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Thermal comfort characteristics of some selected building materials in the regional setting of Ile-Ife, Nigeria

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Abstract

In Ile-Ife, it is very common to see quite a lot of local people engaging in mud bricks moulding, concrete block making, mud house construction and the bricklaying profession in general. These have particular bearing on the economy and the political situation of the people involved as in the profession there is set of rules and regulations guiding the rate and procedure for carrying out any such moulding or construction work. Considering the importance of this, the present study investigated the thermal performance of some selected building materials in the ancient city of Ile-Ife in Nigeria. The work demonstrated how a building envelope responds to outdoor conditions through graphic illustrations. This was followed by constructing three physical building models, with model 1 constructed of mud bricks, model 2 constructed of concrete blocks and model 3 constructed of cast concrete. Each of the models was first roofed with galvanised Iron roofing sheets, later with aluminium roofing sheets and finally with asbestos roofing. Readings were taken by inserting TGP-4500 Data loggers into appropriate positions. The results showed that internal temperatures in the mud-brick and cast concrete buildings remained fairly stable despite external diurnal fluctuations. Humidity data collected also showed that fluctuations in external humidity levels do not affect humidity levels within the mud-brick and cast concrete structures significantly. On the other hand, the structure made of concrete blocks responded more to external fluctuations in temperature and humidity. Moreover, humidity levels in the cast concrete building were the least, followed by those in the mud-brick house; while the concrete block structure had the highest level of humidity. It was also discovered that aluminium roofing gave the highest internal temperature, followed by galvanised iron roofing and the least was seen with asbestos roofing. For external diurnal fluctuations, building model 3 with cast concrete gave the most satisfactory performance in terms of thermal comfort; however, building model 1 with mud bricks also gave a satisfactory performance close to that of model 3. The study concludes that building model 1 with mud bricks roofed with Asbestos is the best building model in terms of thermal comfort and affordability. The study also concluded that developing model 1 (mud bricks) in the regional setting of Ile-Ife will go a long way to developing people's sustainably.

1. Introduction

There are three basic fundamental needs of every man and woman which are food, clothing and shelter. The basic function of building is to provide shelter from harsh climatic conditions (sun and rain, heat and cold), external aggressions (protection from animals and attacks from humans), privacy and storage of possession. Hence, buildings are meant to protect man against harsh climatic conditions **[1]**, **[8]**, **[12]**, **[13]**. A building cannot be built without a fundamental knowledge of the building materials and the determinant factors (thermal performance, strength, cost etc.) that lead to the choice of one material over another **[2]**, **[9]**, **[10]**, **[11]**. A building material is any material which is used for a construction purpose. Many naturally occurring substances, such as clay, sand, wood and rocks, even twigs and leaves have been used to construct buildings. Apart from naturally occurring materials, many man-made products are in use, some more and some less synthetic. The manufacture of building materials is now an established industry in Nigeria and the use of these materials is typically segmented into specific specialty trades, such as bricklaying, carpentry, plumbing, roofing and insulation work. Building design and material properties influence the thermal performance and energy consumption for residential and commercial buildings. Different building materials have different thermal performance levels. For example, the embodied energy of mud brick is estimated to be around 0.7MJ/Kg, less than 30% of the embodied energy of clay bricks (2.5MJ/Kg) and less than 20% of the embodied energy of lightweight aerated concrete blocks (3.6MJ/Kg) **[3]**, **[4]**, **[14]**. According to the Australian institute of Refrigeration, Air-conditioning and Heating the conductivity of 250mm-thick mud bricks with a density of 1540Kg/m3 and specific heat capacity of 1260J/Kg.K is 1.25W/m.K, while concrete with a density of 2240Kg/m3 will have similar conductivity (which is 1.3W/m.K); however the specific heat would be between 800 to 1000J/Kg.K **[5]**. This means that mud bricks can absorb more heat than concrete even though they is less dense. Thermal performance of building materials is of significant importance in identifying the heating and cooling load within a building and hence the capacity of the mechanical equipment required to handle the load. It is important to know that the thermal performance of any building material is the result of several factors, which are: thermal conductivity "k" of the building material, thermal resistance "R" of the building material, emissivity "ε" of the building material, absorptivity "α" of the building material, reflectivity "ρ" of the building material, specific heat capacity "cp" of the building material, density "ℓ" of the building material. Climate is determinant of how much solar radiation gets to the earth's surface and the temperature within that particular geographical location. This in turn influences the thermal performance of building materials used for construction in a particular region. Two of the most important factors determining an area's climate are temperature and relative humidity (R.H) **[6]**, **[7]**.

Regional management is a system of self-coordination where by a region or unit harmonises its ecological functions with the economic and social needs of its people for sustainable development **[15]**. In regional management, the importance of a region as a political entity is emphasised. Political responsibility concerning important decisions regarding regional development is left up to regional actors. The territorial principle is being replaced by the functional principle i.e. political responsibility of regions is no longer solely defined by administrative levels and borders (e.g. governmental districts), but rather also by the concept of Regional Governance which understands a region to be a dynamic area of cooperation between actors which is formed due to the density of social relations between regional actors **[16]**. Through this, the dynamic area of cooperation is able to perform different tasks on which the regional actors mainly decide themselves (for example as an economic, tourist or nature protection region **[16]**). There is inter sectorial cooperation through weakly institutionalised regional networks and partnerships. The potential of networks and cooperation between regional actors is central to the concept of Regional Governance (**[16]**, **[17]**, **[18]**, **[19]**, **[20]** and **[21]**). Cooperation encompasses the horizontal level on the one hand (partnerships on a regional level) and the vertical level on the other (partnerships between the region and higher political levels, which for example can clearly be seen in the EU structural policy's partnership principle). There is also hierarchical steering of incentives through various instruments and forms. The fact that more often than not, regional cooperation in the sense of Regional Governance/Management does not come about naturally, and that it must usually first be initiated, is problematic **[16]**. Different instruments which may act as potential incentives in building regional cooperation must then come into play. Within this context, Benz discusses "the hierarchical steering of incentives" **[16]**, which he refers to as the always important hierarchical potential of the State when initiating regional cooperation. This kind of incentive steering can be fulfilled through different forms: Higher state levels often use competition as an instrument in order to identify regions as promising for successful development of Regional Governance **[22]**. Regional management in Nigeria predates the creation of an entity called Nigeria (1914), when various peoples that existed independently had established their own indigenous systems of administration. The recognised political entities then included: Ife Kingdom, Benin Empire, Kanem Bornu Empire, Sokoto Caliphate, and Oyo Empire, to mention a few [23]. The Empires and Kingdoms had established contact with one another and with other peoples through trading activities. On 1st October 1960, Nigeria became self-governing from British colonial rule and was administered at the centre by the federal government and three regional governments in the east, west and north of the country. In 1963, the Midwest Region was carved out of the Western Region making a federation of four Regions. During this First Republic, a parliamentary system of government was in operation and this lasted until January 1966 when the military took over and this lasted reasonably until 1999 when democratically elected government became stable in the country. During this period of regional settings, the eastern region was particularly noted for buying and selling, and this was used to support its economy. The northern region developed its subsistence farming and was able to build a groundnut pyramid. The western region (where Ile-Ife is located) also developed its cash-crop farming such as cocoa, coffee, kola nut and others, and with this, the region saw tremendous development of its education, social services, health services and infrastructural facilities (e.g. cocoa house) **[23]** and **[24]**. **Figure 1** shows the map of ancient city of Ile-Ife.

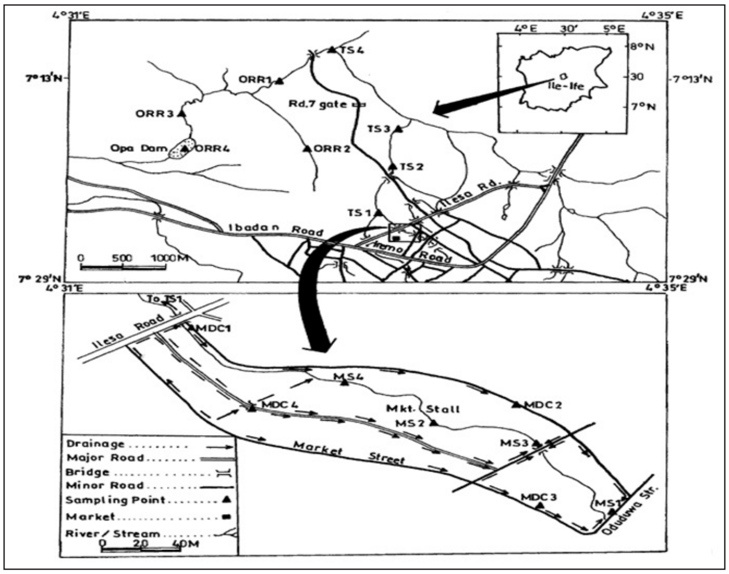

Figure 1: Map showing Ancient City of Ile-Ife. Source: [6]

2. Materials and methods

2.1. Materials

With the service of our qualified builder in the Department of Building at the Obafemi Awolowo University, three building models each with the area of 0.7025m^2 were constructed. Model 1 was constructed of mud bricks, model 2 was constructed of concrete blocks and model 3 of cast concrete. Each of the models was first roofed with galvanised Iron roofing sheets, later with aluminium roofing sheets and finally with asbestos roofing. The models are as shown in **Figure 2** (Figure 2a, 2b and 2c, respectively).

(a): A model mud-brick house (b): A model concrete house (c): A model cast concrete house

Figure 2: Developed building models constructed of various materials

2.2. Method

The thermal behaviour of the aforementioned building materials was studied by taking measurements on site. Temperature and humidity measurements were taken with the help of Tinytag data loggers (TGP-4500). For each set of data, one data logger was placed outside in a shaded area protected from direct sunlight and rain, while the others were placed inside the buildings to record external and internal temperatures concurrently. Data thus collected could help demonstrate how the building envelope performed in terms of its insulation and thermal inertia properties under natural conditions.

3. Results and discusion

For the sake of clarity, temperature and humidity measurements for only three days are presented graphically i.e. from 26th to 28th August 2013 for Model 1 (constructed of mud bricks), model 2 (constructed of concrete blocks) and model 3 (constructed of cast concrete). The 24 hours for which the test was conducted was such that the first hour started from 12:00 midnight.

3.1. Temperature situation under galvanised iron roofing sheet

Figure 3 shows typical behaviour of cast concrete, mud-brick and concrete-block buildings under galvanised iron roofs. It was noticed that the average indoor temperature of building model 1 was higher than ambient temperature by 3.5^{O}C, model 2 was higher by 0.5^{O}C, and model 3 was higher by 4^{O}C. It can be seen that model 3 remains superior in terms of temperature variation among the three models for this type of roofing.

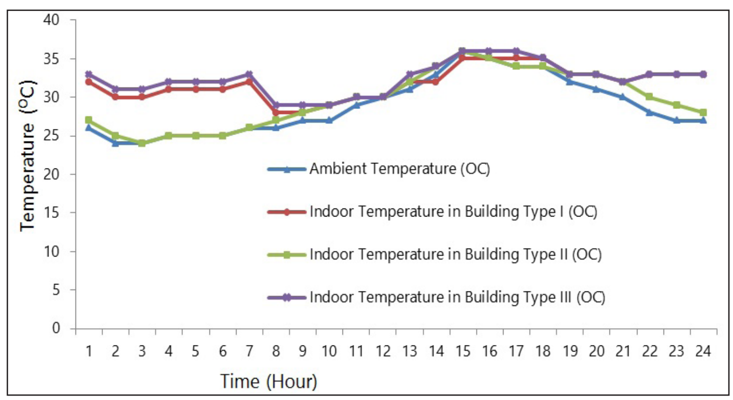

Figure 3: Plot of resulting indoor temperature in the three building types against time of day when roofed with galvanised iron roofing sheets

3.2. Temperature situation under aluminium roofing

Figure 4 shows the typical behaviour of cast concrete, mud-brick and concrete block buildings under aluminium roofs. It can be seen that the average indoor temperature of building model 1 was higher than ambient temperature by 3^{O}C, while that of model 2 was not higher by any degree, and model 3 was higher by 3.5^{O}C. It can be seen that model 3 still remains superior in terms of temperature variation among the three models for aluminium roofing.

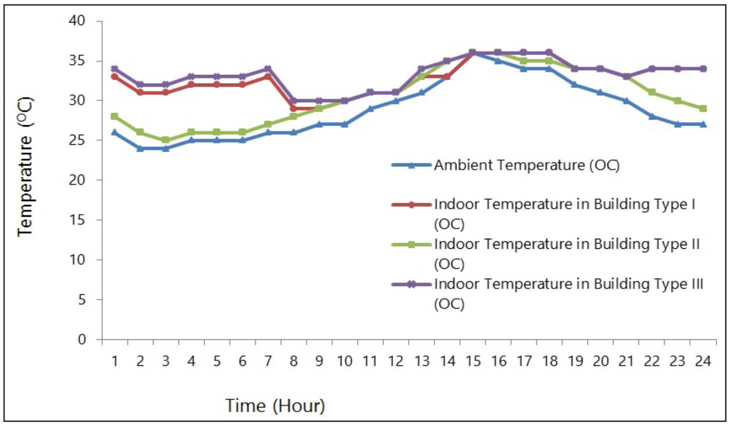

Figure 4: Plot of resulting indoor temperature in the three building types against time of day when roofed with aluminium roofing sheets

3.3. Temperature situation under asbestos roofing

In tropical regions, with reference to Nigeria, materials like zinc, aluminium and asbestos are commonly used in the form of sheets for roofing in modern building constructions **[25]**. **Figure 5** shows the behaviour of cast concrete, mud-brick and concrete block buildings under asbestos roofs. It can be seen that the average indoor temperature of building model 1 was higher than ambient temperature by 4^{O}C, model 2 was higher by 1^{O}C, and model 3 was higher by 5^{O}C. It can be seen that model 3 is superior in terms of temperature variation among the three models for asbestos roofs.

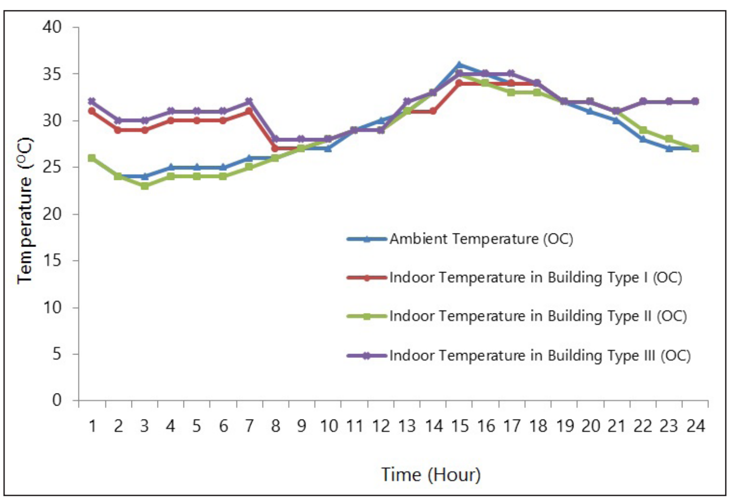

Figure 5: Plot of resulting indoor temperature in the three building types against time of day when roofed with asbestos roofing sheets

3.4. Relative humidity under each roofing sheet

Figure 6 shows typical behaviour for the different building models under a particular type of roofing. It was observed that relative humidity remains stable for all three types of building models with a particular type of roofing sheet. 67.6% relative humidity was noticed for galvanised iron sheets, 80% for aluminium roofing sheets and 64.4% for asbestos. We suspect that the observation to have the same level of relative humidity in all the three types of building models under the same type of roofing must have been occasioned by the fact that irrespective of the types of building involved, the type of roofing must have informed the same level of room temperature in each case which correspondingly determined the same value of moisture content or relative humidity of the air. In general, the results for internal temperatures in the mud-brick and cast concrete buildings (as shown in **Figure 3**, **Figure 4** and **Figure 5**) remained fairly stable despite external diurnal fluctuations. The humidity data collected also showed that fluctuations in external humidity levels do not affect humidity levels within the mud-brick and cast concrete structures significantly (**Figure 6**). We suspect that the good thermal insulation/heavy thermal mass properties of mud bricks and cast concrete are responsible for this observation. It follows that even without providing any air conditioning it is possible to keep internal air temperatures of a building close to thermal comfort levels by preventing extreme temperature conditions and also by avoiding temperature and humidity fluctuations, which cause discomfort to occupants. This can be done by taking into consideration the thermal properties of wall materials during the design stage. On the other hand, the structure made of concrete blocks responded more to external fluctuations in temperature and humidity. Equally, we suspect this to be attributed to the numerous pores in the blocks or the light thermal mass properties of the concrete blocks. It was also discovered that aluminium roofing gave the highest internal temperature, followed by galvanised iron roofing sheets and the lowest values were seen with asbestos roofing. This must be related to the thermal conductivity of each roofing sheet involved.

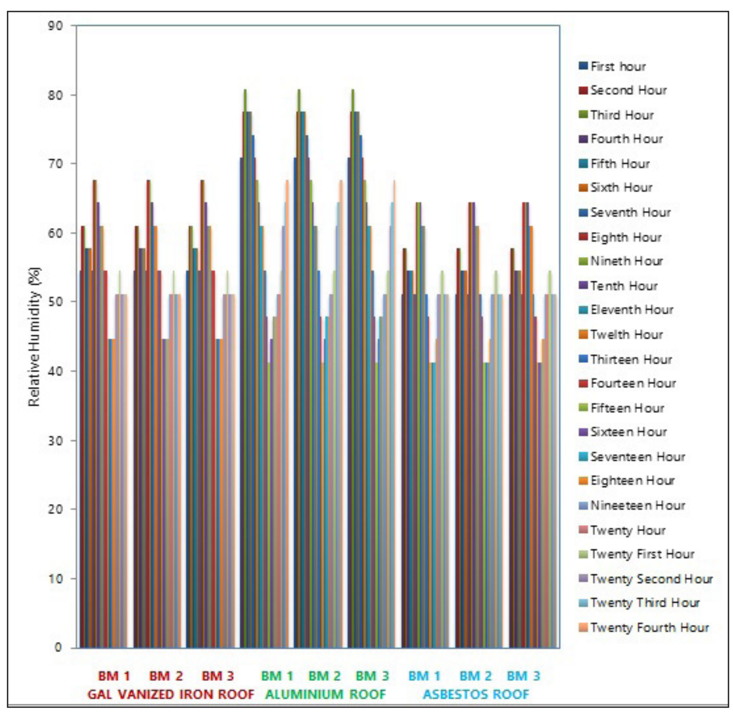

Figure 6: Plot of resulting indoor relative humidity in the three building types against time of day when roofed with the galvanised iron, aluminium and Asbestos roofing sheets

4. Conclusion

This study established that both mud bricks and cast concrete are fairly stable in terms of temperature and humidity variations despite external diurnal fluctuations. By implication, buildings made of mud bricks and cast concrete can be said to be energy efficient as there will be no need to always condition the buildings using extra energy. In addition to these findings, the literature shows that the energy required to produce mud-brick buildings is minimal and the material is completely bio-degradable. Although for the external diurnal fluctuations, building model 3 with cast concrete gave the most satisfactory performance in terms of thermal comfort, building model 1 with mud bricks also gave satisfactory performance that was close to that of model 3. The study concludes that building model 1 with mud bricks roofed with asbestos is the best building model in terms of thermal comfort, affordability and the other aforementioned advantages in Ile-Ife and other similar cities/towns in the tropics. The study also concludes that if the federal government of Nigeria can help develop model 1 (mud bricks) in the region, it will lead to sustainable development for the people.

5. References

[1] Otegbulu AC, Osagie JU, and Afe YO. The built environment perspective of climate change- a focus on household activities in Lagos metropolis. Journal of Sustainable Development 2011; 4(5): 174-187. Doi: http://dx.doi.org/10.5539/jsd.v4n5p174

[2] Runfolaa D M, Polsky-b M, Nicolsonc C, Giner-b NM, Pontius Jr. b RG, Krahe-b J, Decatur A. A growing concern? Examining the influence of lawn size on residential water use in suburban Boston, MA, USA. Landscape and Urban Planning 2013; 119: 113-123. Doi: http://dx.doi.org/10.1016/j.landurbplan.2013.07.006

[3] West S. Improving the sustainable development of building stock by the implementation of energy efficient, climate control technologies. Building and Environment 2001; 36(3): 281-289. Doi: http://dx.doi.org/10.1016/S0360-1323(00)00007-X

[4] Carnes TN. Indoor sound criteria according to the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)—An introduction. Journal of the Acoustical Society of America 2005; 118: 1843. Doi: http://dx.doi.org/10.1121/1.4778485

[5] Ferguson AJ. Handbook of heating, ventilating and air conditioning: 8th Edition. International Journal of Refrigeration 1983; 6(3): 186-187. Doi: http://dx.doi.org/10.1016/0140-7007(83)90102-0

[6] Eludoyin AO, Ofoezie IE, Ogunkoya OO. The effect of oja-titun market effluent on the chemical quality of receiving opa reservoir in Ile-Ife, Nigeria. Journal of environmental management 2004; 72(4): 249–259. Doi: http://dx.doi.org/10.1016/j.jenvman.2004.05.005

[7] Delso G, Ziegler S. PET/MR System Design. In I. Carrio and P. Ros, Eds., "PET/MRI". Springer Berlin Heidelberg; 2014, p. 1-19. Doi: http://dx.doi.org/10.1007/978-3-642-40692-8

[8] Ajibola K. Design for comfort in Nigeria – a Bioclimatic Approach. Journal of Renewable Energy 2001; 23: 57-76. Doi: http://dx.doi.org/10.1016/s0960-1481(00)00113-0

[9] Bodalal A, Zhang JS, Plett EG . A method for measuring internal diffusion and equilibrium partition coefficients of volatile organic compounds for building materials. Building and Environment 2000; 35(2): 101-110. Doi: http://dx.doi.org/10.1016/S0360-1323(99)00005-0

[10] Cengel YA. Heat Transfer. In Capehart BL, editor. Encyclopedia of Energy Engineering and Technology-3 volume Set (Print Version). US: Taylor and Francis Group, LLC; 2007, p. 822-829. Doi: http://dx.doi.org/10.1201/9780849338960.ch97

[11] Wilkes KE, Rucker JL. Thermal performance of residential attic insulation. Energy and Buildings 1983; 5(4): 263-277. Doi: http://dx.doi.org/10.1016/0378-7788(83)90014-2

[12] Glavic P, Lukman R. Review of sustainability terms and their definitions. Journal of clean production 2007; 15 (18): 1875-1885. Doi: http://dx.doi.org/10.1016/j.jclepro.2006.12.006

[13] Gagliano A , Patania F, Nocera F, Signorello C. Assessment of the dynamic thermal performance of massive buildings. Energy and Buildings 2014; 72: 361-370. Doi: http://dx.doi.org/10.1016/j.enbuild.2013.12.060

[14] A. Davraz, R. Karaguzel, I. I. Soyaslan. The importance of hydrogeological and hydrological investigations in the residential area: a case study in Burdur, Turkey. Environmental Geology 2003; 44(7): 852-861. Doi: http://dx.doi.org/10.1007/s00254-003-0830-1

[15] Fürst D, Kilper H. The innovative power of regional policy networks: A comparison of two approaches to political modernization in North Rhine-Westphalia. European Planning Studies 1995; 3(3): 287-304. Doi: http://dx.doi.org/10.1080/09654319508720308

[16] Michael Böcher. Regional Governance and Rural Development in Germany: the Implementation of LEADER+. Sociologia Ruralis 2008; 48(4): 372-388. Doi: http://dx.doi.org/10.1111/j.1467-9523.2008.00468.x

[17] Benz A. Public Administrative Science in Germany: Problems and Prospects of a Composite Discipline. Public Administration 2005; 83(3): 659-668. Doi: http://dx.doi.org/10.1111/j.0033-3298.2005.00468.x

[18] Benz A, Fürst D. Policy Learning in Regional Networks. European Urban and Regional Studies 2002; 9(1): 21-35. Doi: http://dx.doi.org/10.1177/096977640200900102

[19] Simon Guy S, Graham S, Marvin S. Privatized Utilities and Regional Governance: The New Regional Managers? Regional Studies 1996; 30(8): 733-739. Doi: http://dx.doi.org/10.1080/00343409612331350018

[20] Baldassare M. Regional Variations in Support for Regional Governance. Urban Affairs Review 1994; 30(2): 275-284. Doi: http://dx.doi.org/10.1177/004208169403000205

[21] Mangiameli S. The Role of Regional and Local Government in European Governance. In Blanke H, Mangiameli S, editors. Governing Europe under a Constitution. US: Springer Berlin Heidelberg; 2006, p. 457-481. Doi: http://dx.doi.org/10.1007/3-540-31291-9_29

[22] Albrecht M, Elbe J, Elbe S, Meyer W. Analyzing and evaluating regional governance networks: Three challenges for applications. Evaluation 2014; 20(1): 58-74. Doi: http://dx.doi.org/10.1177/1356389013518457

[23] Frankema E, Waijenburg M. Metropolitan Blueprints of Colonial Taxation? Lessons from Fiscal Capacity Building in British and French Africa, *c.* 1880–1940. The Journal of African History 2014; 55(3): 371-400. Doi: http://dx.doi.org/10.1017/S002185371400036X

[24] Adalemo IA, Balogun OY. The Status Of Cartography In Nigeria. In Festschrift A for Ormeling FJ editor. Cartography Past, Present and Future. US: Elsevier Science Publishers Ltd; 1989, p. 15-26. Doi: http://dx.doi.org/10.1016/B978-1-85166-336-1.50006-0

[25] Etuk SE, Akpabio LE, Akpabio KE. Investigation of *Raphia hookeri* trunk as a potential ceiling material for passively cooled building design. Ghana Journal of Science 2005; 43(1): 3-7. Doi: http://dx.doi.org/10.4314/gjs.v43i1.15894