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Article

Bioclimatic design strategies and energy efficiency in an orthopaedic hospital in Nigerian cities: A cross-sectional study

Eghosa Noel Ekhaese*, **Ibrahim Abudulsalam. Mohammed, Praise Ojuoluwa. Akindoyin**

Department of Architecture, Covenant University, Ota 112104, Nigeria
*** Corresponding author:** Eghosa Noel Ekhaese, noel.ekhaese@covenantuniversity.edu.ng

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Abstract: 2050 building stock might be buildings that already exist today. A large percentage of these buildings fail today's energy performance standards. Highly inefficient buildings delay progress toward a zero-carbon-building goal (SDGs 7 and 13) and can lead to investments in renewable energy infrastructure. The study aims to investigate how bioclimatic design strategies enhance energy efficiency in selected orthopaedic hospitals in Nigeria. The study objective includes Identifying the bioclimatic design strategies that improve energy efficiency in orthopaedic hospitals, assessing the energy efficiency requirements in an orthopaedic hospital in Nigeria and analysing the effects of bioclimatic design strategies in enhancing energy efficiency in an orthopaedic hospital in Nigeria. The study engaged a mixed (qualitative and quantitative) research method. The investigators used case study research as a research design and a deductive approach as the research paradigm. The research employed a questionnaire survey for quantitative data while the in-depth Interview (IDI) guide and observation schedule for qualitative data. The findings present a relationship between bioclimatic design strategies and energy conservation practices in an orthopaedic hospital building. Therefore, implementing bioclimatic design strategies might enhance energy efficiency in hospital buildings. The result of the study revealed that bioclimatic hospital designs may cost the same amount to build but can save a great deal on energy costs. Despite the challenges, healthcare designers and owners are finding new ways to integrate bioclimatic design strategies into new healthcare construction to accelerate patient and planet healing.

Keywords: bioclimatic design; energy efficiency; orthopaedic hospital; evidence-based design; zero-carbon-building; energy consumption

1. Introduction

Robinson et al. (2023) defined a hospital as a large building where people who are ill or injured receive medical care and treatment. A hospital is a structure designed, outfitted and intended for illness diagnostics, medical and surgical care for the sick, injured and temporary lodging. Research and instruction are two common uses for contemporary hospitals (Mehta et al., 2020). The orthopaedic hospital usually adds outpatient facilities, along with emergency, psychiatric, and rehabilitation services, to better fulfil the community's varied requirements (González-Rodríguez et al., 2021). The armed forces record the highest number of orthopaedic and bone injuries yearly (Grimm et al., 2019). Many teaching hospitals in Nigeria are insufficient due to the ineffective healthcare delivery system, especially requiring orthopaedic care. Nigeria, the most populous black nation and the largest country in West Africa, has less than 400 orthopaedic surgeons serving a population of over 200 million (GBD, 2019; Tobacco Collaborators, 2021). This development requires attention.

The building sector is the energy consumer in developed countries due to increased energy requirements for indoor microclimate management, increased appliance usage in buildings, and the transformation into service economies (Ahmed et al., 2022; Guarda et al., 2020). Buildings consume about 40% of energy (Salam et al., 2020). Hospital facilities are a building installation and the most energy-intensive installation category owing to load management. Hospitals are the largest energy consumers per area unit in the public buildings sector (Gatea et al., 2020). It is due to their 24-hour-a-day, 365-day-a-year operations (Hama Radha, 2023; Pincus et al., 2017). And the requirement for lifts, heating, ventilation, air-conditioning (HVAC) systems, hot/cold water, and large/special medical equipment (Aridi et al., 2021; Okon et al., 2021; Zheng et al., 2021). Saving energy and lowering energy costs are challenges that most building designers, engineers, and decision-makers consider.

Nigeria has diverse climatic conditions across the six (6) geo-political zones with variations in climatic elements due to daily weather changes that result in an imbalance and discomfort in buildings (Ayanlade et al., 2020; Dorcas Mobolade and Pourvahidi, 2020). Bioclimatic consideration is necessary for performing a comprehensive climatic analysis of the architectural design, building form, and material selected that control the climatic condition (De Luca et al., 2022; Zhang et al., 2021). Bugenings and Kamari (2022) describe bioclimatic architecture as structures and spaces designed for local climates to ensure thermal comfort by utilising solar energy and bioclimatic elements. The bioclimatic design uses the site's local micro-climatic conditions to achieve thermal comfort in the building. The process minimises mechanical means and energy consumption (Ozarisoy and Altan, 2021). Therefore, we need bioclimatic principles for energy efficiency in orthopaedic hospitals in Nigeria. This study fills the gap in how bioclimatic design strategies enhance energy efficiency in selected orthopaedic hospitals in Nigeria. By answering the following questions, what are the bioclimatic design strategies that improve energy efficiency in orthopaedic hospitals? What are the energy efficiency requirements in an orthopaedic hospital in Nigeria? And what impact have bioclimatic design strategies had on energy efficiency in orthopaedic hospitals in Nigeria? The following section reviews the existing literature systematically and methodologically to situate the topic in the current research context.

2. Literature review

2.1. Bioclimatic design strategies and benefits

According to Watson (2020), the bioclimatic design aims to reduce heat loss from the building exterior and boost solar heat absorption. These goals are reversed depending on the climatic season and zone to minimise solar gain and increase heat dissipation inside the structure. Bioclimatic designs are implemented via several strategies, such as minimising conductive heat flow, delaying periodic heat flow, minimising infiltration, providing thermal storage, promoting solar gain, minimising external airflow, promoting ventilation, minimising solar gain, promoting radiant cooling and promoting evaporative cooling. Xhexhi (2023) claims that bioclimatic and energy-conscious building design benefits enhance the overall quality of life. It includes energy conservation, thermal/visual comfort, economic advantages (reduced fuel consumption and cost of electromechanical equipment for heating, cooling, ventilation, and lighting), environmental advantages (less pollution, reduced greenhouse effect) and social advantages. According to Zhang et al. (2022), proper and logical design accounts for adequate energy savings in buildings. These include the building's layout, orientation, size, location of openings, and building envelope protection (insulation, wind, and sun protection). Good sun management (shading) and natural ventilation are essential for a structure to consume less energy. Based on building type, microclimate and technology employed, bioclimatic design can save energy (Elaouzy and El Fadar, 2022). However, utilising bioclimatic design techniques and technology reduces construction costs. Retrofitting older structures increases construction costs by 10% to 15% (Salem et al., 2019).

2.2. Energy efficiency in building

Economidou et al. (2020) described energy efficiency as a cost-effective method of reducing energy consumption through existing and improved technologies and using energy-efficient practices. The concept of energy efficiency is useful. To attain sustainable development goals- energy consumption must be efficient, reasonable and prudent (Bengtsson et al., 2018). Also, technological innovation has provided development opportunities for multifunctional applications in energy, construction, infrastructure, electronics, and buildings (Oyedepo et al., 2022). Buildings account for one-third of the world's greenhouse gas emissions and over 40% of total energy consumption. Structures use 40%, 16% and 25% of the world's energy, freshwater and forest wood. These figures have a detrimental influence on the environment and communities due to climate change consequences. Buildings use the most energy globally compared to other economic subsectors (Guo et al., 2020). Serdeczny et al. (2017) believe that temperature-increased discomfort, community uprooting, priceless goods destruction, flash floods and rising sea levels are some detrimental repercussions. Hence, global interest is in reducing energy consumption in the building sector. Nigeria's building sectors must make their development sustainable to reduce energy consumption due to the building industries' significant growth (Atanda and Olukoya, 2019; Ade-Ojo, 2022). The triangle for low-energy building design shows that saving energy in Nigeria will reduce personal income, delay the construction of new energy facilities, free up funding for other economic activities, increase access to electricity, and decrease load shedding. Since buildings use more than half of Nigeria's energy and contribute to over one-third of the world's greenhouse gas emissions (GHG), built environment professionals should research ways to improve bioclimatic design.

2.3. Energy consumption in hospitals

Pilosof (2020) claims that hospital buildings have several distinct functioning areas. Energy sources such as electricity, gas, steam, and hot and chilled water require sophisticated machinery and equipment in hospital (Shen et al., 2019). Hospital facilities are the second most energy-intensive commercial structure because of their expensive, all-weather operation, complicated medical equipment, stringent cleaning procedures, and environmental requirements. Delivery of healthcare services with efficiency depends on a stable and sufficient power supply (Borges de Oliveira et al., 2021; Franco et al., 2017; Gbadamosi and Nwulu, 2022; Kurz et al., 2022; Zakaria et al., 2021). Power outages affect treatment plans, drug preservation, blood/tissue samples-coolings, surgical instruments sterilisation, water purification, lighting and patient/staff thermal comfort (Sparks et al., 2020). Research on hospital buildings' energy efficiency indicates that achieving a meaningful degree of performance is capital-intensive (Sonta et al., 2021; Sleiti et al., 2022). Hospitals are complex structures with a wide range of energy requirements. The energy requirements intensity for these facilities increases linearly throughout their continuous operation. Hospital energy consumption intensity depends on several variables such as building size, climate, weather, operating schedule and range of activities (Cygańska and Kludacz-Alessandri, 2021; Latha et al., 2022). Hospital buildings have more advanced energy management systems (Chen et al., 2021; Schestak et al., 2020; Zini and Carcasci, 2023). Medical equipment has complex operational requirements, extensive operating times and adaptable control. The percentage of energy savings grows as one combines bioclimatic design strategies and energy-efficient design methods in medical facilities (heat pumps, renewable energy, filtration and water reuse) (Bulakh, 2019; Gupta and Chakraborty, 2021; Zini and Carcasci, 2023).

3. Materials and methods

Research approaches are the plans and procedures that detail the methodology adopted, the data collection, analysis and presentation process of the research hypothesis (Abutabenjeh and Jaradat, 2018; Creswell and Creswell, 2017). Based on the research validity and reliability test, the research approach may be deductive, inductive or abductive. The investigators adopted deductive and inductive research approaches to test the viability of bioclimatic design strategies in implementing orthopaedic hospitals. The study contributes to the development of a more holistic design approach. This study employed a mixed method (qualitative and quantitative) in researching philosophical assumptions or developing theoretical frameworks, as shown in **Figure 1**.

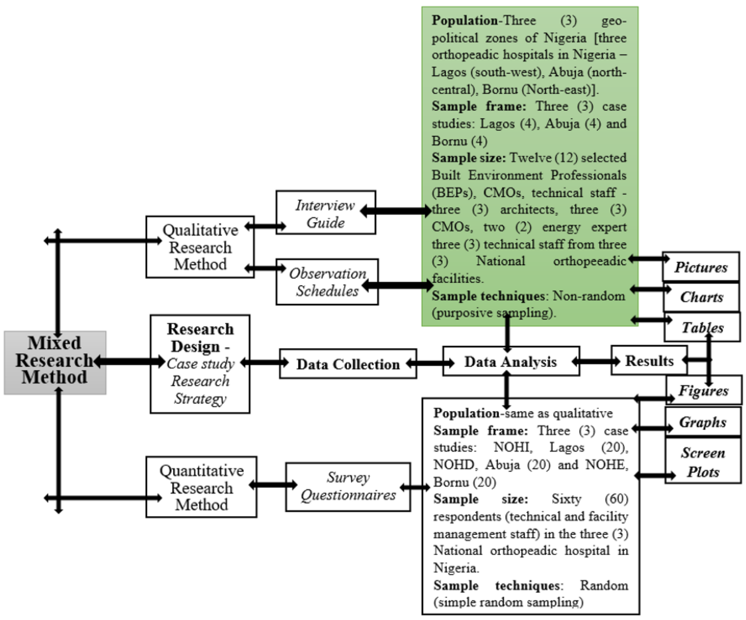

Figure 1. Structure of the research methodology.

The qualitative research used measurable variables analysed through statistical methods to test the validity of objective theories employing a semi-structured survey questionnaire. The qualitative approach used an in-depth interview schedule and direct observation guide to collect data since the bioclimatic design strategy is a complex architecture with a broad scope. The investigators used the case study approach as the research design for bioclimatic design strategies and energy efficiency.

3.1. Research design

Research design is the strategy chosen to achieve the research aim rationally. It is a research plan that guides the research conduct (Akhtar et al., 2016; Ridzuan et al., 2018). A research design may be exploratory or formulating, descriptive or statistical, explanatory or experimental/analytical. Exploratory research seeks to gain new insight into an existing phenomenon and answers the 'why' of research. Descriptive research is statistical research that seeks to identify information and description of the phenomenon. It answers the question of what, who, where, how and when. This study employs a case study as its research design to leverage the descriptive and exploratory research models. The investigators used descriptive research to obtain information on the existing bioclimatic design strategies adopted in orthopaedic hospitals, while the explorative research explores the energy efficiency phenomenon in healthcare facilities.

3.2. Sampling technique

The sampling method is a procedure that guides the selection of sample members from the general study population. The sample frame ensures the representation of the sample population. Sampling techniques are probability and non-probability sampling. Probability sampling (simple random, systematic, stratified random, cluster and multi-stage sampling)—sample size member has an equal chance of getting picked (Rahman et al., 2022). Non-probability sampling (quota, snowball, convenience, purposive and judgmental sampling)—sample size members are chosen based on predefined criteria or preferences. The sampling techniques for this investigation are simple random sampling (quantitative method) and purposive sampling (qualitative approach). The researchers collected the quantitative data from a sample size of sixty (60) respondents and twenty (20) each across the three (3) case studies population. The investigators collected the qualitative data from twelve (12) participants as the sample size. Since the research design is a case study, the investigators used a purposive sampling method in selecting the three (3) orthopaedic hospitals, as shown in **Table 1**, based on the following criteria: i) the geographical spread, and ii) the case study types (National Orthopaedic Hospitals). The investigators distributed questionnaires using a simple random sampling method to the staff of the selected orthopaedic hospitals. Due to time and budget constraints, the investigator did not engage the entire staff population. Therefore, the investigators employ a sample size of 20 staff for each case study, including technical and facility management staff.

Table 1. Demographic information of the participants.

S/N	Name	Age	Sex	Marital status	Education	Occupation	Years of experience
1	MA	51	M	Married	MD	Medical doctor	25
2	TA	53	M	Married	PhD	Environmental engineer	27
3	HL	55	M	Married	MBChB	Medical doctor	30
4	SA	46	M	Married	M.End	Electrical engineer	20
5	EG	52	M	Married	PhD	Biomedical engineer	25
6	IMA	47	F	Married	MD	Medical doctor	20
7	KO	50	F	Married	PhD	Architect	24
8	GK	42	M	Married	M.Sc.	Architect	17
9	DO	55	M	Married	B.Eng.	Civil engineer	30
10	EA	49	M	Married	PhD	Power engineer	20
11	YO	45	M	Married	PhD	Environmental health officer	19
12	EN	43	F	Married	M.Sc.	Architect	18

Mean age: 42.3, mean years of E: 25.4. MD-Doctor of Medicine, PhD-Doctor of Philosophy, MBChB-Bachelor of Chirurgery, M.PH-Master of Public Health, M.Sc.-Master of Science, B.Eng.-Bachelors of Engineering, MBBS-Bachelor of Surgery, M-Male, F-Female.

3.3. Recruitment procedure

Participants for the study were 12 experts: Built Environment Professionals (BEPs), health and medical professionals (HMPs), Energy experts and Sustainability experts and an in-depth individual interview (IDI) for 60 to 90 min. The investigators distributed 12 signed consent forms to the participants as shown in (Appendix A), and they expressed interest in the interview exercise. Following the recommendation in qualitative research to ensure a suitable representation of the lived experiences and diversity of the experts, the investigators used a purposive sampling method with six criteria: Age, gender, marital status, education, occupation and years of experience, as shown in **Table 1**.

3.4. Data collection

The study aims to investigate the bioclimatic design strategies in an orthopaedic hospital to suggest ways of improving energy efficiency. The research objectives include:

1) Identify the bioclimatic design strategies that enhance energy efficiency in orthopaedic hospitals;
2) Assess the energy efficiency requirement in an orthopaedic hospital in Nigeria;
3) Analyse the effects of bioclimatic design strategies in enhancing energy efficiency in an orthopaedic hospital in Nigeria.

Following the aim and objectives, the investigators engaged primary and secondary data. The data were from direct observation to gather information on bioclimatic design strategies in orthopaedic hospitals through a pre-prepared observation guide (Appendix B). The authors used a semi-structured questionnaire to collect data from the technical staff of the three selected orthopaedic hospitals (Appendix C). The study used an in-depth interview guide to collect responses from four (4) Built Environment Professionals (BEPs), three (3) CMOs (Chief Medical

Consultants in the three case studies), three (3) energy experts and two (2) sustainability experts in Nigeria on several issues related to bioclimatic design strategies, energy consumptions in hospitals and energy efficiency compliance in Healthcare facilities (Appendix D). The questionnaire was sectioning according to the three objectives. The investigators distributed the questionnaires to sixty (60) respondents across the selected case studies, as shown in **Table 1**. The secondary data sources are published and unpublished data, which include voice recordings, documentaries, architectural and medical research journals, articles, books, blog posts, websites and YouTube videos. The complete list of all secondary sources used in this work is in the references list.

Table 2 displays that sixty (60) respondents, 20 respondents each-Technical and Facility management staff from the only three (3) national orthopaedic hospitals in Nigeria 100% of the respondents. These include admin staff, nurses, doctors, service engineers, procurement officers, and ICT experts, as derived from the survey results. The table shows the distribution of the respondents in the three National orthopaedic hospitals. The result shows that 85% of the patients work at the National Orthopaedic Hospital, Igbobi, Lagos (NOHI). 90% identified as staff of the National Orthopaedic Hospital, Dala, Kano (NOHD), while 70% work at the National Orthopaedic Hospital, Enugu (NOHE). This result entails that the National Orthopaedic Hospital, Igbobi, Lagos, had the highest number of respondents.

Table 2. The number of questionnaires administered and the response rate.

S/N	Orthopaedic hospital facility	No. of questionnaires administered	No. of questionnaires retrieved	Response rate (%)
1	National Orthopaedic Hospital, Igbobi, Lagos.	20	17	85
2	National Orthopaedic Hospital, Dala, Kano.	20	18	90
3	National Orthopaedic Hospital, Enugu.	20	14	70
Total		60	49	100%

3.5. Data analysis

Data analysis details the data sources and types for collection in any research. The data analysis, interpretation and presentation rely on the research objectives. This systematic procedure ensures the research method’s validity, reliability and reproducibility. This study is valid and dependable owing to the replicability of the mixed research method (Middleton and Spilhaus, 2019). Objective 3, the author analysed the impact of bioclimatic design strategies on energy efficiency using descriptive statistical analysis of the 5-point Likert scale, and the results were in charts, screen plots, and graphs. The researchers sent the questionnaires to the random volunteering staff of the selected facilities. The investigators employed SPSS version 21 (RRID: SCR_002865) to code and analyse the data. Objective 1—The study identifies the bioclimatic design strategies that enhance energy efficiency in orthopaedic hospitals through observation guides and checklists (obtained from literature, personal experience and observation adapted for this study). Objective 2—Assess the energy efficiency requirement in an orthopaedic hospital in Nigeria. An observation guide and in-depth interview schedules from experts would be vital in discussing the energy efficiency requirements. Based on the observations recorded in the three (3) orthopaedic facilities, column 5 of the table, the authors assessed the orthopaedic hospitals on the scale of A—applicable; NA—not applicable; SA—'slightly applicable' to record the components in the selected orthopaedic hospitals. In analysing bioclimatic design strategies to enhance energy efficiency in an orthopaedic hospital in Nigeria, content analysis on data collected through existing literature and performed descriptive analysis to ensure an optimum result.

4. Findings and result

The built environment presents a challenge since there are innovations to explore and identify bioclimatic design strategies that sustain the environment and enhance human health every year (Daemei et al., 2019). The finding indicates that the data analysis relies on the research objectives presented. The assessment technique for qualitative data depends on research objectives, methodology, and analysis. Therefore, the research objectives include identifying the bioclimatic design strategies that enhance energy efficiency in orthopaedic hospitals, assessing the energy efficiency in an orthopaedic hospital in Nigeria and analysing the impact of bioclimatic design strategies on energy efficiency in orthopaedic hospitals in Nigeria. However, the authors presented results sequentially based on the study objectives.

4.1. Result of identifying the bioclimatic design strategies that improve energy efficiency in orthopaedic hospitals

Table 3 indicates that ten (10) bioclimatic parameters were identified from the literature and interviewed experts/professionals in Nigeria's three national orthopaedic hospitals. The investigators observed and recorded these bioclimatic parameters in the checklist of bioclimatic design strategies in the three case studies (NOHI, Lagos, NOHD, Kano and NOHE, Enugu, Nigeria).

The investigators conducted In-depth Interviews (IDI) with twelve (12) Built Environment Professionals (BEPs) and CMOs/COOs (Medical consultants) drawn across Universities in the six (6) geo-political zones of Nigeria. The bioclimatic design strategies that improve energy efficiency in an orthopaedic hospital facility from literature and corroborated by professionals include minimising conductive heat flow, delaying periodic heat flow, minimising infiltration, providing thermal storage, promoting solar gain, minimising external airflow, promoting ventilation, minimise solar gain, promote radiant cooling and promote evaporative cooling (Ahmad et al., 2022; Miller and Burton, 2020).

The effect of energy development on health issues:

"The biggest health impacts accrue to the harvesting and burning of solid fuels, coal and biomass, mainly in the form of occupational health risks, hospitals and general ambient air pollution. Lack of access to clean fuels and electricity in hospitals is a serious health risk". Therapeutic Architect.

Energy efficiency technique and improvement method:

"Energy efficiency, on the other hand, involves using technology that requires less energy to perform the same function. Energy-saving light bulbs, large hospital appliances, smart thermostats, and smart hospital hubs like

Constellation Connect are all examples of technology that can be energy efficient." Architect.

"Energy efficiency improvement methods in orthopaedic hospitals include sealing your ductwork, checking your faucets for leaks, insulating your water heater and pipes, installing a programmable thermostat, washing your laundry in cold water, swapping out light bulbs, replacing appliances before they die and clean and replace filters". Service Engineer.

"An economic savings potential of a hospital facility is between 10% and 20% of current energy use with best practices. The following possible solutions are energy efficiency opportunities for orthopaedic hospitals:

Implement on-site power generation, such as externally mounted solar panels or wind turbines, Swap out older hospital equipment for energy-efficient models, Installing combined heat and power (CHP) systems, Reduce the use of HVAC systems with occupancy-based interoperation to set back cooling when not required, Balancing air and water systems of HVAC that are out of balance and repairing the variable-air-volume boxes that are not working well to reduce excessive air-change rates, Replacing lighting with LED or other energy-saving light bulbs. An intelligent lighting system can reduce hours of lighting operation and intensity with 24% to 38% energy savings. Installation of occupancy-driven wireless thermostats, which would aid in saving 5%–10% of the costs incurred; advanced rooftop unit (RTU) controls for cutting the HVAC energy use by 20%–40%; for retrofitting the building, we can fit existing windows with CO2 demand-controlled ventilation (DCV) sensors. This technology, coupled with room occupancy sensors, can adjust the ventilation accordingly, and Continuous monitoring of the hospital building's energy system can lead to 10% to 15% of their annual energy bills". Sustainability Expert (Architect).

Table 3. Checklist of bioclimatic design strategies in the three orthopaedic hospitals.

S/N	Biolimatic parametres	Description				Level of availability								
			Scale factor: Excellent = 5, (E) Very good (VG) = 4, Good (G) = 3, Fair (F) = 2, Poor = 1 (P)											
			NOHI	NOHD	NOHE	NOHI			NOHD			NOHE		
						A	SA	NA	A	SA	NA	A	SA	NA
1	Courtyards	Presence of courtyard	3	3	5	x	-	-	x	-	-	x	-	-
2	Shading devices	Use of sun shading devices	4	3	2	x	-	-	x	-	-	x	-	-
3	Pond/fountain	Proper landscape	3	5	4	-	-	x	-	x	-	-	-	x
4	Shading plants/vegetation					x	-	-	x	-	-	x	-	-
5	North-South fenestration	Natural ventilation and air quality	4	4	4	x	-	-	x	-	-	x	-	-
6	North-South orientation	Building orientation	3	2	3	x	-	-	x	-	-	x	-	-
5	Solar panels	Renewable energy source	2	3	1	-	x	-	x	-	-	x	-	-
8	Wall insulation	Building shape and form	4	4	4	-	x	-	-	-	x	-	x	-
9	Shaded terraces					x	-	-	x	-	-	x	-	-
10	Roof garden	Visual comfort condition	4	4	5	-	-	x	-	-	x	-	-	x

Note:
National Orthopaedic Hospital, Igbobi, Lagos, Nigeria, means "NOHI" and is located in Lagos, Nigeria.
National Orthopaedic Hospital, Dala, Kano, Nigeria mean "NOHD", Kano, Nigeria.
National Orthopaedic Hospital, Enugu, Nigeria, means "NOHE" in Enugu, Nigeria.
"A"—applicable; "NA"—not applicable; "SA"—slightly applicable.

4.2. Result of assessing the energy efficiency requirements in an orthopaedic hospital in Nigeria

Hospitals account for high energy demand and joint emissions due to their 24/7 operation and use of sophisticated equipment via technology. It represents approximately 6% of total energy consumption in the utility building sector, with Heating, Ventilation, and Air Conditioning (HVAC) systems being the consumer of electrical energy (Shi et al., 2021). Refraining from such products/services becomes a way to save energy or utilise various energy conservation measures over their conventional counterparts. Energy conservation is minimising energy consumption with more efficient equipment and appliances and their sensible utilisation (González-Torres et al., 2022; Sun et al., 2020). It involves several factors affecting energy consumption, such as high maintenance of machinery and the high load of the patient-to-doctor ratio in Nigeria, far more than the regulated 1000:1 prescribed by WHO (Tayler et al., 2022). Orthopaedic hospitals in Nigeria are increasingly becoming destinations for patient care since there are only three in Nigeria. There has been a corresponding growth in the infrastructure supporting the different end energy use. The consumption share depends on occupancy, service, and hospital climatic zones. However, the investigator assessed energy efficiency in an orthopaedic hospital in Nigeria using literature, an observation schedule and an in-depth interview (IDI) of the Built Environment Professionals (BEPs) and CMOs and COO (Medical consultants).

Benefits of Energy Efficiency in Orthopaedic Hospitals:

"Energy-efficient appliances are eco-friendly devices for three reasons: They use less energy, waste less energy and waste fewer resources. Energy efficiency is using less energy to perform the same task or produce the same result. Energy-efficient hospitals use less energy to heat, cool, and run appliances and electronics. Energy-efficient manufacturing facilities use less energy to produce goods". Architect.

"The potential benefits of energy efficiency measures include improved physical health, such as reduced symptoms of respiratory and cardiovascular conditions, rheumatism, arthritis and allergies, as well as fewer injuries". Biomedical Architect.

"Energy Efficiency applications help hospitals save money by reducing their fuel bills while also lowering their greenhouse gas emissions. The proven solutions can increase the efficiency of the hospital heating and steam system to as much as 95% with typical project paybacks. Energy-efficient appliances and equipment use less energy-intensive technologies to reduce the electricity per product". CMO (Medical Consultant).

"Environmental: Increased efficiency can lower greenhouse gas (GHG) emissions and other pollutants and decrease water use. Economic: Improving energy efficiency can lower individual utility bills, create jobs, and help stabilise electricity prices and volatility". Civil and Environmental Engineer.

Recent research has quantified energy consumption rates and identified several opportunities for efficient energy utilisation and saving potential (Fayomi et al., 2021). With all the retrofitting challenges in a hospital, the best time to upgrade its energy efficiency is during construction. Consequently, the need to reduce the energy consumed and enhance building performance becomes eminent (Ogbonnaya et al., 2019). In recent years, an emerging subset of bioclimatic design has been transforming hospital design with sustainable technologies, energy-saving systems, and recyclable or renewable resources and materials. Bioclimatic hospital designs usually cost the same amount to build but can save a great deal on energy costs long-term with:

- Natural light hubs and interior courtyards bring natural light throughout the building.
- Energy star reflective roof with a high *R*-value, a reflective roof or roof insulation and exterior walls reduce heat gain in the building and the accompanying energy usage. Therefore, a minimum of reflective roof insulation reduces annual heating and cooling costs.
- Green roofs can reduce the urban heat island effect, improve stormwater mitigation and absorb pollutants through air filtration. This results in lower maintenance costs and higher energy savings than a traditional roof.
- Energy-efficient glazing: Low E (emittance) glass containing an invisible metal coating sandwiched between the layers of glazing, causing the glass to be reflective. It keeps the building warmer in the winter and cooler in the summer.

Despite the challenges, today's healthcare institutions are finding new ways to incorporate bioclimatic design strategies into new construction to speed up patient and planet healing. Small steps like an energy audit or moving to a greener cleaning protocol would break down such obstacles for better innovations. High-cost energy categories may need to be monitored with an integrated hospital safety management program to identify areas of potential savings. The resulting energy-saving measures would eventually allow us to consider the entire life cycle cost of improvements rather than seeking the lowest initial amount in the safety of the healthcare facility.

4.3. Result of analysing the effects of bioclimatic design strategies in enhancing energy efficiency in an orthopaedic hospital in Nigeria

It is the section where data derived from the distributed questionnaires are analysed. The researcher grouped respondents by gender, age, level of education, duration of employment and occupation. They sent the questionnaires randomly to the staff of the orthopaedic hospitals with an emphasis on technical and facility management staff. They distributed questionnaires to the staff of the following hospitals: 1) National Orthopaedic Hospital, Igbobi, Lagos. 2) National Orthopaedic Hospital, Dala, Kano and 3) National Orthopaedic Hospital, Enugu.

The investigators distributed a total of 60 questionnaires, 20 questionnaires randomly distributed in each of the hospitals. A total number of 49 people responded. These responses were collected and analysed using IBM's Statistical Product for Services and Solutions (SPSS) software. The investigators collected the general respondents' profiles to assess the socio-demographic characteristics of the research participants.

4.3.1. The socio-demographic characteristics of the respondents

As derived from the survey results, **Table 4** shows that the gender distribution of males and females who responded to the questionnaires is 67.3% and 32.7%. This result indicates that the staff working at the National Orthopaedic Hospitals consists of more males than females, with a difference of 34.6%. The age distribution of the respondents between the ranges of 15–25 years, 26–35 years, 36–45 years, 46–55 years, and 56 years and above. The information derived from the bar chart in **Table 4** shows that 23 of the respondents are between the ages of 26–35 years, which equates to 46.9% of the respondents.

Table 4. The table shows the socio-demographic characteristics of the respondents.

S/N	Variables		Frequency	Percent
1.	Gender distribution of respondents	Female	33	67.3
		Male	16	32.7
		Total	49	100.0
2.	The age group of respondents	15–25	18	36.7
		26–35	23	46.9
		36–45	5	10.2
		46–55	3	6.1
		55 and above	0	0
		Total	49	100.0
3	Level of academic qualification	No formal education	0	0
		Primary education	1	2.0
		Secondary education	11	22.4
		BSc/HND	29	59.9
		MSc/MBA	7	14.3
		PhD	1	2.0
		Total	49	100.0
4	Duration of employment	1–5	25	51.0
		5–10	9	18.4
		10–20	11	22.4
		20 years and above	4	8.2
		Total	49	100.0
5.	Occupation of the respondent	Doctor	5	10.2
		Nurse	8	18.3
		Admin staff	9	18.4
		Technical staff	20	40.8
		Others	7	14.3
		Total	49	100.0

Eighteen (18) respondents were between the ages of 15–25 years old (36.7%), Five (5) respondents were between the ages of 36–45 years old (10.2%), and three (3) respondents were between the ages of 46–55 (6.1%). The result shows that most hospital staff were between 26–35 years. The researchers assessed the academic qualification level of the respondents under the categories of no formal education, primary education, secondary education, BSc/HND, MSc/MBA and PhD. The table shows that 29 respondents have BSc/HND qualification, which consists of 59.2% of the respondents; 11 respondents (22.4%) had a secondary education level of education seven (7) respondents (14.3%) had MSc/MBA; one (1) respondent (2.0%) had a primary level of education, and one (1) respondent (2.0%) had primary education. The survey results show the duration of time the respondents have worked or have been working in the orthopaedic hospital. Twenty-five (25) respondents have worked between 1–5 years, which is 51.0%. 11 respondents have worked between 10–20 years old (36.7%). Nine (9) respondents have worked between 5–10 years old (18.4%), while four (4) respondents worked for 20 years and above (8.2%). The survey proved that most staff have worked between 1–5 years. The investigators assessed the occupation of the respondents under the categories of doctor, nurse, admin staff, technical staff, and others.

The investigators used descriptive analysis, a quantitative method in analysing objective 3 (analyse the effects of bioclimatic design strategies in enhancing energy efficiency in Orthopedic hospitals). **Figure 2** shows the result of the descriptive analysis of the impact of bioclimatic design strategies that improve energy efficiency in an orthopaedic hospital. **Figure 2** further indicates the mean figure of each variable. The investigators graded questions in the survey questionnaire using a Likert scale of 1–5, 5 = Strongly agree, 4 = agree, 3 = undecided, 2 = Disagree, and 1 = Strongly disagree.

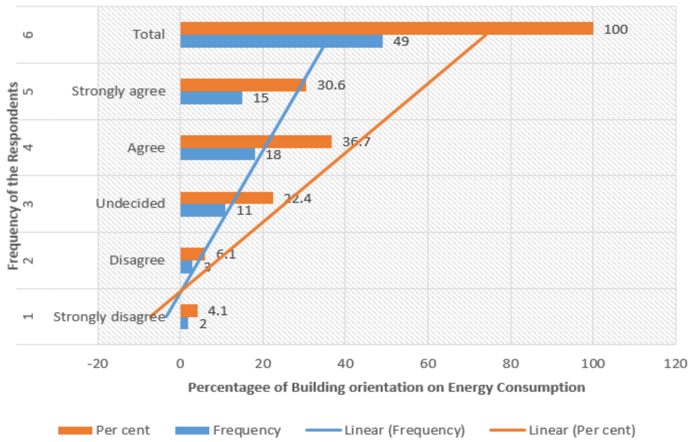

Figure 2. Clustered bars show how the building's orientation or positioning affects the energy consumption within the hospital building.

Figure 2 above indicates that 30.6% of the respondents strongly agreed that the building orientation affects energy consumption. 36.7% of the respondents agreed, 22.4% were undecided, 6.1% disagreed, and 4.1% strongly disagreed. The survey results revealed that 67.3 per cent of people considered that the building's orientation and positioning affected the building's energy consumption.

In **Figure 3**, 22.4% of respondents strongly agreed that the landscape around and within the building complements the hospital's energy efficiency. 55.1% of the respondents agreed, and 8.2% were undecided. On the other hand, 14.3% disagreed that the landscape has no positive impact on the hospital's energy efficiency. The result of this study indicates that landscaping should be an aspect of the design of hospitals.

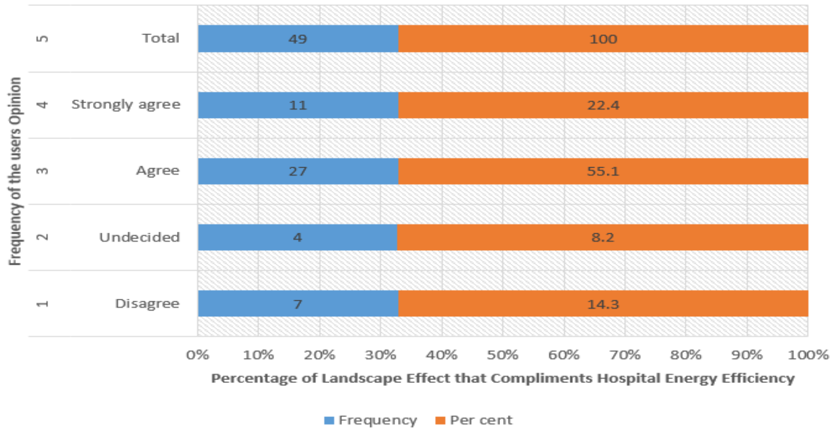

Figure 3. 100% stacked bar charts showing how the landscape around and within the building complements the hospital's energy efficiency.

The results from **Figure 4** indicate that 12.2% of respondents strongly agreed that the existing renewable energy sources reduce energy consumption in the hospital building, 44.9% also agreed, and 14.3% indicated that it was undecided. On the other hand, 28.6% claimed they disagreed. This result further proves that built environment professionals should always incorporate renewable energy sources into the design of hospital buildings.

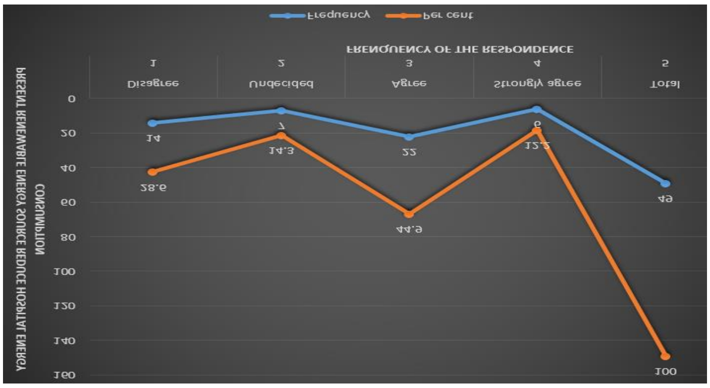

Figure 4. Line charts with markers show how the present renewable energy sources reduce energy consumption in hospital buildings.

Figure 5 indicates that 20.4% of the respondents strongly agreed that the buildings' architectural elements, such as courtyards and shading devices, reduce the energy used in cooling the hospital buildings, 34.7% agreed, and 34.7% indicated that it was undecided. On the other hand, 10.2% disagreed that those elements had anything to do with the energy required in cooling the buildings. This study indicates that designers should consider courtyards, horizontal/vertical fins, and other shading devices in the hospital design.

Figure 6 indicates that 12.2% of the respondents strongly agreed that the shape of the hospital building affects the energy use within its spaces, 38.8% also agreed, and 28.6% indicated that it was undecided. On the other hand, 20.4% disagreed that the building shape had any impact on the energy use within its spaces. This study further proves that designers should consider the form of buildings that promote energy efficiency during the design stage.

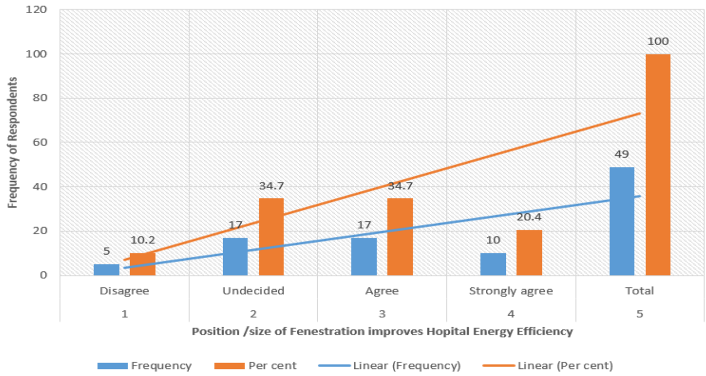

Figure 5. Clustered columns show how the building's architectural elements, like courtyards and shading devices, reduce the energy used in cooling the building.

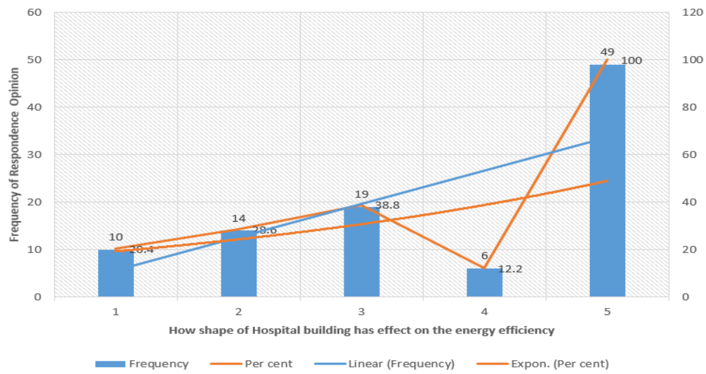

Figure 6. Clustered column lines show how the building's architectural elements, like courtyards and shading devices, reduce the energy used in cooling the building.

The results from **Figure 7** indicate that 22.4% of respondents strongly agreed that the choice of building materials affects heating and cooling within the hospital buildings, 32.7% also agreed, and 22.4% indicated that it was undecided. On the other hand, 14.3% claimed they disagreed, while 8.2% of the respondents strongly disagreed.

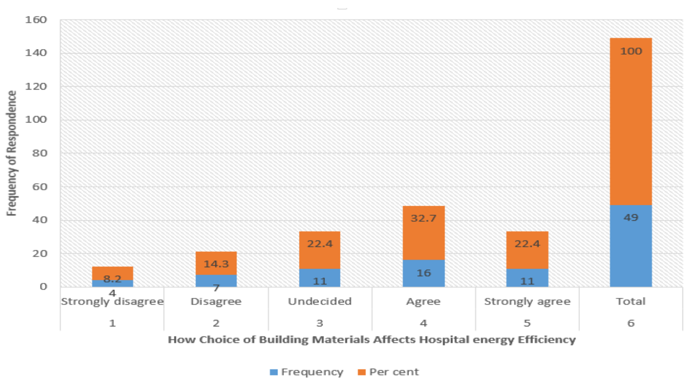

Figure 7. A stacked column chart showing how the choice of building materials affects energy efficiency in hospital buildings.

The results from **Figure 8** indicate that 22.4% of the respondents strongly agreed that the position and sizes of openings/fenestration around the building improve energy efficiency, 46.9% agreed, while 24.5% indicated that it was undecided. On the other hand, 4.1% disagreed, while 2.0% strongly disagreed. The results proved that fenestrations and openings around a building must be well designed and positioned for energy efficiency.

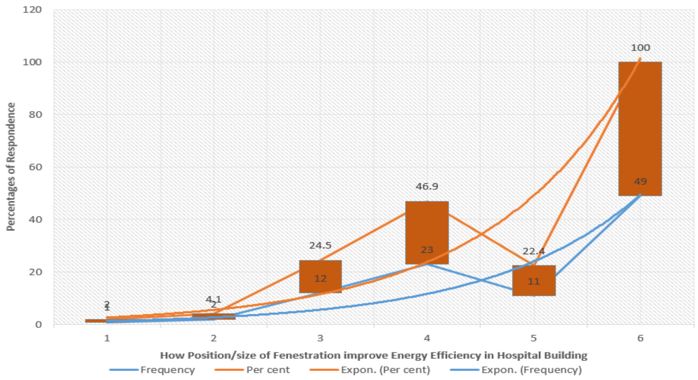

Figure 8. Line chart with up and down bars showing how the position and sizes of openings/fenestration around the building improve energy efficiency.

The results from **Figure 9** indicate that the landscape around and within the building complements the hospital's energy efficiency with the highest mean score of 3.86. Following closely with a mean score of 3.84 is the position and sizes of openings/fenestration around the building, which improves energy efficiency. Conversely, existing renewable energy sources reduce energy consumption in the hospital building, which has the least mean score of 3.41. The results proved that the landscape around and with the hospital and the facilities and openings around the building should be provided, well designed, and positioned for energy efficiency.

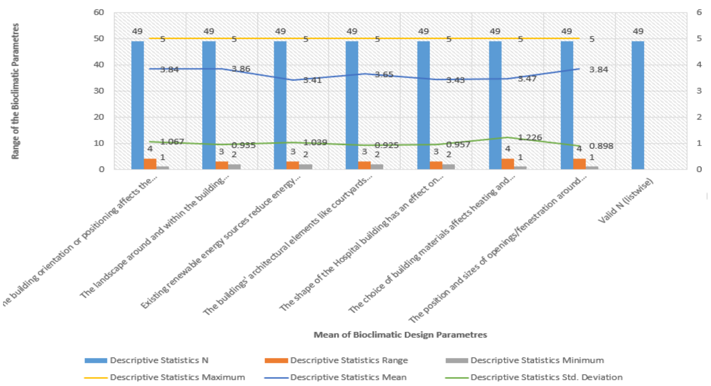

Figure 9. Clustered column-line showing mean and ranges of bioclimatic parameters in a hospital building.

5. Conclusion

The study result indicates that bioclimatic design approaches have enormous potential for enhancing energy efficiency in orthopaedic hospitals in Nigeria. The study's findings are particularly relevant given the possibility that the 2050 building stock will consist of existing structures, many of which do not meet today's energy efficiency standards. The results of this study show a direct link between energy-saving techniques used in orthopaedic hospital buildings and bioclimatic design strategies. Implementing bioclimatic design strategies in hospital design may result in long-term energy cost benefits. Despite the challenges, owners and designers of new healthcare facilities can find a way to include these tactics to accelerate patient and environmental recovery. This study gives insight into sustainable building practices and practical advice for healthcare designers and owners looking to improve energy efficiency in hospital facilities. Further study might investigate the viability of adopting bioclimatic design strategies in different buildings and locations. Overall, this study adds to the body of knowledge on sustainable building practices by emphasising the significance of bioclimatic design techniques in improving energy efficiency and encouraging sustainable development.

6. The implications of the results and findings

The study results and findings indicate that bioclimatic design strategies are significant in renewable energy adoption, developing energy efficiency measures, applying circular economy principles, monitoring responsible consumption, and executing social inclusivity. The bioclimatic design approach considers the local climate and the surrounding environment to create sustainable, energy-efficient and comfortable structures for the occupants. It promotes the health of the building's occupants and reduces the effects by utilising natural resources such as sunlight, wind, and rain to provide heating, cooling, and lighting for buildings. Accordingly, the study has implemented design procedures and bioclimatic approaches to enhance architectural energy efficiency design by integrating the bioclimatic design strategies in the existing legal guidelines to positively impact the quality of life and energy efficiency in hospital design. Architectural structures have a long lifespan, and the energy system will change significantly in years. Therefore, stakeholders and decision-makers should know how energy efficiency can reduce greenhouse gas emissions (GGE) in their life span.

7. Limitations of the article

Unlike experimental research results, which is a tool for understanding cause-and-effect relationships, it allows the investigator to manipulate variables and observe the effects, which is crucial for understanding how different factors influence the outcome of a study. However, this study's limitations include difficulty in deducing the causal direction since the analysis was case study-based and the study was cross-sectional. Also, the authors built the results on self-report and subjective evidence. The investigators drew the results from purposively selected case studies in Nigeria. Hence, the findings may not be generalisable to other populations.

Author contributions: Conceptualisation, ENE; methodology, ENE and IAM; software, ENE and IAM; validation, ENE; formal analysis, ENE; investigation, ENE, IAM and POA; resources, IAM and POA; data curation, ENE; writing—original draft preparation, ENE and IAM; writing—review and editing, ENE; visualisation, IAM and POA; supervision, EE; project administration, ENE; funding acquisition, ENE. All authors have read and agreed to the published version of the manuscript.

Institutional review board statement: The study is in accordance with the

Declaration of Helsinki and under the Covenant University, CHREC research ethics committees.

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Institutional review board statement: Ethical review and approval were waived for this study for the following reasons: information is freely available in the public domain, data collected are non-identifiable, and the data are appropriately anonymised.

Informed consent statement: Informed consent was obtained from all interviewed participants involved in the study. Written informed consent has been obtained from the participants to publish this paper.

Conflict of interest: The authors declare no conflict of interest.

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Appendix A

Informed consent form covenant health research ethics committee covenant university, Ota, Ogun state

Good morning/afternoon. My name is Dr. Eghosa Noel Ekhaese (principal researcher). I am a researcher from Covenant University, Ota, Ogun, Nigeria, conducting research on "Bioclimatic Design Strategies and Energy Efficiency in an Orthopaedic Hospital in Nigerian Cities: A Cross-Sectional Study" towards a research project (book) to be published. I am here to ask you some questions on Bioclimatic Design Strategies, the energy efficiency requirements in an orthopaedic hospital, Its Impacts on Resident Well-being, the effects of bioclimatic design strategies in enhancing energy efficiency, and investments in renewable energy infrastructure. Thank you for choosing to take part in this study. I will be interviewing you today. Before we start the interview, I will briefly explain the exercise and answer any questions you may have.

The aims of the study:

The study aims to investigate how bioclimatic design strategies enhance energy efficiency in selected orthopaedic hospitals in Nigeria. This study may help understand how to reduce energy consumption in healthcare facilities and progress toward a zero-carbon-building goal.

Data collection:

The interview should take between 60 and 90 minutes. During the interview and discussion, I will ask you about your experiences, thoughts and opinions about Bioclimatic Design Strategies and Energy Efficiency in an Orthopaedic Hospital in Nigerian Cities. With your permission, the interview will be video and audio-recorded. The investigator will transcribe the interviews to analyse the conversation.

Confidentiality:

This information will be for academic purposes only. I am asking for your help to ensure that the information I collect is accurate. You may refuse to answer any question or choose to stop the interview at any time. Also, be assured that we will treat your response with strict confidentiality.

I am now going to complete a form with some background information about you. It will allow us to get some context about the results of this study. Thank you. We are now ready to start the interview.

Do you have any questions about the exercise?

Do I have your agreement to proceed?

Respondent's signature and date

(Indicates the respondent's willingness to participate)

Appendix B

Bioclimatic design strategies and energy efficiency in an orthopaedic hospital in Nigerian cities: A cross-sectional study

Observation Guide

This section contains details or requirements to be considered about the selected Orthopaedic Hospitals visited during the duration of this study.

Section A: Building information

1) Name of Building…………………………………………………………………………...
2) Location…………………………………………………………………………………….
3) Year Established…………………………………………………………………………….
4) Facilities in the Building…………………………………………………………......................

Section B:

S/N	Parameter	Available	Unavailable	Description
1.	Courtyards			
2.	Shading devices			
3.	Pond/fountain			
4.	North-South fenestration			
5.	Solar panels			
6.	Shading plants/vegetation			
7.	North-South orientation			
8.	Wall insulation			
9.	Shaded terraces			
10.	Roof garden			

Section C:

Scale factor: Excellent =5, Very Good =4, Good =3, Fair =2, Poor =1.

S/N	Variables	Parameters	Method of application	Scale factor	Remark
1.	Building Orientation	Positioning of the building to the climate			
2.	Building shape and form	Proper design of building shape and form.			
3.	Natural ventilation and air quality	i. Well-designed openings/fenestration ii. Presence of cross ventilation			
4.	Proper landscape	Trees and shade plants around and within the building			
5.	Renewable energy source	Presence of solar panels to generate electricity			
6.	Visual comfort condition	i. Sufficient Daylighting ii. Well-designed natural lighting means			
7.	Use of sun shading devices	Use of shading devices to direct sun glare and heating			
8.	Presence of Courtyard	Well-designed open courtyards			

Appendix C

Bioclimatic design strategies and energy efficiency in an Orthopaedic hospital in Nigerian Cities: A cross-sectional study

Questionnaire

Dear Respondent,

Hello, we are from Covenant University, Department of Architecture. Can you spare a few minutes, please? We working on a project that investigates the Bioclimatic design strategies for energy efficiency in the design of armed forces orthopaedic hospitals. Please kindly take a moment to provide sincere and careful answers to this questionnaire. Please be assured of your anonymity and participation as this will be used for academic purposes only. Thank you for your precious time.

Orthopedic Hospital: ____

Instructions: Please tick the corresponding option in the provided spaces below.

Section A: Respondent's profile

1) Gender:

Male Female

2) Age:

15–25 26–35 36–45 46–55 56–65 66 and above

3) Highest Academic Qualification:

No Formal Education Primary Education Secondary Education

BSc./HND MSc./MBA PhD

4) How long have you been working in the Hospital:

1–5 years 5–10 years 10–20 years 20 years and above

5) Occupation:

Doctor Nurse Admin staff Technical staff others

6) Which Orthopedic hospital do you work in: National Orthopedic Hospital: Igbobi, Lagos

National Orthopedic Hospital, Dala, Kano National Orthopedic Hospital, Enugu

Section B:

Instruction: Please tick as appropriate.

1) The building orientation or positioning affects the energy consumption within the Hospital building.

Strongly agree Agree Undecided Disagree Strongly disagree

2) The landscape around and within the building complements the hospital's energy efficiency.

Strongly agree Agree Undecided Disagree Strongly disagree

3) Existing renewable energy sources reduce energy consumption in the hospital building.

Strongly agree Agree Undecided Disagree Strongly disagree

4) The building's architectural elements like courtyards and shading devices reduce the energy used in cooling the building.

Strongly agree Agree Undecided Disagree Strongly disagree

5) The shape of the Hospital building has an effect on energy use within the spaces.

Strongly agree Agree Undecided Disagree Strongly disagree

6) The choice of building materials affects heating and cooling within the Hospital building.

Strongly agree Agree Undecided Disagree Strongly disagree

7) The position and sizes of openings/fenestration around the building improve energy efficiency.

Strongly agree Agree Undecided Disagree Strongly disagree

8) What time of the day did you take this survey?

6AM–8AM 9AM–11AM 12PM–2PM 3PM–5PM

Appendix D

Bioclimatic design strategies and energy efficiency in an orthopaedic hospital in Nigerian cities: A cross-sectional study

In-depth Interview Guide

Instructions:

This semi-structured interview schedule will be used for interviewees. These include- Architects; Town Planner / Constructing Companies; Psychologists; Sociologists; Environment Specialists (environmental biologists and environmental chemists); CMOs Medical Doctors; Materials Engineers, Service Engineers (Mechanical, Electrical, Civil and Structural), Builders, Art Historian, Beneficiaries/ Inhabitants/residents', etc. The interviewer has to build a satisfactory level of rapport with the interviewee first. The interviewee should be briefed about the purpose of the study. However, data gathered from this interview would be highly confidential and used for academic purposes only.

Demographic information:

Area of expertise/Category of the interviewee: ______________________________

A	Background/demographics questions	Response/answers
1.	What is your name?	
2.	What is your age?	
3.	What is your highest educational level?	
4.	What is your religion?	
5.	What is your gender?	
6.	Are you married?	
8.	Where is your place of birth?	
9.	What is your profession/occupation?	

What is bioclimatic architecture?

What is a bioclimatic design strategy?

What is energy efficiency?

What is the energy consumption of this facility per day, week and month?

What are the existing renewable energy sources available in the orthopaedic hospital building?

Existing renewable energy sources reduce energy consumption in the hospital building.

What is the relationship between bioclimatic design strategy and energy efficiency?

What are the benefits of energy-efficient systems?

What is energy efficiency and how is it beneficial?
What are the advantages and benefits of an energy-efficient appliance?
What is an example of energy efficiency?
What are the health benefits of energy?
What are energy efficiency’s multiple benefits?
What is the effect of energy development on health issues?
What is energy-efficient equipment?
What are methods to improve energy efficiency?
What is the energy efficiency technique?
What are the energy efficiency requirements in an orthopaedic hospital?
How can bioclimatic strategies enhance energy efficiency in an orthopaedic hospital?