

ARCHISEARCH

INTERNATIONAL JOURNAL OF ARCHITECTURE AND ENVIRONMENT

ISSN 2141-9019 2014 Volume 4, Issue 1

ARCHISEARCH

International Journal of Architecture and Environment

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Volume 4 Issue 1 (2014)

Published by:
Department of Architecture, Ahmadu Bello University, Zaria-Nigeria

Cover image:
Dominion Office Building by Zaha Hadid
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https//www.yatzer.com/dominion-office-building-moscow-russia-zaha-hadid-architects/slideshow2
Cover design:
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This publication is typeset in Times New Roman font (size 12) at the Department of Architecture, Ahmadu Bello University, Zaria. Articles published in this journal represent neither the views of the Editor-in-Chief nor the Department of Architecture, Ahmadu Bello University. Responsibility of opinions expressed and accuracy of facts rests solely with individual authors.

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- Introduction outlining the Background to the study; Problem statement; Aim, objectives, hypothesis, premise or research question(s) as well as Organization of paper
- Literature review
- Methodology/research instruments
- Results/Findings and Discussion
- Conclusion, Acknowledgements and/or Appendices
- References according to the latest APA style

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Dr. Abubakar Abdullahi (Editor-in-Chief)
Email: **abdulubale@yahoo.co.uk**
+234 803 703 6780
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Space syntax methods in Architecture and Housing Research[1]

Joy Joshua Maina
Department of Architecture, Ahmadu Bello University
Email: jjmaina@abu.edu.ng

Abstract

Space syntax is an analytical method that emerged within architecture in response for the need to develop a strong theoretical base within the discipline. It has been employed over the last three decades to analyze space and hidden patterns in the built environment. Extensively employed in architecture, urban planning, archaeology, sociology and environmental psychology, its approach and methodologies have remained relatively unknown within architecture and the housing research community in Nigeria. This paper presents a basic overview specifically convex map analysis to researchers unfamiliar with its methods from related literature and the author's research experiences. The paper concludes that combining quantitative results from space syntax analysis with qualitative observations of space use patterns proffer robust results for architecture and housing related studies in future.

Keywords: Architecture, Convex map analysis, Housing research, Space syntax

1.0 INTRODUCTION

Architectural discourse in the last century has largely focused on theories and debates, the results of which have guided the production of architectural form whilst proffering possibilities for improving design solutions and quality of the built environment. Despite their great influence, Hillier (2007) notes that architectural theories have in the last decade generally suffered in two notable ways. First, "they have been strongly normative and weakly analytic . . . second . . . the historic tendency to form architectural theories out of ideas and concepts borrowed from other disciplines" (ibid, p. 2). In being normative, architectural theories have been governed by rules and telling "designers how buildings and environments should be and too little concerned with how they actually are" (ibid). On the other hand, while borrowing ideas from other disciplines opened architecture up to a wider intellectual debate (Leach, 1997), it fostered the tendency to turn away from "lessons waiting to be learned from the extensive study of experimental 20th Century architecture" (Hillier, 2007, p. 2). The consequence was a lack of internal development of architecture as a discipline.

It was out of the concern to develop an appropriate theoretical framework for genuine analysis within architecture that Hillier and Hanson (1984) proposed the idea of space syntax

[1] This is a modified version of a paper presented at the Dept. Architecture Seminar Series, 2014

based on the direct study of buildings and spaces which together, make up the built environment. Space syntax is basically 'a method for measuring space and identifying patterns in space use . . . based on the assumption that order in space originates in social life' (Asquith 2006, p. 4). The methods of analysis have been employed to analyze individual buildings, houses, settlements, urban areas and cities over the last two decades across many disciplines.

In urban planning, space syntax was employed to correlate spatial integration with observed pedestrian movements in Stockholm (Marcus, 2010), the World Squares for All projects and Trafalgar Square in Central London (Major, Penn, Spiliopoulou, Doxa and Fong, 1999; Foster, 1997) as well as for the re-planning of the famous Old Market Square in Nottingham (Hillier, 2007). In archaeology, space syntax analysis was employed to determine social identities in a monumental building of the late Bronze Age c. 1650-1100 BC in Cyprus (Fisher, 2009). It was also employed to infer social factors responsible for the layout of ancient Teotihucan (Hillier, 2007) as well as to establish social and cultural aspects of space use in domestic spaces in Doura-Europos, Ancient Near East (Benech, 2007). In Sociology, Choi (2001) demonstrated how power was displayed and sustained via the spatial morphology of traditional villages and houses in Korea while Kong and Kim (2012) developed a spatial index based on visual analysis to predict sales and shopping. In Environmental psychology, space syntax methods have been employed to investigate way finding and visual functioning in university campuses, educational structures and museums (Greene and Penn, 1999; Bafna, Antunez, Hyun, Lee and Lu, 2009; Schneider et al. 2013; Psarra, 2007). Architecturally, space syntax methods have been extensively employed to investigate spatial order, crime and security (Awtuch, 2009; Major, Penn and Hillier, 1999; Shu, 1999), space and sustainability (Hillier, 2009), house form and culture (Dawson 2006, Orhun 1999, Hanson 1998) as well as cultural and housing transformation patterns for settlements and houses (Cil, 2007).

Despite its growing awareness and influence on research and practice as illustrated above, space syntax methods and applications remain comparatively unknown within the architectural and housing research community in Nigeria. This paper therefore presents an overview of its concepts and ideas to researchers unfamiliar with its methodology and analytical procedures from literature and the author's research experience in the course of completing a doctorate program.

The paper is organized in five sections after the introduction. Section 2 reviews literature on the origins and theoretical foundations of space syntax while its method of analysis in architectural and housing research is presented in Section 3. Section 4

demonstrates these applications in architectural and housing research in Nigeria, followed by conclusions and references to the study in Sections 5 and 6 respectively.

2.0 OVERVIEW OF SPACE SYNTAX

2.1 Theoretical background

Human beings perceive the built environment as the physical form that is built and seen and as spaces used for activities and movement (Hillier, 2005). 'For most of history of architecture, theory and criticism focused only on the first, the physical form' (ibid, p. 2). Architecture began to only theorize about space from about the 19th Century, with little consensus as to what space is and how it matters. 'Everyday intuition tells us that the space created by buildings and cities exists for us as patterns of differentiated and related spaces, which somehow reflect or embody patterns of life. But this intuition has proved hard to address analytically, since it presents both philosophical and methodological difficulties' (ibid). Philosophically and by implication methodologically, it is difficult to capture or characterize space in that it seems to be the emptiness surrounding things rather than a thing in itself (Hillier, 2005). Furthermore, even if it does exist, does it do so as an independent entity or as part of the structures that often delineate it? As such, the theoretical ideas and paradigms about space at the turn of the 20th Century rarely addressed space as found in real life architecture and urban design. Consequently, space syntax 'seeks to extend commonsense intuitive view of space as relations . . . to the far more complex spaces that we routinely create and seem to understand through architecture and urban design by making these complexes of spatial relations explicit rather than implicit' (ibid, p. 4). In other words, space syntax addresses the study of space as relatedness, as created by buildings and cities and experienced by the people who use them.

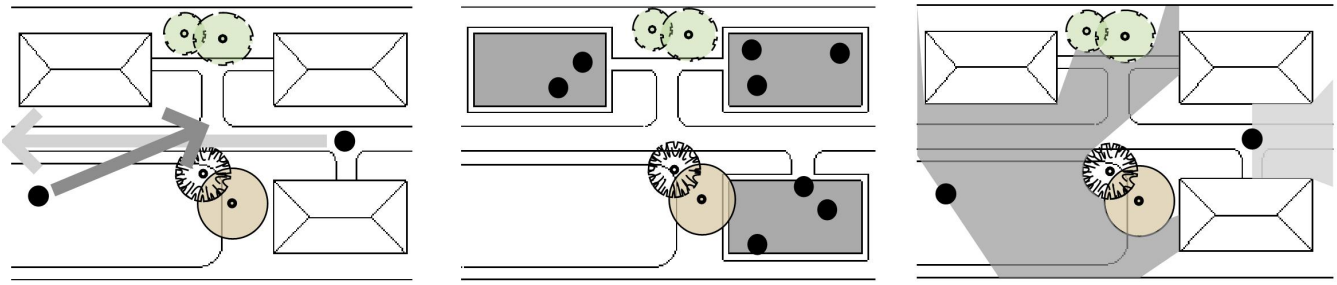
2.2 Foundations and theories

Space syntax is a theory and set of methods about space built on two ideas-that of space being an intrinsic aspect of human activity and its relationship to other spaces which make up the layout of a building or city as a whole (Hillier, 2005).

2.2.1 Space as an intrinsic aspect of human activity

The common view of space is as a background to human activity. This presupposes space as an entity, which depends on the said activity. To effectively conceptualize space, it needs to be conceived as an intrinsic independent aspect of everything human beings do e.g. moving through space as a line (or axis), interacting with people within bounded areas such as rooms or open parks in a city (or convex spaces) and seeing vistas from a stationary point in

between buildings via changing visual fields as an isovist (Figure 1). Each of these movement or sight patterns possess and can be described by their geometric characteristics, which are independent of human activities carried out within them.



a) People move in lines *b) People interact in convex spaces* *c) People see changing visual fields or isovists as they move around the built environment*

Figure 1: Space, an intrinsic aspect of activity and not just a background for it.

2.2.2 The inter-relations between spaces as part of a whole layout

These geometrical constructs however rarely exist in isolation but are part of a whole spatial layout of a street, building or city in a pattern rarely explicit but often intuitively known. This is referred to as the configuration of space, 'meaning the simultaneously existing relations amongst the parts which make up the whole' (Hillier, 2005, p. 5). Mathematically, space syntax seeks to formulate 'the configurational properties of space that we intuit as manifested in the way in which we construct real spatial patterns through buildings and cities' (ibid, p. 6). It quantitatively expresses the relationship between geometries delineating human activity as part of a whole system or layout of connected spaces using a specific mathematical measure or figure such as the integration value (IV). Space syntax is about 'applying configurational measures to the patterns of different geometric elements that are created by buildings and cities' (ibid, p. 7). The choice of which geometry to choose from, be it lines, convex spaces, isovists or even points for analysis will depend on which aspect of functionality and movement is being investigated.

3.0 METHODS OF ANALYSIS

3.1 Basic elements of analysis

There are three basic geometric elements in space syntax analysis (Klarqvist, 1993). These include the axial line, convex space and isovist field. The theory behind these elements is that human beings move in lines, interact in convex spaces and view vistas in changing panoptical views when moving around the built environment (Hillier, 2005, van Nes, 2011).

The axial space or line is a straight line possible to follow on foot; it represents the longest sight line one has in a building, urban space or street, which serve as movement routes especially in the urban realm (Figure 1a). In the last two decades, "the axial line has been the basic spatial element in the methodology and theoretical development of space syntax in urban studies" (van Nes 2011, p. 166). This is because movement in the urban network is mostly linear passing through streets, roads, alleys, highways, paths, subways, sidewalks, bridges etc. Relationships between such features of the urban network are analyzed using an axial map, "which depicts the least number of axial lines covering all convex spaces of a layout and their connections" (Klarqvist, 1993, p. 11)

A convex space is defined as a space such that "all points within that space can be joined to all others without passing outside the boundary of the space" (Hillier 1998, p. 68). This depends on the panoptical view or one that encompasses everything that is visible. In space syntax, this definition usually means an enclosed space bounded on all sides used for occupation or human activity such as sitting or standing (Figure 1b). Consequently, convex maps are employed in the analysis of building plans, layouts or public spaces bounded by a group of buildings such as open parks. These are analyzed syntactically using a convex map, which represents "the least number of convex spaces that fully cover a layout and the connections between them" (Klarqvist, 1993, p. 11).

An isovist field represents the panoptical view a person has from a given point(s) in an urban or enclosed space (Figure 1c). It is mostly employed for way finding or orientation purposes (van Nes, 2011). Isovist analyses are therefore useful for analyzing the degree of visibility of the location of a focal part of a building or urban area e.g. views from room openings in a museum to a specific display or views to a tower or important building in a city. Additionally, "isovist analyses are useful in studies on how trees and vegetation can block the degree of inter-visibility in parks. It can identify places attractive for junkies to operate or places where there might be a risk of getting raped" (van Nes, 2011, pp. 173-174). An isovist map represents "the areas that are visible from convex spaces or axial lines" (Klarqvist, 1993, p. 11).

All three types of syntactic maps can be converted or transformed into graphs, often in the form of justified permeability graphs (JPGs, commonly known as J-graphs). A J-graph is a figure representing the relationship of movement and permeability between spaces in a layout. It examines patterns of connections between nodes or vertices (axial lines convex spaces or a point in an isovist field) and the links between them. Because architectural floor plans and housing layouts are represented as convex spaces, the succeeding section primarily

focuses on convex map analysis. It is pertinent to note however, that axial and isovist map analyses follow the same basic principles, the specifics of which will be the focus of a forthcoming paper.

3.2 Convex map analysis for architectural and building plans/layouts

3.2.1 Convex map JPG

A convex plan is usually constructed from the architectural floor plan of a layout or house (Figures 2-3), which is converted into a graph displaying nodes or rooms and lines or connections. All spaces in the map are then labeled (Figure 4). A bubble-like graph showing the line of movement, accessibility and permeability is then produced from the map (Figure 5). To produce a j-graph for a particular space, the space is placed at the bottom and is called the root node. Spaces of equal step depth from this space or root node are then placed on a horizontal line and multiplied by the number of spaces in each step. These are then added to give the total depth, $\underline{d}$ for the root node (Figures 5-7). The JPG may then be subjected to mathematical analysis to produce a set of values describing the graph. These include mean depth, relative asymmetry, real relative asymmetry, integration values and difference factor (Hillier and Hanson 1984, Hanson 1998, Osman and Suliman 1994, Bafna 2003).

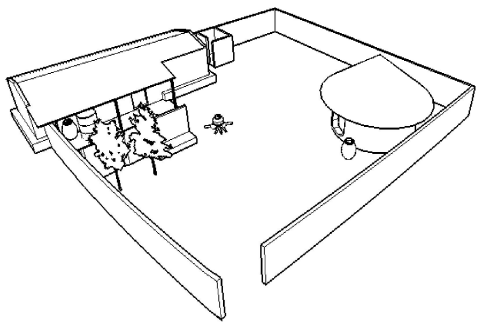


Figure 2: Compound X

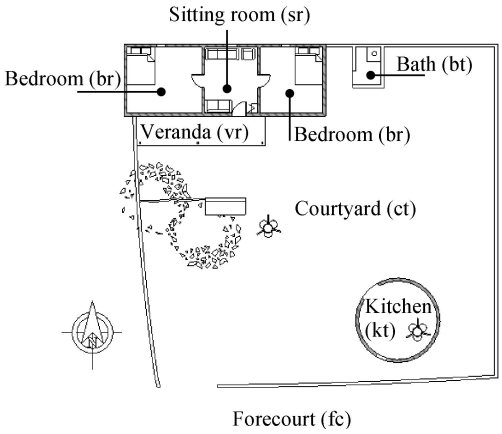


Figure 3: Compound X, floor plans, Adapted from Maina (2013b)

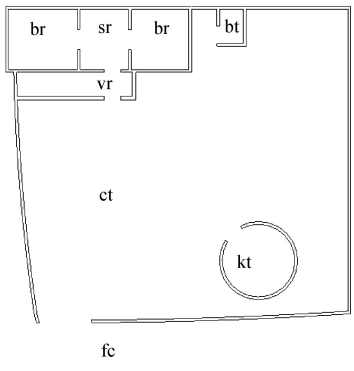


Figure 4: Compound X, labeled floor plan

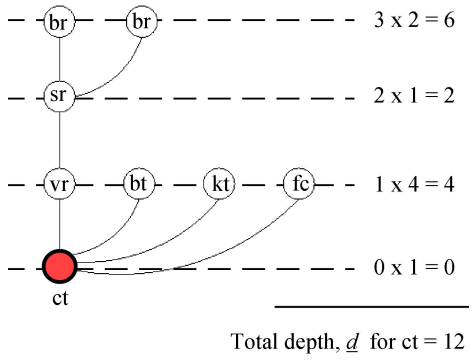


Figure 5: JPG for Courtyard as root node/space

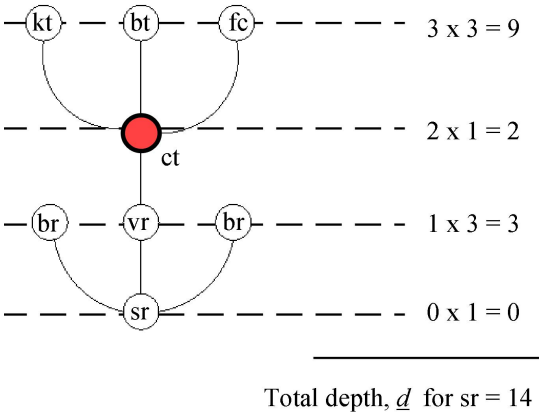


Figure 6: JPG for Sitting room as root node/space

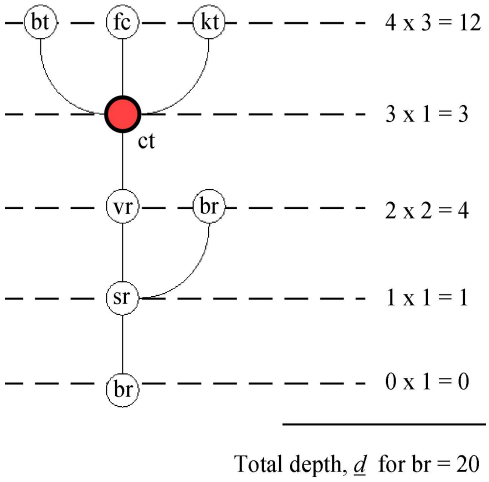


Figure 7: JPG for Bedroom as root node/space

i) Mean Depth, MD, is given by $\underline{d}/k$-1, where $\underline{d}$ is the total depth of all spaces from a root space and k the total number of spaces in the complex. For the courtyard space (ct) in Compound X (Figure 5), $\underline{d} = 12$, $k = 8$).

MD = 12/8 - 1 = **1.714**

ii) Relative Asymmetry, RA is the MD expressed as "a fraction of the maximum possible range of depth values for any node in the graph with the same number of nodes as the system" (Bafna, 2003, p. 25). For the courtyard space/node (ct) in Figure 5,

RA = 2 (MD – 1)/(k – 2) = 2 (1.714 - 1)/ (8 – 2) = 1.4285/6 = **0.238**

iii) Real Relative Asymmetry, RRA

RRA is a ratio of the RA values of the nodes of a given system and the RA values of the central node of an idealized diamond-shaped graph with the same number of nodes as the system (Dawson, 2008). It is obtained by the algorithm RRA = RA/D value for idealized k spaces (See Appendix). For Figure 5, D value for 8 spaces = 0.328.

RRA = 0.238/0.328 = **0.7259**

3.2.2 Integration Value, IV

This is a numerical figure calculated for each space in a complex as a reflection of the extent to which that space integrates or organizes access and movement, and by implication social network and activity within the complex (Hillier, Hanson and Graham 1987, Hanson 1998, Batty 2004, Hillier 2007). It is calculated as the inverse of the RRA. The higher this value, the more integrated that space will be on the floor plan or architectural layout. For Figure 5,

IV = 1/RRA = 1/ 0.7259 = **1.3776**

Research over time has established that spaces with high levels of social function and activity in a floor plan or urban network tend to have corresponding high IVs (Table 1). For instance, the courtyard and veranda spaces in Figure 2 support more than half (52%) of all functions and activities observed in the compound (Table 2). These also happen to be the most integrated spaces in the compound, having the shallowest JPGs (Figure 5) with the least depth, *d*. On the other hand, the bedrooms, situated deep within the layout are the least integrated, having the least number of observed functions (2), similar to the bath (Table 2).

Table 1: Syntactic values, Compound X

***k* - space**	**MD**	**RA**	**RRA**	**IV**	**IV 2sf**
Forecourt	2.57	0.523	1.596	0.626	0.63
Courtyard	1.714	0.238	0.725	1.379	1.38
Kitchen	2.57	0.523	1.596	0.626	0.63
Bath	2.57	0.523	1.596	0.626	0.63
Veranda	1.714	0.238	0.725	1.3776	1.38
Sitting room	2	0.333	1.016	0.984	0.98
Bedroom	2.8571	0.619	1.885	0.529	0.53
Bedroom	2.8571	0.619	1.885	0.529	0.53
Maximum	2.8571	0.619	1.885	1.379	1.38
Mean	2.357	0.452	1.378	0.836	0.84
Minimum	1.714	0.238	0.725	0.529	0.53

Table 2: Observed activities, Compound X (Source: Maina, 2013b)

Space	**Number of activities**	**Space**	**Number of activities**
Courtyard	18	Kitchen	2
Veranda	4	Bath	2
Forecourt	9	Bedroom	1
Sitting room	5	Bedroom	1

Several computer software programs such as Axman, Uba Pesh, Orange box, Axwoman, Mindwalk, Webmap etc have been developed to compute values for integration. The example illustrated below employs Depthmap version 10 developed at University College London (UCL). Floor plans have to be imported as DXF files before analysis in Depthmap. This procedure generated the same IVs for all eight spaces in Compound X, presented in Table 1.

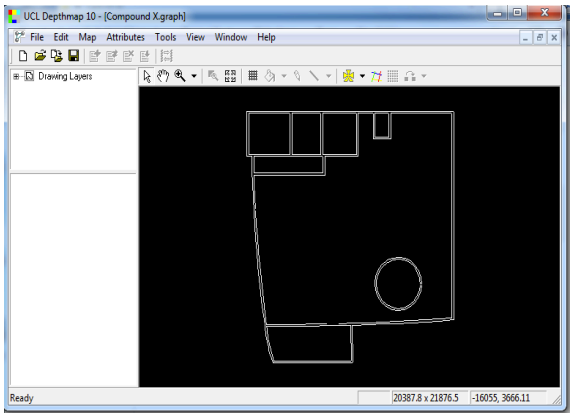


Figure 8: Importing the dxf file into Depthmap

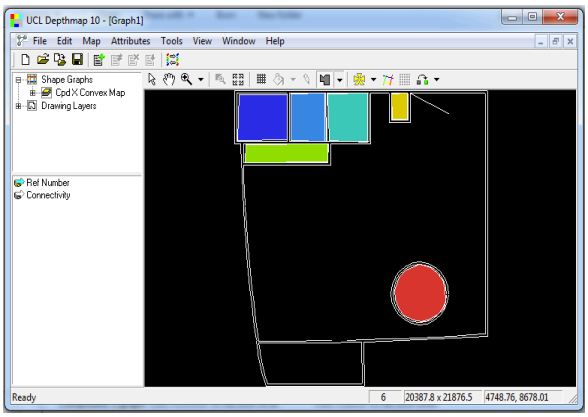


Figure 9: Creating the convex map

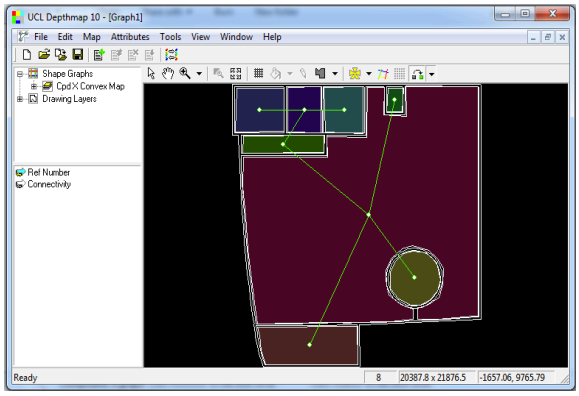


Figure 10: Linking the spaces, after which the analysis is run

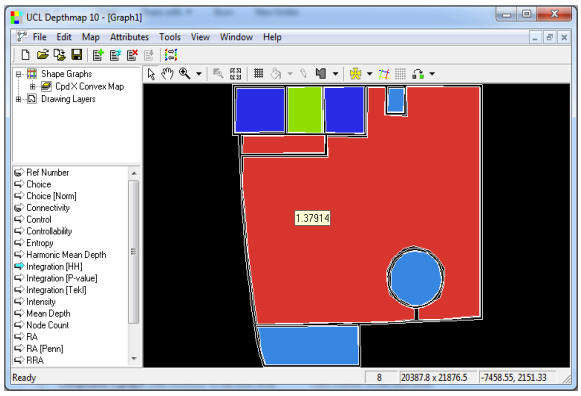


Figure 11: IV for courtyard space, 1.37814

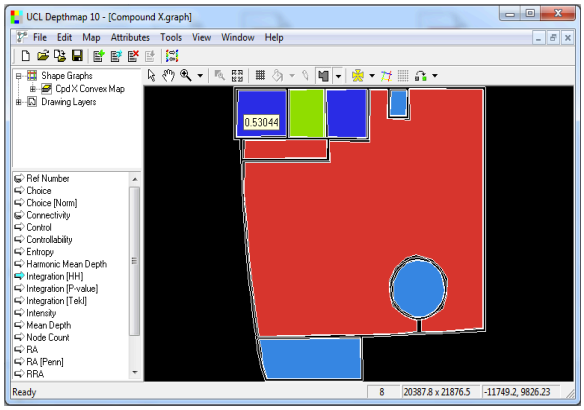


Figure 12: IV for one of the bedrooms, 0.532

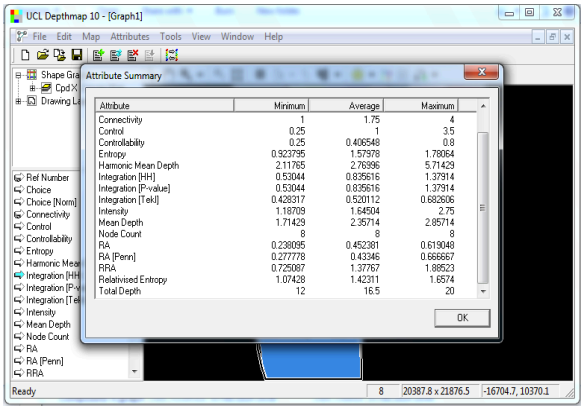


Figure 13: Summary of syntactic measures-RA, RRA etc

Apart from the IV, other syntactic values can be computed, which quantitatively represent building and urban layouts. These include Connectivity, Control and Global choice (Klarquist, 1993).

3.2.3 Connectivity

Connectivity measures the number of immediate neighbors that are directly connected to a space (Klarquist, 1993). The courtyard space in Figure 11 for instance has a connectivity measure of 4 because it is directly connected to the forecourt, kitchen, veranda and bath. This is a *local static* measure. Integration is however a *global static* measure as it describes the average depth of a space to all other spaces in the floor plan or layout. Together the connectivity and integration values of a layout can be correlated to establish how intelligible a layout is. From Figure 14, the intelligibility value of Compound X is approximately 0.7, showing the degree of how far the configuration of the layout can be inferred globally as a whole system by observing its local connections from its internal structure.

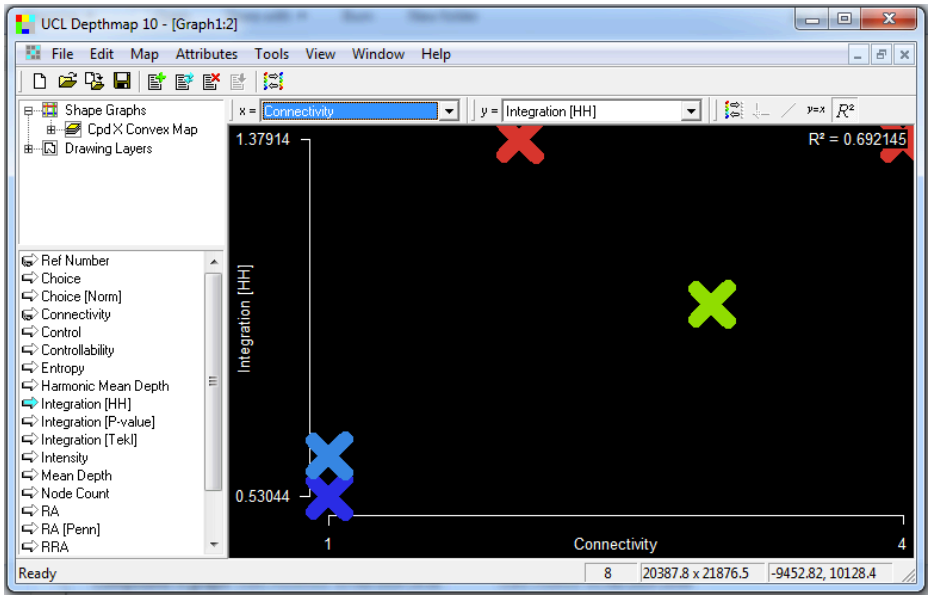


Figure 14: Intelligibility of Compound X, $R^2 = 0.692545$

3.2.4 Control value

Control value "measures the degree to which a space controls access to its immediate neighbors taking into account the number of connections that each of these neighbors has" (Klarquist, 1993, p. 12). It is a *local dynamic* measure, which reveals how well a space permits or restricts access to other spaces in the entire layout.

3.2.5 Global choice

Global choice, a *global dynamic* measure represents the flow through a space. "A space has a strong choice value when many of the shortest paths connecting all spaces to all spaces of a system pass through it" (ibid).

3.2.6 Difference Factor, *H**

In most cases, IVs differ for different spaces within a floor plan as illustrated in Table 1. This is one way social and cultural relations are expressed through space. These different values across several houses in a locality can be combined to establish if a cultural pattern or genotype exists using the difference factor, *H**. An inequality genotype is described "not as a given rank order of labeled spaces, but a statistically stable pattern of variation of those" (Bafna, 2001, p. 9). "If these numerical differences in functions are in a consistent order, then a cultural pattern exists, one that can be detected in things rather than just the way it is interpreted by minds" (Zako, 2006, p. 67). In other words, if IVs across many houses in a

locality differ in a similar pattern, a cultural genotype most likely exists in the area. This can be determined quantitatively using the algorithm[2]:

$$H = -\left[\frac{a}{t}\ ln\left(\frac{a}{t}\right)\right] + \left[\frac{b}{t}\ ln\left(\frac{b}{t}\right)\right] + \left[\frac{c}{t}\ ln\left(\frac{c}{t}\right)\right] \qquad H^* = \frac{H - ln2}{ln3 - ln2}$$

(Hanson, 1998, p. 28) where *H** is the difference factor calculated for each house or layout employing the minimum, mean and maximum RRA values obtained from JPG analysis of the house. For Compound X (Table 1 and Figure 13),

a = Minimum RRA value = 0.725
b = Mean RRA value = 1.378
c = Maximum RRA value = 1.885
t = 3.263 (i.e. 0.725 + 1.378 + 1.885)

H = - [0.725/3.263 ln (0.222)] + [1.378/3.263 ln (0.422)] + [1.885/3.263 ln (0.578)]
= - [0.222 (-1.505077897)] + [0.422 (-0.8627499649)] + [0.578 (-0.548181410)]
= - [-0.334127293] + [-0.364080485] + [-0.317159695] = 1.015367474
H* = 1.015367474 - 0.693/1.0986 – 0.693 = 0.322367474/0.4055 = **0.79**

If there are other houses with *H** of say 0.78, 0.8 and 0.77, then it can be inferred that a cultural genotype likely exists within the sample especially if other characteristics such as most integrated space, number of *k* spaces, depth *d* from the outside space and space-link ratio[3] are also consistent. This is beneficial in characterizing and categorizing the implicit socio-cultural factors that shape housing and domestic architecture in a specific locality.

Employing the methodology presented in this section, Muhammad Oumar (1997), Maina (2013), Adeokun, Ekhaese and Isaacs-Sodeye (2013) analyzed the domestic architecture of Hausa and Tangale cultures in the North as well as Yoruba and Benin cultures in Southern Nigeria respectively. These studies were basically carried out to advance our knowledge of traditional Nigerian housing especially regarding constancy and change in a modern age as well as proffer suggestions for the emergence of observed housing trends in contemporary times. The details of these studies are presented in the next section.

[2] Although other methods have been developed to compare the properties of graphs (Conroy-Dalton and Kirsan, 2008), the inequality genotype remains the most common (Ostwald, 2011).

[3] Space-link ratio is the number of links plus 1 divided by the total number of k spaces in a floor plan or layout. A tree like JPG will have a value of 1 while values greater than 1 indicate the degree of 'ringiness' or formation of rings in the floor plan (Hillier, Hanson and Graham 1986). For Compound X, the space link ratio will be 7+1/8 = 1 (Figure 10). This illustrates that there are no alternative routes or no rings within the floor plan. This influences the choice value of spaces.

4.0 APPLICATION OF SPACE SYNTAX FOR ARCHITECTURE AND HOUSING RESEARCH IN NIGERIA

4.1 Decoding Hausa living spaces

In *Gidaje*[4]*, the socio-cultural morphology of Hausa living spaces*, Muhammad Oumar (1997) set out to establish the basic characteristics and dominant spatial themes in Hausa domestic architecture, an area which had hitherto been 'largely sidelined if not totally ignored most especially in academia' (ibid, p. 33). The methodology employed surveys and space syntax analysis of 160 houses within the walled city of Kano in order to document the social, economical, spatial and physical properties of the compounds and to verify the hypothesis that a strong relationship exists between the spatial organization of Hausa domestic architecture and the social life its inhabitants.

The findings reveal three notable characteristics of Hausa domestic architecture. First, Hausa compounds had to be flexible enough to accommodate the physical growth of families. This result supports earlier findings in other Hausa cities, notably Zaria and Katsina proffered by Schwertfeger (1982) and Popoola (1984) respectively. Spatially, the study reports that Hausa houses in the study area contain a minimum of three spaces that include the *zaure* (entrance), *tsakar gida* (courtyard) and *daki* (room) together with the *bandaki* (toilet). These 'constitute what may spatially be termed universals . . . in simple terms, no house is fully constituted if any one of these spaces is missing' (ibid, p. 246). Secondly, two basic inequality genotypes exist within the surveyed sample, 'one commonly found in smaller single family houses and the other associated with socially big and larger houses' (ibid, p. 247). Thirdly, the study findings support the hypothesis that Hausa domestic architecture represented by the sample supports the socio-cultural set-up of the Hausa society. Additionally, three factors culturally determine spatial form of the Hausa house. These are the discrete demarcation of physical spaces, a strong bias towards diurnal gender restriction and exclusivity in quotidian and non-kindred use of space through the control of social space accessibility (Muhammad Oumar, 1997).

4.2 The spatial morphology of Tangale domestic spaces

In *Mana-the socio-cultural facets and spatial morphology of Tangale domestic spaces*, Maina (2013b) set out in part, to establish socio-cultural factors determining house form and residential structure in order to inform future housing policies in Tangale land, located in Northeast Nigeria. This is a region facing enormous security challenges and insurgency

[4] Houses (plural) in the Hausa language; *gida* (house, singular).

especially in the last three years. Additionally, the study sought to investigate the continued abandonment of government provided prototype units despite rising housing costs, insecurity and delinquency by comparing survey responses from 130 respondents, syntactic analysis and space use patterns observed within 45 community built compounds and 20 prototype units in Billiri, the main town occupied by the Tangale community[5]. 'Underlying this inquiry is the premise that certain traditional themes may not have been adequately incorporated in the design of the abandoned modern houses . . . this deficiency accounts for the abandonment of the housing units (Maina, 2013a, p. 311).

The study findings reveal five factors influencing house form and residential structure across the surveyed compounds. These include kinship, security, basic needs, gender roles and social status (Maina, 2013b). The comparative analysis also revealed the cultural themes of kinship, security and basic needs were not adequately reflected in the location and design of the prototype units, suggesting possible reasons for their abandonment (Maina, 2013a,). Whilst the community-produced compounds were located in occupied clan lands inhabited by patrilineally related households, the abandoned units were located in an area considered insecure by Tangale standards. Additionally, many compounds had single entrances and exits facing footpaths and streets to enhance security, unlike obtained in the prototype units. These requirements are critical in light of the enormous security threats faced by communities in Northeast Nigeria and ultimately influence the value of housing in the study area.

Basic needs were also found to influence spatial organization as settings for domestic activities. Space syntax analysis confirmed the courtyard as the most integrated space for 80% of the community-produced compounds (Maina, 2013a), correlating with space use patterns observed within them. Syntactically, two cultural genotypes were inferred from the sample. 'The first genotype is suggestive of the vernacular tradition in the community . . . closest in configuration to the traditional house form in Tangale land or its conservative mode' (ibid, p. 314). More than half the number of surveyed compounds belonged to this group. The second genotype is suggestive of a hybrid between traditional compounds and modern bungalows in the community, in transition or transformation between traditional and contemporary compounds, lending towards a generative mode. Whilst the H^* value of the prototype units classified them within the first genotype, the absence of courtyards within the units negates a fundamental characteristic of that genotype, furnishing more possibilities for their abandonment. Furthermore, whilst the compounds contained an average of 4 bedrooms, the

[5] These were part of the Federal Government's intervention in public housing delivery across all Local Government Area headquarters in the early 80's.

abandoned units contained a single bedroom designed to accommodate low-income families who frequently have large households, which necessitate flexible designs as families grow. This lack of flexibility proffered yet another reason for the continued abandonment of the government provided units (Maina, 2013a).

Consequently, the study recommends in part, locating future residential development within occupied clan lands in line with traditional practices towards enhancing security in the area. Future housing units also ought to contain basic spaces for Tangale compounds notably courtyards, verandas and provision for additional bedrooms and storage spaces as family sizes increase. Specifically, the study recommends that 'when the most integrated space in a house is not a courtyard, it should have a step depth of 1 from a courtyard or veranda' (ibid, p. 320). Together, these measures support the daily activities of the vast majority of Tangale households.

4.3 Investigating Yoruba and Benin domestic architecture

Space use patterns and building morphology in Yoruba and Benin compares three studies of traditional and contemporary dwellings from Ile-Ife and Benin City in Southwest Nigeria sharing a common natural history, exposure to similar external influences and a close geographical contiguity (Adeokun, Ekhaese and Isaacs-Sodeye, 2013). The first investigates the relationship between activity patterns and the spatial morphology of 126 houses while the second study focuses on culinary related activities within the domestic spaces of 75 houses. Both studies were conducted in Ile-Ife. The third analyses the spatial morphology and meaning in space use in 1141 Benin households. The space syntax methodology mainly focuses on the measures derived from the J-graph method specifically symmetry/asymmetry, depth, distributedness/non-distributedness[6], connectivity and control. All three studies involved the use of questionnaires investigating space use, meaning and the socio-economic characteristics of surveyed households.

Syntactic results from the comparative study reveal that Benin houses tend to be deeper than their Yoruba counterparts for both traditional and modern dwellings. Additionally, Benin traditional houses 'employed more transition spaces than the Ile-Ife traditional house, where movement is controlled by the *Orowa* space and is invariably direct from one function space into another mainly because of a stronger need for privacy and gender separation' (ibid, p. 18). The *Orowa* space in Ile-Ife traditional house functions as a

[6] 'Symmetry occurs when spaces bear identical reciprocal relationships to each other and no space unilaterally controls access to any other space, while asymmetry occurs when a particular space must be traversed in order to gain access to a third space. Distributedness assesses if there is a ring indicating alternative routes and non-distributedness, a single sequence of spaces' (Adeokun, Ekhaese and Isaacs-Sodeye, 2013, p. 9).

covered courtyard, which was shallow in an already shallow genotype, whilst the courtyard system in the Benin traditional house, *Oto Eghodo* were found to be deeper. Not surprisingly 'the multifunctional *Orowa* space proved to be the most integrated space in the house and vital to life in the traditional area' (ibid, p. 12). The *Orowa* genotype was the shallowest genotype in both Ile-Ife studies, where 6 main genotypes were identified in the first domestic space studies and 7 genotypes identified in the second study.

With regards use of space, a strong continuity in space use meaning was found in the Benin sample in comparison with those documented in Ile-Ife despite differences in spatial morphology described in the preceding paragraph in part because of the relatively structured manner space is employed in the Benin sample. The Ile-Ife samples presented a relatively low specialization of space use especially in key spaces such as living rooms and bedrooms. 'The generic function used to describe convex spaces rarely captured the variety of activities that occurred within many of the key space labels; indicative of high intensity of use of just a few space labels[7]' (ibid, p. 19). The Benin sample however reveals a more marked specialization in space use. 'The stratification of domestic activities and objects was also evidenced in the special function spaces encountered in the *Oto Eghodo* house (e.g. menstruating room etc) which are completely absent from the *Orowa* house' (ibid, p. 22).

The overarching conclusion to these findings is that although both cultures share a similar colonial past and geographical proximity, variations observed in the spatial morphology and domestic activity patterns reflects the openness of Yoruba culture to new experiences while the Benin culture is more modulated and structured by traditional customs and practices (ibid).

5.0 CONCLUSIONS

This paper presented the theoretical foundations and methodology of space syntax as a strategy for architectural and housing research with examples of how these methods were employed for studies in Nigerian communities. The examples presented reveal the rich quality of data and results accruing from such studies. Importantly, the examples illustrate one of the strengths and advantages of space syntax analysis: its ability to verify qualitatively generated theories and intuition from observed phenomena in quantitative terms. This is especially beneficial in a scientifically motivated and controlled age where hard facts are often preferred over observed entities, which though valid, are often considered non-generalizable and

[7] This finding on non-specialization of spaces/dominant use of few space labels correlates with observations of space use within Tangale compounds, Northeast Nigeria (See Maina, 2013b, p. 259-260)

subjective in nature. As all the three examples reveal, combining space syntax analysis with observations and documentation of space use offers more robust and realistic results for future architectural and housing studies.

6.0 APPENDIX

Table of D values for k-spaces for idealized diamond-shaped complexes. Source: Hillier and Hanson (1984), p. 112

k	D value	k	D value	K	D value	k	D value	k	D value
1		8	0.328	15	0.259	22	0.214	29	0.184
2		9	0.317	16	0.251	23	0.209	30	0.181
3		10	0.306	17	0.244	24	0.205	31	0.178
4		11	0.295	18	0.237	25	0.2	32	0.174
5	0.352	12	0.285	19	0.231	26	0.196	33	0.171
6	0.349	13	0.276	20	0.225	27	0.192	34	0.168
7	0.34	14	0.267	21	0.22	28	0.188	35	0.166

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ARCHISEARCH

APPLICATION OF CULTURAL AND TRADITIONAL FEATURES IN THE DESIGN OF CULTURAL CENTRES

Sylvanus Musa Hassan
Kaduna State University Nigeria
Email: architectsly@gmail.com

Abstract

In designing a cultural centre the Architect faces the challenge of how to best express the key cultural and traditional features of a society. This paper studied how tangible and intangible cultural and traditional features were identified, adapted, conceptualized and ultimately expressed by Architect's in the design of cultural centres. Case study qualitative research is used to analyze cultural centres, based on four variables; namely, the cultural and traditional specific features used by the designer, design concept, choice of location, and the building materials and construction technology used. The results revealed the various techniques used to express cultural identity; which include the use of abstract or direct mimicry of tangible and/or intangible cultural and traditional features in form, spatial patterns, surface ornamentation, building materials and techniques, and the location of buildings in areas that reinforce the cultural and historical identity of the society. The paper concludes that a combination of various techniques is the most commonly used and effective way to express cultural identity. The outcome of this research will hopefully provide architects and other designers with an understanding of the techniques used in expressing cultural identity, and possibly serve as a tool for criticizing and analyzing future works.

Keywords: Architecture, Cultural Centres, identity, design concept, traditional techniques

1.0 INTRODUCTION

Architecture can be viewed as an evidence of the traditions and cultural heritage of the society that creates it, ensuring the continuous dissemination of knowledge to future generations. Emmons, Hendrix, and Lomholt (2012) suggested that Architecture is an agent of recovery, reaffirmation, and a means of attesting to societal values and culture.

Therefore, Architects can play a role in the preservation and conservation of cultural heritage through the design of buildings such as cultural centres, which serve as the embodiment and means of visually expressing societal cultures and traditions.

The problem for the architect is therefore one of finding the most efficient means of expressing cultural identity in a way that can be easily appreciated. The research therefore studies some select cultural centres from around the world with, with a view to identifying the techniques used by the Architects to express cultural identity, from concept development to construction materials and techniques.

This paper is in six sections, following this introduction is the literature review, which sheds light on culture and tradition, cultural heritage and preservation, and cultural centres; this is done in an attempt to provide an appreciation for cultural centres as a tool for synergizing culture, tradition and architecture. The methodology sheds light on the research techniques used in conducting the study. The case studies section analyzes the various cultural centres selected based on four variables, culture and tradition specific features identified and used by the designers, location, design concept, and the choice of building materials and construction techniques. The results section highlights the findings from the case studies in a tabulated format, and finally the conclusion culminates the paper with a brief outline of the inferences.

2.0 LITERATURE REVIEW

2.1 What is culture and tradition?

"Culture includes distinctive spiritual, material, intellectual, and emotional features of a society or group, essentially culture is life; it defines a people and identity (Dasylva, 2006). Going by this definition it can be said that culture and tradition consists of tangible and intangible features like arts, crafts, architecture, and folklore and so on.

2.2 What is Cultural Heritage?

Cultural heritage as defined by The United Nations Educational, Scientific and Cultural Organisation (UNESCO) is:-

a. Monuments: Architectural works or structures of an archaeological nature, inscriptions, cave dwellings and combinations of features, which are of outstanding universal value from the point of view of history, art or science;
b. Groups of buildings: Separate or connected buildings which, because of their architecture, their homogeneity or their place in the landscape, are of outstanding universal value from the point of view of history, art or science.

These definitions show that Architecture is an important part of the cultural identity of a society or people, and provides evidence as to the history of the society's technologies, arts and crafts.

2.3 Why the Preservation of Cultural Heritage?

Conservation is defined by the Encarta dictionary (2009) as, "to protect something from harm or decay, to keep something especially an important environmental or cultural reserve from harm, loss change or decay"; while preservation is defined as "Make sure

something lasts, to keep something protected from anything that would cause its current quality or condition to change or deteriorate or cause it to fall out of use".

Falola (2001) suggested that cultural heritages and traditions are fading away with every generation, in terms of traditions and even language. There is therefore a need to preserve cultural heritage, by creating an avenue or meeting point for the dissemination, and show casing of cultural and traditional knowledge.

2.4 What is a Cultural Centre?

Quraishi, (2003) states that a cultural centre provides an avenue for the display of visual and performing arts peculiar to a culture, it also serves as an architectural master piece for displaying cultural heritage.

Therefore, a cultural centre can be defined as a meeting place for people who share the common goal of preserving their cultural heritage, providing accommodation for a variety of activities geared towards creating cultural awareness, and expressions (such as plays, drama, song and dance, exhibitions, lectures, seminars and so on.). Architecturally, it is a monumental facility, an expression of the heart and soul of a society or people.

3.0 METHODOLOGY

The research approach for this study involved a case study qualitative research of cultural centres to identify the techniques used by Architects in the design of the cultural centres. The case studies are analysed based on the following variables:-

a. Location: Identify the influencing factors behind the choice of location and its relevance.
b. Culture and tradition specific features: Identifies the particular tangible and/or intangible features used by the designer.
c. Design concept: Highlights the tangible and intangible cultural and traditional features of the society identified and used by the designer, and techniques of applying and representing same in the design, in the form of spatial plan, elevations, and form.
d. Building materials and construction techniques: Identify the materials and technologies used and the intention of the designer.

The information acquired from the analysis is presented in tabulated format presenting the variables against the case studies, to delineate the techniques used by the designer in expressing cultural identity.

4.0 CASE STUDIES

4.1 Case Study 1: Nigeria Cultural Centre, and Millennium Tower, Abuja, Nigeria.

4.1.1 Brief History

This project is currently under construction in Abuja. The design of the project was awarded to Professor Architect Nicolleti Manfredi in March 2007; while the construction work is carried out by SALINI NIGERIA LIMITED. The Nigerian Cultural Centre and Millennium Tower (NCCMT) consist of two facilities, the main building which will have a museum, and auditorium and a hotel and a tower.

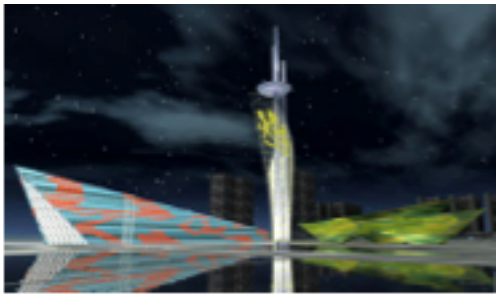


Figure 1: Computer generated view of Nigeria cultural centre. Source: Studio Nicoletti Associati

4.1.2 Location

The project is located in Abuja, Nigeria, in an area which helps to emphasize the cultural character of the building and provides easy access to tourists, figure 4. The location of the NCCMT in Abuja in close proximity to constitution avenue, Abuja national Mosque, the central bank and also having a view towards Aso rock villa, enhances the cultural identity, symbolism and significance of the building.

4.1.3 Culture and Tradition Specific Features

According to the architectural firm STUDIO NICOLETTI ASSOCIATI, the inspiration for the design of the NCCMT was derived from some important elements in Nigeria's rich culture, especially from the Yoruba Tradition. The shape of the floor plan and the arrangement of interior spaces (Figure 6, 7) mimics the Afin enclave (Figure 2). The Cultural Centre like the Afin enclave, is a very large triangular space; housing a small city protected by high lateral walls and a transparent roof. The interior spaces of the cultural centre which house a variety of activities is an attempt by the designers to create a modern 'Afin' for culture and leisure. The vertical profile and elevations (Figure 5) are designed to imitate the volumetric organisation of the Osun Osogbo sacred forest shrine (Plate 1). The millennium tower rises above the low-lying cultural centre like the shrine which consists of low lying elements surmounted by a very tall sculpture. The finishing of the facade (Figure 8, 9) mimics

the traditional mural design of the entrance to the Emir's palace Zaria (Plate 2), and the art works of the Yoruba calabash (Plate 3).

4.1.4 Design Concept

The design shows the representation of tangible cultural and tradition features in spatial plan, elevations and three dimensional forms, through the combination of modern design, materials and construction technology. The structure when completed will become iconic and symbolise the embodiment of the various Nigerian cultures in a modern context.

4.1.5 Building materials and construction technology

Modern building materials including reinforced concrete steel and glass make up most of materials used in the design, no attempt was made to hide these materials, rather the designer attempted to visually mimic cultural features using the modern building materials.

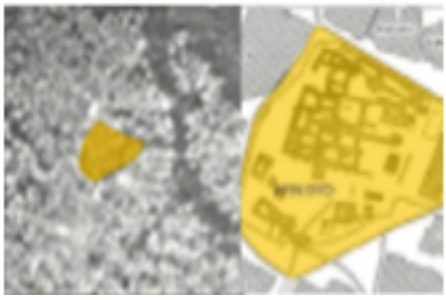


Figure 2: Satelite picture showing the boundaries of the Afin enclave. Source: Studio Nicoletti Associati.

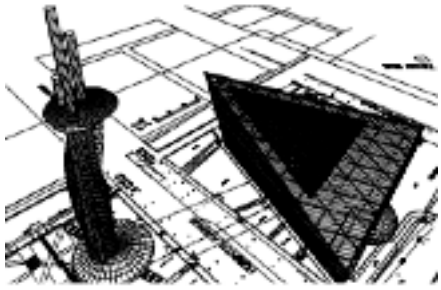


Figure 3: Computer generated view of the NCCMT. Source: Studio Nicoletti Associati.



Plate 1: The Osun Osogbo sacred forest shrine. Source: Studio Nicoletti Associati.



Figure 4: Location of the NCCMT in Abuja. Source: Studio Nicoletti Associati.

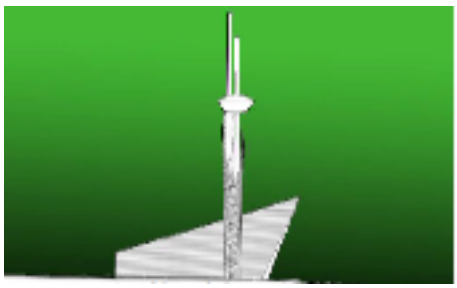


Figure 5: Profile of the NCCMT based on the Osun Osogbo sacred forest. Source: Studio Nicoletti Associati.

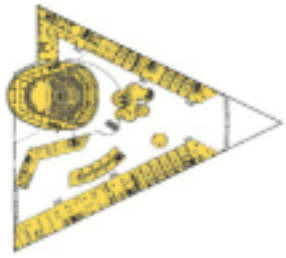


Figure 6: Floor plan of the NCCMT based on the Afin enclave. Source: Studio Nicoletti Associati.

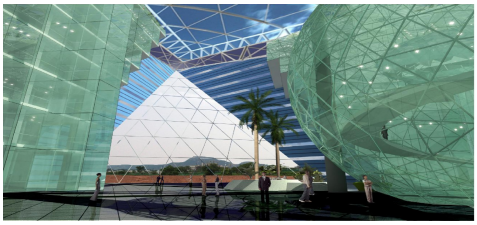


Figure 7: Computer generated interior view of the NCCMT. Source: Studio Nicoletti Associati.



Plate 2: Emir's palace Zaria. Source: StudioNicoletti Associati



Plate 3: Art work on a Yoruba calabash. Source: Studio Nicoletti Associati



Figure 8: The design of the facade. Source: Studio Nicoletti Associati.

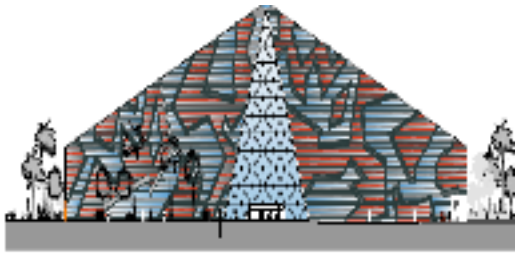


Figure 9: The design of the facade Source: Studio Nicoletti Associati

4.2 Case Study 2: Uluru Kata Tjuta Aboriginal Cultural Centre, Australia.

4.2.1 Brief History

The cultural centre was designed by Architect Gregory Burgess-Gregory Burgess Architects (GBA) in 1990, and constructed by Sitzler brothers. The architects set up a work studio in the local community, and sent time learning and collaborating with the people before starting the design.



Plate 4: An aerial view of the cultural centre. Source: GBA

4.2.2 Location

Located one kilometre to the south of Uluru in central Australia; this is within the Uluru – Kata Tjuta National Park and community of the Anangu people, thus creating a meeting point for the Aborigines and visitors, who have the opportunity to experience the beauty of the Aboriginal lands. The Aborigines also enjoy socio-economic development, and are directly involved in the activities of the cultural centre (Toogood, n.d).

4.2.3 Culture and Tradition Specific Features

The design form of the building was inspired by a combination of features; the culture of the local aborigines-specifically the Anangu folklore about the battle of two mythological snakes 'Liru' and 'Kuniya', the unique features of the undulating desert landscape with its wavy patterns, and local building materials and construction technology.

4.2.4 Design Concept

The cultural centre consists of two snake-like buildings around a central court yard, resembling the two mythological snakes 'Liru' and 'Kuniya' of the local Anangu folklore, as they faced each other ready for battle. The form and finishing also tries to capture the sinuous form of the serpents with the presence of skin, and shadows, (Toogood, n.d). The outdoor traffic routes are designed using a curvy pattern to further reinforce the serpentine design and capture the dynamic nature of the desert landscape. Traditional paintings and art works embellish the walls of the building. According to information available on the website of the cultural centre, the Design jury committee for the project in 1994 observes, "The architect of this project aspired to celebrate the spirit of the Anangu culture, through sensitive and effective collaboration in the concept evolution stage. The superbly crafted undulating forms of the Uluru-Kata Tjuta Cultural Centre blends in with the natural setting yet are striking and futuristic. Moreover, the two buildings are designed to be energy efficient and are successful in maximizing the environmental factors in climate control."

4.2.5 Materials and Construction Technology

There is a combination of natural building materials, sourced locally from the site, and modern construction techniques. The round timber logs forming the frame of the building are connected using nuts and bolts and further reinforced with a rigid steel frame that is hidden from sight. Locally made adobe bricks line the walls, and help to provide thermal insulation to the building from the desert weather. The roof structure which is undulating in nature is carried by round timber poles; plywood is used to connect the different sections of the undulating roof form.



Plate 5: Inside the exhibition gallery.

Source:GBA

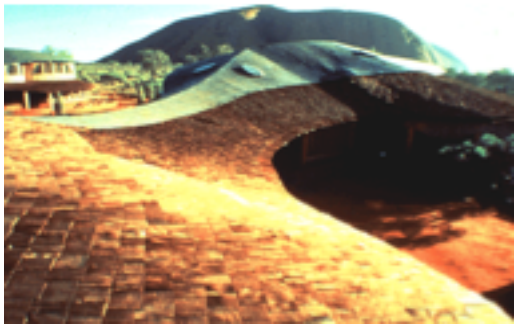


Plate 6: The undulating roof structure.
Source: GBA

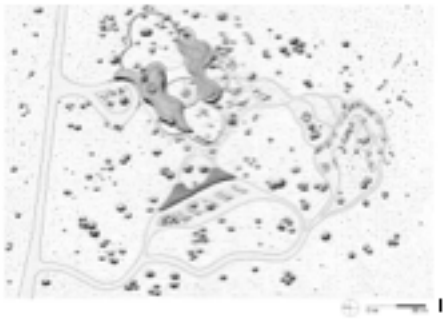


Figure 10: Site plan. Source: GBA



Figure 11: Floor plan. Source: GBA



Figure 12: Elevations. Source: GBA



Plate 7: The building under construction.
Source: GBA

4.3 Case Study 3: The African American Cultural Centre, Pittsburgh, United States of America.

4.3.1 Brief History

The African American Cultural Centre (AACC) was designed by Allison G. Williams in 2003. The state council that commissioned her wanted a facility that would bring cultural awareness of the founding history of Pittsburgh, education, thought, debate and entertainment. The AACC was Renamed the August Wilson AACC in 2006, in honour of the Pittsburgh play writer (Lowry, 2003).



Plate 8: The AACC.
Source:https://dbharlemrenaissaisance3.wikispaces.com/August+wilson

4.3.2 Location

The AACC is located at Liberty Avenue and 10th Street, animating the Penn-Liberty historic district, Liberty Avenue. Thus the location is an important element in the character of the cultural centre, Lawry (2003).

4.3.3 Culture and tradition specific features

The Swahili trading ships that transported African culture to distant shores was the main inspiration for the design of the AACC, this provides the concept for representing the spread of African culture in America.

4.3.4 Design Concept

The modern and contemporary design of the AACC tries to mimic the sail of a ship (Swahili trading ship) as seen by the curved glass facade. The transparent glass facade will help to display the activities on the inside of the building thus adding to the visual character of the cultural centre (Lowry, 2003).

4.3.5 Materials and Construction Technology

The cultural centre is built mainly of a reinforced concrete frame supporting structure, covered with plate glass and metal cladding on the facade. Thus it is basically transparent in appearance. Some of the glass panels carry arts works from different African origins.

5.0 RESULTS

The variables used in analyzing the cultural centres are the choice of the location, the culture specific features that influenced the design concept, the choice of building materials and construction technology. The analysis revealed the techniques used by the designers in expressing cultural identity. The results of the findings are presented in Table 1.

Table 1: Analysis of case studies

VARIABLES	Culture and Tradition Specific Features	Design Concept	Building Materials & Construction Technology	Location	Conclusive Description
Case Study 1 Nigerian Cultural Centre and Millennium Tower, Abuja Nigeria	-Afin enclave and Osun Osogbo sacred forest shrine of Yoruba culture. -Mural and sculpted art works of the Hausa culture. -Patterns of artwork on Yoruba calabash.	-Design form and plan concept inspired by cultural features. -Form directly mimics cultural features -Use of surface ornamentation.	-Use of modern building materials.	-Close proximity to cultural landmarks.	Modernised expression of cultural identity
Case Study 2 Uluru Kata Tjuta Cultural Centre, Australia.	-Aboriginal Folklore of the Anangu people. -Desert landscape -Locally available building materials.	-Design form and plan concept inspired by cultural features. -Form directly mimics cultural feature and environment -Use of surface ornamentation	-Use of natural and locally available building materials with modern construction techniques.	-Proximity to cultural landmark	Traditional expression of cultural identity
Case Study 3 African American Cultural Centre, Pittsburgh, America.	-Sail of Swahili trading ships.	-Design form inspired by a cultural feature. -Form abstractly mimics a cultural feature	-Use of modern building materials	-Located at a historical site with cultural significance.	Modernised expression of cultural identity

6.0 CONCLUSION

The study has shown that even though the designers come from different backgrounds and worked on different cultures, they used some common design trends in an attempt to:-

a. Either capture/express the cultural heritage of the people region or locality, literally or abstractly; thus creating architecture that is culturally unique.
b. Or to preserve cultural identity.

The application of culture in design will therefore involve the use of a prominent cultural feature, which can be tangible or intangible. The general idea is to symbolise the culture of the people visually using a chosen element or a combination of elements, thus the building created is visually expressive of the culture.

Based on the analysis of the case studies, the following techniques have been identified as design trends or methods of applying cultural elements in design of cultural centers.

i. Adopting prominent cultural and/or traditional features (tangible or intangible) as the basis for generating a design concept, visually mimicking the cultural feature literally and/or abstractly in 2-dimensional plan and/or 3-dimensional form.
ii. Use of surface ornamentation on walls to display various traditional arts and crafts like motifs, murals, patterns, paintings, pictures and so on.

iii. Use of natural and/or modern building materials, and construction techniques peculiar to the culture or region, so as to preserve historical cultural heritage.

iv. Selection of a site within or in close proximity to a community, cultural landmarks, buildings and so on with historical and cultural significance. Thus creating a synergy between building and scenery, and also providing cultural integration.

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ARCHISEARCH

COMPARISON OF LIGHT TRANSMITTANCE OF CONVENTIONAL ARGON FILLED WINDOWS AGAINST AEROGEL FILLED WINDOWS FOR USE IN RESIDENTIAL BUILDINGS

Rukayyatu Bashiru Tukur[1] and Amina Batagarawa[2]
Department of Architecture, Ahmadu Bello University, Zaria.
[1]rbtukur@abu.edu.ng (alt: rukkytukur@gmail.com, ruqayyahtukur@yahoo.co.uk)

Abstract

Glazed windows in buildings have for several years been used for communication between the exterior and interior. As such, they have been used to transmit daylight and subsequently have been of benefit when open or closed. It is therefore as a result of this, that testing of aerogel was carried out to seek the daylight transmittance potential of aerogel in windows without compromising thermal comfort in a closed building envelope. This was especially important where the priority of the window was for lighting and visual purpose rather than for insulation purposes. Results indicate that for lighting purposes, aerogel filled windows compete favorably with regular inert gas filled windows such as argon (as used in the tests), and there was a loss of an average of only 7% transmittance without the corresponding loss/gain in temperature although this is not the main area of study for this paper.

Keywords: Aerogel, Aerogel-filled window, Argon filled window, Daylight, Transmittance,

1.0 INTRODUCTION

Daylighting is recognized as an important element in architecture and a useful strategy in energy-efficient building designs, which gives a sense of cheeriness and brightness that can have a significant positive impact on the people (Li, 2010). As such, the building envelope is punctuated with windows to allow for appropriate natural lighting to be achieved (Tukur, 2013). At the thermal envelope of buildings, the window area is the weakest part with respect to heat loss, but at the same time, this area also provides advantages (Jensen, Schultz, and Kristiansen 2004). The aim of this research is to examine the viability or otherwise of introducing a new material within the double-skin clad window to see if there will be an interference in the quality of light tranmittance, whilst still strengthening the heat losses/gains at the window point. The test therein done, are just for light transmittance, and further testing in other research will deal with the area of thermal comfort.

2.0 REVIEW OF RELATED LITERATURE

Researchers have striven to find ways of maximising the quantity and quality of natural light in buildings, with the least loss of thermal comfort. As a result of this, various researches have been carried out to investigate the use of aerogel filled windows so as to be able to achieve both thermal comfort as well as natural lighting comfort. Aerogels are dry gels with a very high porosity (Hüsing and Schubert 1998) and were discovered in the early 1930s by Kistler (Kistler, 1931). Aerogel has a high performance thermal insulation, with a thermal conductivity of 13mW/(mK). However, the high cost of aerogel is what hinders its wide-spread use and over shadows its highly promising properties (Baetens, Jelle and Gustavsen 2011). Silica aerogels have very interesting optical properties with high transmittance of radiation within the range of visible light (i.e. radiation with a wavelength between 380 and 780nm) (Baetens et al, 2011). Futhermore, aerogels have a high transparency in the infrared spectrum (i.e. a T_{IR} of 0.85) (Baetens et al, 2011). However, if transparency is not desired, the direct-hemispherical transmission in the visible range can be strongly reduced with up to 50% by adding only a few vol% isopropanol or other opacifiers to the aerogel (Reichenauer, Fricke, Manara and Henkel 2004). Aerogels are reasonably transparent in the infrared spectrum as in Figure 1.

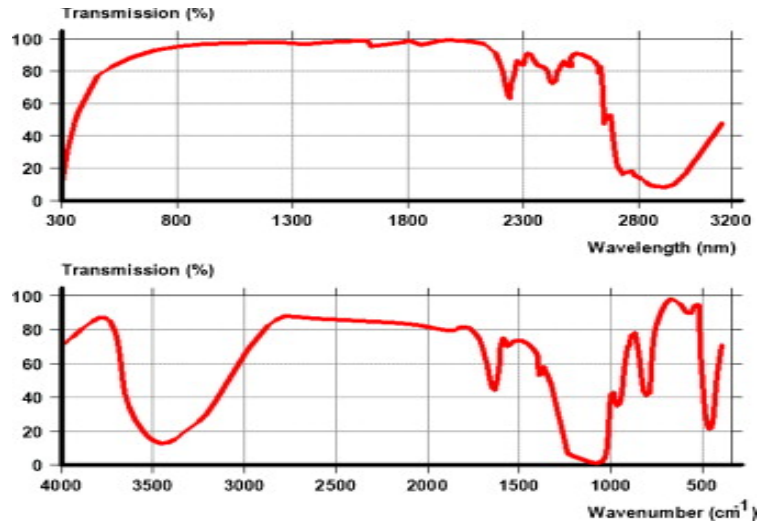


Figure 1: The transmittance of a silica aerogel in the ultraviolet, visible and near infrared spectrum (top) and the infrared spectrum (bottom). Source: Baetens et al, (2011)

3.0 THE WINDOW TESTS

The tests were carried out with the use of double-skinned windows with varying thicknesses and fillings of full silica gel or full argon gas filling or in the 3rd condition, half-silica and half argon. Three types of windows (see Figures 2 and 3) were tested. For each

window, there were 2 settings, and each of the tests was run for 1 hour (60 minutes) each. The three types of windows tested were as seen in Table 1.

Table 1: Window Sample Specification

Window Type & Specification	Window Size	Thickness of Glass Panes (Inner & Outer)	Thickness of Cavity
20mm Argon-filled cavity	300mm x 300mm	4mm	20mm
10mm Aerogel-filled cavity	300mm x 300mm	4mm	10mm
6mm half filled with Aerogel & half filled with Argon Gas	300mm x 300mm	4mm	6mm

3.1 METHOD OF TEST (PROCEDURE)

The method carried out was through the use of a solar simulator to represent natural light while recording the data with the employment of a DT500 DataTaker®. The sample window was placed on a built in frame and mounted on a white plain raised surface. Light sensors, energy sensors, pyranometer as well as temperature sensors (as seen in Figure 2) were wired onto the window and solar light from the solar simulators were shone on the window; data was relayed to the DataTaker®. The program on the datataker was set to relay information at 1 minute interval. The data was thus collected, and processed.

3.2 THE TEST CONDITIONS

3.2.1 Test Condition 1

A 6mm sample window was placed on the frame and raised to a height of 150mm off the plain white raised surface. A *Kipp and Zonen*® globe type pyranometer used to measure solar radiation was placed on top to ensure that solar radiation is maintained at a constant figure so as to act as the control and constant element during the test. An energy sensor was placed above and the data was taken for approximately 1 hour. With the same window sample, the globe pyranometer was still placed on top so as to ensure that the solar radiation was constant. Consequently, a Skye energy sensor was placed below the window, and the test was again run for approximately 1 hour and data received was recorded. As the sample was a half-aerogel and half-argon window, the test was carried out under the same condition for both sides.

3.2.2 Test Condition 2

A 10mm cavity sample window was placed on the frame and raised to a height of 150mm off the plane white raised surface. A *Kipp and Zonen*® globe type pyranometer used to measure solar radiation was placed on top to ensure that solar radiation is maintained at a constant figure so as to act as the control and constant element during the test. An energy sensor was placed above and the data was taken for approximately 1 hour. With the same window sample, the globe pyranometer was still placed on top so as to ensure that the solar radiation was constant. Consequently, a Skye energy sensor was placed below the window, and the test was again run for approximately 1 hour and data received was recorded.

3.2.3 Test Condition 3

A 20mm cavity window sample was placed on the frame and raised to a height of 150mm off the plane white raised surface. A *Kipp and Zonen*® globe type pyranometer used to measure solar radiation was placed on top to ensure that solar radiation is maintained at a constant figure so as to act as the control and constant element during the test. An energy sensor was placed above and the data was taken for approximately 1 hour.

With the same window sample, the globe pyranometer was still placed on top so as to ensure that the solar radiation was constant. Consequently, a Skye energy sensor was placed below the window, and the test was again run for approximately 1 hour and data received was recorded (See Figure 2).

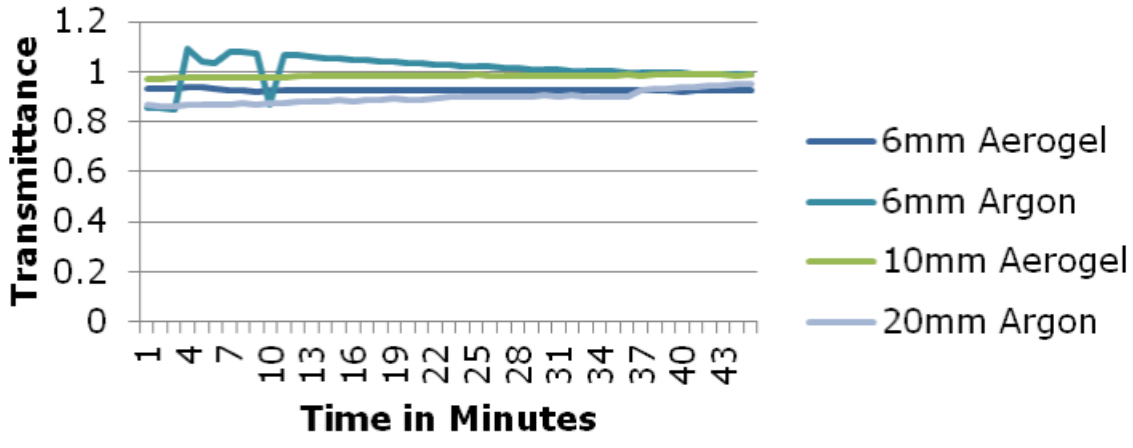


Figure 2: Transmittance of Window Sample within the Visible Light Range

3.3 The Test Rig

The test rig was set up in an indoor laboratory under controlled temperature. The Apparatus used are as seen in Figures 3 and 4, which include:

i. *Kipp and Zonen®* Globe Pyranometer

ii. Skye® Lux Sensor

iii. Solar Light Simulator

iv. Datalogger (DT500 *Datataker®*)

v. "K" Type Thermocouple

vi. Sample Windows



(a) Pyranometer



(b) Skye® Lux sensor



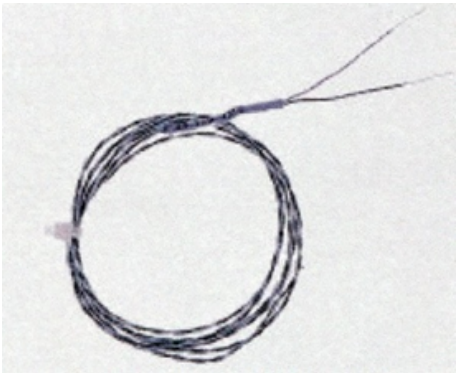
(a) Solar Light Simulators



(d) Typical Solar Light Simulators



(f) Datalogger (DT500 Datataker)



(g) "K" Type Thermocouple

Figure 3: The apparatus and equipment used in the experiments are as seen above in figures a -g



(a) Aerogel/Argon 6mm window



(b) Aerogel 10mm window

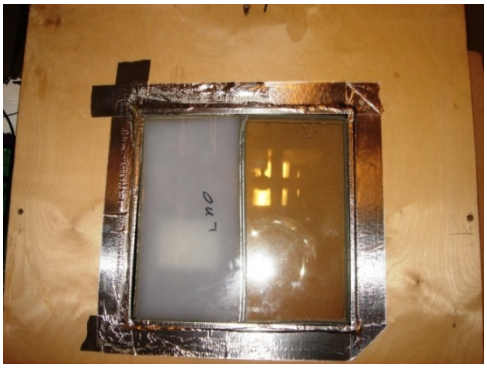


(c) Argon 20mm Window

Figure 4: a - c: Various Sample windows:



(a)Aerogel/Argon Window testing-purposes)



(b) Argon/Aerogel Window (Argon Half covered for



(c) Solar Simulator Lights

Figure 5: a - c: The Test Rig & Set-up

4.0 RESULTS AND ANALYSIS

The solar radiation set as around 600 W/m^2. The surface temperature of window surface is around 50^{o}C. The laboratory ambient temperature is approximately 20^{o}C. The test was lasting one hour under same stable test conditions. The test results for transmittance of different window samples in the vision range have been summarized in following figures.

As shown in the Figure 1, the transmittances of the three window samples are close. The average transmittance of radiation within the range of visible light i.e. between a wavelength of 380nm and 780nm is 93%, 94%, 91%, 92% for 6mm cavity Aerogel Window, 6mm cavity Argon window, 10mm cavity Aerogel filled double glazing window, and 20mm cavity Argon gas filled double glazing window respectively. Going by the test data obtained, we can conclude that the average transmittance of Argon- Aerogel window is 93%. From the test results thus, it can be inferred that the Aerogel window has good transmittance, and the thickness of aerogel does not affect the transmittance to a significant value. Furthermore, In any case, aerogel glazing offers the possibility to provide diffuse natural light (Reim M., Beck, A., Korner, W., Petricevic, R., Glora, M., Weth, M., Mercaldo, L.V., Addonizio, M. L., Noce, M. D., Veneri, P. D., Scognamiglio, A. and Privato, 2011).

5.0 CONCLUSION

In architectural applications of windows, in many instances only light transmittance into the building envelope is desirable and examples of office buildings, industrial building and even residential buildings abound. As such, visibility is not of utmost importance, especially as the window acts a favorable medium for heat gain in the tropics. With the ever-searching quest to find thermal comfort, in the midst of hard economic times in harsh weather conditions, it has become imperative to find ways in which we can keep warm/cool as the need may be. This has necessitated the need to find better and lasting solutions to make the building envelope thermally effective, as well as visually pleasing. This has therefore led to the investigative nano-properties of aerogel as both a thermal insulator as well as a light transmitter. Even though the tests were carried out with a view to establish the properties of aerogel in terms of light transmittance, the properties of aerogel have also proven to be effective in terms of thermal insulation. Thus, testing for transmittance of aerogel in windows was carried out with the bench mark for the test being the use of standard argon filled windows against aerogel filled windows. The aerogel filled window proved to be effective and gave a transmittance of 93%.

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ARCHISEARCH

COST IMPLICATIONS OF ENERGY CONSUMPTION IN OFFICE BUILDINGS OF KADUNA METROPOLIS, NIGERIA

Murtala Muhammad Salihu
Department of Architecture, Ahmadu Bello University, Zaria
murtalasg@gmail.com

Abstract

The study is aimed at assessing the economic impact of cost associated with energy provision and consumption in office buildings. Four office building facilities are purposefully sampled; where an energy audit is conducted through the collection of data from two-year bills of utility and back-up sources of electricity supply. Inventory of all energy consuming appliances and systems in the four facilities are also taken to obtain its estimated energy demand. Data collected is analyzed, where cost of energy supply is estimated. Findings revealed that the major actor in energy consumption is the cooling demand, followed by other electrical equipment and lighting respectively. Fulfilling such demand is found to be hindered by lack of regular supply of electricity from the national grid which resulted to a level of dependence on backup power generators, making it an economically unsustainable agent of cost accumulation in management of office buildings. The study concludes that the quantity of electricity consumed in the building affects the cost of the building operation and its projected running cost; where normalized energy use index of 175KWh to 296KWh were recorded, and a normalized range of total energy consumption cost of between 2,982NGN to 5,027NGN/PA was discovered. The study recommends a primary assessment strategy that related policy makers and professionals need apply towards addressing energy related problems in the industry; for future proposals such as retrofitting options and other feasibility studies.

Keywords: Energy consumption, Energy cost, Energy supply, Economy, Office buildings

1.0 RESEARCH BACKGROUND

Assessing the cost of energy consumption for operating office buildings is a necessary step towards fostering the economic aspect of sustainability directed not just towards any given facility, but its entire setting within a locality. This is because, office buildings form the major building stock of a city's central business district (Mu'azu, 2012), thereby playing a role in the total challenges that relates the city's cost of energy provision, and distribution. Some of these energy challenges bear a direct impact of the economic boom our world enjoys today; which has significantly raised the level of our basic requirements and living standards, and created a platform for an evident population growth experienced globally (Rai, 2004). This rise in standards of economies has subsequently created the need for more elaborate office building stock, both in number, scale and basic requirements; putting it in a constant and increasing state of intricate energy demand (Ochoa & Capeluto, 2009).

The office building is a building typology that requires uninterrupted energy supply within its activity period, hence it is regarded to be amongst the major energy consuming building typologies (Mu'azu, 2012). In terms of energy consumption per meter square, office buildings consume about 70-300KWh/m2 to function effectively, which is 10-20 times higher than the residential sector (Sadrzadehrafiei et al, 2012). This sort of energy requirement entails a great deal of effort to sustain building performance, a task that has been identified as a key area where significant progress towards meeting the global ambitions of energy efficiency can be made (Ausiello & Raimondo, 2014).

Similar studies of assessing the pattern of energy use in office buildings have been carried out in the past across Nigeria; an instance is that of Akambami (2010) where he pointed out that, office buildings uses 40% of the total energy supply by the National grid, and out of the total energy supply, 40% of it is used for cooling, 12% for lighting while 48% to power appliances. However, with all this magnitude of energy requirements the national grid does not supply adequate power across all sectors of the building economy (Oyedepo, 2013), this resorts to a large portion of the industry to rely on diesel and petrol generators as primary or back-up source of electricity, which can be expensive, polluting and a significant source of greenhouse gas emission (Energy Commission of Nigeria (ECN) 2015). The study is in line with the aspirations of the National Energy Master Plan (2014), which highlighted that, the driving force behind sustainable energy is to push industrialization of the country by 2030 at a rate of 11-13%.

The aim of this study is to uncover the track record of energy consumption patterns of office buildings in Kaduna metropolis, and present the estimated cost implication associated with such energy consumption. Information obtained from such exercise can be instrumental in identifying opportunities of improving efficiency, decrease in energy costs (Canadian Industry Program for Energy Conservation (CIPEC), 2014). The International Energy Agency (IEA) 2014 states that investment in energy conservation provides a better return than investment in energy supply. The study is therefore geared towards pin pointing the sensitive areas that can be enhanced to attain a practical and sustainable trend in energy conservation in relation to cost of consumption in office buildings, create balance between energy demand and supply.

2.0 ENERGY CONSUMPTION AND NIGERIAN ECONOMY

Numerous researches have been carried out with regards the need for the building industry to live up to the expectations and aspirations of all spheres of sustainability. This study reviews the economic aspects of sustainable built environment; it centers on the primary aspect of

capital investment, management and process of continuous operation of commercial corporate building stock with special regards to economic implications in the cost of energy consumption.

2.1 State of Energy Provision and Distribution in Nigeria

Energy requirement is essential for all operations in the building industry; like in all other sectors, it serves as the pillar of wealth creation evident by being the nucleus of operations and engine of growth of Nigeria's economy (Ogundipe & Apata, 2014). The output of the energy sector (electricity and the petroleum products) usually consolidates the activities of the other sectors, which provide essential services to direct all production activities (Energy Information Administration, 2010).

Unfortunately; even though energy provision in either public or private sector is capital intensive anywhere, it has been found to be facing a more serious challenge in Nigeria (Oyedepo, (2013). This is because study has shown that Nigerian has been found to be a consuming nation rather than producing economy cutting across many sectors; where in energy issues, a negative relationship has been found to exist between its consumption and production (Kabir, Zaku, Tukur, & Aikhuele, 2013). Although a major oil producer and investor in the electricity sector, an estimate carried out by the World Factook (2015), holds the country as low as 69th place in per capita electricity consumption globally; and the 210th in the list of world countries that exploit the use of electricity from other renewable sources.

Energy provision has been a discouraging factor for the Nigerian economy; a study carried out by Ibitoye and Adenikinju (2007) estimated that up to 60% of the population are unconnected to the national grid, especially those in the remote areas. Political instability, mismanagement, limited funds, long period of return of investment and maintenance neglect are all factors that result in electricity generation deficit, brought about by poor utility performance, and weak transmission and distribution infrastructure (International Conference on African Development Issues (ICADI) 2015).

Challenges as stated above are the sum of all reasons stated in the reviewed literature; where it was concluded that cost of energy production enjoys a free fall nature of energy billing with no regular accountability for energy costs, where government budget has to step-in on settling the payment deficit incurred (Muazu, 2012). However, the resultant use of backup generation system for long hours of the day throughout the year, also consequently leads to cost of diesel and other fuels used in running the generating plants by building owners (Umar, 2015). This sort of endeavor has formed a major glitch to the development of the building industry and the economy in general; whether our economy is ready for developmental take-off

should be based on its readiness to ensure adequate and regular power supply, which represent a crucial factor that supports economic growth in developing countries (Ogundipe & Apata, 2014). In line with these energy use imbalances for buildings, a movement has recently been stimulated for the establishment of a Green Building Council and related energy use standards for buildings in Nigeria under the auspices Architects Registration Council of Nigeria (ARCON); this was instigated by numerous researchers, positing the need to create a platform for a rating system, and the inexistent energy benchmarking that can guide and assess all aspects of energy provision, conservation, mode of consumption and resultant impacts on the environment for the sustainable future of our great nation and the world in general (Gyoh, 2011; Mu'azu, 2012; Ogunsote, 2011; & Imaah, 2010)

2.2 Economic Impacts of Energy Consumption in Office Buildings

Like in all commercial endeavors running an office building entails a lot of financial inferences. Study has shown that lower utility rates amount to an increase in net annual income which also is a yard stick for determining a building's value (Yudelson, 2010 pp37). Income generation as the key factor in commercial buildings has a direct bearing with a countries economy with regards to its net energy consumption. Where it is believed that national income enhances energy consumption (Adnan & Riaz, 2008); although Huang et al, (2007) contended that energy consumption is dependent on the type of income group predominant in a given area; where in the low income group, there exists no causal relationship between energy consumption and economic growth; in the middle income groups, economic growth leads energy consumption positively; and in the high income group countries, economic growth leads energy consumption negatively due to great environmental improvement impacts. Arising from this argument, adequate supply of energy thus becomes central to the radical transformation of the nation's economy (Energy Information Administration, 2010).

In office buildings energy services are desired for useful production, processing and indeed rendering of services that form the primary function of such a building set up. Major energy consumption is incurred through requirements such as lighting, provision of air-conditioned indoor climate, refrigerated storage, transportation, and related industrial processes. This sort of endeavor require a lot of energy that could in the long run challenge the annual income of a facility, thereby obstructing the primary target of profit and its stipulated margin. Study conducted around Abuja and other Northern Nigerian cities, all had findings that were in tune with the fact that; although there are many great potentials in energy provision, the energy requirement is a far cry from its supply in the country (European Scientific Journal, 2013); and that the similar methods of determining the Energy Use Index

(EUI) in all studies agreed to the fact that HAVC requirements, electrical appliances and lighting are the respective agents of energy consumption in office buildings in these regions (Muazu, 2012; Batagarawa, Hamza & Dudek, 2012; Umar, 2015).

3.0 MATERIALS AND METHODS

The context of the study is office buildings in Kaduna metropolis which falls under the hot and dry climate of north western Nigeria. A very hot and dry air characterizes the climate and ambient temperature ranges between 27ºC and 39ºC accompanied by continuous low relative humidity (Koenigsberger et.al, 1974).

To conduct the study, purposive sampling method was adopted in selecting four office buildings within Kaduna metropolis (Table 1) the selection is made in a manner that it will represent different variety of office buildings based on variation in size (large and small), ranges in floor heights and total floor area (between 5000m^2 to 500m^2), track record of optimum utilization of the facility, types of ownership, and ease of access for data collection. The buildings selected were Northern Nigerian Development Company (NNDC), Bank of Industry, Investment House and Federal Inland Revenue Office (Katsina Road Branch).

Table 1: Criteria for selection and representation in sampling

	Name Of Building	Ownership	Floor Heights	Total Area	Usage
1	NNDC Building	Public	Above 10 Floors	Above 5,000m^2	Full capacity
2	BOI Building	Federal Government	Above 5 Floors	Above 3,000m^2	Full capacity
4	Investment House	State Government	2 To 4 Floors	Above 1000 m^2	Full capacity
5	FIRS Building	Federal Government	2 Floors	Above 500 m^2	Full capacity

Collection of primary data was carried out mainly through an energy audit exercise; an endeavor used to analyze the energy consumptions produced by a building with the aim of proposing measures to reduce them (Generation 2015; DOE, 2011). To achieve the aim of the research therefore, data collection was conducted through a Walkthrough Energy Audit of energy consuming and/or providing equipment and systems in the case studies. Self-administered questionnaires and interviews are also employed in the study. The method of assessing collected data involves estimations of energy consumption, supply and subsequent cost of supply. Calculations on the estimated end-use demand were grouped into cooling, lighting and electrical appliance.

To conduct calculations and/or estimations in demand and supply of electrical energy on the case studies, various formulas as forwarded by Oyedepo et el, (2015) were adopted and adapted from the study; the formulas were used to calculate the total electricity demand,

cooling and ventilation loads, demands for lighting and other appliances and finally the total electricity supply from both grid and back-up generators.

As the primary thrust of this study, all subsequent calculations are geared towards exposing the cost implication of providing energy for the operation of office buildings within context. Therefore, estimated cost of energy supply is carried out; after which the normalized cost of energy supply, and the total energy consumption cost is presented to enable the provision of data that may help in further study that may involve other related endeavors like bench marking and retrofitting exercises.

4.0 RESULTS AND DISCUSSION

As outlined in the methodology, discussions on the result of all data collected will be discussed and presented under relevant columns as presented below

4.1 A walkthrough Inventory of selected buildings

Table 2 below shows the inventory of each facility studied. The tallest amongst the buildings is the NNDC Building with eleven floors and 329 rooms in four different blocks. Next is the BOI main building with nine floors and 112 rooms, Investment House has four floors and 68 rooms, while the least is the FIRS building with two floors and 18 rooms within two blocks. All the buildings have a high track record of energy consumption as exposed by the records of both utility and backup bills collected. It was also recorded that all buildings have energy consuming appliances like Lifts, HAVC systems, lighting and other office equipment, except for the FIRS Building that has no lift.

Two year utility bills and cost of diesel and maintenance were also collected and presented on the table. For the NNDC Building, supply from the National Grid costs 11,236,000NGN/annum while back up costs 15,562,000NGN/annum from a 625Kva generator; utility billing rate for BOI Building is to the tune of 7,692,000NGN/annum, and 1,869,996NGN/annum from a 500Kva plant; Investment House has a total annual electricity bill of 3,660,000NGN, and back up bill of 1,116,000NGN; while the smallest of all buildings which is the FIRS Building has a utility bill of 1,020,000NGN, and back up bill of 1,302,000NGN.

Table 2: walkthrough inventory of the four office buildings

Item	NNDC Building	BOI Building	Investment House	FIRS Building
Number of Floor	11,6,7&2(4 blocks)	9&1 (2 blocks)	4 & 1 (2 blocks)	2 &1 (2 blocks)
Avg. Room/Bay Area (m^2)	24	24	34	20
Num. of Rooms	329	112	68	18
Total Area	11312	3816	2653	528
Usage	Full capacity	Full capacity	Full capacity	Full capacity
Avg. utility Bill/annum (NGN)	11236000	7692000	3660000	1020000
Avg. Backup Bill/Annum(NGN)	4185000	1869996	1116000	1302000
Utility Supply	National Grid	National Grid	National Grid	National Grid
Backup (Kva)	625	500	250	100
Activity period/Time	8 hrs/8am-4pm	8 hrs/8am-4pm	8 hrs/8am-4pm	8 hrs/8am-4pm
Major Energy Consuming systems Present	Lifts, HAVC, lighting/office equipment	Lifts, HAVC, lighting/office equipment	Lifts, HAVC, lighting/office equipment	HAVC, lighting & office equipment

4.2 Estimated Energy Demand

The total estimated demand for the four buildings based on three set of categories namely cooling, lighting and a group of other appliances was carried out. Equations 1 and 2 as adopted by Oyedepo et el, (2015) are used progressively during the study. Total energy demand (TED) in kW is given by:

$$TED = \frac{sw}{1000} \; n \times F_d \text{ (in kW)} \quad \text{.....equation 1}$$

Where n is the number of appliances (cooling, lighting and other electrical appliences), SW is the system wattage and F_d is the demand factor. F_d is the assumed average percentage of available appliances used at a building's peak time. In this study, the demand factor is taken as 34%. This is because all appliances except for the exterior lighting are calculated based on the activity period of the buildings, which is eight out of the twenty four hours of the day.

To estimate the total energy consumption of all the appliances therefore; equation 2 as stated below is adopted.

$$TEC = \frac{sw}{1000} \; n \times h \text{ (in kWh)} \quad \text{.....equation 2}$$

Where h is the total hours used by the appliance during the year. Which in this case is assumed to be 2080 hours (8 hours of the day x 260 working days of the year). This sequence of estimation was carried out on all electricity consuming appliances for each facility studied to determine the disaggregated end use demand.

Cooling was found to be significantly higher in the N.N.D.C Building and reduces down the list due to variation in sizes of the facilities and hence a variation in cooling demands. The same goes for lighting and demand from other appliances; where office equipment like computers, printers, scanners, photocopiers, and utility machines like refrigerators, televisions, fans, and lifts were calculated. The disaggregated of energy demand across the four office facilities, revealed that cooling takes the highest demand of about 2,338,105.40 kWh per annum, constituting of about 53% of the total energy demand in all the facilities. Office appliances used had about 1,353,391.04kWh, making up 35%; and lighting being the least of all consuming about 505,173.92 kWh, which is 12% of the total energy demand. Figure 1 shows the disparity in total end-use demand for each facility, while percentage representation is expressed graphically in Figure 2.

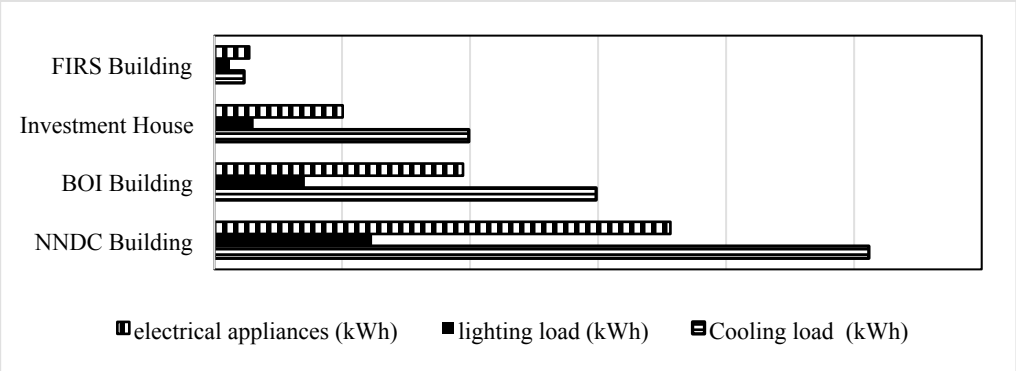


Figure 1: Disaggregation of load in cooling, lighting and other appliances in each facility.

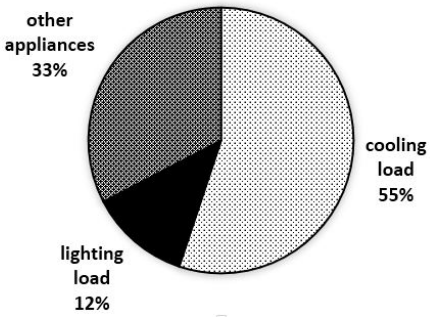


Figure 2: Percentage of total end-use demand across all buildings studied

Normalized electricity consumption per Meter Square of each disaggregated end-use and the averages per annum across all the studied facilities was carried out. This was done by dividing each disaggregated end use demand by the total square meters of the facility. The normalized energy demand is given in (KWh/m2). It was discovered that the BOI Building has the highest normalized annual demand of 296KWh/m2, followed by Investment House with 249 KWh/m2, and the NNDC Building having the lowest value of 175Kvh/m2. This shows that even though the NNDC Building is the largest of all the facilities, it has the lowest annual energy demand.

4.3 Estimated Electricity Supply

Electricity supply by both utility and backup sources are estimated using the acquired utility bills of two years; and calculating the output of the power generators against the target backup hours laid out by the facility managers. To estimate for the average monthly utility supply, the monthly utility charges are divided by the utility rate per KWh, which is 26.24 NGN. For the backup system, the generator capacity is multiplied by its hours of operation against the number of working days in a month. The total electricity supply therefore; is estimated using a formula adopted from Batagarawa (2013), and is used as the Equation 3 below; Where Qt is the total supply per annum. Qu is consumption from utility records. Qg, is the supply from the back-up power generator.

Qt= Qu + Qg ……..equation 3

The hours of distribution from both utility and backup is shown in Table 3. It shows that utility hours are in all cases more than the backup hours all year round and are highest in Investment House and NNDC building with 6.5 hour each, while B.O.I Building and FIRS Building have 6.0 hours each. The rate of Annual Power Supplied was found to be highest in the N.N.D.C Building and the B.O.I Buildings with 601,773.00KWh and 482,880.00 KWh respectively, while FIRS Building has the lowest of 77,377.68 KWh, followed by the Investment House with 259,305.48KWh. Figure 4 illustrates graphically the variation in range of supply between the utility and backup sources in each facility.

Table 3: Estimated electricity supply from the utility and backup, hours of supply and total annual energy supply in each facility.

	power supply (hrs)		Avg Monthly Supply (Kwh)		Annual Power Supplied (KWh)
	Utility	**Backup**	**Utility**	**Backup**	
NNDC Building	6.5	1.5	34,679.00	15,468.75	601,773.00
BOI Building	6	2	23,740.00	16,500.00	482,880.00
Investment House	6.5	2.5	11,296.29	10,312.50	259,305.48
FIRS Building	6	2	3,148.14	3,300.00	77,377.68

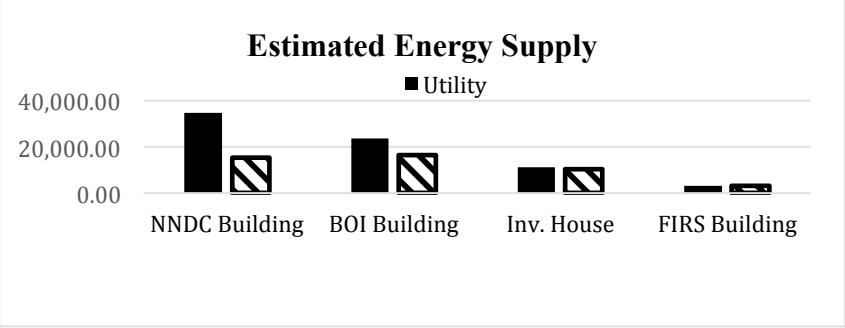


Figure 4: Estimated energy from the utility and backup

4.4 Cost of Electricity Supplied from Utility and Back-Up Bills

The actual energy consumption paid for by the management of the facilities is made up of emoluments from electricity supply by the utility company and diesel generator supply in the buildings. The actual two year bills paid to the utility company are collected and the monthly average determined, which in summation gives the annual cost in Nigerian Naira (NGN). The same was done from the collected receipts and results of the interview with the plant operators, where the total cost of fuel and oils were generated.

It was discovered that the NNDC building has the highest rate of consumption of up to 26,798,000.00NGN per annum, a total summation of an average monthly utility bill of 936,333.33NGN and average monthly cost of diesel and maintenance of 1,296,833.33NGN. BOI Building has 641,000.00NGN for average utility cost and 155,833.00NGN from backup generation system cost, summing up to about 9,561,996.00NGN per annum. Investment House has a total of 4,776,000.00NGN per annum for an accumulated monthly averages in utility and backup bills of 305,000.00 NGN and 93,000.00 NGN respectively; while the FIRS Building has the lowest total annual rate of 2,322,000.00 NGN from monthly averages of 85,000.00NGN for utility bills and 108,500.00NGN for the backup bills.

4.5 Total Energy Consumption Cost

To determine whether the cost of energy paid for is commensurate to the actual energy consumed, the total energy consumption cost (TECC) is calculated. As gathered from the interview and physical observations; this stems out of the fact that in all the facilities studied, none has employed the use of the prepaid meters supplied by the utility companies. The bills paid therefore are based on estimations from maximum demand metering or clamp meters supplied. the total energy consumption cost is obtained by inputting the actual rate of unit electricity tariff on the estimated energy demand earlier determined; it is computed as adopted from Oyedepo et el, (2015) given as:

TECC = TEC x CUE (in NGN) …….Equation 4

Where TEC is the total energy consumption, and CUE is the current cost of a unit electricity in Nigerian tariff, which is 26.24NGN FOR commercial buildings. Further calculations of normalized total energy consumption cost are also done in m^2 for each facility.

Table 4 exposes the difference between the actual energy consumption paid for by the management and the actual total energy consumption cost incurred in the facilities. Where going by the actual demand per annum, as earlier disaggregated; the NNDC with annual

consumption of 2,094,125.24kWh has a TECC of up to 54,949,846.30NGN per annum. The BOI with 1,122,496.00kWh has 29,454,295.04NGN per annum. Investment house has a TECC of 17,332,897.07NGN from a 660,552.48 kWh demand, while FIRS Building has 123,963.44 kWh summing up to 3,252,800.66NGN per annum.

Table 4: Total energy consumption cost, and the normalized cost per m^2.

	TEC(kWh)/annum	TECC (NGN)/annum
NNDC Building	2,094,125.24	54,949,846.30
BOI Building	1,122,496.00	29,454,295.04
Investment House	660,552.48	17,332,897.07
FIRS Building	123,963.44	3,252,800.66
average	1,000,284.29	26,247,459.76

The highest recorded normalized range of TECC is 5,027NGN from 296 KWh/m2 normalized value found in the BOI building. FIRS and Investment House have 4,052NGN and 4,234NGN respectively from 239KWh/m2 249KWh/m2 normalized energy demand ranges. While the NNDC recorded the lowest normalized TECC of 2982NGN from a normalized annual demand of 175KWh/m2

5.0 CONCLUSIONS

The study focused on assessing the cost of energy supply and distribution in office buildings of Kaduna metropolis. The study confirmed that, cooling for thermal comfort for the interior takes the highest rate of energy demand in the buildings; it is responsible for about 55% of the energy use index, and therefore has that equal bearing on the resultant cost of energy consumption. Other electrical appliances constitute 33%, while lighting has the least with 12% due to the presence of adequate natural lighting during the activity period.

It was observed that there is disparity between energy demand and supply in all facilities, where the estimated annual energy supply falls short of meeting up with the required annual demand in the buildings. This is why the cost of energy supply in the facilities is on the high side, due to insufficient supply from the national grid; which led to alternative dependence on backup supply to cover up the supply deficit, making the cost of supply economically unsustainable.

Despite the high cost of energy consumption however, the study affirmed the claim highlighted from the literature that electricity supply experiences a free-fall billing against energy consumption in our buildings. The study confirmed that there is a huge gap between the total cost of electricity supplied from utility and back-up bills. Similar gap was also discovered

in the total energy consumption cost, which this proves that the energy consumed, though massive in term of quantity and cost is not commensurate to the due rates. The normalized energy demand has been found to be within the stipulated range for office buildings as highlighted by the literature, where the normalized total energy consumption cost per annum ranges between 2,982NGN/m^2 to 5,027NGN/m^2**.**

From the cost analysis carried out, the study posits that high energy consumption rate indicates high cost of operation, a trend that can be reduced to a significant level in order to bring down the cost of operating buildings. The relevance of this study therefore is that, it may serve as a reference point in appreciating the magnitude and impact of cost of energy consumption in running corporate buildings. It may also serve as a useful information for all related policy makers and professionals involved in running such facilities in paving way for pin pointing the basic areas in which retrofitting options are required in order to reap the economic and social benefits of running and maintaining office buildings in a sustainable manner.

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ARCHISEARCH

Towards Evolving Mixed Mode Cooling Strategies in Conserving Energy for Office Building with Ventilated Façade in Hot Dry Climate

Bulus Bello Umar[1], Abdullahi Abubakar[2] (PhD) and Amina Batagarawa[3] (PhD)
[1, 2 &3]Department of Architecture, Ahmadu Bello University, Zaria
Email[2]: abdulubale@yahoo.co.uk

Abstract

Mixed mode cooling systems require an integrated design approach including facade optimization for solar heat gains, exposed thermal mass made possible by the structure design and interior space planning, improved understanding of complex heat and fluid flow phenomena and coordinated intelligent controls strategies to enable high performance. The aim of this study is to evaluate mixed mode cooling strategies in conserving energy by simulating office building with ventilated façade in hot dry climate towards developing effective and efficient architectural design parameters for the climate. The evaluation is conducted using computer simulation with Vasari Beta 3 to predict the level of energy consumption by sets of building models (Model A, B and C); these models are designed with single skin, double skin facade and shading device technology respectively, with mixed-mode cooling strategies incorporated into it to maintain thermal comfort. The mixed-mode cooling strategy adopted for the optimisation is Passive Downdraught Evaporative Cooling (PDEC) system to maintain thermal comfort. The developed model provides office space for two people, and is arranged in four floors. In addition the cooling set points and occupancy schedules were based on working day, which exclude weekends and holidays. This study predicts that mixed-mode building can be designed to be energy efficient with up to fifty four percent (54%) energy savings in office building with glazed ventilated and shaded façade in a hot dry area by optimizing the energy performance of the building using mixed mode cooling strategies.

Keywords: Energy saving, hot dry climate, office building, mixed mode cooling strategy, ventilated glazed façade

1.0 INTRODUCTION

Today, about half of the energy consumption in industrialised countries is invested in buildings, primarily for heating, cooling, lighting, movement, and also in the production of building materials, building construction and demolition of buildings (Al-Homoud, 2003; Wong, 2008). In office building's architecture, glass envelopes have gained popularity since the rise of modernism, even in warm climates (Poizaris, 2009). Glass is a material with a huge innovative potential, offering the possibility of a completely transparent building envelope and is not only seen as a symbol of financial prosperity but also as a reflection of organizational transparency. Traditional glass facades however, have a number of implicit disadvantages (Hamza, Gomaa, & Underwood, 2007), the most relevant in this context being poor thermal

insulation properties for weather conditions and high overheating risks, even in extremely cold climates, and in noisy environments poor acoustic insulation can also be an important drawback (Poizaris, 2008).

The energy efficiency of highly glazed office building is usually questionable, because glazed facade produce high cooling loads, leading to the adoption of HVAC (Heating, Ventilation and Air-Conditioning) systems which require significant amount of energy to cool these buildings (Monna & Masera, 2010; Poirazis, 2008). Mechanical cooling systems have enabled the development of unique building types that rely on high energy input for their normal operation, as opposed to the traditional, vernacular and historic practices (Burdick, 2011).

Economic and industrial development in countries with hot, dry climate led to an increasing demand for electricity for air conditioning and lighting to overcome the discomfort during the harsh weather (Monna & Masera, 2010). Akambami (2010) pointed out that office building in Nigeria uses 40% of the total energy supply by National Power Holding Company (PHCN), and 40% of it is used for cooling, 12% for lighting while 48% is used to power appliances. A study by Batagarawa, Hamza, & Dudek (2011) has shown that 75 % of the energy used to maintained office buildings in Nigeria is from an alternative power source. The results from these studies is indicative of the need to reduce the cooling loads in office building, thereby reducing the energy consumption and cost, and also cut down the greenhouse gaseous (GHG) emissions (Ramos & Ghisi, 2010).

Fisk (1999) highlighted that in extensively glazed modern office buildings with air tightness, indoor activities could affect the indoor comfort of the space which could generate health issues such as Sick Building Syndrome (SBS) and Building Related Illnesses (BRI). In addition, recent challenges of climate change and global warming have driven the need to conserve energy in buildings (Artmann, 2008;Altan, Ward, Mohelnikova, & Vajkay, 2008). Also with rising energy prices, the need to cool the building efficiently so as to conserve energy is further increasing (Oppong & Badu, 2012). In deciding how to cool a building, there has been a historical tendency by the designers towards choosing either mechanical or passive cooling strategies.

2.0 LITERATURE REVIEW

Mixed-mode cooling is a strategy that incorporates both natural and mechanical cooling system on an individual space or whole building scale (Brager, 2007). This strategy brings together the advantages of both natural cooling and those of the mechanical cooling to provide

the best of both the systems. According to Hu & Karava (2012) mixed mode cooling systems require an integrated design approach including facade optimization for solar heat gains, exposed thermal mass made possible by the structure design and interior space planning, together with improved understanding of complex heat and fluid flow phenomena and coordinated intelligent controls strategies in form of evaporative cooling to enable high performance. The evaporative cooling can be successfully achieved using techniques called Passive Downdraught Evaporative Cooling. The passive downdraught evaporative cooler (PDEC) is composed of; evaporative device, a shaft, wind catcher and water tank or reservoir. In the evaporative cooler, water is pumped over an evaporative device by a pump which is the only component that consumes power for the system.

Envelope components and their arrangements are important parameters in determining the thermal performance of buildings. An understanding of these parameters by designers can contribute greatly to energy savings in building design (Al-Homoud, 2003). The ventilated cavity of double glazed facade can be connected to the outside so as to induce natural cooling in addition to the mechanical cooling systems that are installed within the buildings (Kleiven, 2003; Poizaris, 2008).

Literature so far reviewed reveals that energy saving of mixed mode buildings could be evaluated through simulation to predict the performance of a proposed new building design under future temperature scenarios, or physical monitoring (Ezzeldin, et.al, 2008). under extreme design conditions Simulation programs were used to evaluate the effects of different technologies and design strategies on the comfort and energy consumption in a building (Monna & Masera, Effect of Tall Office Building Enveloped technologies and Design Strategies on comfort and Energy consumption in Hot-arid Climate., 2010).This system allows for easy quantification of mechanical, heating and cooling load; calculations of internal temperature and frequencies; analysis of facades; analysis of natural and mixed-mode cooling and incorporation of passive thermal mass techniques. Thermal simulation is the most appropriate method of investigating the performance of different mixed- mode cooling strategies.

Vasari Beta 3 a computer simulation program that simulates an abstract model of a particular system and it is an easy-to-use design tool for creating building concepts (Vidmar & Roset, 2013). With integrated analysis for energy and carbon, providing design insight where the most important design decisions are to be made, the program was released in June 2013 (autodeskvasari.com).

Vasari can calculate wind flows and the result can be used to define several groups of physical and appearance properties, it also provide library of predefined materials (Vidmar & Roset, 2013). Air temperature, air humidity, wind direction, wind speed and solar radiation are the parametric inputs for climatic analysis.

The aim of the study is to explore mixed mode cooling strategies in conserving energy by simulating office building with ventilated façade in hot dry climate towards developing an effective and efficient architectural design parameters for the climate.

3.0 RESEARCH METHODOLOGY

The simulation is meant to validate the potential of energy conservation by optimising glazed office building designed with double skin facade technology having mixed-mode cooling strategy incorporated into it. The simulation predicts the performance of a building with mixed-mode cooling strategy known as Passive Downdraught Evaporative Cooling (PDEC) system, incorporated into a building with permutation for:

1. Single skin
2. Double skin
3. Shading device

The predictions cover the evaluation of Models A-C using two indicators:

1. Monthly electricity consumption
2. Disaggregation of total electricity consumption

Vasari Beta 3

The computer program for energy analysis is a simulation program called Vasari Beta 3; Vasari was first developed in 2012 by Autodesk. It is adopted for analysis in this research because of its easy operation as observed by Vidmar & Roset (2013). The analysis result depends on certain input parameters (see Table 1); these parameters are indicators of performance. The models are prototype of 3m x 4m office space and arranged in four floors. It is assumed that there is no occupancy and internal heat gain during weekends and holidays in the building. The developed model provides office space for two people, and is arranged in four floors. In addition the cooling set points and occupancy schedules were based on working day, which exclude weekends and holidays.

Table 1: Summary of simulation parameters

S/N	Input Parameters	Output Parameters
1	Location	Climate data
2	Façade/ construction technology	Cooling demand
3	Glazing percentage	Solar radiation
4	Weather station	Location coordinate: Latitude and longitude
5	Cooling system or strategies	Energy consumption, gaseous emission
6	Shading pattern	Heat reduction, glare control
7	Building dimension	Total conditioned Floor area
8	Building schedule	Duration of use
9	User population	Internal condition

Source: (Authors, 2014)

Loading data into Vasari is done online by selecting a weather station. It is the only simulation computer program that is capable of using multi-core CPU technology, which makes it the quickest application so far (Vidmar & Roset, 2013). Vasari export models to external format (gbXML, dwg, dxf, dwf), and results are process using csv. Csv files save data for analysis and is examined using spread sheet calculation. Vasari lacks some features from urban modelling perspective, the available ones have been implemented very well (Vidmar & Roset, 2013). Adding some more functionality that geared towards outdoor design such as calculation, humidity and evapo-transpiration analysis has improved its performance.

The results of the analysis in all the three models are indicated by:

- An evaluation of heat gains in the models
- An evaluation of energy consumption
- An evaluation of heat gains in the model covers four sources of heat in a building: facade conduction, equipment, occupants and lights. The focus of this research is the façade conduction component.
- An evaluation of energy consumption covers

The simulation predicts the performance of a building when a mixed-mode cooling strategy is incorporated into a building with double skin facade technology. The independent variable has permutations in the facade pattern classified into Model A-C.

Modelling

Thermal comfort for the model without Passive Downdraught Evaporative Cooling (PDEC) system is shown in Table 2, the Models A-C operate under thermally comfortable settings in all simulations.

Table 2: Annual temperature variations in the simulation models

Months	Max Temp (ºC)	Ave. Temp (ºC)	Min Temp (ºC)
Jan	39.3	26.0	14.5
Feb	40.1	28.5	16.7
Mar	43.9	29.7	17.2
Apr	42.1	29.7	16.4
May	38.3	27.2	20.6
Jun	33.6	26.0	18.1
Jul	33.9	25.0	19.5
Aug	31.5	24.2	19.6
Sep	31.1	24.1	18.2
Oct	34.2	25.5	18.2
Nov	36.8	24.7	13.1
Dec	35.1	22.8	10.9

3.1 Model A

This model is considered as the base scenario, it has a single skin facade technology with the concept of Passive Downdraught Evaporative Cooling (PDEC) system and Chillers Slab (Under floor cooling) incorporated into it. The analysis of this model is aimed at understanding how mixed-mode cooling strategy affects the amount of energy consumed to maintain thermal comfort in office building with single skin facade. This is an optimised office building developed to predict the amount of expected energy consumption in a glazed office building in hot dry climate (see Plate I).

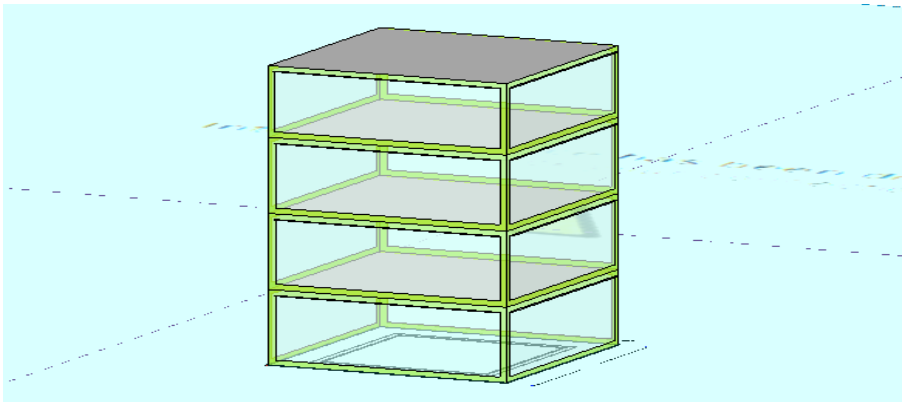


Plate I: MODEL A: Single skin facade with mixed mode cooling strategy

The model is developed with single skin facade technology and Passive Downdraught Evaporative Cooling (PDEC) system and chilled slab is incorporated as a mixed-mode cooling strategy. The model is considered as base case scenario.

3.2 Model B

This model has a double skin facade technology and adopting the combination of Passive Downdraught Evaporative Cooling (PDEC) system and Chilled Slab to achieved thermal comfort. This is targeted at predicting how much energy is utilised when an office

building is designed with double skin facade technology and mixed-mode cooling strategy is incorporated into it (see Plate II).

3.3 Model C

This model is developed to predict energy utilisation in optimised office building designed with double skin facade technology, shading devices and a combination of Passive Downdraught Evaporative Cooling (PDEC) system and Chilled Slab is incorporated into it to achieve thermal comfort. This analysis focuses on predicting how shading devices influences energy consumption in the optimised double skin office building (see Plate III).

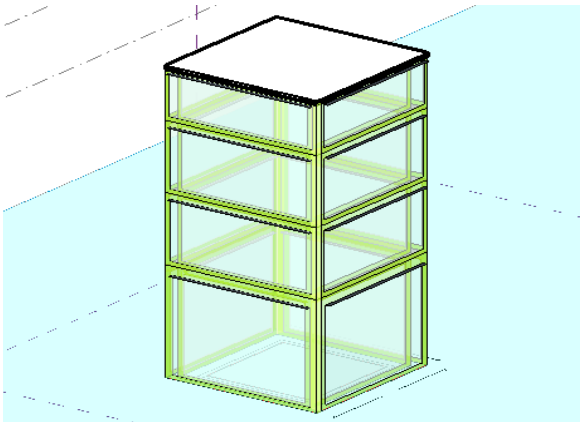


Plate II: MODEL B: Double skin facade with mixed mode cooling strategy

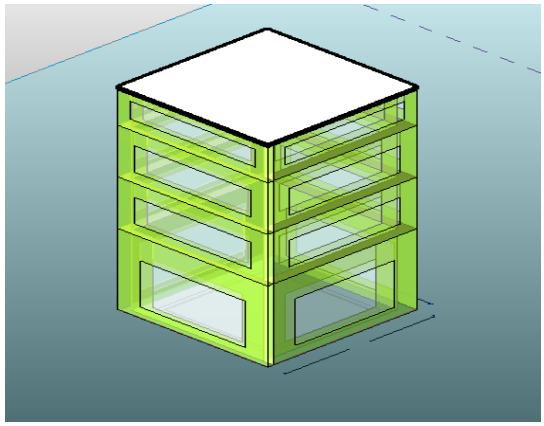


Plate III: MODEL C: Double skin facade with mixed mode cooling strategy and shading device

The aim of predicting the percentages of energy saving from each of the models is to determine which facade technology works best with the adopted mixed mode cooling strategy to conserve energy. The developed model provides office space for two people, and is arranged in four floors. In addition, the cooling set points and occupancy schedules were based on working day, which exclude weekends and holidays.

4.0 RESULTS

The predictions cover the evaluation of Models A-C using two indicators:

1. Monthly electricity consumption
2. Disaggregation of total electricity consumption

4.1 Model A

The model is developed with single skin facade technology and Passive Downdraught Evaporative Cooling (PDEC) system and chilled slab is incorporated as a mixed-mode cooling strategy. The model is considered as base case scenario.

4.1.1 Monthly electricity consumption

The cooling demand is higher in the hotter months and gradually lowers in the cooler months. From the temperature index April is the hottest month of the year with the temperature of 43ºC, its cooling requirement is the highest at 11,860Kwh. Figure 1 shows the total monthly electricity consumption in the model for a period of twelve months.

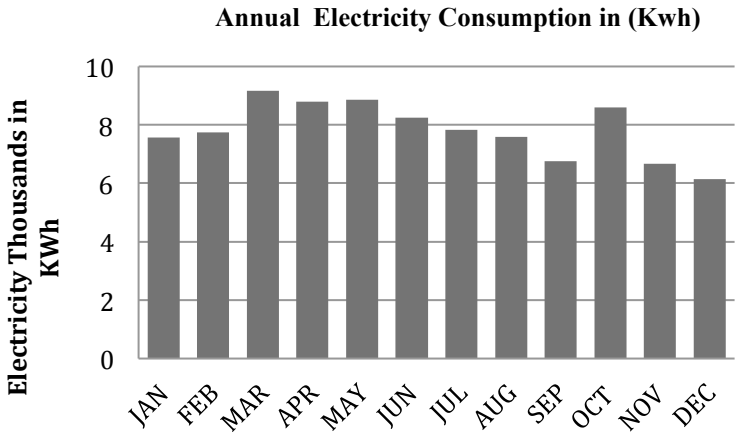


Figure 1: Annual cooling loads in Model A. Source: Project Vasari analysis (2014)

4.1.2 Disaggregation of total electricity consumption

The results of the simulation in model A shows that when mixed mode cooling strategies using passive downdraught evaporative cooling and central air conditioning system is incorporated in to the building with single skin facade technology, the predicted results indicates 40% for cooling appliances, while 4% is used for lighting equipment.

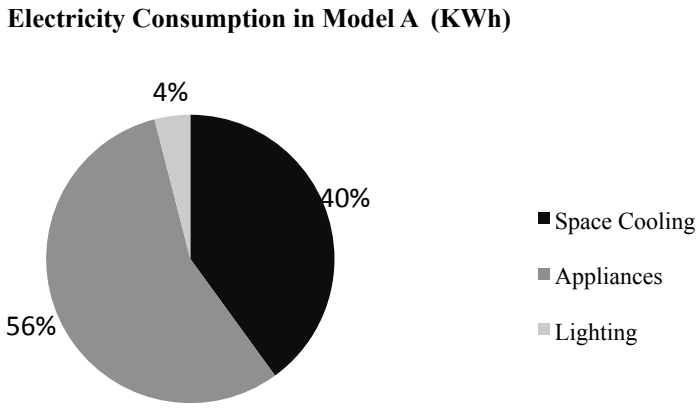


Figure 2: Annual end use intensity model A. Source: Author's analysis (2014)

4.2 Model B

This model is developed with double skin facade technology; with a ventilated cavity of 1200mm between the two layers of the double skin facade (see Plate II).

The model analyses the performance of this optimised office building using mixed mode cooling strategy by combining the concept of Passive Downdraught Evaporative Cooling (PDEC) system with Floor slab cooling system. This is aimed at predicting energy conservation in glazed office building within hot dry climate.

4.2.1 Monthly electricity consumption

The result of prediction from simulating model B indicates a significant drop of about 10% in consumption compare to the Model A. The expected monthly consumption predicted from the simulation, while Figure 3 analyses the level of monthly consumption.

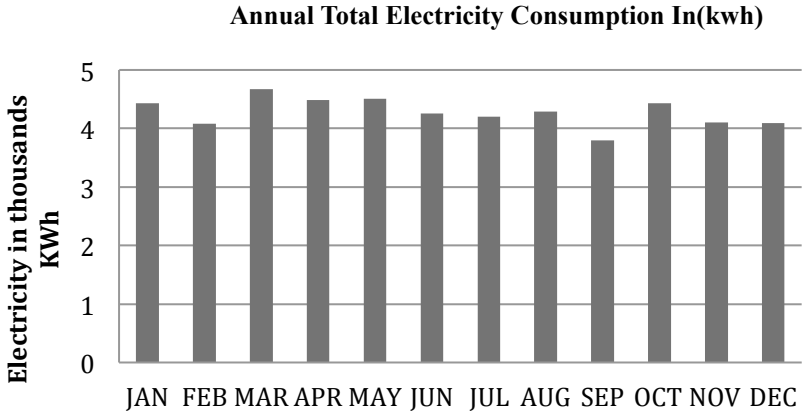


Figure 3: Annual cooling loads in Model B. Source: Project Vasari (2014)

4.2.2 Disaggregation of total electricity consumption

The disaggregation of quantity of energy consumed in model B (see Figure 4) predicts 30% of the total energy used by cooling system, while 17% is used in lighting sources.

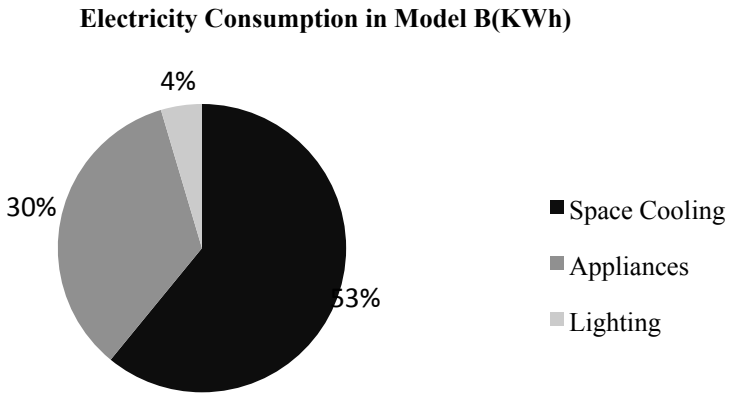


Figure 4: Annual Energy end use intensity in model B. Source: Project Vasari (2014)

4.3 Model C

This model is developed with a double skin facade technology, the skin layers are separated by ventilated cavity of 900mm (see plate III). It is 3mx4m in dimension and made up of four floors, each occupied by two (2) people. The optimised model predicts and compares the performance of mixed mode cooling strategies (Passive Downdraught Evaporative Cooling (PDEC) system with central air conditioning).

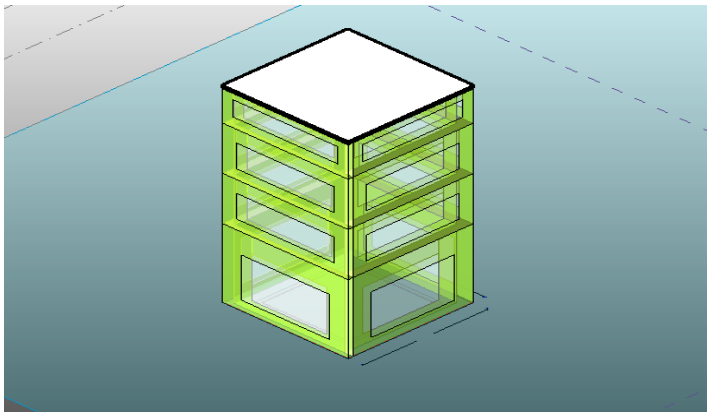


Plate III: MODEL C: Double skin-shaded facade with mixed mode cooling strategy.

Source: Project Vasari analysis (2014)

4.3.1 Monthly electricity consumption

The result of model C with double skin facade has adopting PDEC system and central air conditioning system as the mixed mode cooling strategies, indicates a little drop of about 2% in energy consumption as compared to the Model B. The model in Figure 5 predicts the monthly consumption level.

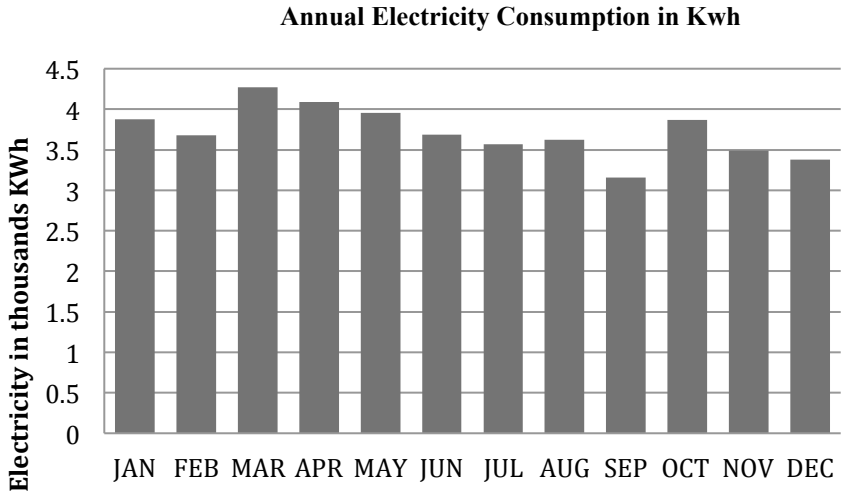


Figure 5: Annual cooling loads in Model C. *Source: Project Vasari analysis (2014)*

4.3.2 Disaggregation of total electricity consumption

The predictions from model C indicates a disaggregated consumption for the components of electrical equipment within the building (see Figure 6), it reveals that 28% of the total energy is used for spaces cooling, while the remaining 10% is meant to power the lighting equipment.

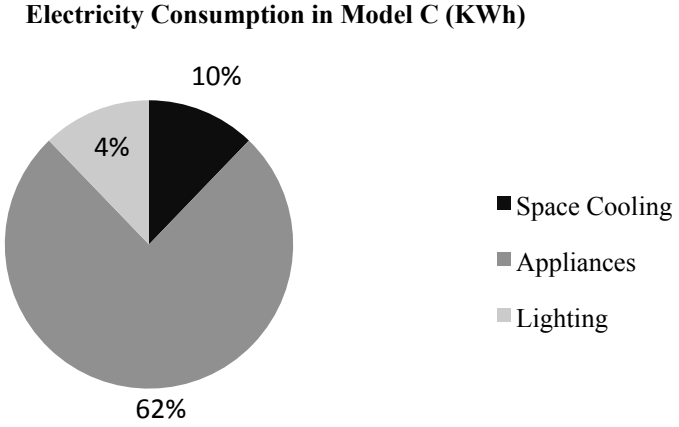


Figure 6: Annual end use intensity model C. Source: Project Vasari analysis (2014)

4.4 Towards Evolving Mixed Mode Cooling Strategies

Table 3 shows monthly electricity consumption in all three models. The total consumptions are 93999.7kWh, 51336.1kWh and 44658.4kWh respectively. Model A consumes the most electricity followed by Model B and finally Model C. This result is consistent with improvements in cooling strategies adopted by firstly, adding a double skin to ventilate the façade and secondly, shading leading to a savings of up to 52%.

Table 3: Annual electricity consumption in the simulated models

	MODEL A (KWh)	**MODEL B (KWh)**	**MODEL C (KWh)**
Jan	7566.7	4432.6	3894.5
Feb	7749.9	4083.8	3676.1
Mar	9161.7	4671.1	4269.6
Apr	8796.3	4488.2	4091.6
May	8855.1	4503.4	3952.0
June	8257.4	4256.9	3687.7
July	7833.2	4199.0	3571.1
Aug	7588.7	4288.6	3625.4
Sep	6762.1	3792.9	3153.9
Oct	8603.5	4432.9	3871
Nov	6674.2	4099.7	3489
Dec	6150.9	4087.0	3376.5
Total	**93999.7**	**51336.1**	**44658.4**

Table 4 predicts that the average aggregates for lighting, appliances and space cooling are 10%, 54% and 33% respectively, indicating that appliances consume the most electricity in

the three models. However, a change in façade technology has an impact on space cooling in a range of 40%, 30% and 28% respectively with the most cooling predicted in Model A and least in Model C. This predicts the gradual thermal improvement with the addition of ventilation in the double skin and then the shading device in Models B and C.

Table 4: Annual end use intensity for the three energy modes

Components	MODEL A	MODEL B	MODEL C
Lighting	4%	17%	10%
Appliances	56%	53%	52%
Space cooling	40%	30%	28%

Source: Project Vasari analysis (2014)

5.0 CONCLUSION

This study has demonstrated that mixed-mode building can be designed to save up to 52% of total electricity consumption using ventilated and shaded façades in a hot dry area. From the simulation analysis conducted, Passive Downdraught Evaporative Cooling (PDEC) system in a ventilated and shaded façade has more potential than the conventional single skin facades used in buildings. This is shown through predictions in monthly electricity consumption comparisons and disaggregation of total electricity in the three models evaluated. The Models A-C cover single skin façade, ventilated double skin façade and shaded facades respectively.

Predictions show that ventilating the façade using double skins is able to save up to 45% of electricity consumed per annum, while an additional 7% can be saved by shading the façade itself. A look into the aggregates making up total consumption predicts that space cooling is the second largest aggregate consuming electricity in the models, but more importantly, the savings in electricity consumption are improved by 10% by ventilating the façade using double skin, and a further 2% by shading the façade.

Given the potentials inherent in mixed-mode cooling strategies in energy conservation, office towers with glazed façade should be simulated and tested before they are constructed in order to achieve good energy performances in the building. There is diverse low energy cooling strategies that can be analysed and adopted to conserve energy in office building design. This can inspire designers to think of energy conscious design approach in addressing energy challenges. Since office towers remain paramount as tools for administrative duty in both private and public sector, the cost of running the building should be the concern of the designer in order to increase the profit margin of the establishment occupying a building.

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ARCHISEARCH

TIME SERIES ANALYSIS OF GREEN SPACES CONVERSION IN AHMADU BELLO UNIVERSITY, NIGERIA

Idris Iliyasu Isah[1] and Mukhtar Abdurrasheed[2]
[1&2]Department of Urban and Regional Planning, Ahmadu Bello University
Email[1]: urbanist2005@gmail.com

Abstract

One of the most important parameters in planning and design of a campus is the selection of appropriate land surface to develop green areas. It has been observed that the core area of Ahmadu Bello University Zaria main campus is confronted with several challenges that serve as a barrier to physical, economic and social benefit from green areas. The increasing population and the demand for more spaces results to the conversion of green spaces into impermeable hard concrete surface especially in the core area. Green spaces have been converted to different land uses every year, and the consequences of which exposed the environment to increase in soil temperature, local climate change, instability in hydrological regime, and the loss of important species; all of which ultimately have negative effect on the ecological environment and human settlement. For a better understanding of challenges in the campus, quantitative data drawn largely from secondary sources and field measurement was also collected and analyzed. In addition, proper assessment was done on the campus green areas according to the data gathered so as to understand the physical, social and economic characteristics of green areas through the classification of the problems in order to know the kind of intervention required. The Landsat (satellite) images which were the major data acquired were classified so as to see the changes that have occurred within different years (1990-2013) using GIS as a tool. The outcomes of the findings show that, there have been massive infill development at the core area and that reduced the green spaces from 73ha in 1990 to 61ha in 2013, i.e. 11.9ha (16.3%) were lost to built up in 23 years; the implication of this is the abuse of the university physical development plan and distortion of the appealing nature of the Campus environment. The paper draws conclusion and made recommendations which include: review of the campus master plan, preservation of the existing recreational spaces and providing more to serve the ailing need of both staff and students.

Keywords: Built up, Climate Change, Green Spaces, Physical Planning.

1.0 INTRODUCTION

Provision of a Conducive physical environment is crucial for staff and students in a tertiary institutions. Green areas play vital roles in healthy and responsive working and learning environments. It also connects and organizes fragmented open spaces and buildings as well as facilitates the movement of people in and around campus under safe and comfortable conditions. The Green area allows campus residents to undergo their daily activities such as walking, jogging, biking, experiencing nature, watching people, meeting friends, displaying artworks and many more.

Furthermore, Hendershott et al. (1991) argued that factors other than education contributes to student life and that student comfort must be considered in relation to many other environmental factors. A place without green areas will pave way to some environmental issues such as contaminated air, noise pollution, loss of environmental aesthetics and so on. From this perspective, the campus planner is useful in providing and upgrading the green areas of tertiary institutions.

In Nigeria Tertiary Institutions, based on observation, students' perception of their overall academic experience and the campus environment is related to academic accomplishment. Additionally, the designed environment of any tertiary institution can influence the degree of the performance and otherwise of the students. Observations made on Ahmadu Bello University Main Campus has strong assertion that increasing population and campus expansion over time is responsible for the conversion of softer green spaces into impermeable hard concrete surface especially in the core academic areas. Green spaces are being converted to different land uses every year, this causes lots of environmental consequences such as: increased soil temperature, local climate change, instability in hydrological regime, and the loss of important species; all of which ultimately have adverse effect on the ecological environment and human habitation. Understanding people-ecological relationships from the perspective of a university campus planning could prove useful, as most tertiary institutions do not emphasize the appearance of the physical environment in relationship to learning even though research has shown that manipulating the physical environment to achieve specific results is viable (Drew, 1971).

In this paper, an approach that integrates mapping analysis with geographical information system (GIS) technology was developed and implemented to identify the campus green space system development overtime and it is with the view to establish the extent of green space conversion, its effect and factors responsible for it.

2.0 LITERATURE REVIEW ON CAMPUS GREEN AREAS AND DEVELOPMENT

Kaplan (1992) defined nature to include: one plant or many plants, and also the place created by them. It includes a street tree as well as trees in an atrium. It also refer to fields, woods, and land that have not been developed. People can interact with plants and nature actively or passively. Active interactions with nature such as green fields and plants, are related to improved psychological and physiological health in children and adults (Kaplan, 2001; Lim, 2006). These benefits include increased self-esteem and reduced stress levels. Alternatively, passive interactions are those that are visual and more observational in character (Lim, 2006),

and these interactions have been found to improve life satisfaction. For example, Ulrich (1984) found that patients in hospitals with access to windows that enable viewing of natural areas results to reduction of incidence of reported illness. Lewis (1994) explained that both types of interactions with natural areas have positive mental and physical effects on individuals. The term green area, for the purpose of this paper, shall mean areas allocated for the planting of trees, shrubs and growing of grasses.

2.1 Green Areas and Institutional Competitiveness

The quality of green spaces also serve as criteria for institutional competitiveness, though in terms of the social, planning, economic and ecological perspectives pointed out as cited by Baycan, (2002, p:2).

a. **Social Perspective:** a particular type of green Area can offer a wider diversity of land uses and opportunities for a wide range of activities that help to foster active life styles and can be of real benefit to health. Well managed and maintained green areas contribute to social justice by creating opportunities for people of all ages to interact. Green areas provide safe play areas for students, which contribute to physical, mental and social development.
b. **Planning perspective:** A network of high quality green areas linking various land use developments can help to improve the accessibility and attractiveness of local facilities and employment centers. Well-designed networks of green areas help to encourage people to travel safely by foot or by bicycle for recreation or commuting. Furthermore, they provide a barrier to noise and can function as a visual screen against unwanted developments such as derelict areas or Slum etc.
c. **Economic perspective**: a green area might deliver products such as wood or fruits and also compost and energy as a result of green area production. Their presence can create an increase in the economic value of an area and even provide new jobs.
d. **Ecological perspective**: green areas moderate the impact of human activities, for example; absorbing pollutants and releasing oxygen, contributing to the maintenance of a healthy environment by providing clean air, water, soil, improving climate and maintaining the balance of the natural environment.

2.2 The Practice of Green Area Development for Tertiary Institutions in Some Selected Countries

Institutional greens are among the most recognizable and memorable campus spaces. They provide settings for classes, special events, recreation, and contemplation. Campus greens

and open green spaces should reinforce the high-quality values and vision of the university (Ayorinde, 1981:6). Characteristics of these spaces should include:

- Seamless and universally attractive campus landscape
- Quality design and thoughtful use of architectural and landscape materials
- Notable pedestrian "front doors" at the campus edge
- Efficient pedestrian and bicycle access and circulation
- Clear incorporation of a campus wayfinding program
- Incorporation of sustainable design principles
- Support of campus art
- Thoughtful incorporation of utilities and infrastructure.

The following are some of the selected case studies reviewed for consideration in the paper:

2.2.1 The Jackrabbit Green concept

The Jackrabbit Green Development Plan, a concept plan applied in the formulation of University of Wisconsin-stout in 2006. It serves as a guide for the creation of a strong east-to-west pedestrian corridor along the north end of the campus. The concept plan for the Jackrabbit Green establishes a pedestrian corridor highlighted by gathering nodes, campus art, landscape and wayfinding signage. The plan consists of a series of open spaces connected by sidewalks within the core of campus. The existing north/south corridors connecting to the Jackrabbit Green will be enhanced, extending improvements to the historic College Green and other prominent open spaces throughout campus. The plan incorporates a stage and amphitheater into this space, activating an area of campus that has become a center for student activity. The completion of the Jackrabbit Green resulted to a contiguous unified corridor spanning a significant portion of the university campus.

2.2.2 The College Green concept of University Saint Malaysia

Over the long history of the campus, the function of the College Green has evolved. In 2006 a new campus 5 year medium term development strategy was proposed for 2007 – 2012. The implementation resulted to the expansion of the campus to the north and east, relocating much of the residential, academic and student service functions of the campus further away from the College Green. The College Green has undergone numerous changes including the addition and removal of buildings, designation of new purposes for existing buildings, the reorganization of walkways as traffic patterns changed, and the evolution and rejuvenation of the landscape. As the campus expanded, new greens and corridors have developed on campus, though none is more treasured or significant as the College Green.

As the campus fabric is redefined, it is recommended that the university consider options to re-engage the College Green. The development of pedestrian corridors should include strong connections to the College Green. The repurposing of buildings or additions of new buildings near the green should be studied as ways to attract a portion of the student population back to the College Green. Removing the street and parking from the west side of the Administration Building will create the opportunity to develop that space into a major north-south campus pedestrian corridor. Changes to the College Green should be done with great respect for the history of space, with the goal of re-engaging the student population and reinforcing the significance of the College Green.

2.2.3 Nsukka Campus green space

The main campus of the University of Nigeria Having arrays of residential structures, structurally arranged in such a way that on one side there are clusters of hostels sprinkled with places of leisure and relaxation and on the other cluster are beautiful staff residences surrounded with beautiful flower gardens. For lovers of aesthetics, the main campus environment is an edifice of architectural beauty and art. With earthy stones and green vegetation, the campus also has works of arts placed at strategic points in the University, pleasant to the eyes relaxing to the mind.

2.3 The study area

The Ahmadu Bello University grew from the seeds nourished at the Samaru Agricultural Research Station in 1924. ABU is located in Samaru Zaria, Kaduna State of Nigeria and it lies between 11^0 5' and $11^0$15' N; 7^0 34' and $7^0$6' E. Zaria is a nodal town for both road and rail transportation modes. It is a confluence of the North-Eastern and North-Western axes of the country. Beyond its two campuses located across Zaria, ABU also has over thirteen outstations across the country. Zaria itself is a very large, heterogeneous city whose population is about 1, 490,000 people came from different parts of the world. It is second in size only to the State capital, Kaduna. Zaria is accessible from different parts of the country by air via Kaduna, Kano, and Abuja and by rail and road via Kaduna, Jos, Kano and Sokoto.

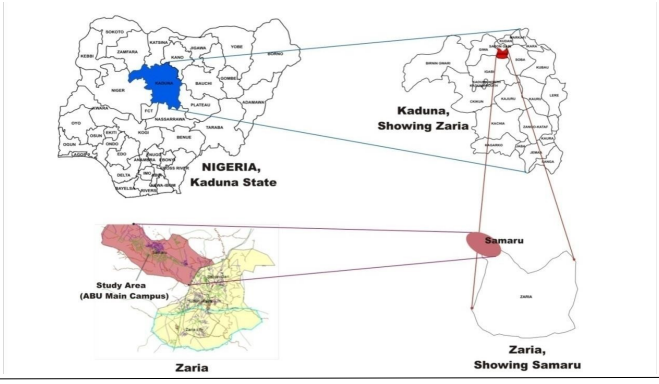


Figure 1: ABU Main Campus in Regional Context. Source: Digitized and updated satellite imagery, 2014

2.3.1 Vegetation/Green areas

The study area lies in the natural vegetation zone known as Northern Guinea Savanna in which Isober linia Doka, Isober linia Dalzielii and Uapaca Togoenia are among the most common trees; these usually mature between 10 and 15 meters high with broad leaves and well developed grasses and shrubs.



Figure 2: ABU Main Campus in Regional Context. Source: Digitized and updated satellite imagery, 2014

2.3.2 The Campus Physical Development Plan

The campus master plan is a physical manifestation of the university's strategic plan. At its best, it is a roadmap for the future of the campus. The ABU Campus Master Plan of 1980 comprises of the residential, commercial, academic also known as the core area, public/semi public, recreational areas, etc. The campus master plan also has a provision for green areas, which includes the park and gardens.

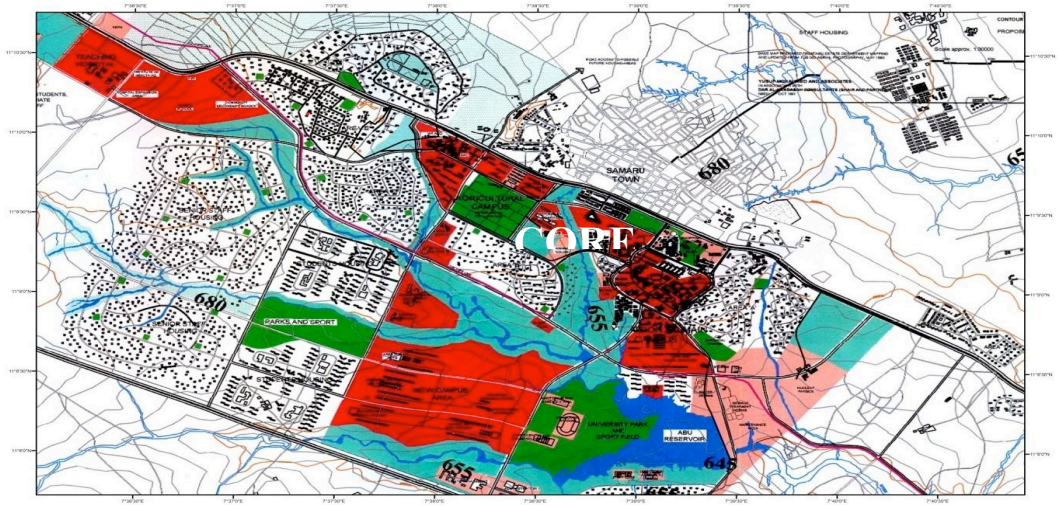


Figure 3: ABU Physical Development Plan. Source: ABU Physical Development Master Plan (1980-1995).

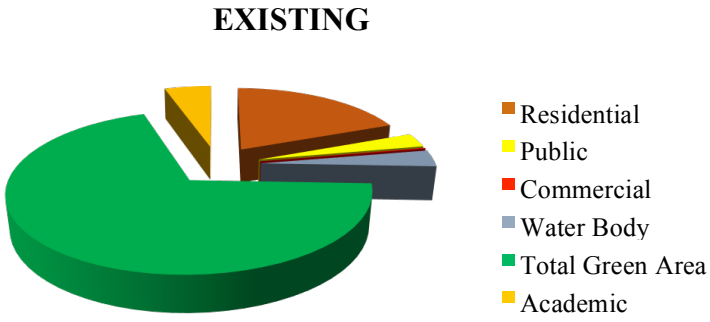
2.3.3 Existing Land use

All the existing developments on the main campus and agricultural complex are sited at the north of Kubani River. A breakdown of the existing land use is provided in Table 1.

Table 1: Existing Landuse of ABU Zaria main Campus 2015

S/N	Landuse	Area cover (hectare)	Percentage (%)
1.	Residential	331.57	19
2.	Public	51.19	3
3.	Commercial	2.4075	0.9
4.	Water Body	60	4
5.	Total Green Area	1239.0834	68.1
6.	Academic (core area)	88	5
	Total	**1771.2675**	**100**

Source: Digitized and updated satellite imagery, 2014



3.0 RESEARCH METHODOLOGY

Two types of data were collected, primary and secondary. The primary data include physical data that were acquired directly from the field survey; such data were generated using a handheld GPS as well as physical inventory and measurements survey. The secondary data comprised of Base map of the Ahmadu Bello University Main Campus, Land use/Land cover maps for different year period (1986 – 2013), Landsat imagery of the study area, Topographic

Map of the study area and data on staff and students population on campus. The data collected were analyzed using GIS 10**,** Autocad 2015, Land Dev. 2012, Autocad Civil 3D and ILWIS 3.4 version as well as Maximum likelihood method for classification and the use of overlay technique. Graphically, the methodology is shown below.

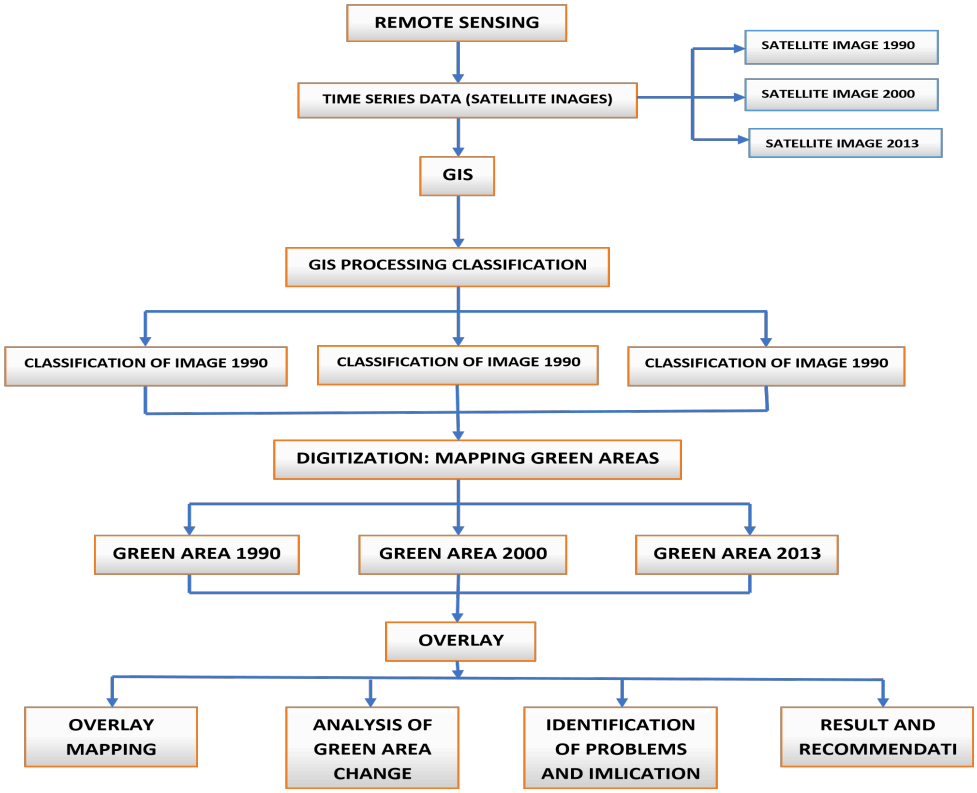


Figure 4: Research Methodology. Source: Author, 2014

4.0 RESULTS AND DISCUSSIONS

4.1 Assessment of Change on Green Area from 1990 to 2013 in the Core Area of ABU Main Campus

In recent years, green areas in the study have undergone depletion, especially in the core area. The common approach is to consider the behavior of green area changes taking place and in most cases the changes of such green areas are identified by visual interpretation. However, to establish this change and the extent of the changeover period, the area under study has to be observed at different spatial and temporal scales. This is made possible by the availability of dated and recent satellite imagery at relatively good resolutions that enabled visual analysis and interpretation. The analysis interprets and processes satellite images at different temporal scales to establish a time series analysis of the spatial transformation of the ABU main campus core area between 1990 and 2013.

Table 2: A.B.U. Core Area in 1990

Year	***Area Coverage (Ha)***
1990	73

Source: Satellite imagery, 1990

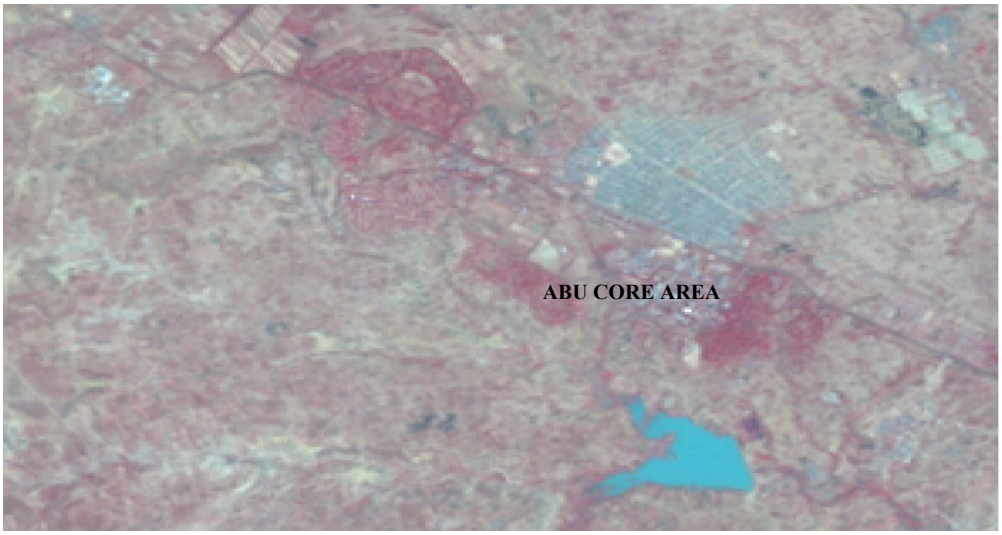
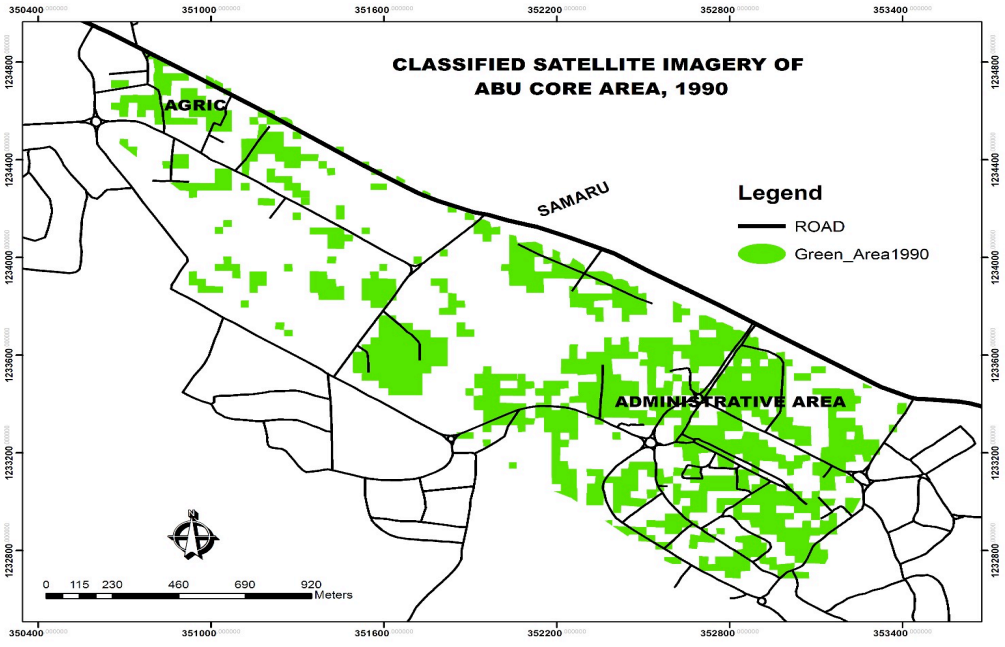


Figure 5: 1990 Landsat 30m Resolution Image, ABU main campus. Source: Quick bird, 2014 and Author, 2014



4.2 Green Area Coverage 2000

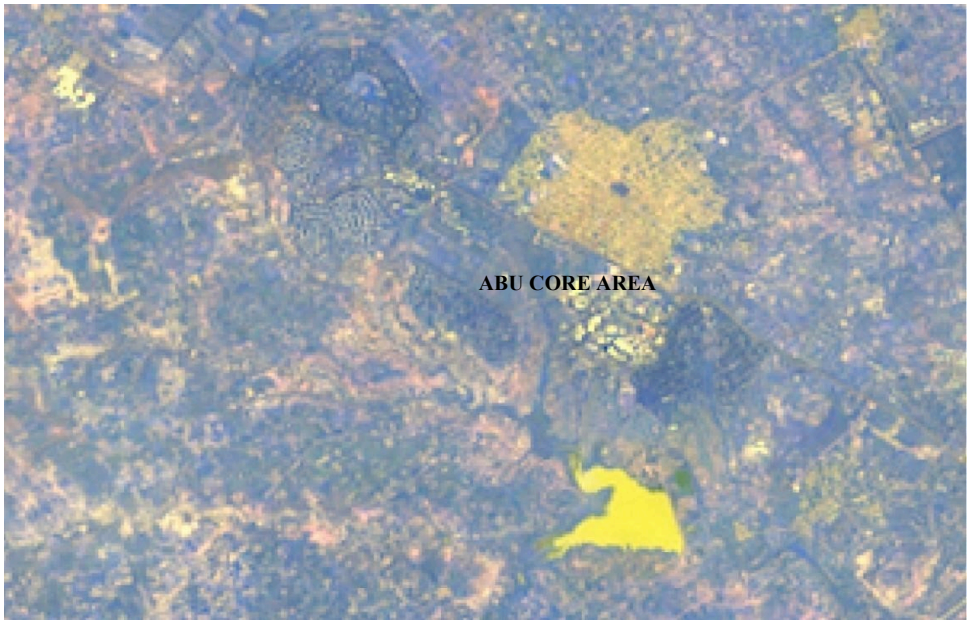


Figure 6: 2000 Landsat 32m Resolution Image, ABU main campus. Source: Author (Derived Maximum likelihood), 2015

Table 3: Statistics of ABU Core Area 2000

Year	***Area Coverage (Ha)***
2000	68.3

Source: Satellite imagery, 2000

4.3 Green Area Coverage 2013

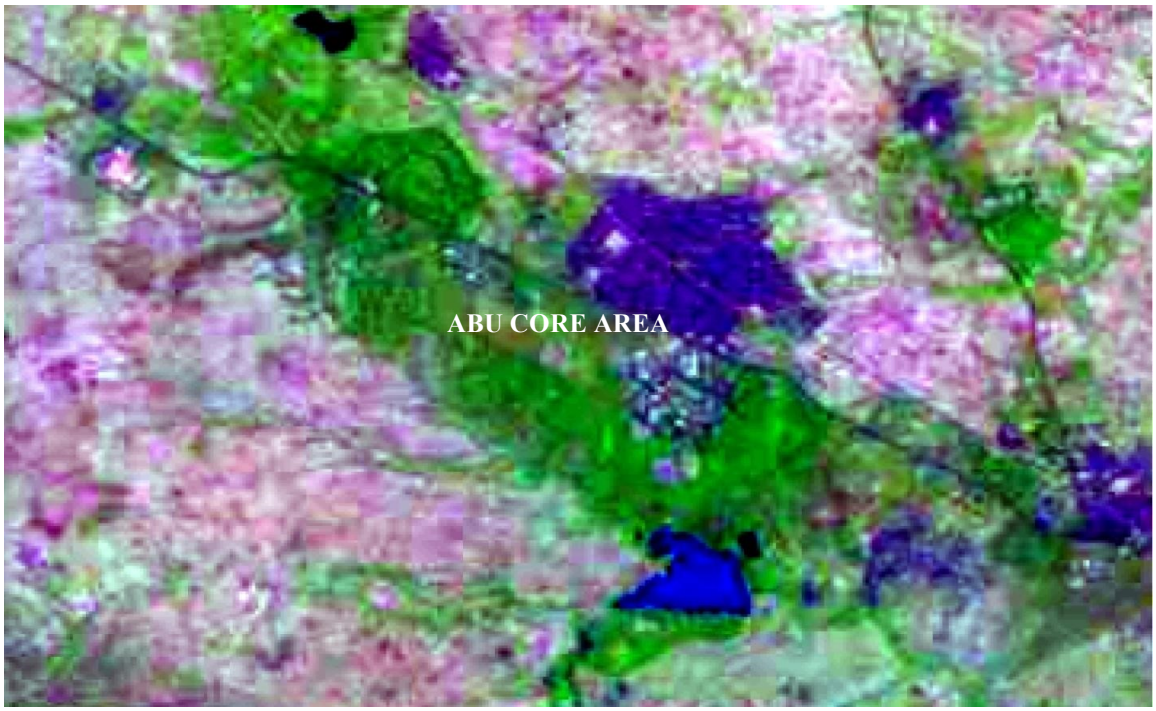


Figure7: 2013 Landsat 30m Resolution Image of ABU main campus. Source: Quick bird 2013

Table 4: Statistics of ABU Core Area 2013

Year	Area Coverage (Ha)
2013	61

Source: Satellite imagery, 2013

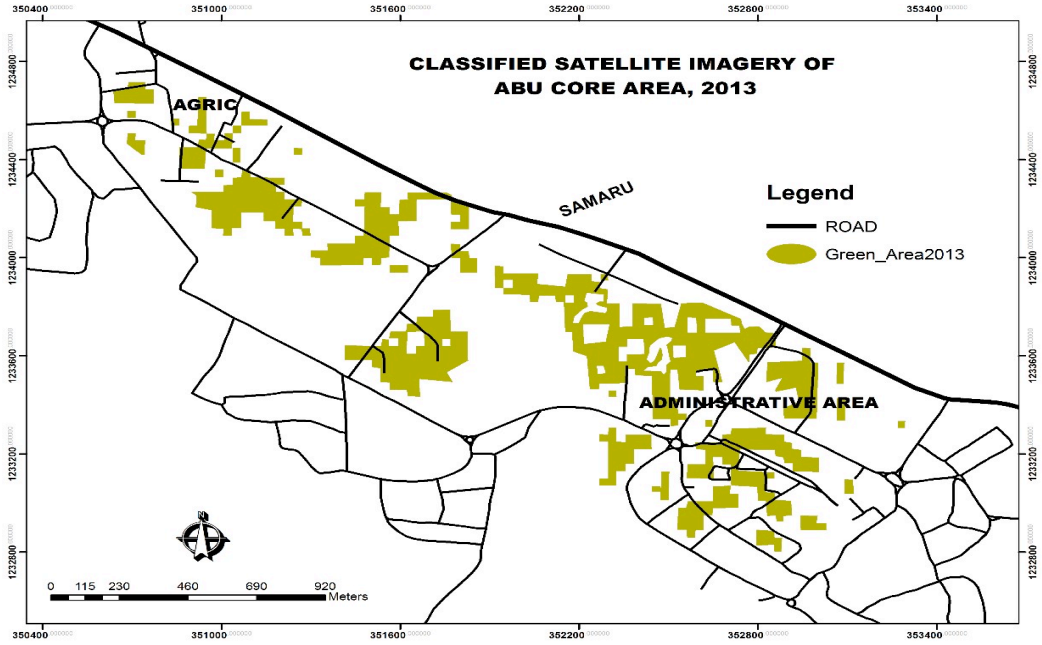


Figure 8: ABU Core area 2013 Green area Extent. Source: Author (Derived Maximum likelihood Classification), 2013

4.4 Overlay of classified satellite imagery of ABU core 1990, 2000 and 2013 green area extent

This is a spatial analysis that involves the overlapping of layers, i.e. the ABU core area satellite imagery of 1990, 2000 and 2013, known as map overlays (Figures 9-10). This paved way to identifying green space change between these three years in ABU core area.

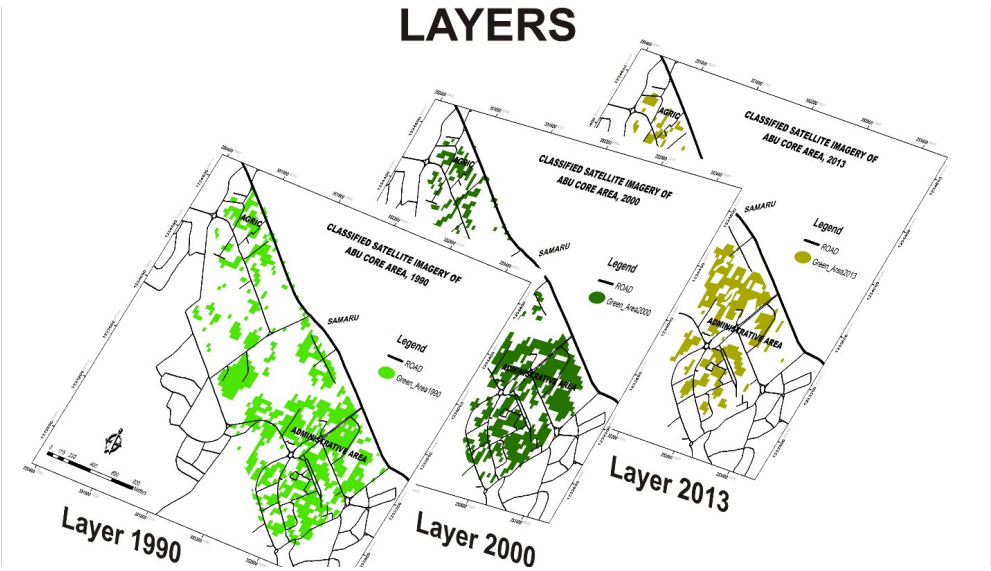


Figure 9: Overlay of classified satellite Imagery ABU core 1990, 2000 and 2013 green area extent. Source: Source: satellite imagery, 1990, 2000, and 2013.

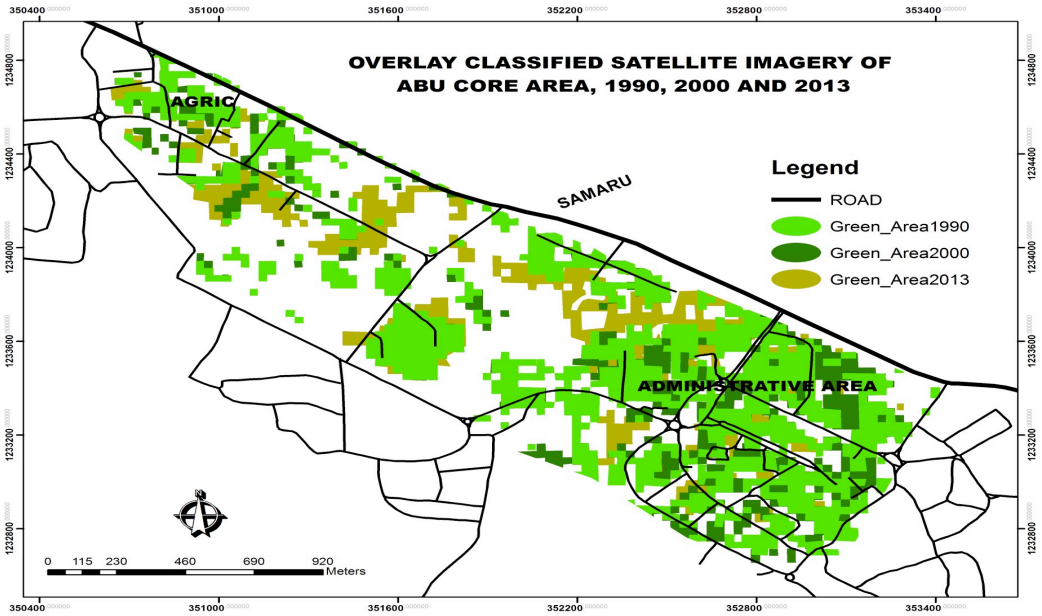


Figure 10: Result of the Overlay 1990, 2000 and 2013

4.5 Result of the Overlay 1990, 2000 and 2013

Table 5: Statistics of Overlay 1990-2013 ABU Core Area

Years	Area Coverage (Ha)	Percentage
1990	73.4	35.6
2000	71.3	34.6
2013	61.5	29.8
Total	206.2	100

Source: Derived

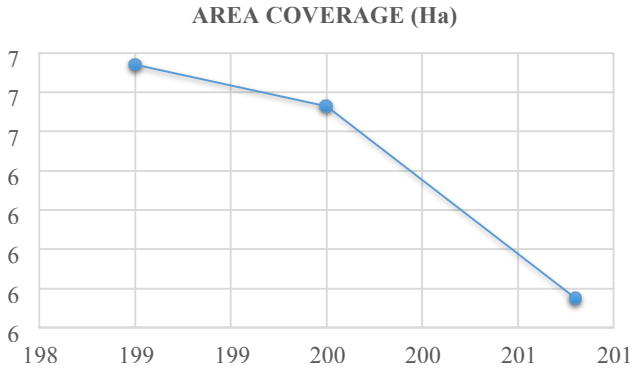
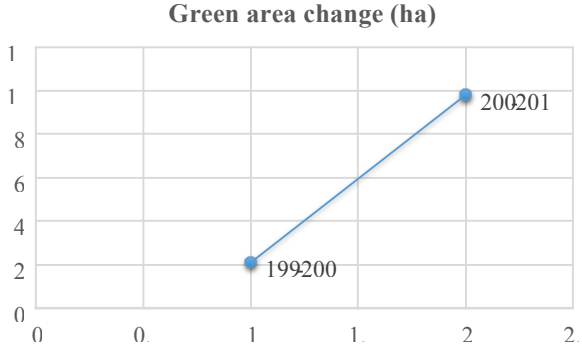
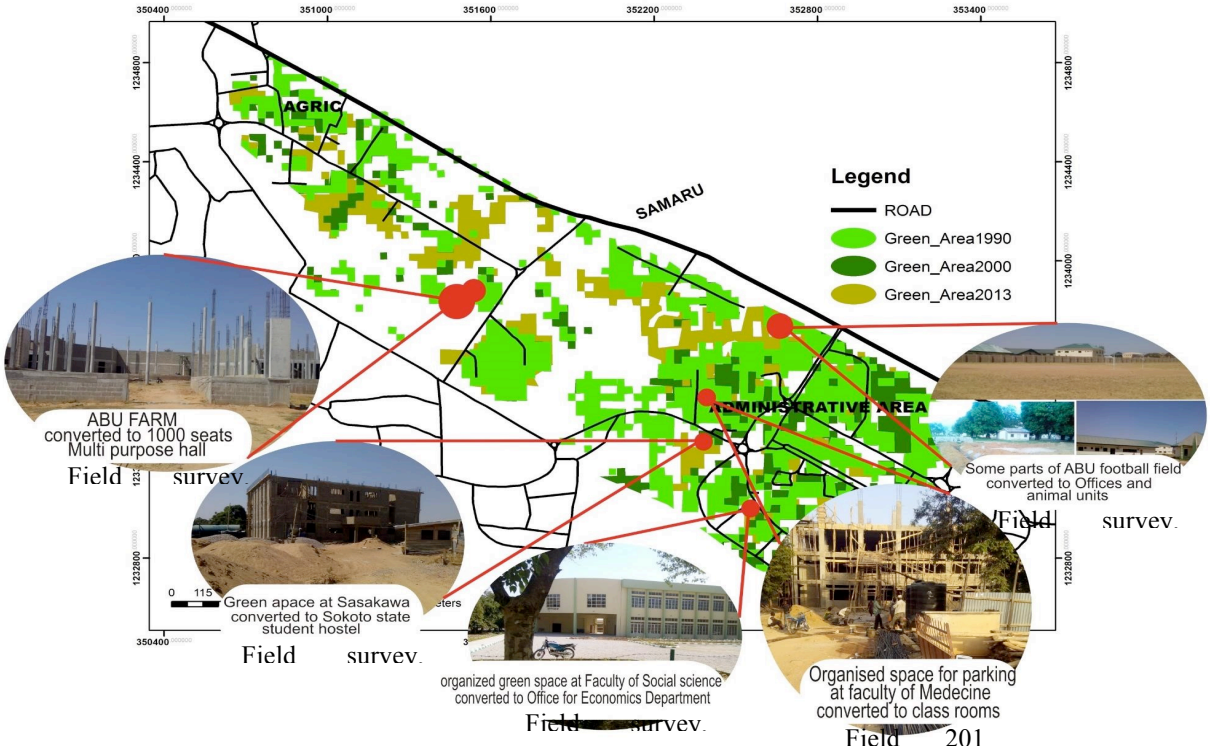


Table 6.0: Green Space Change over these three Periods

Study period	Time span (years)	Green area change (ha)
1990-2000	10	2.1
2000-2013	13	9.8
Total	23	11.9

Source: Derived





4.5 Summary of findings

From the analysis made using the satellite imageries of different years and reviewing the campus master plan provision for green areas coupled with the existing developments on the campus, the following problems were identified:

1. Deviation from the master plan provision of green areas. Areas such as the demonstration secondary school, veterinary hospital, multipurpose hall at the university farm etc. (fig 4.6) were not planned to be in their present locations. The locations that they are placed were meant for a recreational park based on the provision of the campus master plan of 1980. This has become a problem because it reduces the number of recreational areas meant to serve the campus sufficiently.
2. Inadequate maintenance of green areas by the university management (parks and garden department) and the public (staff and students). This has resulted to misuse of green spaces and facilities.
3. Some of the proposed green spaces are not implemented. Spaces such as Park, University sporting park and other recreational centers for both staffs and students.
4. Low Attention Given to Green Areas makes the green spaces diminish in quality and quantity due to intense construction activities on campus.

5.0 CONCLUSION AND RECOMMENDATION

Green spaces fulfill many functions in a University environment, they also influences people's quality of life. The ecological benefits bestowed in green spaces that range from protecting and maintaining the biodiversity to helping in the improvement of built environment cannot be overlooked in today's sustainable planning and design approaches. In other to meet the social and psychological needs of people, green spaces in the ABU Main Campus should be easily accessible and in adequate quality and quantity. Green spaces need to be uniformly distributed throughout the Campus areas, and the total area occupied by green spaces in the Campus should be large enough to accommodate the population needs. Bringing green space to the Campus landscape can promote and inspire a better relationship with the environment while supporting important services and enabling atmosphere for Teaching, Learning and Research. Green space is part of and also represents habitats and ecosystems. The promotion and conservation of green space in the Campus is in the hands of the management.

Given the above, the paper therefore makes the following recommendations for the improvement of green areas of the campus:

a. The analysis revealed that some of the developments of green spaces were not in accordance with the provision of ABU master plan. Therefore the review of the ABU master plan should be done from time to time (5-10years), and it should serve as a guide to the development of the campus.

b. The rehabilitation and maintenance of the existing green spaces will be of great importance towards enhancing the environment of the institution, hence the need for a proper maintenance and improvement programme for the existing organized open spaces.

c. Since the existing recreational facilities within the campus are insufficient to serve both staff and students more recreational facilities should be provided to meet up with the requirement of the campus green open spaces.

d. The university management should consult the services of local and professional planners to review the existing green Spaces and develop a strategic campus open space Plan and development guide for implementation and monitoring.

e. Building strong collaboration for public private partnership in the provision of campus green infrastructure and maintenance.

f. There is a need to Fast-track the completion of the University Master Plan which is ongoing, so as to open up phase two of the university for onward development, this will help in addressing the excessive and persistent conversion of open green spaces for building construction on campus.

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ARCHISEARCH

DISAGGREGATION OF ENERGY CONSUMPTION IN CORPORATE BUILDINGS OF KADUNA METROPOLIS, NIGERIA

Murtala Muhammad Salihu
Department Of Architecture, Ahmadu Bello University, Zaria
murtalasg@gmail.com

Abstract

The study is aimed at investigating the pattern and rate of energy consumption in corporate buildings of Kaduna metropolis. Quantitative and qualitative surveys are conducted to obtain relevant primary data; through the use of questionnaires and physical observation techniques administered on six purposively sampled building facilities around the city. Data collected from two-year bills of utility supply, on-site back-up sources of electricity supply and inventory of all energy consuming appliances in the facilities are analyzed; where estimated energy demand, energy use index and rate of energy supply is estimated. Findings revealed that the major agents of consumption are demands for cooling, lighting and other electrical appliances, taking approximately 52%, 36% and 12% of the total loads respectively. From the acquired estimated values, the study also revealed that the rate of energy supply is not commensurate to that of its demand in the facilities. The exercise clearly identifies the core areas in which energy challenges lie in office buildings, and may therefore be a primary tool of identifying the key areas in which energy conservation measures can be applied by building owners and related policy makers.

Keywords; Disaggregation, Energy Consumption, Corporate Buildings, Kaduna Metropolis, Energy Audit

1.0 RESEARCH BACKGROUND

In the Nigerian context, electricity and petroleum products used in energy production chiefly drive the energy sector. Electricity therefore forms the nucleus of operations and the major engine of growth for all sectors of the economy; it consolidates all the activities of the other sectors, which provide essential services to direct the production activities of the economy (Energy Information Administration, 2012).

Unfortunately, even though the overall picture reveals availability of enormous energy resources in the country which far exceed its energy requirement, electricity demand by far outstrips its supply, which has furthermore been reported to be epileptic in nature. (European Scientific Journal, 2013; Muazu, 2012). Arguably, the singular impediment to the attainment of Nigeria's vision to become one of the 20 developed economies in 2020 is power supply; because of the direct bearing it has on other economic indicators like unemployment rate and low capacity utilization in the manufacturing sector (European Scientific Journal February, 2013; Esso & Loesse, 2010).

These energy challenges have a direct impact on the operation of corporate and commercial buildings, which the office buildings fall within. It is a building typology that require an uninterrupted energy supply within its activity period. In terms of energy consumption per meter square, office buildings consume about 70-300KWh/m2 of energy to function effectively, which is 10-20 times higher than the residential sector (Sadrzadehrafiei et al, 2012). Some of the major components and systems responsible for energy consumption in commercial buildings are mainly cooling and ventilation Systems, lighting, and other related electrical appliances and technologies (Atikol, 2014).

To curtail the negative impacts associated with energy consumption, either economic, environmental or even social; an initial end use energy disaggregation exercise is carried out to pinpoint the exact areas that priority must be given when planning energy conservation strategies on any given facility (Canadian Industry Program for Energy Conservation (CIPEC), 2014). Such strategies may take the form of whole or building component retrofitting exercise, downsizing of generation plants, rationing of energy use and use of renewable sources of energy supply.

The aim of this study therefore is to carry out such an energy use disaggregation on corporate buildings of Kaduna metropolis. This is carried out through a walkthrough energy audit exercise, geared towards uncovering the energy use and supply pattern of such facilities as a basis for further relevant research and subsequent decision making.

2.0 LITERATURE REVIEW

Rise in economic development comes with consequent rise in energy demand. Even though it has been argued that this does not necessarily cut across all economic sectors or regions of a given country, it plays a vital role in determining the pattern in which energy is consumed in the area (Adnan & Riaz, 2008; Huang et al, 2007). Several studies have been conducted on energy consumption across Nigeria to determine such patterns in which energy demands are met or otherwise; where the results mostly show similarities in their findings due to related connections in either the context, methods or focus (Aderemi, et al, 2009; & Noah et al, 2012). Although review of relevant literature showed that most of such research focused on rather generic issues and building typology other than office buildings, attempt has been made by many other researchers on the same subject matter in different locations other than the context of this study.

In their studies; Batagarawa, Hamza & Dudek, (2012) and Muazu, (2011); looked at energy consumption in Nigeria and Abuja respectively. In the case of disaggregation of energy

consumption in office buildings in Nigeria, the researchers posited that the major consumers in energy consumption were cooling, lighting and electrical appliances with 40%, 12% and 48% values respectively. The case of Abuja as reported by the latter researcher showed that commercial and residential sectors account for 37% and 61% consumption respectively, pointing to the fact that office buildings have a significant impact on energy consumption of a city.

Although a similar study with corresponding results was carried out in North Eastern part of the country by Umar (2014), it presented a sort of contrast by focusing on the role of the building envelop and its role on cooling of the interior. Results showed that the quest for thermal comfort in office environment resulting to cooling is the highest consumer of energy in all the buildings studied in that research.

A closer in context kind of review was made on a study carried out by Yohanna, Humphrey & Aondover (2013) where they assessed energy use pattern in Kano and Kaduna, with focus on residential buildings only. The study concluded that lighting, cooling and ventilation, preservation and cooking were the major players in consumption with 42.19Kwh/m^2, 15.92 Kwh/m^2 and 7.84 Kwh/m^2 respectively. This affirms the magnitude in variation of results acquired with difference in typology and study area. It further necessitates the need to assess the energy use index of office buildings in Kaduna metropolis in order to provide a substantial primary data for further scrutiny into the best energy conservation strategies to apply, or even to simply lay a foundation for further researches like retrofitting options or energy simulation exercises.

3.0 METHODOLOGY

This study involves the use of both qualitative and quantitative research. Within the study area, purposive sampling method was used based on some set criteria; where data was collected by taking a walkthrough inventory of selected facilities. Energy audit was subsequently carried out to determine its consumption and supply patterns as a major tool for the energy use aggregation.

3.1 Sampling

Purposive sampling method was adopted in selecting six office buildings within Kaduna metropolis based on their variation in size, floor area, verticality, number of room spaces, type of ownership, track record of optimum utilization of the facility and ease of access for data collection. This is to make an effort of ensuring all kinds of office buildings around the city are impartially represented. Table 1 shows the representation of the categories for which each of

the buildings represent. The buildings selected were Northern Nigerian Development Company (NNDC), Bank of Industry, Investment House, High Point Building, Federal Inland Revenue Office (Katsina Road Branch), and Kaduna State Microfinance Bank (Rigachukum Branch).

Table 1: Criteria for selection and representation in sampling

	Name Of Building	Ownership	Floor Heights	Total Area(m^2)	Usage
1	**NNDC Building**	PLC	Above 10 Floors	Above 5,000	Full capacity
2	**BOI Building**	Federal Government	Above 5 Floors	Above 3,000	Full capacity
3	**High Point**	Private	5 Floors	Above 1,500	Full capacity
4	**Investment House**	State Government	2 To 4 Floors	Above 1000	Full capacity
5	**FIRS Building**	Federal Government	2 Floors	Above 500	Full capacity
6	**Microfinance Bank**	State Government	Single Floor	Below 50	Full capacity

3.2 Data Collection

Data is collected through the use of self-administered questionnaire, interviews with the facility managers, and physical-visual count of appliances and systems. Further collection of tangible data was also made through obtaining records of maintenance details and cost from utility bills, and back-up generator usage for a period of two years.

3.3 Energy Audit

To achieve the aim of the research, a Walkthrough type of Energy Audit was carried out using a uniform data collection process and tools. Calculations and/or estimations in demand and supply of electrical energy on the case studies were conducted by inputting collected data from the key loads that makes up the total energy consumption. As observed from review of literature and field investigations the key loads recorded are for lighting, HAVC systems, and other electrical appliances. The energy audit process adopted was as outlined by Krarti, (2000); and DOE, (2011) and is summarized in the following steps:

- Walk through inspection of facility.
- Identifying electricity equipment and taking down their ratings.
- Examining of site drawing (if available)
- Identifying how and where energy enters the Facility, Department, System or piece of equipment.
- Preparation of load inventory of facility or piece of equipment.
- Assessing demand profile of both utility and back up (generator)
- Assessing all energy tariff for both Utility and back up.

After the field processes as stated above; aggregated electricity demand estimations are done. For the purpose of this study formulas are adopted based on a study conducted by

Batagarawa, (2011). The demand load is calculated by the equation for each type and specification as shown in Equation (1):

Load = Energy rating x Quantity x hours of usage …...Eq (1)

The hours of use is estimated based on the answers supplied by the respondents and observation. A physical count of all appliances for cooling and ventilation, lighting and other equipment is made by the researcher. All Q are in (kWh); the formulas for adopted in estimated electricity demand for cooling and ventilation, lighting and demand from other appliances are given below;

- Cooling/Ventilation demand (QC) is: QC=Qc1+Qc2+Qc3+Qcn…….……Eq (2)
- Lighting demand (Ql) is: Ql=Ql1+Ql2+Ql3+⋯Qln…..……...…….Eq (3)
- Appliances demand (Qa) is:Qa=Q-(Qc+Ql)……..……Eq (4)

Where (n) represent the variation in type and specification of cooling and ventilation, lighting fixtures and other equipment or appliances. Estimation of total electricity demand is also carried out using the formulas below.

- Total electricity demand: Qt= Qc + Ql + Qa ……..…… Eq (5)
- Total electricity supply (Qt); Qt=Qu+Qg ……..…….……..Eq (6)
- Total supply by back-up generator Qg=(Qu x G)/U ….…….…….Eq (7)

Where (Qt) is the total supply for a particular period of time, usually one year in this case. Qu is the total electricity supplied from the utility supply and Qg is the total electricity supplied by the back-up power respectively; and U and G are the percentages of the time utility and the back-up power are in use respectively. Normalized Energy demand is calculated by summing up the total energy demand by the building's area (m^2). At the end of the audit, the findings were documented and computed in an audit report. Data analysis and presentation of results were discussed.

4.0 RESULTS AND DISCUSSION

As underlined in the research objectives, the first step is to conduct a Walkthrough exercise on all the office buildings. Findings revealed; as shown in Table 2, that the N.N.D.C Building has the highest number of floors (eleven floors) and total floor area of up to 11,312 m^2. It also possesses the highest rate in utility bills and cost of managing the backup system, which is to the tune of monthly averages of 936,334NGN and 1,296,834NGN respectively. Micro finance bank, the smallest building studied is a single floor building of 40m^2 area with

average monthly utility and back up rate of 10,000NGN and 14,400NGN respectively. Information for all other buildings studied is also shown in the table based on the actual and/or approximate magnitude of the nature of floor heights, number of rooms, average room and total floor areas, and utility/backup supply rates for three years. It should be noted however that the number of rooms as shown in the table are according to the structural grid, actual internal partitioning may therefore bring about variation in the captured number. Stating the number of rooms is instrumental in giving a clearer perspective on the magnitude of appliances requirement for each facility; the more the number of room spaces in any facility, the more appliances needed to make if function in full swing.

Table 2: walkthrough inventory on nature of spaces and energy supply rate

	Name Of Building	No of Floors	No. of Rooms	Avg. Room Area (m^2)	Bldg. Floor Area(m^2	Avg. utility Bill/month NGN	Avg. Backup Bill/month NGN
1	**N.N.D.C Building**	11,6,7&2 (4 blocks)	329	24	11312	936,334	348,750
2	**B.O.I Building**	9&1 (2 blocks)	112	24	3816	641,000	155,833
3	**Investment House**	4 & 1 (2 blocks)	68	34	2653	305,000	93,000
4	**High Point**	5&1 (2 blocks)	19	24	446	12,500	10,000
5	**F.I.R.S Building**	2 &1 (2 blocks)	18	20	528	85,000	108,500
6	**Microfinance Bank**	1	4	10	40	10,000	14,400

Table 3 gives an insight on the major energy consuming systems present in each building. It also shows the variant sizes of backup system present in the facilities, with the N.N.D.C Building having a 625KVA generating plant, the B.O.I Building has 500KVA, Investment House has 250 KVA; while High Point and F.I.R.S Buildings have 100KVA each, and Microfinance Bank has a 20 KVA generator.

Table 3: Inventory of type of utility/backup supply and energy consuming systems present

	Name Of Building	Utility Supply	Backup (Kva)	Major Energy Consuming systems Present
1	**N.N.D.C Building**	National Grid	625	Lifts,HAVC, lighting/office equipment
2	**B.O.I Building**	National Grid	500	Lifts,HAVC, lighting/office equipment
3	**Investment House**	National Grid	250	Lifts,HAVC, lighting/office equipment
4	**High Point**	National Grid	100	HAVC, lighting & office equipment
5	**F.I.R.S Building**	National Grid	100	HAVC, lighting & office equipment
6	**Microfinance Bank**	National Grid	20	HAVC, lighting & office equipment

4.1 Estimated Energy Demand

The total estimated demand for the six buildings based on three set of categories namely cooling, lighting and a group of other appliances was carried out as adapted from literature. Except for the exterior lighting, all other categories were calculated based on the activity period of the buildings only; which is eight hours of all the working days of the annual calendar. For the cooling load (QC), estimation was made on the air conditioning types, its number and wattage; this is significantly higher in the N.N.D.C Building and reduces down the list due to variation in sizes of the facilities and hence a variation in cooling demands. The same goes for lighting (Ql), and demand from other appliances (Qa); where office equipment like computers, printers, scanners, photocopiers, and utility machines like refrigerators, televisions, fans, and lifts were calculated.

Table 4 expresses the disaggregation of energy demand across the six office facilities, where cooling takes the highest demand of about 52% of the total demand. Critical study of energy demand by the office appliances used, puts it in second place with about 36%, and lighting being the least of all consuming about 12% of the energy demand as shown in Figure 1. The disaggregation in the total end-use demand in term of percentages is expressed graphically in Figure 2.

Table 4: Disaggregation of energy demand across the six offices

	Cooling load (kWh)	Lighting load (kWh)	Other appliances (kWh)	Total (kWh)
NNDC Building	1,023,979.60	247,144.64	713,101.00	1,984,225.24
BOI Building	597,580.80	142,005.76	388,909.44	1,128,496.00
Investment House	398,387.20	61,605.44	200,759.84	660,752.48
High Point Building	56,022.20	16,023.00	93,221.40	165,266.60
FIRS Building	46,686.00	24,288.76	54,878.68	125,853.44
Microfinance Bank	12,449.60	4,096.32	12,720.68	29,266.60
Total	**2,135,105.40**	**495,163.92**	**1,463,591.04**	**4,093,860.36**

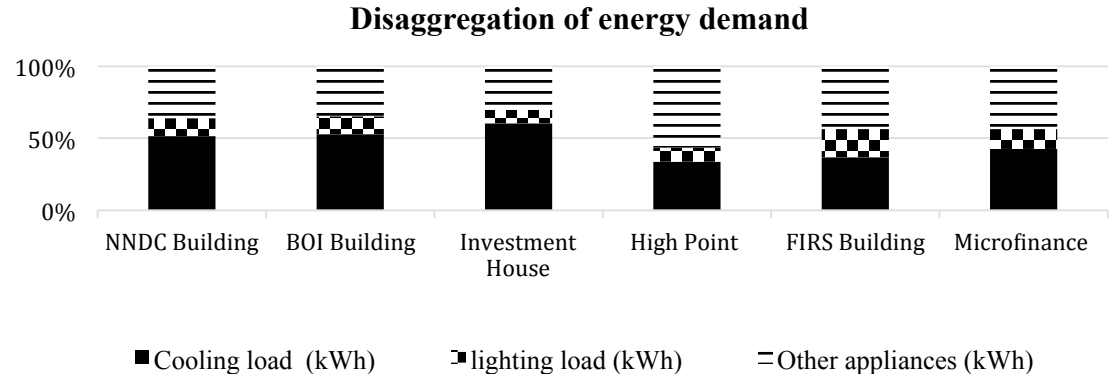


Figure 1: Disaggregation of load in cooling, lighting and other appliances

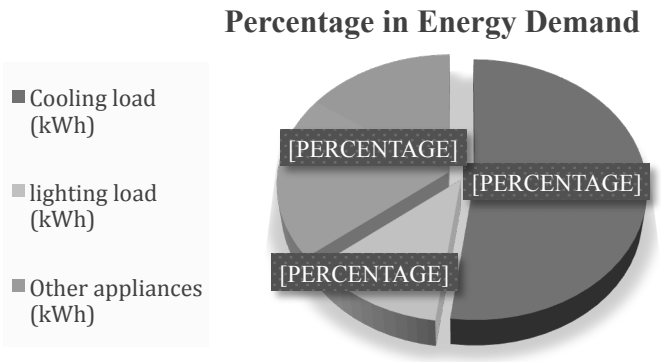


Figure 2: percentage of total end-use demand across all buildings studied

4.2 Normalized Energy use

Normalized electricity consumption per meter square of each disaggregated end-use (ED), and the averages per annum across all the studied facilities was carried out. Table 5 shows that the Microfinance Bank has the highest normalized annual demand (ND) of 742KWh/m2, followed by High Point building with 371 KWh/m2, with the NNDC Building having the lowest value of 175Kvh/m2. Figure 3 illustrates the magnitude in the variation of normalized values in all facilities.

Table 5: Normalized Cooling, lighting and Appliances demand per meter square

	Cooling Demand		**lighting Demand(kWh)**		**Appliances Demand**		**Avg. Annual Demand**	
	ED (KWh)	ND (KWh/ m^2)	ED (KWh)	ND (KWh/ m^2)	ED (KWh)	ND (KWh/m^2)	ED (KWh)	ND (KWh/ m^2)
NNDC Building	1,023,980	91	247,145	22	713,101	63	1,984,338	175
BOI Building	597,581	157	142,006	37	388,909	102	1,128,690	296
Investment House	398,387	150	61,605	23	200,760	76	660,752	249
High Point	56,022	126	16,023	36	93,221	209	165,428	371
FIRS Building	46,686	88	24,289	46	54,879	104	125,988	239
Micofinance Bank	12,450	311	4,096	102	12,721	318	29,680	742
Total	**2,135,105**	**923**	**495,164**	**267**	**1,463,591**	**872**	**4,094,876**	**2,072**

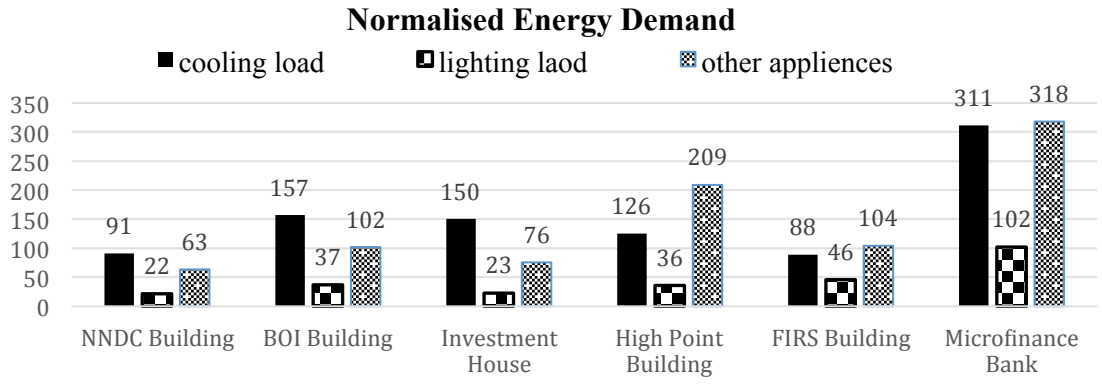


Figure 3: Normalized energy demand comparison between the buildings

4.3 Estimated Electricity Supply

Energy supply by both utility and backup sources were estimated using the acquired utility bills of two years; and calculating the output of the power generators against the target backup hours laid out by the facility managers. The hours of distribution from both utility and backup is shown in Table 6. This shows that utility hours are in all cases more than the backup hours all year round; with highest recorded on the Investment House, while the lowest is on the High Point Building. The cost of annual power supplied is however highest in the B.O.I Building and the N.N.D.C Buildings with 221,740 and 220,304 (KWh) respectively, while High Point Building has the lowest of 18,555 (KWh).

Table 6: Estimated electricity supply from the utility and backup, hours of supply and total annual energy supply in each facility.

	power supply (hrs)		Avg Monthly Supply (Kwh)		Annual Power Supplied (KWh)
	Utility	**Backup**	**Utility**	**Backup**	
NNDC Building	6.5	1.5	34,679.00	15,468.75	601,773.00
BOI Building	6	2	23,740.00	16,500.00	482,880.00
Investment House	6.5	2.5	11,296.29	10,312.50	259,305.48
High Point Building	7	1	555.50	1,500.00	24,666.00
FIRS Building	6	2	3,148.14	3,300.00	77,377.68
Microfinance Bank	6.5	1.5	370.37	9,900.00	123,244.44

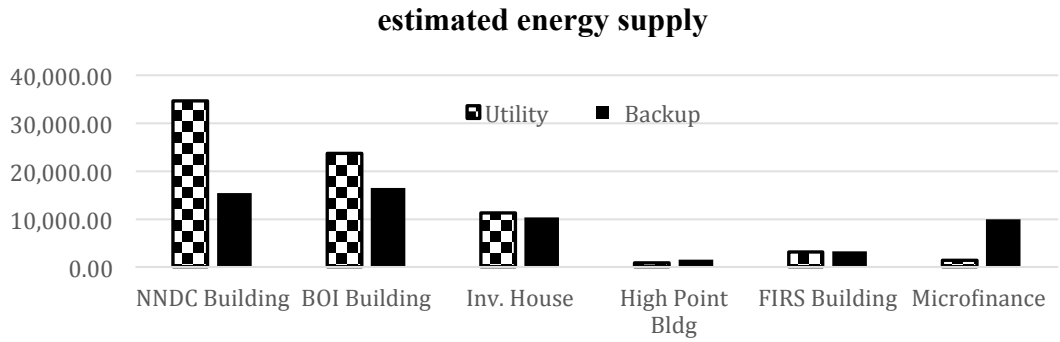


Figure 4: Estimated energy from the utility and backup

4.4 Normalized Energy Supply

Table 7 and Figure 5 shows the differences in the total estimated annual energy supply and the normalized values. It indicates that even though the Estimated Annual Energy Supplied is higher in the N.N.D.C and B.O.I Buildings, the Estimated Normalized Energy Supply in the Microfinance Bank and the F.I.R.S Buildings are higher with 358.61Kwh/m^2 and 77.80Kwh/m^2 respectively even though they have the lowest Estimated Annual Energy Supply of 41,077 Kwh/m^2 and 14,344 Kwh/m^2 respectively.

Table 7: Estimated annual energy supply per meter square in the six office buildings

Offices	Est. Annual Energy Supplied (Kwh)	Appr. Floor Area (m^2)	Estimated Normalised Energy Supply (Kwh/m^2)
NNDC Building	220,304.00	11,321.00	19.64
BOI Building	221,740.00	3,816.00	58.11
Investment House	135,046.29	2,653.00	50.90
High Point Building	18,555.50	446.00	41.60
FIRS Building	41,077.68	528.00	77.80
Microfinance Bank	14,344.44	40.00	358.61

5.0 CONCLUSION

The study confirmed that in the office buildings of Kaduna metropolis, cooling for thermal comfort for the interior takes the highest rate of energy demand. It also discovered that, the estimated energy demand observed in the study revealed that the annual energy supply falls short of meeting up with the required annual demand in the office buildings.

In terms of cost of electricity supply, it was observed that the rate of utility supply is high due to an unstructured kind of free-fall billing system commonly used, especially on the bigger facilities. It was discovered that, though the rate of consumption for the backup generation systems is high in Kaduna, it is usually dependent on the target hours of use and the output capacity of the power generators for any given premises. Through the normalization exercise, the study showed that estimated normalized energy supply is higher in the smaller buildings than the larger ones, alluding to the fact that cost of energy supply in the smaller buildings per square meter is higher than the larger ones; and that the energy supplied in such buildings exceeds the actual energy required in them.

Motivated by the need to minimize the cost of operation and maintenance of office building stock; the above stated deductions of this study, to an extent gives a clear understanding of the pattern of energy demand, supply and subsequent distribution in office buildings of Kaduna metropolis. For all related policy makers and professionals involved, the study is generally an investigative tool that clearly identifies the core areas in which energy challenges lie in such facilities in the region; it may therefore pave way for pin pointing the basic areas in which retrofitting options are required in order to reap the economic, social and environmental benefits of running and maintaining such facility in a sustainable manner.

The study also creates an avenue for further research, where issues like economic implications of running facilities as it relates to effect of cost in energy provision and its effect on profit margins; or rate of carbon emissions with respect to level of energy use and demands in such facilities.

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