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Implications of Construction Materials on Energy Efficiency of Buildings in Tropical Regions

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Abstract

Construction materials play important roles on energy consumed for conditioning building internal spaces. Thermal properties of construction materials are the least factors considered during material selection process since strength, economy, and aesthetics are more sought after. Also, with the rising rate of global warming, more solar radiation would reach building surfaces, leading to increased energy requirements for cooling, especially in the tropical regions. For future buildings to be sustainable, they must have low energy requirements. This research considers the impacts of common construction materials in Nigeria on the energy required for conducive thermal comfort within building envelopes. Five types of building materials combination models of rammed earth wall with thatched roof, shipping container wall and roof, sand-crate block wall with aluminum roof, brick wall with concrete roof and glass wall with concrete roof were considered. Autodesk Ecotect environmental simulation and analysis software was used for the research. Building models were created for each of the selected materials and subjected to climate data of Ota in Nigeria. From the results obtained, rammed walls with thatch roofs model, similar to traditional systems of the old proved to be the most energy efficient construction material combination for a one storey building in this tropical climate while the shipping container model and glass wall with concrete roof model proved least energy efficient. The resulting temperature curves and the cooling load chart for the considered material models will be a useful tool for designers in search of materials for energy efficiency in the tropical regions.

Keywords: Construction materials, Energy efficiency, Global warming, Thermal comfort, Tropical climate

INTRODUCTION

Traditional African structures and by extension traditional Nigerian building structures may appear to be uninspiring and of inferior standards considering the nature of wooden or mud houses with thatched roofs in a degraded environmental set up. But a deeper investigation reveals that the varied indigenous Nigerian buildings tend to serve very functional and holistic purposes [1]. These structures are not merely a collection of crude construction materials, resulting from man's instinctive response to the dwelling needs as may appear. They share many characteristics with the modern structures of other human race, including those of the more technologically advanced cultures such as the Europeans. In the evolution of African settlements, building models of imported origins played significant roles in determining the choice of building materials and construction techniques. These imported models were adapted by the local people according to Langley [2] and became the foundations for common African architectural forms. Nigeria's architectural history has been principally influenced by the imported cultures of North Africa, Brazil, and Europe and the interaction between them influenced several aspects of the society up the point of crystallizing into the architectural and structural materials that defined the society [3, 4]. Fundamentally, a building structure can be defined as a system of spaces for a specific uses, guaranteeing controlled local climate [5]. It must also be safe for human use, be buildable, maintainable and adjustable or can be demolished as the need arises. This means that any building that is structurally robust but fails in controlling the local climate does not meet the standard requirements. Nigeria building structures have existed for centuries and have continued to become better over time in terms of aesthetics, structural forms and modern building materials and technologies emerge. This have culminated to the most recent structural developments around the country following international and modern trends with the adoption of modern building materials, evolved planning methods used by the builders at every stage in the evolutionary chain employed to achieve building operation. But this great evolution is not without a cost as the construction materials adopted are imported or borrowed from other part of the world. This negates the fundamental principles for architectural designers and builders to be inspired by the rich cultural heritages peculiar to their localities at any time. It must be remembered that the longer lasting and sustainable buildings have environmental impact advantages that in the long run will be beneficial to the society. According to Odjugo [6]; Odjugo [7]; Ede and Oshiga [8]; Ede et al. (2015) [9], the world is becoming more conscious of the inability of the earth's ecosystem to continue to adapt naturally to the stresses caused by excessive human activities and that many known effects of climate change on some sectors of the economy are already receiving appropriate evaluations with mitigation strategies being proffered while the building sector is scarcely considered especially in the developing nations. This brings us to the concept of green building.

Green building aims to reduce a building's impact on the environment throughout its life cycle. In developing nation like Nigeria, there is an obvious need for sustainable, environmentally friendly and energy-efficient or low-energy buildings. With the rising costs and non-availability of electric energy for ventilation and cooling, green building is one of the ways forward to ensure the building envelope does not cause excessive heat gain and storage thus increasing energy requirements for cooling and in turn, leading to increase in greenhouse gas emissions. Various works have been conducted by architects and structural engineers on traditional African architecture and how the styles and trends of new construction materials and architectural forms are affecting the efficiency contemporary buildings. Nsude [10] and Ikebude [11] researched on the negative foreign impression tending to downgrade the traditional African building structures as not having identifiable architectural values or showing any recognition for aesthetics. From the few available literatures, it was evident that each traditional setting had its own peculiarities with a common denominator of all their building materials such as wood, mud etc. being collected from the locality of the site and processed with less energy. A study by Ede and Okundaye [12] appraised the use of timber as structural members for residential buildings, while [13, 14, 15] considered the structural, economic and environmental impacts of using concrete and timber for residential buildings. These researches showed that the use of readily available and sustainable timber material will be very beneficial for constructing affordable houses for the teaming masses. So we see that building green is not a new concept in Nigeria and that it is characterized with an effortless practice unlike what is obtainable with imported construction materials like concrete which have taken over as the core construction material. Much energy is expended in its production, in transporting it to construction sites and working it into the final building. Green building is today considered an important tool for global warming control, especially for developing nations where building activities continue to be on the rise. To comprehend better the green content of the indigenous Nigerian building structures, a brief literature review of the evolution of Nigerian buildings and architecture will be appropriate.

LITERATURE REVIEW

Every Nigerian society throughout history sought to promote the physical, emotional and even spiritual uplifting of its members ensuring that every man had a befitting place of residence for himself and his family, through communal work force [16]. A study by Adeyemi [17] posited that the notion that buildings of African traditional materials are substandard has been a major obstacle to the development of indigenous African architecture. He studied the characteristics of African traditional building materials like adobe, mud, wood etc. used in some of the ancient buildings and found out that aside from being economical, possessing impressive load carrying capacities, thermal moderation capabilities, ease of workability during construction, etc. which are some of the sought after ideals for building materials of the 21st century. The huge lapses between the past and present architecture of developing African nations and the rest of the developed world is to be blamed on the wholesome transplantation of foreign forms of architecture on the indigenous architecture, even when the imported models do not satisfy fully the needs of the local users of the structures as compared to their old indigenous forms of architecture [18]. He classified Nigerian architecture into the North and the South with the classifications best pronounced by the similarity in the traditional styles of the kingdoms and towns in the North and the South of Nigeria. This research reviewed architectural forms from the great kingdoms of Kano and Katsina in the north to the Benin Kingdom and Igbo towns of the south so as to draw a clear picture of where Nigeria architecture came from and answer the burdening question of whether the architecture of today has any link with that of the past. From this research, it is clear that the Nigerian traditional style existed prior to the intrusion of the European, North African, and Brazilian trends. The European trend is due to colonial conquests and European Christian missions to Nigeria, the North African trend is due to influences of Islam and the Brazilian trend is due to the return of freed slaves from the Americas. These three architectural cultures fused to produce Nigeria's documented architectural history. In the recent times, modern styles developed in the west began to appear as many of the architects and engineers were trained and educated abroad.

In the North, earth with a large content of clay was mixed with water and other additives to make Sun dried Bricks (*tubali*) which are then used to build the principal load bearing walls. Certain alterations to building materials to improve the building properties [19] and workability [20] were also done by the Hausas of the North. Flat or dome-shaped roofs were also made of mud. Mud roofs without special water resistant additives are very much challenged in the rainy seasons due to water retention and material weakening but are good to withstand wind load [21]. Similar to the materials used in Northern Nigeria, the materials used for building structures in Eastern Nigeria were also locally sourced. Various types of mud, timbers, thatches, ropes and string were very popular building material among them.

THE ADVENT OF MODERN BUILDING STYLES IN NIGERIA

According to Otitoola [22], the first major entry of Modern Architecture to Nigeria can be traced to the appointment of

Maxwell Fry in 1947 as consultant for the University College, Ibadan. Maxwell Fry who had previously worked with Le Corbusier, learnt about his modern exposition of the Louvre and *Brise Soleil*. Prior, to that moment, the colonial rule brought with it civilization and the construction of public buildings (schools/institutions, warehouses, banks, hospitals, courthouses) and residences. Relatively grandiose places of worship were built. The constructions were mainly timber framed and masonry structures raised well above ground, covered with corrugated iron sheets and large well-shaded windows. The abolishment of the slave trade led to the return of many, and with them, architectural influences and styles. Storey houses typical of Afro Brazilian architecture and churches, built with sand-crete blocks with strong gothic themes were introduced. Several of these survived and can still be seen Lagos and a few old cities such as Calabar and Ibadan in Southern Nigeria and Kaduna in Northern Nigeria. At the end of the colonial rule, indigenous architecture had become a mixture of imported influences, superimposed upon elements which were either strongly influenced by climate or religion. A time of growth and development led Nigerian architects, who were then trained abroad, often working with their British counterparts to design buildings which attempted to suit climate and local conditions, simple geometric forms, concrete external walls with concrete, steel and aluminium sun shading devices. This mark the beginning of adopting concrete as the dominant construction material.

Concrete is known for many good properties especially, high compressive strength, but very weak in tension [23, 24]. In Nigeria, concrete is adopted in the form of framed reinforced concrete structures with concrete-sandcrete block walls for buildings of greater heights in the urban areas and concrete-sandcrete block masonry for mono-storey buildings. In developing nations where building collapse is widespread, concrete structures are the most affected [25, 26]. Another property of concrete is its high thermal mass the capability of storing up thermal energy, which would be dissipated at a later time. The use of concrete for buildings has gained wide acceptance in extreme regions as a result of its thermal mass as energy consumed for heating would be reduced but the downside to this for Nigeria's hot and humid climate is that much energy, by means of mainly mechanical cooling, would be consumed to offset the thermal discomfort when stored up heat is eventually radiated back to the interior. To be added to this stored up heat from solar radiation is the heat generated inside buildings by the presence of people, technical equipment, artificial lighting and goods [27]. It is known that the 21st century has been characterized by global warming due to increased industrialization and the built environment is known to be contributing intensively to the global annual greenhouse gas emissions and consumes a large portion of energy available to mankind. A key contribution to the embodied CO_2 impact from the built environment comes from the cement matrices content of concrete (paste that holds concrete constituents together). The value for different concrete products will differ depending on the additives substituted for cement. For example, the use of ground granulated blast furnace slag (GGBS) or fly ash (pulverized fuel ash or PFA) to partially substitute cement in concrete can significantly reduce the embodied CO_2 and lead to reduced greenhouse gas emissions associated with the production of concrete [28]. Many recent concrete researches are focusing on sustainability of construction materials [29, 30, 31].

Having reviewed the evolution of building materials and technology in Nigeria, in the next sections, the focus would be on how the energy efficiency of materials used for Nigerian buildings. The research aspires to deepen the understanding of the thermal-based properties of construction materials and how they affect thermal comfort and sustainable building development in tropical region like Nigeria. A typical reinforced concrete building and shipping container building, which are becoming a common feature in Nigeria are shown in Figures 1 and 2, respectively.

Figure 1: Steel and Concrete composite construction in Lagos State, Nigeria

Figure 2: A shipping container building in Nigeria

Metal boxes and shipping container buildings and are used mostly as storage facilities, shops and service centres. The reasons for adopting these metallic container structure are less cost (30-40% cheaper than conventional structures) and faster erection time [32].

With the advances in building technologies notwithstanding,

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building with earth is still being practiced in some part of Nigeria. An old mosque in Zaria, Northern Nigeria showing a detail of the tubali wall technique and one of the recent building with earth block walls spotted in Karimo village of Abuja are shown in Figures 3 and 4, respectively.

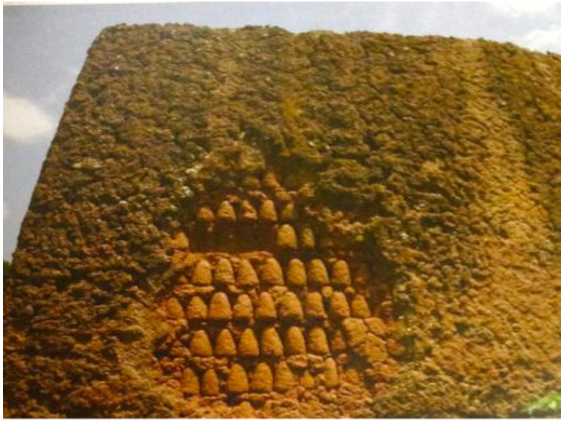

Figure 3: An Old mosque in Zaria, Northern Nigeria showing a Detail of the *Tubali* technique [35].

Figure 4: A recent construction using earth block walls

METHODOLOGY

Nigeria is the study area for this work. Nigeria enjoys a truly tropical climate characterized by the hot and wet conditions associated with the movement of the Inter-Tropical Convergence Zone (ITCZ) north and south of the equator. Since temperature varies only slightly, rainfall distribution, over space and time, becomes the single most important factor in differentiating the seasons and climatic regions. According to [15], choice of building material has depended majorly in the past on material strengths, costs, availability, ease of workability during building erection, aesthetics and available technical expertise but in more recent times, environmental and sustainability factors are becoming compelling aspects of material choice. This research will examine the energy implications of buildings executed in different materials as expressed by the CO_2 emissions.

METHOD OF ANALYSES

The method used for conducting this research was based on a comparative analysis of the energy implications of a building executed in different materials. This was achieved by using Autodesk Ecotect environmental analysis software [33]. An Autodesk Revit building model was exported to the Autodesk Green Building studio (GBS) web service and Autodesk Ecotect for analysis and simulation. The workflow of this energy analysis research consisted of developing building models, assigning weather zones, importing weather and climate data, performing approximate quantitative analysis of daylight factors and daylighting levels and temperature distributions, calculating monthly heating or cooling load, calculating hourly temperature profile for hottest day, analysing data and presenting results. Method of analysis adopted was similar to the study of [34]. The building model was generated in the model environment of the Ecotect simulation software. A view of the model is shown in Figure 5. Figure 6 shows the building site selection in the Autodesk GBS web service.

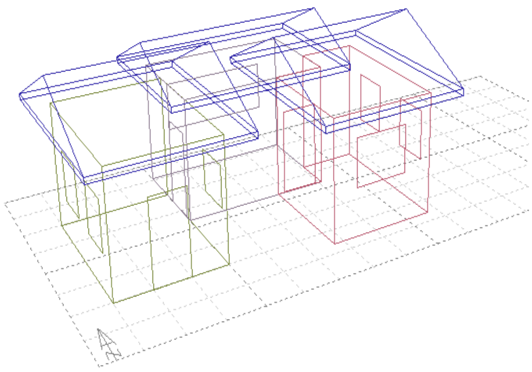

Figure 5: 3D-render of the building model showing North offset

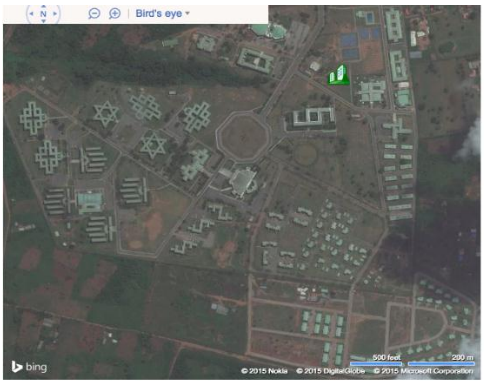

Figure 6: Screen shot Illustrating building site selection in the Autodesk GBS web service

The weather data used was from the year 2006 alone since suitable weather data in formats recognizable by the simulation software were not retrievable. However, the data is representative of Nigeria's past and current tropical climate. Both the monthly load/discomfort and indoor vs. outdoor temperature analysis result show the heating and cooling loads for each month and the indoor temperature of the building if there were no heating, ventilation and air conditioning (HVAC) system in place. For comparative purposes, building materials were alternated and combined in a number of ways, similar to building practices in Nigeria, so that the knowledge of which combination of materials is energy efficient will be obtained. The material combination is shown in Table 1.

Table 1: Schedule of building material combination

WALL MATERIAL	ROOF MATERIAL
Rammed Earth (wet clay)	Straw Thatch
Steel (metal)	Steel (Metal)
Concrete Block (225mm)	Concrete
Clay bricks (225mm)	Concrete
Glass walls (glass standard 20mm)	Concrete

RESULTS AND DISCUSSION

Autodesk Ecotect was the tool used for simulation. Autodesk Ecotect is able to calculate the monthly loads/ discomfort, the energy that would be required to maintain the building's indoor temperature between 18^0C and 21^0C. When energy is expended greenhouse gas emissions also take place, more so the cost of providing this energy would also be affected by magnitude of energy required (i.e. cost of unit energy multiplied by the total energy required). The other result generated by the simulation software is the passive gains breakdown. What this tells us is how much cooling load different elements constitute of the total cooling load to the HVAC system in use. An example of the weather data is presented in Table 2. In the table, solar radiation represent an instantaneous power density in units of Wh/m^2. The focus of this research is on the gains due to conduction of the building material fabric and these values are compared for the different building material envelop assemblies. The solar radiance varies throughout the day from 0 Wh/m^2 at night time when the sun is down and increases when the sun comes up, however cloud cover causes the solar radiance to vary greatly during the day when the sun is up. The solar radiance is strongly dependent on location and local weather. Figure 7 shows the corresponding monthly temperature distribution for 2006.

Table 2: Monthly weather data for Owode, Ogun state, Nigeria. Generated from Autodesk Climate servers

Weather Element / Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Relative Humidity – 9am (%)	84	83	83	80	87	88	88	90	89	90	76	61
Relative Humidity – 3pm (%)	52	57	54	58	71	70	75	74	74	70	49	39
Average Temperature (^{O}C)	27.7	28.3	28.3	28.3	26.6	26.2	25.4	24.8	25.2	26.0	26.9	27.0
Maximum Temperature (^{O}C)	35.3	35.8	35.4	35.9	34.0	33.6	30.9	29.8	30.1	31.9	34.8	35.9
Minimum Temperature (^{O}C)	22.6	23.6	22.9	23.6	22.9	22.1	22.0	21.4	21.7	21.6	20.7	18.8
Equivalent Daylight Hours (Hrs)	7.2	6.2	6.4	6.9	4.3	6.0	3.5	2.5	3.2	5.6	8.5	9.7
Daily Solar Radiation (Wh/m^2)	6547	6771	6823	6864	5350	5984	4034	3622	4339	5531	6847	6867
Cooling Degree Hours (Hrs)	5411	5262	5861	5712	4575	4143	3714	3260	3430	4163	4653	4973
Heating Degree Hours (Hrs)	0	0	0	0	0	0	0	0	0	0	0	1
Solar Excess Degree Hours (Hra)	3011	2813	3138	3055	2461	2664	1855	1666	1931	2544	3048	3159

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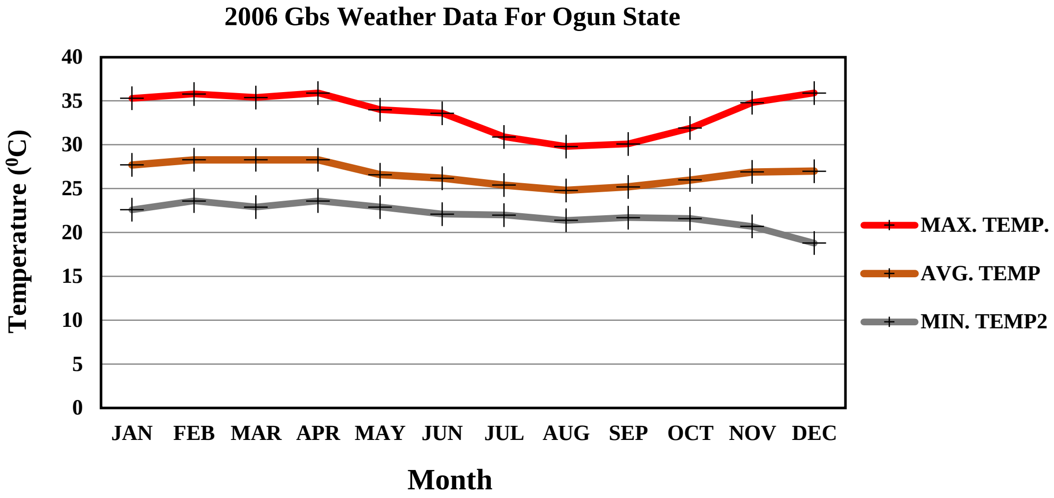

Figure 7: shows the corresponding monthly temperature distribution for 2006.

SOLAR ACCESS ANALYSIS

After the weather file has been uploaded in the recognizable format, the resulting view is shown in the Figure 8. The blue line represents the sun's path throughout the year, while the yellow line shows the sun's path for a particular day, in this case 3rd November. Then the best orientation tool was used to determine what orientation would result in the least amount of solar radiation reaching the building. The resulting view and results are displayed Figures 9, 10 and 11.

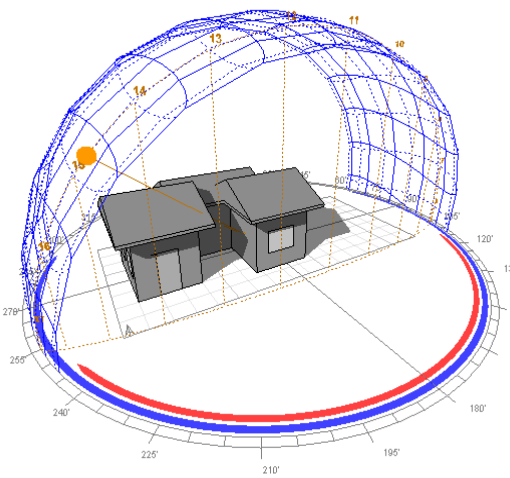

Figure 8: 3D-RENDER-Sun path diagram and shadow of building

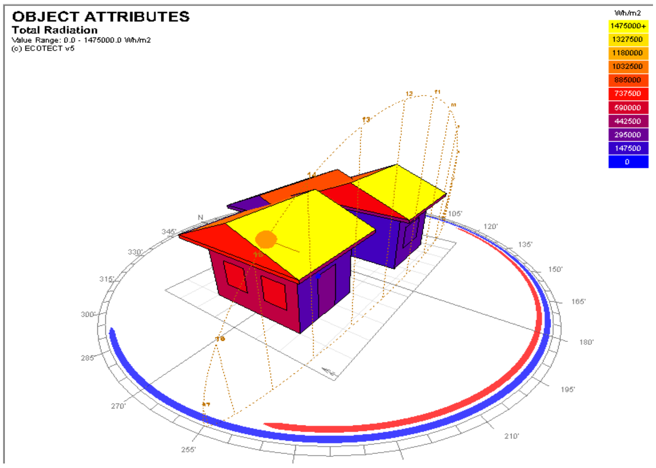

Figure 9: solar access analysis: 0^O orientation

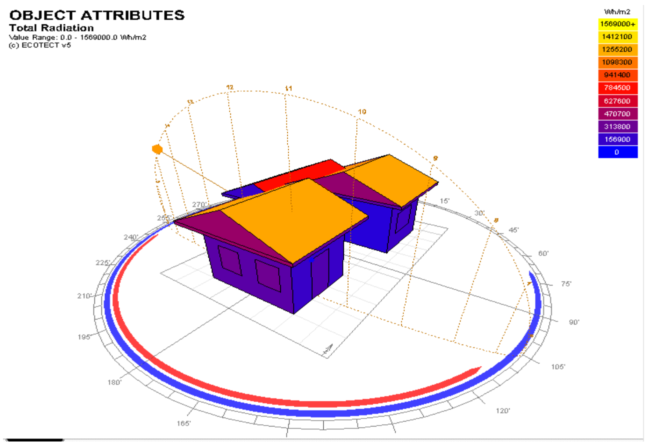

Figure 10: solar access analysis: 90^O orientation

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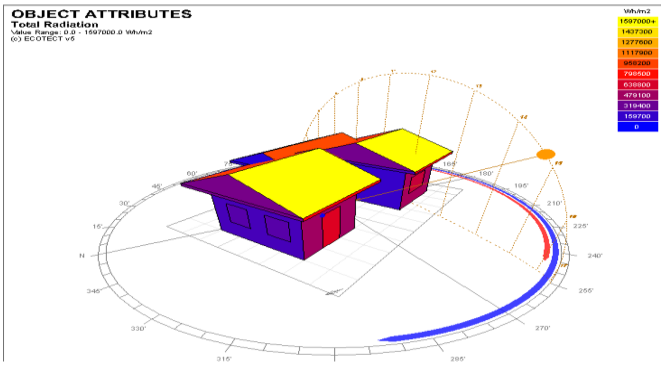


Figure 11: solar access analysis: 295^{O} orientation

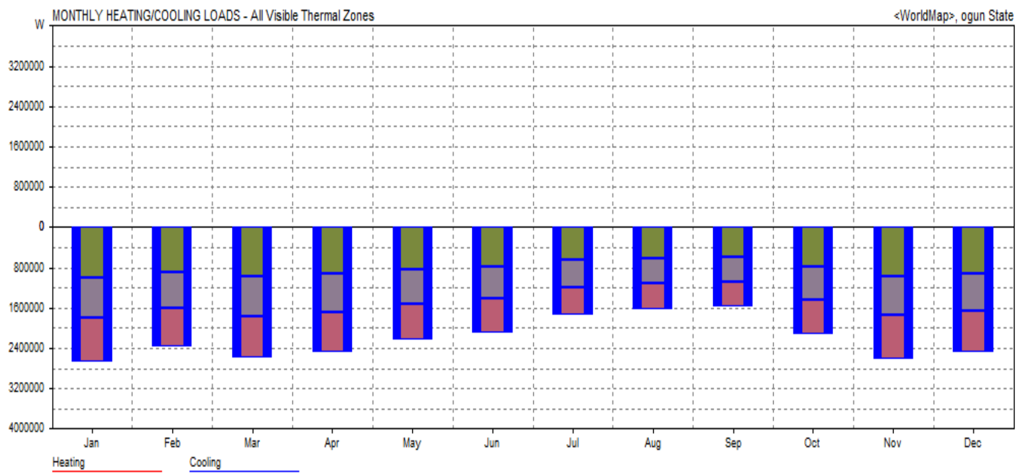
From these Figures, it can be seen that the incident solar radiation on the building surfaces is reducing in this order - 0^o, 90^o, 295^o (*see color code*). The 90^o orientation does show the least amounts of solar radiation reaching most parts of the roof with just one surface of the roof above this value. The optimal orientation should be a compromise after all the surfaces have been considered. On the 295^o orientation, the building is turned away the most from the sun's path therefore it is the orientation with the least solar energy gain to the building envelop as a whole.

THERMAL ANALYSIS: MONTHLY LOADS/ DISCOMFORT

The results of the thermal analysis of the different materials' combination models are shown here. The thermal properties of some of the common materials considered in this research are shown in Table 3. Figures 12 and 13 show the monthly cooling loads for the shipping container model and the rammed earth-thatched roof building model, respectively. The abyssal differences in the monthly cooling loads of the shipping container model and the rammed earth-thatched roof building model are very evident. Figure 14 shows the annual cooling loads for some of the common building materials combination models. The differences of the various models are very evident.

Table 3: thermal properties of some of the common materials considered in this research

Thermal properties	Rammed earth wall (300 mm)	Thatched roof (100 mm)	Shipping Container	Aluminium roof (10 mm)	Sandcrete block wall with plaster (225+10 mm)	Lightweight concrete roof (150 mm)
U-value (W/m^2.K)	2.65	0.62	5.62	5.62	1.12	1.12
Admittance(W/m^2.K)	6.42	0.63	5.56	5.56	3.56	2.28
Solar Absorption (0-1)	1	0.9	0.6	1	0.506	0.9
Visible transmittance (0-1)	0	0	0	0	0	0
Thermal decrement (0-1)	0.1	1	0.99	0.99	0.37	0.78
Thermal lag (hrs)	12.12	-	0.3	-	5	-
Emissivity	0.9 (int. & ext.)	0.88 (int.) 0.87 (ext.)	0.9 (int. & ext.)	0.90 (int.) 0.88 (ext.)	0.88 (int.) 0.87 (ext.)	0.88 (int.) 0.87 (ext.)



Figures 12: show the monthly cooling loads for the shipping container model

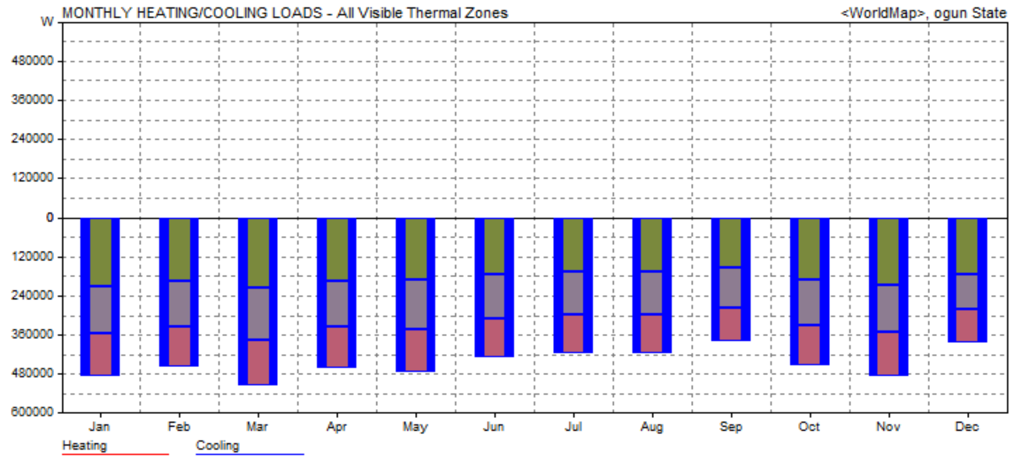


Figure 13: show the monthly cooling loads for the rammed earth-thatched roof building

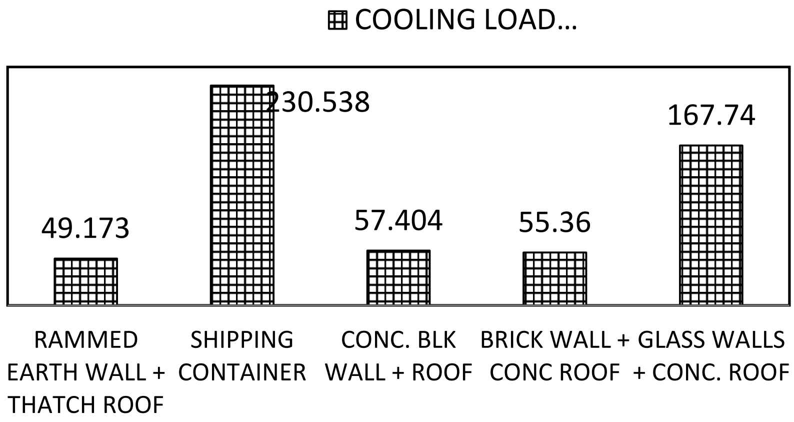


Figure 14: showing annual cooling loads for some of the common building materials combination models.

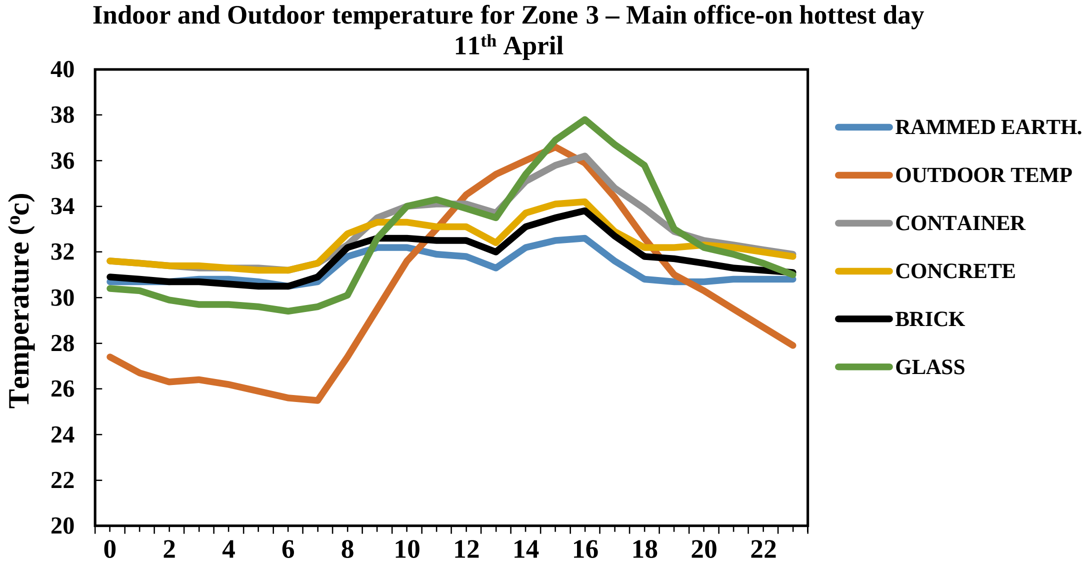


Figure 15: Plot of indoor vs. outdoor temperatures for the building materials combination models on the hottest day

It can be seen that the rammed earth wall-thatched roof model have the least annual cooling loads while the metallic shipping container model and the glass wall- concrete roof model have very high values. The indoor versus outdoor temperatures for the building materials combination models for the hottest day of the year (11th April) are plotted in Figure 15 considering no HVAC system in place.

For the hottest day's highest outside temperature of 36.6ºC at about 3:00 pm, the lowest corresponding indoor temperature was for the rammed earth wall building envelope (32.5ºC) while the highest corresponding indoor temperature was for the glass walled building envelop (36.9ºC). The rammed earth wall-thatched roof building model obviously had better thermal resistance than all the other building types and this is supported by the low annual energy consumption values required to keep the buildings' interior within the upper and lower temperature bands. Also, the rammed earth walled building model showed the lowest indoor temperatures throughout the day as compared to other building models considered. In the same way the glass walled building having the highest indoor temperature required the largest energy to maintain the temperature within the upper and lower bands. However, it does not necessarily have the highest temperatures throughout the day. For instance it can be seen that at 5:00 am in the morning when outside temperatures drop to 25.9ºC the corresponding indoor temperature was 29.6ºC, which is the least among all the different models. This shows that the glass walls are more responsive to the environment than the other materials and that was responsible for it attaining the highest temperature when the outside temperatures got to the peak. This brings attention to the concept of thermal mass. Thermal mass refers to the ability of building materials to store incident heat and dissipate this stored heat at night time when temperatures drop. The rammed earth walls are 300 mm thick, have a high thermal mass than the concrete walls of 225 mm They are also thicker than the glass walls, which are only 20 mm thick. The incident solar radiation is absorbed by thicker walls in the daytime thus reducing the heat reaching the building's interior and consequentially low energy is required to cool these buildings but since the glass walls are not thick, more incident solar radiation is absorbed to the building interior resulting to increased energy consumption.

CONCLUSION

From this research, it can be said that the knowledge of the past is absolutely necessary for one to understand the present and prepare for the future. Results of this research shows that;

i. Indigenous Nigeria's building structures had intrinsic values that need to be conserved for the continuity of human race. Indigenous buildings in the North and South of Nigeria portrayed robustness by combining aesthetics and structural mechanisms that ensured rigidity against loads (self-weight, imposed load, winds, rainfall) thereby ensuring optimum longevity of the building and less impactful on the environment as compared to today's modern buildings.

ii. The local materials used for these buildings were eco-friendly as compared to the modern materials produced using very large amounts of energy and which also generate sizeable greenhouse gases (CO_2) to match thus creating on its own large environmental hazard. Transporting these materials to site and working them in place also contributes its own quota to this environmental risk.

iii. Sustainability and energy efficiency need be considered side-by-side other material properties if an improvement for the future environment is envisaged. There has been too much focus on improving the mechanical properties of materials so that they are more robust and even on lowering the embodied energy of construction materials by substituting them for waste materials but little is done for improving thermal properties.

iv. There is no regular electric power supply to condition the building's interior for improved thermal comfort within building interiors in many developing nations. Alternate sources of electric energy are expensive and not affordable by the masses so that a look into the development of thermally suitable materials for the all the year round for hot climate regions is a step in the right direction and would be readily accepted by stakeholders in the building industry.

v. Finally, results obtained show that traditional construction materials like rammed earth or clay and thatch roof is more energy efficient than most of the materials commonly used in Nigeria today. They also have lower indoor temperatures due to the high thermal mass of the walls. It also has a low u-value and thus a better thermal resistance to Nigeria's hot and harsh weather. Moreover, because rammed-earth structures use locally available materials, they have low embodied energy and generate very little waste and greenhouse gases. The development of better climate responsive building structures will calm the global warming trend.

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REFERENCES

[1] Okoye, V., 2012. "Exploring traditional African architecture and modern urbanism. [Online]. Available at: http://africanurbanism.net/traditional-

igbo-design [Accessed: 20 April 2015].

[2] Langley, 1976. “Changes in the Production of the Built Environment in Rural Areas. In: African Environment, 2, London, pp. 37-51.

[3] Akwuobi, O.E., 2009, “Enugu State secretariat complex: Fusion of architecture and hightech”, MSc. Thesis in Architecture, University of Nigeria, Enugu.

[4] Adeyemi, E.A., 1976, “Changing Traditional Culture and modern architecture”, Archiforum Magazine, 1, pp.12–19.

[5] Dmochowski, Z.., 1990, “An introduction to Nigerian traditional architecture”, Northern Nigeria Ethnographica Ltd., (ed.), London.

[6] Odjugo, P.A.O., 2010a, “General Overview of Climate Change Impacts in Nigeria”, Journal of Human Ecology, 29(1), pp. 47–55.

[7] Odjugo, P.A.O., 2010b, “Regional evidence of climate change in Nigeria”, Journal of geography and regional planning, 6(3), pp.142 – 150.

[8] Ede, A.N. and Oshiga, K., 2014, “Mitigation Strategies for the Effects of Climate Change on Road Infrastruture in Lagos State”, International journal of Science Commerce and Humanities, 2(1), pp.173–184.

[9] Ede, A.N., Adeyemi, K.K. and Joshua, O., 2015, “Effects of Climate Change on Built Environment in Lagos, Nigeria”, International Journal of Engineering Technology and Computer Research, 3(2), pp.14–22.

[10] Nsude, G.C., 1987, “The Traditional Architecture of the Igbo of Nigeria”, PhD Thesis, Thames Polytechnic, UK

[11] Ikebude, C., 2009, “dentity in Igbo Architecture: Ekwuru, Obi, and the African Continental Bank Building”, Thesis for MA of Arts, Ohio University, Ohio.

[12] Ede, A.N. and Okundaye, J.O., 2014. “Appraisal of Timber as Structural Members for Residential Buildings in Nigeria”, International Journal of Engineering & Technology, 14(1), pp.108–112.

[13] Adebayo, S.O., 2014. “A Comparative Study on the Use of Concrete and Timber as Structural Members for Residential Buildings in Nigeria”, an unpublished students project for B.Eng. in Civil Engineering, Covenant University, Ota, Nigeria.

[14] Ede, A.N., Adebayo, S.O., Ugwu, E.I. and Emenike, C.P., 2014. “Life cycle assessment of environmental impacts of using concrete or timber to construct a duplex residential building”, Journal of Mechanical and Civil Engineering, 11(2), pp.62–72.

[15] Ede, A.N., Adebayo, S.O., Bamigboye, G.O. and Ogundeji, J., 2015. “Structural, economic and environmental study of concrete and timber as structural members for residential buildings in Nigeria”, The International Journal of Engineering and Science, 4(3), pp.76–84.

[16] Igbaro, J., Akinbileje, T.Y. and Umoru- Oke, N., 2010. “Art as a Tool in the Built Environment”, African Research Review, 4(2), pp.545–559.

[17] Adeyemi, E.A., 2008. “Meaning and Relevance in Nigerian Traditional Architecture: The Dialectics of Growth and Change”, Covenant University public lecture series 21, Covenant University press, Ota, Nigeria.

[18] Prucnal-Ogunsote, B., 2001. “Classification of Nigerian Architecture”, AARCHES Journal, 1(6), pp.48–56.

[19] Agboola, P.O.S. and Zango, M., 2014. “Development of Traditional Architecture In Nigeria: Case study of Hausa House Form”, International Journal of African Society Cultures and Traditions, 1(1), pp.61–74.

[20] Osasona, C.O, 2007, “From traditional residential architecture to the vernacular: the Nigerian experience”, [Online]. Available at: http://www.cpdiafrica.org/wp-content/uploads/2016/05/From-Traditional-Residential-Architecture-to-the-Vernacular-The-Nigerian-Experience.pdf.

[21] Eneh, A.E.O. and Ati, O.F., 2010. “The influence of rainfall on Hausa Traditional Architecture. Research Journal of Applied Sciences”, Engineering and Technology, 2(8), pp.695–702.

[22] Otitoola, Olufikayo. 2005. "Breathing Wall: A Modernist Architectural Heritage". ArchiAfrika Conference Proceedings: Modern Architecture in East Africa around Independence (Dar es Salaam, Tanzania, July 27-29), pp. 67-70.

[23] Li, Z., 2011. “Advanced Concrete Technology”, John Wiley & Sons, Inc., Hoboken, New Jersey.

[24] Neville, A.M., 2011. “Properties of Concrete”, 5th ed., Pearson Education Limited, England, London.

[25] Ede, A.N., 2010. “Structural Stability in Nigeria and Worsening Environmental Disorder: the Way Forward”, West Africa Built Environment Research Conference Accra Ghana, 2010, pp. 489–498.

[26] Adeniregun, A.O., 2010. “Study of building collapse in Nigeria: Effects of poor construction materials and poor workmanship”, An unpublished students project for B.Eng. Civil Engineering, Covenant University, Ota, Nigeria.

[27] Riemer, H., 2016, “Internal Heat Gains”, [Online]. Available at: https://www.educate sustainability.eu/kb/content/internal-heat-gains-qi [Accessed: 10 October 2016].

[28] The Concrete Center, 2013, “Embodied carbon dioxide of concretes used in buildings”, [Online]. Available at: http://www.concretecentre.com/PDF/SCF_Table 7 Embodied CO2_April 2013.pdf, [Accessed: 10 September 2016].

[29] Olofinnade, O.M., Ndambuki, J.M., Ede, A.N., and Booth, C. 2017. “Application of Waste Glass Powder as a Partial Cement Substitute towards more Sustainable Concrete Production”, International Journal of Engineering Research in Africa, 31, pp 77-93.

[30] Olofinnade, O.M., Ede, A.N., and Ndambuki, J.M. 2017. “Sustainable Green Environment through Utilization of Waste Soda-Lime Glass for Production of Concrete”, Journal of materials and Environmental Sciences, 8, pp 1139-1152.

[31] Olofinnade, O.M, Ede, A.N, Ndambuki, J.M, and Bamigboye, G.O. 2016. "Structural Properties of Concrete Containing Ground Waste Clay Brick Powder as Partial Substitute for Cement", Materials Science Forum, 866, pp. 63-67.

[32] Kolawole, Y., 2014, “Container housing offers cheaper, faster option for mass housing”, [Online]. Available at: http://www.vanguardngr.com /2014/09/container-housing-offers-cheaper-faster-option-mass-housing-tempohousing-nigeria/ [Accessed: 10 September 2016].

[33] Autodesk, 2014, “Green Building Studio Validation”, [Online]. Available at: http://knowledge.autodesk.com/support /green-building-studio/learn explore/caas/CloudHelp/ cloudhelp/ENU/BPA-GBSWebService [Accessed: 20 November 2016].

[34] Enyi-Abonta, E., 2015. “The evolution of building structures in Nigeria”, An unpublished final year students project for B.Eng. in Civil Engineering, Covenant University, Ota, Nigeria.

[35] Esiebo, A., 2006. “Nigeria Culture and Natural Heritage”, In: Laia 2006. Laia Libros, Barcelona, Spain, Barcelona.