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Energy Efficiency of the NBRRI Interlocking Compressed Stabilized Earth Blocks For Sustainable Buildings in Nigeria

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Abstract
The rising rate of global warming is leading to an increase in energy demand for cooling. The amount of energy consumed by building materials is an essential factor in determining the energy efficiency of the building. Strength, economy, and aesthetics are parameters more sought after when selecting building materials. Thermal properties of building materials, which is an essential parameter in determining energy efficiency, are the least sought after. For buildings to be sustainable, they must have low energy requirements. In this study, the importance of selecting CSEB in designing an energy-efficient building is considered and discussed. The coefficient of Thermal Conductivity of the NBRRI interlocking CSEB is found to be 0.4765 $Wm^{-1}K^{-1}$, which is within the range of coefficient of Thermal Conductivity of Building Bricks (0.35 – 0.7) $Wm^{-1}K^{-1}$. This low value of Thermal Conductivity shows that CSEB is the most energy-efficient walling material among other alternative walling materials.

Keyword: *CSEB, Thermal Conductivity, Energy Efficiency, Sustainability*.

I. INTRODUCTION

History of Walling Materials

Building materials have been used for centuries in a variety of ways to provide safe, climatically comfortable, and easy-to-construct habitats and shelters. People's clear choices of material have often been determined by the availability of local materials and the demands of nature.

The earliest humans may have lived in caves and used trees for housing, but eventually, they learned how to innovate and use natural materials such as soil, stone, and wood, which were readily available around them, in the building of houses and shelters. Mud and clay were among the first building materials they used because of their ease of mouldability and their adhesive properties when used with natural fibers. The adhesive quality of clay made it easy to work with and form into shapes. People used straw, grass, husks, and other agricultural waste and fibers to make the structures more durable and provide the strength to cope with severe weather conditions. They added dung to such mixtures and typically used wooden molds to form adobe. Earth was often compacted using wooden planks to construct walls, known as "rammed" walls, and other building structures [1].

In recent times, humans have developed more advanced and versatile composite building materials such as concrete, cement, and flowable and aerated concrete. Concrete is generally made of sand or gravel, mixed with cement and water. When the mixture dries, it becomes hard and stone-like. Before the mixture sets, it can easily be poured into molds and formed into different shapes. Because concrete is brittle, it is often reinforced with steel or other metals. Now, even fiber reinforced concrete is used extensively to construct structures for specialist applications [1].

New technology has also made construction using metal more practical than before. Most high-rise buildings and skyscrapers are built using frames made from steel or other metals. While steel was traditionally the favored metal for such constructions, new alloys are now sometimes preferred based on their resistance to corrosion.

Light-weight concrete can be used to make buildings lighter, save materials, and make structures more stable and durable. Plastic is another widely used modern building material. Formed from polymers, plastics can be molded easily while in their liquid state. Compared with metal and many other materials, plastic is less dense and lower in cost

Plastic is often used for pipes and in building interiors. Nowadays, wood-plastic composite offers a forest-produced wood and helps save natural resources.

Modern buildings often use glass, not only for windows but as the primary exterior building material. Glass skyscrapers and other structures have become popular as a result of their aesthetic appeal. Transparent glass also allows natural light to be used to illuminate the interiors of buildings.

Despite all these developments, which are especially relevant for those in higher-income groups and urban sectors, people living in semi-urban areas and village-dwellers still use various forms of earth blocks, which are more readily available and have superior thermal and acoustic properties [1].

Compressed Stabilized Earth Blocks (CSEB)

The compressed stabilized Earth block is the modern descendent of the molded earth block, more

commonly known as the adobe block. It is estimated that about 1.7 billion people worldwide live in earthen houses: About 50 % of the population in the developing countries and at least 20% of the urban and suburban populations [2]. The idea of compacting earth to improve the quality and performance of molded earth blocks is, however, far from new, and it was with wooden tamps that the first compressed earth blocks were produced. This process is still used in some parts of the world. Earth blocks are a construction material made primarily from soil. Types of earth blocks include compressed earth blocks, compressed stabilized earth blocks, and stabilized earth blocks. Compressed stabilized earth blocks are building materials made primarily from damp soil, which is compressed at high pressure to form blocks. If the blocks are also stabilized, using a chemical binding agent such as Portland cement, they are known as compressed stabilized earth blocks. Creating compressed stabilized earth blocks (CSEBs) differs from rammed earth in that the latter uses a larger formwork into which earth is poured and manually tamped down. Rammed earth methods result in forms that are larger than adobe or individual building blocks (such as a whole wall, or more, at any one time) and uncompressed.
CSEB is a block unit formed from a loose, damp mixture of laterite, cement, and water, which is then compacted mechanically to form a hydrated block that is characterized by higher compressed strength and improved durability as compared to a laterite block produced similarly without the addition of cement [3]. Typically, around 21MPa is applied in compression, and the original soil volume is reduced by about half [4].

Unlike burnt clay brick, CSEB and other earth products are not burnt but are stabilized by pressure, so their carbon footprint and embodied energy are shallow compared to conventional building materials. The embodied energy and carbon emission of an average kiln-fired brick of size 22cm*10cm*7cm traveled 150 km is 2247.28MJ/m3 and 202.255 kgCO2 /m3, respectively, whereas for a CSEB with 5% cement of size 24cm*24cm*9cm has an energy of 572.58MJ/m3 and carbon emission of 51.531 kgCO2/m3 which is almost one-fourth of the kiln brick [5]

Structural characteristics of CSEB

Both the mechanical and structural characteristics of CSEB have been researched extensively - including manufacturing technique, block density, level of compaction, type and amount of stabilizer used, soil-stabilizer ratio, the addition of fibers or other additives, curing conditions, the temperature in the early days after casting,. [6].

Raw Materials for production of CSEB

The primary raw material for the production of SCEB is raw earth or soil. OPC cement in little quantities and water, coarse sand, or stone dust may be added depending on soil quality. The physical properties of soil have greater relevance in the manufacture of compressed earth blocks. They include color, particle
size break-up, structural stability, adhesion, bulk density capillary, porosity, specific heat, moisture content, permeability, linear contraction, and dry strength. Soil classified as clayey sands are excellent for making blocks. The optimum soil composition for compressed soil/mud block is 7% gravel, 53% sand, 20% silt, and 20% clay [7].

The Nigerian Building and Road Research Institute (NBRRI)

The Federal Government of Nigeria established the Nigerian Building & Road Research Institute (NBRRI) to conduct integrated applied research and development in the building construction sectors of the economy. NBRRI is geared towards evolving technologies and processes to increase local content and capacity utilization of alternative/local building materials and evolving cost-effective shelter methods.

II. The NBRRI Interlocking CSEB

The NBRRI interlocking CSEB is made of suitable soil (laterite) stabilized by the cement of not less than 5% by weight with a minimum compaction effort of 20MPa. The NBRRI cement stabilized laterite block is based on the concept of Compressed Stabilized Earth Block (CSEB) and is produced by compressing a soil and cement mixture with suitable moisture content in the NBRRI Interlocking Semi-Automated Block Making Machine. The machine has the primary advantage of impacting adequate compressive effort on blocks to achieve suitable and adequate compressive strength.

The NBRRI interlocking CSEB is a technology that employs dry stacking of blocks with nor mortar needed for bonding of blocks during use in construction; rather, blocks interlock via tongue and groove joints at the lateral and posterior positions [8].

The production process of the NBBRI Interlocking CSEB

The materials used for the NBRRI interlocking CSEB are laterite, cement, and water.

Laterite

The primary raw material for producing the NBRRI interlocking CSEB is laterite soil with fair grain size distribution and good cohesive performance. The soil to be chosen should be free from organic matters.

Stabilizer (Cement)

The stabilizer used as a binder to produce NBRRI interlocking CSEB is 5% ordinary Portland cement. This implies that the mix ratio of laterite to cement is 19:1.

Water

Clean and potable water is used. Water that contains salt and organic matter is avoided because it affects the binding qualities of cement. Generally, sea and stagnant water are characterized by salt and organic matter, respectively.

There are five (5) processes in the production of NBRRI CSEB interlocking; these include the following; [8].

i. Sieving of Soil

Usually, when soil is brought from the field, it may contain boulders and lumps. To obtain a powdery material that can be efficiently mixed with the stabilizer (cement), the soil has to be sieved. This is done manually or bypassing the soil through a locally constructed sieve (8ft by 4ft) of mesh 8-12m.

ii. Mixing materials

Calibrated containers such as graduated buckets, head pans, wheelbarrows are used to measure the exact quantity of required materials (i.e., laterite and cement). This is achieved by volume or weight. Mixing is done manually or in an NBRRI laterite mixer machine.

iii. Ejection of Blocks from the Machine

When ejecting the blocks from the machine, the following points are taking into consideration:

- If cracks appear, the moisture content of the mix is checked and remix properly
- If the soil sticks to the mold, the moisture content and mix check, then the mold is cleaned
- If the edges are rough, the moisture content of the mix is checked, remixed, and the mold cleaned

iv. Stacking

The lower layers of the blocks in the stack are checked for cracking. If cracks appear, it can be due to many reasons:

- The ground is rough, which can be corrected by leveling it with a layer of wet soil.
- The stacking is too high and should be reduced; a stacking of up to 5 layers is recommended.

v. Curing

The stacked blocks are covered with polythene. If water drops are not seen on the internal surface of the polythene, the polythene may not have been appropriately fixed and therefore allows water to evaporate. The blocks are cured for 21days.

Fig 1: NBRRI Interlocking CSEB

Fig2: NBRRI Interlocking CSEB Making Machine

III. THERMAL CONDUCTIVITY OF NBRRI INTERLOCKING CSEB

Block samples were molded at different diameters and thickness using the NBRRI Semi-Automated Interlocking CSEB Machine and compressed at 20MPa. The molded block samples were exposed to controlled fire at varying temperatures inside a kiln for 1½ hours.

Table 1: Sample Dimensions

Dimension (mm)	Diameter (D)	Thickness (d)
Reading 1	110.80	16.04
Reading 2	112.84	16.80
Reading 3	111.63	16.99
Reading 4	111.53	17.17
Reading 5	111.15	16.85
Reading 6	112.50	16.12
Average	**111.74**	**16.66**

Table 2: Steady Temperatures Measured Using

Temperature (^{0}C)	θ_1	θ_2
Before Interchanging	92.2	64.0
After Interchanging	92.0	64.2
Mean Temperature	**92.1**	**64.1**

Table 3: Cooling Rate of Block Sample after Heating

Temperature (^{0}C)	73.4	72.2	71.2	69.5	68.7	67.8	67.1
Time (S)	30	60	90	120	150	180	210
Temperature (^{0}C)	66.4	65.4	65.2	64.5	64.0	63.4	62.9
Time (S)	270	300	330	360	390	420	450
Temperature (^{0}C)	62.3	61.7	61.2	60.4	59.8	59.3	58.5
Time (S)	480	510	540	570	600	630	600

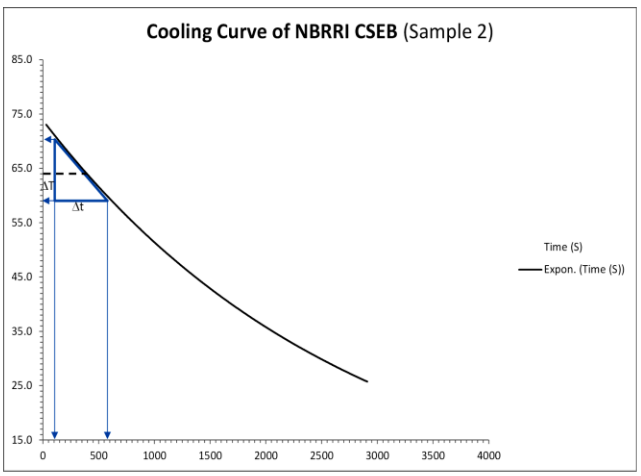

Figure 3: Plot of Temperature

$$\frac{\Delta\theta}{\Delta t} = \frac{70-59}{580-100} = \frac{11}{480}$$

$$k = \frac{7}{22} \times 4 \times \frac{11}{480} \times \frac{0.01488 \times 380 \times 0.9956}{(0.11092)^2 \times 28}$$

$$k = 0.4765 Wm^{-1}K^{-1}$$

Unit thermal conductance, U, is the thermal conductance for a unit area of material and can be determined by dividing the thermal conductivity of a material by its thickness, as demonstrated in Equation (1) [9].

$$U = \frac{k}{\Delta x} \quad (1)$$

The heat transfer rate in each component of a building system is then given by,

$$q = UA\Delta t \quad (2)$$

Where,

$\boldsymbol{q}$ = heat transfer rate (W)

$\boldsymbol{U}$ = unit thermal conductance (W/m^2·K)

$\boldsymbol{A}$ = surface area normal to flow (m^2)

$\boldsymbol{\Delta t}$ = overall temperature difference (K)

Table 4: Dimension of the NBRI CSEB

Dimension	**NBRRI CSEB**
Length, L (cm)	23
Width, W (cm)	18
Area, A (cm)	414

$\boldsymbol{\Delta t}$ $= 92.1 - 64.1 = 28\ k$

$U = \frac{0.4765}{0.18} = 2.647 W/m^2$

q $= 1.92 \times 0.0414 \times 28 = 3.068W$

Table 5: Heat Transfer of NBRRI CSEB

NBRRI CSEB	
Thermal conductivity(W/mK)	0.4765
Thickness (m)	0.1800
Conductance (W/m^{2}K)	2.6470
Area (m^2)	0.0414
Heat Transfer (W)	**3.0680**

Table 2: Steady Temperatures Measured Using Two Thermometers

Building Material	**Thermal conductivity (W/mk)**	**Specific Heat Capacity (W)**
Clay	3.252	19.12
Plywood	0.12	12158
Particleboard	0.0170	1300
Hardwood	0.16	1255
Cement mortar	0.72	780
Cement block	0.72	835
CSEB	0.4765	3.06

This result shows that CSEB is the most energy-efficient walling material among the alternative walling materials.

Advantages of Interlocking CSEBs

Energy-saving. Earthen walls have different thermal behavior than any other materials. As clay is just stabilized and not burnt, it can still absorb and release some moisture through evaporation and condensation. Thus if the outside temperature is higher: the wall will evaporate moisture. This will cool down the wall and thus the building inside. Moreover, if the temperature is lower outside: the wall will condense moisture. This will create heat in the wall and thus the building inside. This phenomenon is called “latent heat”.

Saves Cost. The main manufacturing cost of the block involves only conveying the earth to the site, a routine procedure since the earth is material within easy reach of most building sites. Furthermore, if the earth comes from excavating the site itself, two birds are killed with one stone, compounding the savings. Moreover, it is an excellent material with excellent energy-saving potential in heating and cooling terms.

Clean technology. No contamination or noise, gaseous or thermal pollution of any type is produced during the block manufacturing process.

Non-toxicity. The material gives off no type of radiation or toxic product during its useful life. It has low energy emission. It is observed that the energy efficiency of CSEB having way less embodied energy.

Durability. It is a long-lasting and easily maintained material; appropriately clad, it suffers no attacks from micro-organisms.

Main Uses of CSEB

CSEB finds application in the following area:

- As an ordinary load-bearing masonry
- As infill masonry
- Special applications such as ventilations. Cable duct, chamfers, vaults and arches
- As reinforced masonry

RESULTS AND CONCLUSION

The thermal conductivity of the NBRRI CSEB in this research is 0.4765 W/mk. This value was compared to the thermal conductivity of other building/walling materials. By comparison, CSEB can exhibit a third of the thermal conductivity of, say, clay brick.

This research has proven that the NBBRI CSEB has less embodied energy and global warming potential than other conventional walling materials. Thus, CSEB has the capacity for adaption as walling material compared to other walling materials due to its improved energy efficiency and thermal capabilities.

The potential impact of choosing the NBRRI CSEB over other walling materials in a building envelope in different thermal conductivity was investigated. Based on thermal conductivity, The NBRRI CSEB significantly reduced energy consumption, global warming potential, and economic cost, saving up to 95% heating and cooling cost.

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