ENVIRONMENTAL PERFORMANCE OF NATURALLY VENTILATED LIBRARY BUILDINGS IN BAUCHI, NIGERIA

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This thesis dedicated to my late father Sheikh Sa'idu Nafada, my mother Fatima Shehu and to my new born child Aisha.

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ABSTRACT

Naturally ventilated libraries (NVLs), which have been in existence since 1948 in Nigeria, are common types of library buildings in Africa that depend on wind flow through window openings for ventilation. Their propagation was propelled by chronic shortages and unreliable electric power supply. However, there is limited information about the indoor environmental quality (IEQ) performance of NVLs which is essential for the health, comfort and productivity of library users. The objective of this research is to investigate indoor environmental performance of NVLs with the aim of promoting their use. Post Occupancy Evaluation (POE) was carried out in four academic NVLs in Bauchi to assess their indoor environmental performance. The study used a 3-way interaction concept to form an integrated assessment of passive characteristics, environmental conditions and library users' perception to achieve the objectives of the study. A mixed mode approach was used as the methodology. A range of data collection techniques were used namely: observation and walk through, interview, physical measurement of IEQ variables and a survey questionnaire distributed to 593 respondents. From the observation, the result shows that cross ventilation is the dominant ventilation system prevailed in the case study buildings. The spatial configuration of the study spaces was in line with cross ventilation principles. A neutral temperature of 27.70°C and thermal comfort range of 27.20°C to 28.28°C were identified in the study halls. Multivariate statistical analysis of Structural Equation Modelling (SEM) inferred from the NVLs indoor environmental performance model showed that indoor environmental conditions has a direct and significant effect on the indoor performance. The NVLs indoor environmental quality performance model has a large effect size of 0.45. No complaint was expressed from the library users about excessive environmental discomfort. The outcomes of the three objectives established that the indoor environmental quality performance of NVLs is comfortable to the users. The study concludes that the NVL buildings in Nigeria are acceptable and patronized by the library users. Therefore, the use of NVLs should be maintained and promoted. The research also proposes design recommendations for NVL's policy makers and aid architects and building design professionals in promoting low-energy library design.

ABSTRAK

Perpustakaan dengan pengudaraan semulajadi (NVLs) yang telah wujud sejak tahun 1948 di Nigeria adalah perpustakaan umum di Afrika yang bergantung kepada aliran angin melalui bukaan tingkap untuk pengudaraan. Penyebaran pengudaraan semulajadi perpustakaan ini didorong oleh kekurangan bekalan kuasa yang berterusan dan tidak stabil. Walau bagaimanapun, terdapat kajian yang terhad tentang prestasi alam sekitar dalaman NVL yang penting untuk kesihatan, keselesaan dan produktiviti pengguna perpustakaan. Objektif kajian ini adalah untuk mengkaji prestasi persekitaran dalaman NVL dengan tujuan mempromosikan penggunaannya. Penilaian Post Occupancy Evaluation (POE) telah dijalankan di empat bangunan akademik NVL di Bauchi, bagi menilai prestasi persekitaranya. Kajian ini menggunakan konsep interaksi 3 hala bagi membentuk integrasi penilaian dari ciri-ciri pasif, keadaan persekitaran, dan persepsi pengguna perpustakaan untuk mencapai objektif kajian. Pendekatan kaedah mod campuran digunakan sebagai metodologi. Pelbagai teknik pengumpulan data iaitu pemerhatian dan tinjauan; temuduga; ukuran ketara dan tidak ketara bagi pembolehubah IEQ dan kaji selidik yang diedarkan kepada 593 responden telah digunakan. Hasil pemerhatian menunjukkan bahawa pengudaraan silang adalah sistem pengudaraan yang utama yang digunakan dalam bangunan kajian kes. Tata susunan ruang di kawasan kajian adalah sejajar dengan prinsip pengudaraan silang. Suhu neutral ialah 27.70°C dan julat keselesaan termal antara 27.20°C hingga 28.28°C telah dikenal pasti di kawasan kajian. Kesimpulan dari analisis statistik multivariat bagi Model Persamaan Struktur (SEM) menunjukkan bahawa keadaan persekitaran dalaman NVL mempunyai kesan langsung dan signifikan terhadap prestasi persekitaran dalaman. Model prestasi persekitaran dalaman NVL mempunyai saiz kesan yang besar sebanyak 0.45. Tiada aduan yang dinyatakan oleh pengguna perpustakaan tentang ketidakselesaan alam sekitar yang keterlaluan. Hasil dari tiga objektif ini menunjukkan bahawa prestasi persekitaraan dalaman NVLs adalah selesa untuk pengguna. Kajian ini menyimpulkan bahawa bangunan NVL di Nigeria boleh diterima dan dikunjungi oleh pengguna perpustakaan. Oleh itu, penggunaan NVL perlu dikekalkan dan digalakkan. Kajian ini juga mencadangkan reka bentuk masa hadapan untuk NVL bagi pembuat dasar; membantu arkitek dan pereka bentuk bangunan yang profesional dalam mempromosikan rekabentuk perpustakaan bertenaga rendah.

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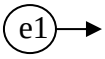
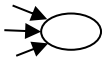
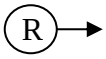
LIST OF ABBREVIATIONS

AGFI	-	Adjusted Goodness of Fit Index
ASHRAE	-	American Society of Heating, Refrigeration, and Air Conditioning Engineers
AVE	-	Average Variance Extracted
CR	-	Critical Ratio
CFA	-	Confirmatory Factor Analysis
CFI	-	Comparative Fit Index
COPE	-	Cost-effective Open-Plan Environment
EFA	-	Exploratory Factor Analysis
EFR	-	Environmental Feature Rating
GFI	-	Goodness-of-Fit Index
IAQ	-	Indoor Air Quality
IEQ	-	Indoor Environmental Quality
KMO	-	Kaiser-Meyer-Olkin
NIMET	-	Nigerian Meteorological Agency
NV	-	Natural Ventilation
NVB	-	Naturally Ventilated Buildings
NVL	-	Naturally Ventilated Library
PMV	-	Predicted Mean Vote
PPD	-	Predicted Percentage of Dissatisfied
RMR	-	Root Mean Square Residual
RMSEA	-	Root Mean Square Effort of Approximation
SE	-	Standard Error
SEM	-	Structural Equation Modelling
SRMR	-	Standardized Root Mean Square Residual
WTSV	-	Weighted Thermal Sensation Vote

LIST OF SYMBOLS

χ^2	-	Chi square
%	-	Percentage
º	-	Degree
'	-	Minutes
df	-	Degree of freedom
	-	Error term
	-	Latent construct
	-	Exogenous construct
	-	Endogenous construct
	-	Observed Variable
	-	Residual
	-	Effect
	-	Correlation
*	-	multiplication/note
***	-	P-value significance
<-->	-	Correlation/relationship
<	-	Less than
>	-	Greater than

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The role of library in academic and educational development at any level, particularly in colleges and universities is indispensable (Khan *et al.,* 2014; Okiy, 2012). A library building was posited to serve as a pole star of academic life, nourishing student's academic pursuit (Imamoğlu & Gürel, 2014). Academic library has been described by many researchers as the foundation, mind laboratory and the heart of a university (Okpala 2016; Ugwuanyi *et al.,* 2011;Oakleaf 2010). Due to the academic functions of library-building, it is impractical for any academic institution to succeed, without having a library building as an essential part of its campus landscape. Hence, Agboola (2001) elaborated library buildings to be as old as the institutions they represent, providing the first avenue for student's interaction and knowledge pursuits.

Academic library as a place has remained relevant and resolute (Drake, 2007), even with the advent of the digital library predominance in information and communications technology (ICT) (Campbell, 2006). Globally, academic library buildings have been increasingly changing into a contemporary role as a study space (Kim, 2016; Cha & Kim, 2015). Apart from the knowledge resources available in the library, the satisfaction and comfort of the library users are also important (Cha & Kim, 2015; Kilic & Hasirci, 2011; Rempel *et al.,* 2011; Kassim, 2009; Musoke, 2008). Researchers have investigated the cognitive perception of building occupants in relation to the indoor environment on the basis of mechanical and natural ventilation with a view to determine their responses to different environments (Chenari *et al.,* 2016; Al Horr *et al.,* 2016; Smith & Pitt, 2011; Brager & Baker, 2008; Hummelgaard *et al.,* 2007; Krausse *et al.,* 2007). Conventionally, library buildings are large

consumers of energy to power air-conditioning, lighting, lifts, computers, security and surveillance equipment (Edwards, 2009).

It was reported that the major percentage of the world's energy is used in keeping, running and maintaining a comfortable climate within the building interiors (Davis & Gertler, 2015; IEA, 2015). The excessive use of air conditioning globally to achieve comfort is growing fast. For instance in 2013, 64 million air conditioned units were sold in China (Davis & Gertler, 2015). Henley (2015) reported that 70% of air conditioning in China use electricity, with a similar situation in the US having 87% and India 40%, several other countries including Nigeria are inclined toward a similar trend. Additionally, majority of electricity generation worldwide use of fossil fuel, captured at 66.7% in 2014 (IEA, 2016). This situation jeopardizes the international struggle against global warming risk due to billion tons of carbon dioxide emissions (Alshehry & Belloumi, 2015; Ramanathan, 2005). Davis & Gertler (2015) posited that 10% of negative emissions from air-conditioning surpasses the overall global aviation's carbon dioxide (CO_2) emissions. Hence, to reduce the malignant greenhouse emission due to cooling ventilation, artificial lighting for comfort; alternative energy sources and adoption of passive building strategies have triggered a huge research interest (Chenari *et al.,* 2013; Kamal, 2012). Fifth Assessment Report (AR5) on climate change in the Intergovernmental Panel on Climate Change (IPCC, 2014), has sternly called upon the adoption of climate responsive buildings worldwide.

Many educational buildings including library buildings in many parts of the world are passively and naturally ventilated (Nomura & Hiyama, 2017; Ogoli, 2014; Lomas, 2007). The passive cooling and renewable energy in place of fossil fuel provided an effective alternative technique, reducing the impact of greenhouse gasses pollution on the environment (Aflaki *et al.,* 2015). Although optimum temperature, relative humidity and air movement at certain levels are difficult to achieve by passive strategies. It provides some degree of comfort with little or no electrical energy for operation (Salcido *et al.,* 2016; Ben-David & Waring, 2016). Human beings were found to accept and prefer a wide range of temperature in naturally ventilated buildings (NVB) above the comfort zones defined by international thermal comfort standards (Kumar *et al.,* 2016; Moujalled *et al.,* 2008). Occupants of NVB are said to be more

comfortable than mechanically ventilated buildings, by naturally adapting to a wide range of indoor conditions (Brager *et al.*, 2011; Fountain *et al.*, 1996).

Lack of adequate ventilation and indoor air quality has been the cause of health concern such as sick building syndrome in many air-conditioned buildings, including libraries leading to occupant's discomfort (Vasile *et al.*, 2016; El-nafaty *et al.*, 2014). Brager & de Dear (1998) stated that natural ventilation remains good option to decrease the energy consumption for cooling of building the interior, providing a good indoor air quality (Norhidayah *et al.*, 2013). Natural ventilation has been increasingly recommended as a means of energy saving, good indoor air quality and acceptable thermal comfort to a wide range of buildings including libraries (Khanal & Lei, 2011).

Tropical architecture using natural ventilation has been one of the elements adopted in library design, either taken wholly, with mechanical assistance or with partial air-conditioning (Edwards 2009). In Nigeria, according to Nigerian Ministry of Education (2010), presently there are 269 government-funded tertiary institutions with each institution attached to a library building as part of its landscape (education.gov.ng). According to Agboola (1995), natural ventilation was adopted in ventilating libraries in many Nigerian academic campuses. This includes permanent library buildings for the five "first-generation university" constructed between 1948 to 1962 in Ibadan, Nnsuka, Zaria, Ile Ife, and Lagos. Eight "second generation university" library buildings between 1970 to 1975 in Benin, Maiduguri, Calabar, Ilorin, Jos, Port Harcourt and Sokoto. The proposed 18 "third generation" library buildings between 1980 to 1998, which as a result economic recession only six library buildings were constructed in Abeokuta, Makurdi, Bauchi, Yola, Owerri and Ekpoma (Sa'id *et al.*, 2016; Agboola, 2001). Subsequently, several other hundredth of academic library buildings were established constructed and managed by the federal and state governments in Polytechnics, Monotechnics, and Colleges of Education.

However, assessment report sponsored by the MacArthur Foundation (2005), on four selected university library buildings in Nigeria, has identified unreliable electric power and lack of government funding as common issues crippling academic libraries (Linn, 2007; Urbana, 2005). Stella (2012) similarly argues that power outage

was rated second after inadequate funding, as the primary factor responsible for the slow pace of ICT development in Nigerian academic libraries. The budget allocation for the educational sector including libraries between 2000-2008 was 9% of total budget (Mordi, 2008). The budget allocation was further reduced to 6% in the 2017 national budget as against the stipulated 26% recommended bench mark on education by the United Nations (UNESCO) (premiumtimesng.com 2016).

Power instability in Nigeria has made headlines at different times in the newspapers and magazines. Between 2015 and 2017 many issues on the power generation were reported. Premium Times Nigeria (2015) reported power generation situation to be at "all-time low crashes to 1327MW" due to malfunctioning of 18 out of the 23- power plants after being generated at 2800MW in the month of May 2015. A similar situation was reported by Premium Times Nigeria (2016) in the month of March 2016 that "output in sharp fall to 2800MW" which later rose to 4387MW. Furthermore, the Energy Mix Report (2017) "Nigeria's power generation" report indicates that an average of 3687MW was generated in in first quarter (Q1); highest being 5846MW on the 24th of January 2017 and lowest being 1618MW on 18th of January 2017 respectively. Daily Trust (2017) in April reported that "45 electric turbines down" as the national grid lost 2,239MW due to technical and gas shortage. This inadequacy in the electricity transmission and gas shortages has influenced the use of clutter diesel and fuel generators among the private and government organizations. The Manufacturers Association of Nigeria (MAN) has claimed to spend over $11, 340 million dollars weekly in running and maintaining their generators; Mobile Telecommunication Network (MTN) Nigeria, also reported of spending more than $5.5 million dollars in purchasing diesel to run their generators for 19 hours daily (Todd & Madeleine, 2014; Aliyu *et al.*, 2013). Nigeria was reported to have the highest number and durations of power outages compared with her emerging economic giant counterparts, Mexico, Indonesia, Nigeria and Turkey (MINT); with an average of 30 to 33 times outages monthly as reported by Aladejare (2014).

The system, known as the "System Average Interruption Duration Index (SAIDI)" indicates the average total of electric power interruption per consumer in a year measured in minutes. SAIDI is one of the indices used in measuring the

performance of steady power distribution called Distribution System Reliability (DSR) (Subcommittee 2012). The SAIDI reliability index is extraordinary poor in Nigeria (Oyedepo 2012). Ogujor and Orobor (2010) study has showed that France has SAIDI value of 52 min/year; Singapore has approximately SAIDI value of 1.5 min/year; USA has 88min/year while Nigeria has a SAIDI value of more than 60000 min/year based on the MAN assessment. A higher SAIDI value of 87639 min was reported by Ogujor (2007). The average cumulative daily power supply between April 2013 to September 2015 was 6.2 hours; with the highest being (September 2014 recording 8.2 hours and September 2015 having 10.8 hours) and lowest being (March 2014 with 4.4 hours and May 2015 with 3.9hours) respectively. This assertion was further buttressed by the study of Abiodun & Akinrebiyo (2015) indicating three hours as the reliable available daily electricity power.

From the above perspective, a strong connection exists between accessibility of power and proliferation of naturally ventilated library (NVL) buildings in Nigeria. The early existence of NVL buildings is not to weaken over dependence on electricity demand but spontaneous based on the lingering power issues, increase energy prices and dwindling subventions. However, Nigeria like other tropical countries, building design using natural ventilation is traditionally a well-accepted passive strategy and practice (Huang *et al.,* 2015).

Apart from low energy benefits in NVL building, the performance of the NVL space is crucial to maximize users' expectation and return on building investment in passive ventilation. Occupant's feedback reliably supports designers and organizations tackle existing buildings problems responsibly. Building performance evaluation (BPE) successfully improves design features, building system effectiveness and productivity of users (Barrett, 2013). Proactive interaction and feedback from users must be collected and evaluated to establish pro-environmental conditions (thermal, visual, acoustic and indoor air quality). This is to support the design of NVL building for efficient indoor performance and readers' comfort (Sanoff, 2016). The efficiency of learning environment is sustained by the quality of the academic building (Famade *et al.,* 2015; Oyo *et al.,* 2008). A number of studies have suggested both the occupant's

perception and the physical measurement to be considered in evaluating performance of a buildings (Preiser *et al.*, 2001).

Comfort levels and satisfaction or dissatisfaction with the indoor environmental quality (IEQ) is a subjective phenomenon determine according to the users' contextual perception and should not be taken as one size fits all (Parkinson & deDear, 2015). Furthermore, environments that give occupants the opportunity to change certain conditions were shown to have higher satisfaction tendency compared to the environment with restrictions (Parsons, 2014a; Roaf *et al.*, 2010). Additionally, where 80% of the users are satisfied with the conditions of the indoor environment, the building is said to be performing well towards meeting the requirements of the occupants (ASHRAE 2012; Peretti & Schiavon, 2011). The focus of sustainable building performance is inclined towards achieving low-energy and human comfort. Library users' level of satisfaction with IEQ should be considered.

Therefore, this study seeks to explore and evaluate the environmental performance of NVL. The study will ascertain whether the NVL can be promoted based on the outcome of library users' cognitive perception of the prevailing IEQ in the selected NVL in Bauchi. The research problem is formulated and presented in the coming section.

1.2 Research Problem

The first Nigerian library constructed in 1948 in University of Nigeria Ibadan was commended a masterpiece in the tropical architecture library building (Agboola 2001). The library provides good natural air flow and cross ventilation that support users comfort. Thus, the library design minimized the need for expensive mechanical ventilation devices. The ventilation was achieved naturally because of the way the library building was designed, that is the long narrow shape was oriented to be widely ventilated and drive the natural wind flow for effective cross ventilation. Altogether, first-generation libraries constructed between 1948 and 1962 were initially built to sustain natural ventilation; the increase in the population of library users and book

stacks necessitated the extension of the library buildings including the library building in University of Nigeria Ibadan. In University of Ibadan, the second phase of library the building's expansion was ironically designed without proper considerations for natural ventilation. Consequently, ventilation design of the library buildings expansion failed due to unstable and interrupted electric power supply (Agboola, 2001; Agboola, 1995; Orimoloye, 1988).

The European standard for library buildings in Nigeria was adopted until 1977 when the National Universities Commission Master Planning and Consultants Group (NUCCOM) drafted a guide for library planning that was used for many years. An attempt was made in 1980 to promote the tropical design of library buildings piloted through a seminar organized by the Committee of University Librarians of Nigerian Universities (CULNU) termed "Seminar on Tropical Library Architecture" to brainstorm with the building industry professionals to produce a solution for tropical library building design (Agboola 2001).

In retrospection, electric power plaque has incapacitated African countries including Nigeria, ranging from unreliable power supply, scheduled blackout, frequent and random outages are appalling (Ouedraogo 2017). The Nigerian Ministry of Education and Nigerian University Commission (NUC) suggested to Nigerian universities the need to reduce energy consumption to achieve low energy bills and boost environmental performance (Unachukwu 2010). Contrastingly, natural ventilation has been used to ventilate library buildings without hitches from 1948 to date in several Nigerian institutions. NVL buildings are assumed to continue to be operational in Nigeria; however, limited is known about the indoor performance of NVL building from the users. Limited is also available in the existing body of knowledge about questions relating to library users' comfort ability, productivity and wellbeing. It will be difficult to draw a conclusion or ascertain the performance of NVL buildings, as limited research was known NVL buildings (Ogoli 2014; Stoakes *et al.,* 2011; Krausse *et al.,* 2007).

Additionally, Nigeria has limited building performance information on IEQ physical data derived based from cognitive perception; due to inadequate post-

occupancy evaluation research (Adewunmi *et al.*, 2009). Few studies were conducted for instance, public housing (Ibem & Amole, 2013; Clement & Kayode 2012; Ilesanmi, 2010; Fatoye & Odusami 2009) and Student hostel (Oladiran & Yaba 2013; Adewunmi *et al.*, 2011; Amole 2009), with limited or no study in many non-domestic public building sector such as the library building. Most academic library buildings in Nigeria rely on natural ventilation because of unreliable electric power. This has led to indoor environmental quality (IEQ) or condition which may or may not be adaptable and comfortable to the users. Considering the propagation of NVL buildings in Nigeria; the need to ensure that the library buildings performed well in dispensing acceptable indoor environment for the readers' comfort is necessary. Therefore, there is a need to investigate NVL buildings; to understand the library users' adaptability in order to promote the use of NVL as a solution to sustainable library buildings in Nigeria.

1.3 Research Aim

The main aim of this thesis is to study the indoor environmental quality (IEQ) performance of NVL that will promote the use of NVL buildings in Nigeria.

1.4 Research Objectives

The research objectives formulated for this study are:

1. To assess the performance of passive design elements suitable for IEQ performance in the selected NVL;

2. To determine the thermal comfort parameters suitable for the IEQ performance in the selected NVL;

3. To evaluate the relationship between the users' satisfaction with the actual and perceived IEQ conditions in the selected NVL.

1.5 Research Questions

The Main research question is: does the design of NVL building in Nigeria offers an acceptable indoor environmental quality (IEQ) performance to the users?

This question is essential for the promotion and adoption NVL buildings in Nigeria. However, the research questions formulated to answer the objectives in Section 1.4 are:

RQ1: What is the performance of existing passive design elements in the selected NVL buildings?

RQ2: What is the users' perception of thermal comfort performance; the calculated neutral and thermal comfort range in the selected NVL buildings?

RQ3a: What are the factors involved in measuring the users' satisfaction of IEQ in NVL buildings?

RQ3b: What is the relationship between the perceived IEQ satisfaction and overall indoor performance of NVL buildings?

RQ3c: What is the significant effect of perceived IEQ satisfaction on the overall indoor performance of the selected NVL buildings?

In respect of the formulated objectives and research questions for this study is showed in Table 1.1. Three research questions RQ1, RQ2 and RQ3; with RQ3 having 3 sub research questions namely: RQ3a, RQ3b, and RQ3c respectively. RQ1 is set up to investigate the passive design strategies of the selected library buildings enumerated in research objective 1; RQ2 is established to determine the thermal comfort performance as in objective 2; and RQ3 to answer research objective 3. RQ3a, RQ3b and RQ3c are to determine the relationship between the indoor performance, and the perceived satisfaction of library users as formulated in objective 3.

Table 1.1: Mapping research objectives and research questions

SN	Research objectives (RO)	Research questions (RQ)
1	RO1	RQ1
2	RO2	RQ2
3	RO3	RQ3(a) RQ(3b) RQ(3c)

1.6 Research Significance

Three (3) aspects showed the significance of this study. Firstly, the performance evaluation of non-domestic buildings is not yet an established field of knowledge and authority in Nigeria. The need to conduct research for objective assessment of existing building's performance is important for the improvement and sustainable building designs especially in NVL. The findings of this study will provide a framework for user-centred NVL design. The findings will contribute to the body of knowledge on NVL buildings to academicians, building professionals, designers, librarians and policy makers with the needed tool to navigate in the future research in this area of study.

Secondly, Nicol *et al.,* (2012) have called upon architects to stop sacrificing the responsibility of comfort in buildings to the engineers who perceived comfort not as a goal but a product. This study will contribute to the drive for sustainable and climate responsive buildings in the design and construction of NVL buildings with significant IEQ performance and users' satisfaction. Previous studies on the performance of NVB were conducted from case study buildings in hospitals, residential, classroom and hostel buildings (Nimlyat & Kandar, 2015; Ogbonna & Harris, 2008). Table 1.1 shows the related research in NVL and identify the present research gap with respect to NVL buildings. The selected case study for this study were not evaluated before, as such, the findings will add more knowledge about the performance of NVL. Additionally, the outcome of this study will also provide a framework for the promotion of NVL buildings in Nigeria.

Table 1.2 : Research gap for NVL

SN	Title	Author(s)/Date	Parameters	Context
1	Design and operating concept for an innovative naturally ventilated library	MJ Cook, KJ Lomas, H Eppel (1999)	Thermal comfort and ventilation	UK
2	Environmental performance of a naturally ventilated city centre library	Krausse, B., Cook, M., Lomas, K. (2006; 2007)	Energy consumption, indoor temperatures and CO_2 levels	UK
3	Low energy architecture for a severe US climate: Design and evaluation of a hybrid ventilation strategy	Lomas, K.J., Cook, M.J., Fiala, D. (2007)	Dynamic thermal modelling and computational fluid dynamics	US
4	Architectural design of an advanced naturally ventilated building form	Lomas, K.J. (2007)	Advanced naturally ventilated (ANV) system	UK;US
5	Commissioning hybrid advanced naturally ventilated buildings: A US case-study	Lomas, K.J., Cook, M.J., Short, C.A. (2008; 2009)	Active and passive environmental control systems	US
6	The Lanchester library-building a sustainable library	Pat Noon (2011)	Sustainable energy, daylighting and ventilation	UK
7	Relationship of indoor and outdoor air pollutants in a naturally ventilated historical building envelope	López-Aparicio et al., (2011)	Pollution and Indoor air quality assessment	Czech Republic
8	Exploiting a hybrid environmental design strategy in the continental climate of Beijing	Short et al., (2012)	Ventilation and passive cooling	Beijing
9	Performance of Natural Ventilation in Deep-plan Educational Buildings: Case Study	David Mwale Ogoli (2013)	Natural ventilation and daylighting and thermal comfort	UK
10	Formal calibration methodology for CFD models of naturally ventilated indoor environments	Hajdukiewicz, M., Geron, M., Keane, M.M. (2013)	Air speeds and air temperatures	Ireland
11	Environmental Performance of Naturally Ventilated Library Buildings in Bauchi, Nigeria	**Present study**	IEQ performance: (Thermal comfort, IAQ, Visual and Noise Qualities)	Nigeria

Finally, the motivation for this study within the context of Nigeria is in response to the proliferation of NVL buildings. According to Fergus *et al.*, (2013), experts in the field of environmental study have called for knowledge expansion on indoor environmental quality (IEQ) from different contexts around the world to set up standards and comfort guidelines. Similarly, according to Olesen & Parsons (2002), meta- analysis is the only possible way of achieving worldwide true standard for

reliable comfort temperature articulated with cultural and technological difference. This study will provide additional insights to the current debate on the sustainable library design. Consequently, this study will proffer practical recommendations for low energy library policy in Nigeria.

1.7 Research Scope and Limitation

This study has some limitations. Firstly, the study is limited to the performance evaluation in government funded academic library buildings in North-Eastern Nigeria, with a maximum of two floors. Four academic NVL buildings were selected as case study buildings. The study is limited to the study halls only. This includes open reading room for both reading room associated with book stacks and reading room without book stacks respectively. Other sections of the library buildings such as offices and auxiliary room are not within the scope of this research. However, staff working at the reading halls are considered as library users as well.

Thermal comfort was regarded as a pseudo-determinant of energy use. Thermal comfort was rated higher in determining environmental comfort among the rest of the indoor environmental quality components such as: visual quality, acoustic quality, and indoor air quality (Dhalluin & Limam 2012; Lai *et al.* 2009; Clausen & Wyon 2008). The physical measurement in this study was limited to thermal comfort parameters and visual quality only due to limited and shortages of physical measuring instruments. The spot measurement in the study halls did not carry out simultaneously for the whole case study buildings due to afore mentioned reasons. The data were recorded at approximately 10 minutes interval in each study hall and the average reading was used for the analysis. The library operational hour is 9am to 10pm daily; however, night measurement of physical data was limited in this study, physical data was collected during the day between 9am to 6pm only. The longitudinal measurement of the environmental condition was conducted for six months from April to August 2014. These are the months characterized by higher temperatures in a year. Computer simulation is not used to predict optimum performance in the study buildings. However, users' perception of IEQ parameters in the case study buildings is assumed

to be the comfort meters as suggested by Nicol *et al.* (2012) and Adebamowo (2007); to measure the perceived prevailing IEQ conditions.

1.8 Research Methodology Outline

The methodology for this research is organized around the evaluation of indoor environmental quality (IEQ) performance of NVL buildings with more focus on the users' perception. The study therefore attempts to determine the extent to which user satisfaction was met with respect to natural ventilation principle and indoor environmental performance measures within the NVL buildings.

The research adopted the case study approach with a mixed method of data collection. The mixed method involved both qualitative and quantitative data sets. The main instruments of data collection are walkthroughs, observations, photographs, interviews, questionnaires, and physical measurements. Post occupancy and building performance evaluation were conducted in four academic NVL buildings in the North-East of Nigeria as case studies. Evaluation of case studies started with a descriptive approach, showing the character of the passive strategy including ventilation principle compatibility and energy use in the study areas. This was followed by the interview, questionnaire survey as well as the corresponding physical data measurement from the study buildings. Based on the study findings, a design suggestion for effective performance evaluation of NVL was proposed to guide the building professionals improve performance and promotion of NVL buildings in Nigeria.

1.9 Thesis Structure

This section provides a brief outline of the organization of the thesis chapters. This thesis report has eight chapters.

Chapter One: presented an overview of the whole thesis. It presented the background of the study, research problem, aims and objectives, significance, conceptual framework, scope of the study, brief overview of research methodology and an organization of chapters.

Chapter Two: presented a review of academic literature on ventilation principle for naturally ventilated non-domestic buildings and indoor environmental quality (IEQ) parameters. It evaluates the current level of knowledge in the design and evaluation NVB. The chapter reviewed energy concern in naturally ventilated library building, Indoor environmental quality indicators and assessments, underlying concepts of building performance and key building performance evaluation features.

Chapter Three: described the research methodology, the research design, the methods used in conducting data collection of this study, the research processes, the analysis and ethical issues.

Chapter Four: presented and discussed the data and analysis of the passive design strategy, energy consumption and perception of stakeholders. The chapter is formulated to answer the first objective of the study.

Chapter Five: presented and discusses the data and analysis of the physical measurement of indoor environmental conditions and the perception of library users on thermal comfort parameters of the NVL case study buildings. The chapter is formulated to answer the second research objective of the study.

Chapter Six: presents and discusses the analysis of library users' perception for the development of the conceptual graphical performance evaluation model based on the research findings. The chapter is formulated to answer the third objective of the study.

Chapter Seven: present an overview of the research, the summary of findings, research implication, conclusions and recommendations. Consideration was given to

the research limitations, contribution to knowledge and areas for further research on this topic.

1.10 Summary and Conclusion

This chapter of the study consist of nine 9 sections. The first section discusses the research background highlighting the circumstances surrounding the evolution of academic NVL in Nigeria. The NVL has been existing in Africa and Nigeria for decades and their continuation was exacerbated because of dwindling power supply. The research problem is the second section in where lack of empirical support on IEQ performance in NVL in Nigeria was identified. Research aim; Research objectives; and related Research questions intended to answer the research objectives represent the third, fourth and fifth sections. Three research objectives and five research questions were formulated for this research. The Research significance, Research scope and limitation as well as the Research methodology outline represent the sixth, seventh and eighth section respectively. NVL is posited to be significant as it brings practical and useful typology for developing countries, especially Nigeria. The Thesis structure is the last section, the ninth section in this chapter, consisting brief highlights of the all chapters. Figure 1.1 shows the overall research flow from chapter one to seven designed for this study.

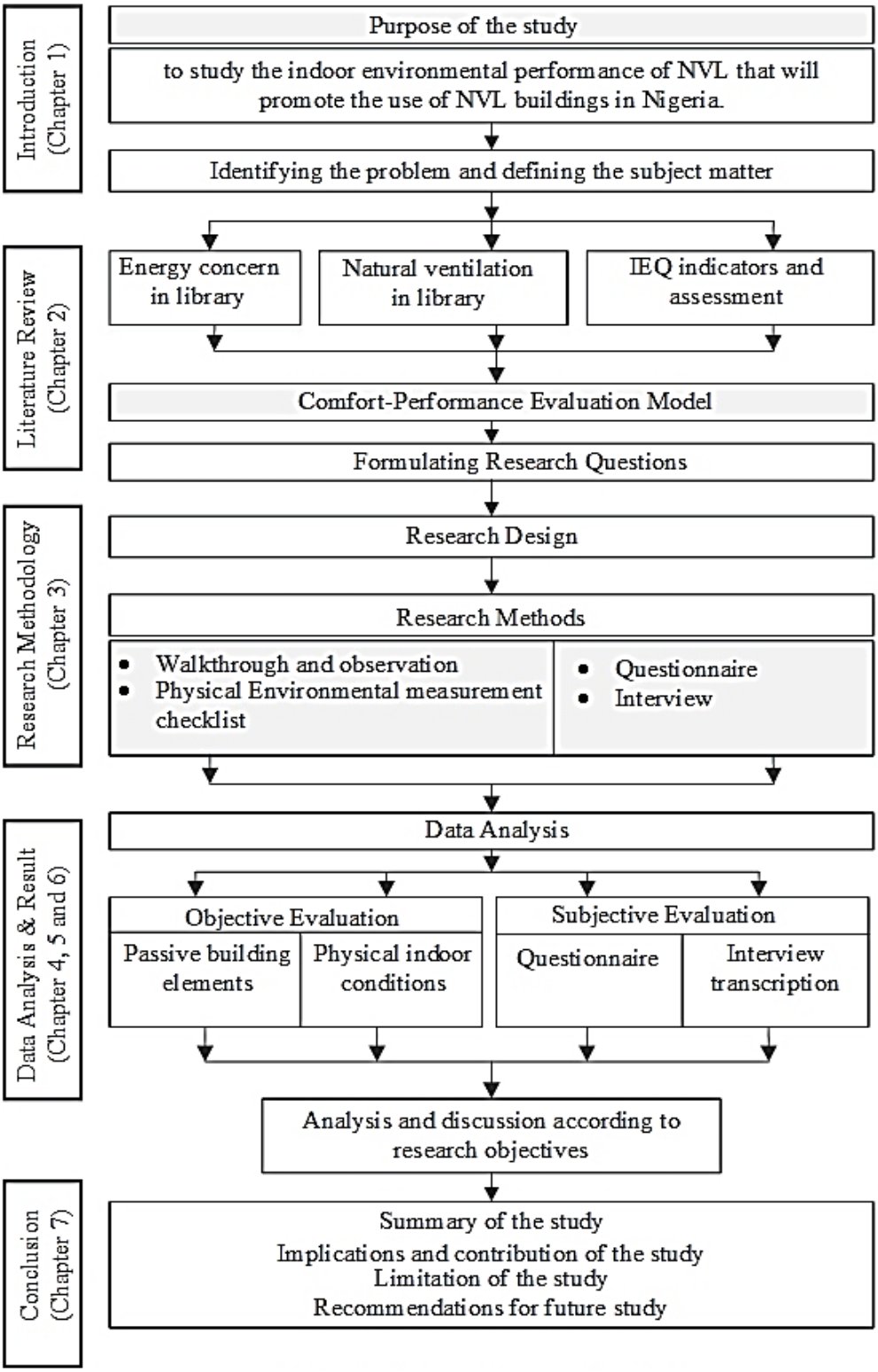

Figure 1.1 : Research flow plan.

The next chapter presents a review of literature for the indoor environmental quality performance of NVL buildings.

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