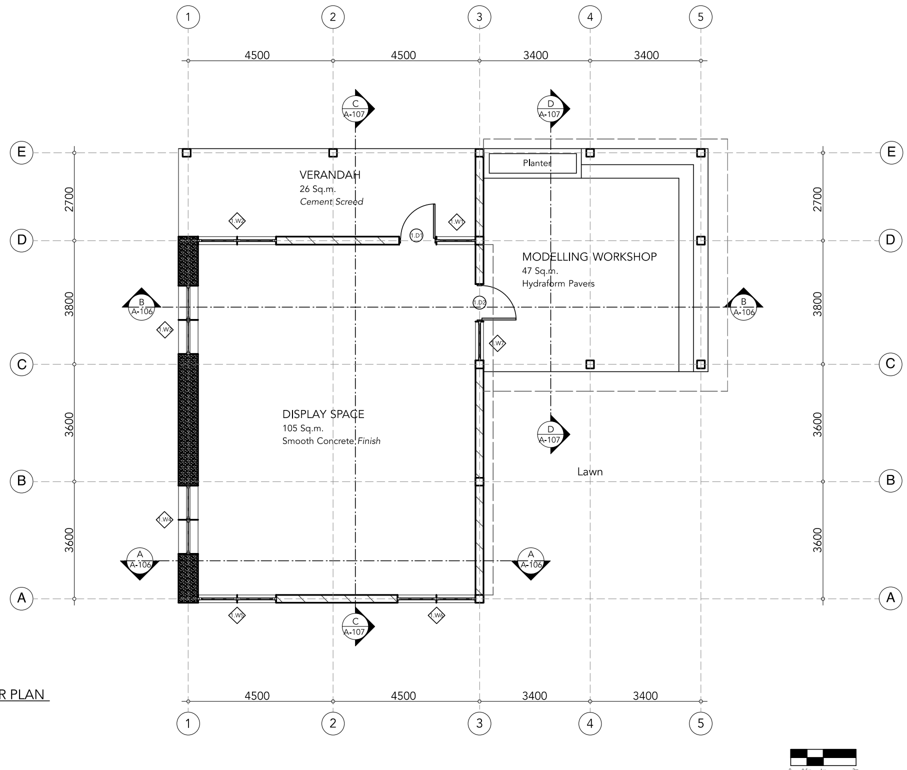
Appendix 1

Appendix 2

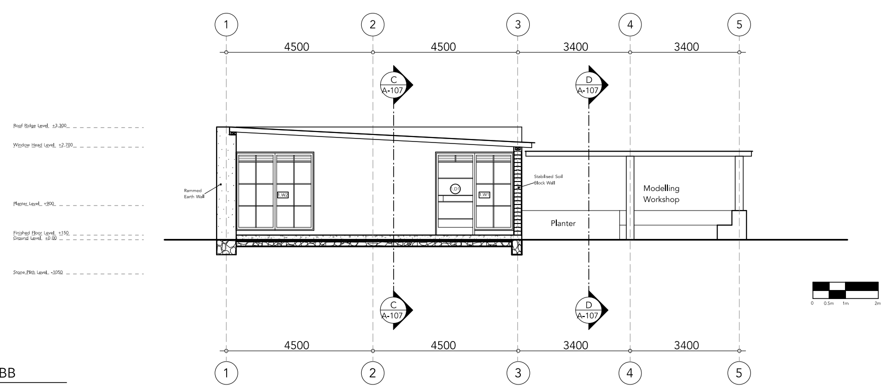
The **I**nventory for **C**arbon and **E**nergy (ICE) tool provides a summaried database for Embodied Energy and Carbon Coefficients estimated from UK industial fuel consumption data; listed below are a **few** materials from the tool that one can use to test wall thickness and material choices to estimate walling choice Energy values.

Material	EE - MJ/kg	Estimated from UK industrial fuel consumption data
BRICK		
Fired Clay Brick	6.43	** Computed by ELITH team in Uganda by measuring fuel at different kilns in Nkozi area
General (Common Brick)	3.00	
Limestone	0.85	
EXAMPLE: Single Brick	6.9 MJ per brick	Assuming 2.3KG per brick
MORTAR		
Mortar (1:4)	1.11	
Mortar (1:6)	0.85	
Mortar (1:1:6 Cement:Lime:Sand mix)	1 .11	
Mortar (1:2:9 Cement:Lime:Sand mix)	1.03	
ISSB		
Cement stabilised soil @ 5%	0.68	Assumed 5% cement content
Cement stabilised soil @ 8%	0.83	Assumed 8% cement content
CONCRETE BLOCK		
Block - 8 MPa Compressive Strength	0.59	Estimated from the concrete block mix proportions, plus an allowance for concrete block curing, plant operations and transport of materials to factory gate.
Block - 10 MPa	0.67	
Block -12 MPa	0.72	
Block -13 MPa	0.83	
PLASTER	1.8	
PAINT		
Waterborne Paint	59.00	
Solventborne Paint	97.00	

Volume (m^3) = **L**ength(m) x **W**idth (m) x **H**eight (m) **as measured from the wall
Mass (Kg) = **D**enisty (Kg/m^3) x **V**olume (m^3) ** Values available *(see reference)*
Energy Value (MJ) = **EE** (MJ/Kg) x **M**ass (Kg)



03 GROUND FLOOR PLAN
A-101 Scale 1:100



11 SECTION BB
A-106 Scale 1:100