Enhancing energy efficiency through passive design: a case study of halls of residence in Covenant University, Ogun State

O A Alagbe¹, M A Caiafas¹, B O Olayemi¹ and O O Joel¹

Department of Architecture, Covenant University, Ogun State, Nigeria.

Abstract. Nigeria faces several energy challenges and currently does not generate adequate energy to meet the needs of the people. Plans and efforts have been made to generate more energy across the country, it is very important to explore affordable and natural ways to achieve energy efficiency and reduce excessive energy use in buildings. This objective of this paper is to investigate passive design strategies and the impact of passive systems such as natural ventilation and natural lighting to improve energy efficiency. This study also examines the current passive design strategies implemented in the halls of residence in Covenant University halls of residence from the building user’s perspective to identify the comfort levels provided by the passive systems implemented in the building.

1. Introduction

One of the most important factors for national development is energy. In the world today, energy consumption has grown significantly. Until recently, [1] noted that the building sector was not a unique slice when final energy consumption was categorized. Presently, buildings are responsible for about 40% of the total primary energy consumption. Buildings and energy systems are facing different challenges due to excessive energy consumption. According to [2] the energy demand in buildings is rising due to growth in population, extended building use and demand for comfort and satisfaction in buildings. Recently total energy consumption has been growing faster than the population due to the increase in the need for individual energy [3].

Study by [4] found out that residential and commercial end users consume most of the energy in the building segment accounts for about 20% of the energy delivered worldwide. Energy in buildings is mostly consumed by the extensive use of artificial lighting, heating and cooling systems and other electrical components. In Nigeria, like other developing countries, energy consumption and energy efficiency are a major challenge. With an installed grid capacity of 6,000MW, less than 4,000mw of electricity is generated currently [5], only about 40% of the population has access to electricity [6]. Currently, most buildings in Nigeria concentrate on aesthetic values with barely any attention to achieve energy efficiency [7]. Passive design systems can be used to improve energy efficiency in buildings through the use of natural elements. The aim of this research is to identify passive design strategies that can be used to improve energy efficiency and reduce energy consumption and in buildings in Nigeria.
2. Literature Review
2.1. Passive Design
Passive design is an approach to building design that relies on the climate and site conditions of a location to maximize the comfort and health of building users while minimizing energy use. The primary aim of the passive design is to reduce the use of any active mechanical systems to maintain occupant comfort. Passive design solutions are most cost-effectively.

Passive methods of controlling the temperature and humidity inside buildings were first used in ancient eras. These methods slowly became outdated with the extensive use of electrical energy and artificial systems [8]. In developed countries with very hot climates, interest in affordable passive cooling systems for buildings have been growing rapidly [9]. These systems are created by different densities of hot and cold air that rely on natural convective movement. Nevertheless, the use of mechanical equipment like fans can be used to enhance passive cooling in buildings. Although the use of natural cooling or heating source is the primary focus of passive systems, there has to be a source of power to start the process. Different passive systems would have different effects on different aspects of the design.

2.2. Passive Cooling
One of the sustainable approaches to naturally cooling and ventilating a building is through passive design strategy [10]. Passive cooling is considered one of the most appropriate strategy of all other passive design strategies to be adopted based on the local climate of Lagos State, making it the basis of consideration for this paper. Passive cooling is considered an "alternative" to mechanical cooling that requires excess energy loads. Passive cooling draws from the forces of the earth of nature such as cool breezes, shade and cool night-time breezes, along with typical building elements, like insulation, overhangs and low energy glass windows, reducing or eliminating dependence on mechanical cooling to a minimum. This approach requires the use of a controller which restricts and puts the overall effect of heat gain on check providing the building's interior spaces with a comfortable temperature from that of the external natural surroundings [11].

[12] stipulated that “a building's total energy use for cooling purposes changes based on the local climate over a region and design standards. Just like other passive design strategies, the incorporation of passive cooling in building design is based on the building interaction with its surroundings. Therefore, before a passive cooling strategy is adopted the local climate must be analysed, matched and suited.

2.3. Classification of Passive Cooling Techniques
Passive cooling depends on a number of procedures that drastically lower a load of cooling devices in buildings when applied collectively. These procedures can be categorized into three groups:

1.) Solar and heat protection (reducing heat gain).

2.) Heat modulation (purging built-up heat).

3.) Heat dissipation (cooling people directly).

Solar and heat protection (reducing heat gain): Internal heat gains can be attributed to people, lights and equipment and the heat generated from people and equipment added to space is an instantaneous cooling load. The reduction of heat gains (internal and external) within a building can be achieved through microclimate (vegetation and water surface), solar control (insulation, shading and glazing).

Heat modulation (purging built-up heat): Maintaining the thermal comfort within a building can be achieved by 2 methods, [13] First; the buildings thermal mass (customarily within the buildings walls, floors and partitions), lowering cooling needs during the heat peak of the day and transferring the
retained heat to building parts at night to regulate the temperature. Passive cooling can be used to cover the remaining cooling needs of the building during the day.

Second; the building is pre-cooled through nocturnal (night-time) ventilation, the coolness stored is then shifted to be made use of in the early hours of the early hours of the following day. This leads to a reduction in energy use for cooling by up to 20% [14]

Heat dissipation (cooling people directly): The building’s design is a significant component with the potential of impacting the cooling needs of a buildings natural cooling technique. Natural cooling refers to the use of natural heat sinks for the dissipation of excess heat from interior spaces. In achieving heat dissipation, the following have to be considered: natural ventilation and natural cooling.

2.4. Passive Lighting

The goals of incorporating lighting controls and daylighting in a building’s lighting design include using natural light to maintain adequate indoor light levels while reducing energy consumptions from electric lighting systems. Lighting controls are important for adjusting artificial lighting based on ambient light levels, occupancy, and the lighting requirements for occupants’ tasks.

Lighting Controls: Lighting controls can produce significant energy savings. Since most people simply do not turn off lights when they leave the room, lighting controls such as occupancy sensors will turn off lights when spaces are vacant. These controls sense the presence of people using infrared or ultrasonic motion sensors. Daylight sensors are another type of lighting control. When sufficient daylight is available, these controls dim or turn off electric lighting, resulting in additional energy savings. Furthermore, a common energy-efficient option for outdoor lights is photosensors.

Daylighting: In conjunction with proper lighting controls, daylighting can result in significant energy savings through reduced electric lighting loads and the corresponding decreased cooling load. When daylighting measures is effectively integrated in to a building, it minimizes the dependence on mechanical lighting while maximizing the use of natural lighting within the building’s interior spaces.

2.5. Applications of Passive Design Strategies

The principles of passive cooling can be applied architecturally through the following:

1.) Design for climate: Passive design taps into the local climate to sustain buildings thermal range within spaces eliminating the dependence on artificial heating or cooling. One of the approaches of passive design strategies is designing with the local climatic conditions of an area in mind. It is of utmost importance for a building designed with passive design strategies to be integrated with the surrounding local climate for optimal productivity.

2.) Site and orientation: When designing a building, the orientation of the site must be taken into consideration, this has an influence on the building design as it helps to maximize the effectiveness of other passive cooling strategies. Various site considerations can create design opportunities or constraints on passive design approaches used. Considerations such as the orientation of the building on site, shade from surrounding buildings and vegetation, wind flow patterns, etc. need to be analysed to optimize the integration of passive cooling strategies. This begins with climate analysis, the basic analysis of the local climate gives the architect an idea on how solar heat gain can be minimized and natural ventilation maximized and these two factors are the essential goals required for passive cooling.

3.) Building shape and massing: Solar access, wind patterns (airflow around and within the building) and heat loss and gain as well as the rate of heat loss or gain can be affected by the buildings shape and mass through the external envelope. The thermal performance of a building
can be affected by the relationship between the area of building envelope encompassing the volume of spaces within the building. The ventilation within and around the building could also be affected by the building shape and mass, as this directly determines the airflow pattern around the building.

4.) Building envelope: This is a very important element to be considered in the passive design. A buildings external envelope is designed to withstand the solar heat gain while at the same time allowing internal heat gains to be expelled from the building’s envelope.

5.) Landscape considerations: Landscaping is a significant factor in modifying the micro-climate of a region. If properly done, the landscape can be used to reduce direct solar gains from striking the building and heating up building envelope. It is one of the ways of providing a buffer for building façades from direct sunlight, noise, etc.

6.) Shading: Shading of a building envelope can reduce temperatures, improve comfort as well as save energy and in order to control solar heat gain in building interiors, the most basic strategy is to incorporate shading devices into the building envelope. Sun shading devices could be internal or external and it is important to reduce or eliminate solar radiation for getting into the building. Various shading devices include; horizontal devices, vertical devices and egg-crate devices.

7.) Natural ventilation: When adopted properly in building design, natural ventilation can improve occupants indoor comfort levels and conditions while minimizing the energy use of mechanically ventilated (air conditioned) buildings. By improving a buildings indoor air quality, natural ventilation can, in turn, contribute to lowering indoor air pollutant concentration. Natural ventilation can be achieved by 2 methods, controlled (through openings such as windows) or uncontrolled (through unintentional openings such as gaps around windows).

2.6. Passive Design for Energy Efficiency

Energy efficiency can be achieved through the adoption of passive strategies to minimize cooling, ventilation, heating and lighting loads in building design based on climate needs and conditions. Passive design is a terminology used to describe a wide scope of approaches or strategies set out to derive energy efficient building design and increased occupant comfort. Therefore passive design and energy efficiency go hand in hand. If a building is totally designed following passive design principles and strategies, energy efficiency will be achieved. This is because passive design sets out to minimize energy use in buildings and create comfort for building occupants.

In 1991 the United Nations described energy efficient buildings as buildings with minimum levels of energy inputs. Well-designed passive buildings are energy efficient buildings as they maintain the best indoor environmental comfort for humans with minimum energy cost.

3. Methodology
3.1 Study area:

The study area is Covenant University, Ota, Ogun State, Nigeria. There were 4 project areas categorized and analyzed based on their similarities in design and layout, these included: Post Graduate Halls of Residence, (Peter/ Esther/ Paul/ John Hall), (Mary/ Deborah Hall) and (Joseph/ Daniel/ Lydia/ Dorcas Hall). These 4 areas are represented in Figures 1, 2, 3 and 4, each building has a different building design, orientation and spatial organization.

Covenant University operates 2 programmes, the undergraduate and Post Graduate programmes, each of which has their own various halls of residences at different locations on campus for both males and
females. The structures for each are 4 storey floors with courtyards integrated into the building design to encourage airflow within building spaces, maximizing natural ventilation.

3.2 Pre-survey:
An on-site survey on the 3 halls of residence was carried out to analyse the physical building structure and orientation based on a detailed passive design check-list. Questionnaires were also administered to obtain information on:

1. The thermal comfort of the building occupants within their living spaces.
2. Room orientation based on ventilation and lighting.

Information on thermal comfort of the occupants within the room types was obtained through structured questionnaires and site survey through the use of a check-list was carried out and analysed. A total of 126 questionnaires were administered in the selected halls of residence.

3.3 Passive cooling variables:
- The building orientation allows for a majority of the structure to be located away from the sun path allowing for lower building exposure and lower cooling needs.
- The buildings external walls have non-structural shading devices.
- Building forms make use of suitable shapes and arrangements allowing for natural lighting and ventilation within the internal spaces of the halls of residence.
- Courtyards were used to mitigate temperature rise within the building and encourage air flow patterns.

![Figure 1. Building orientation of Peter Hall](image1.png)

![Figure 2. Building orientation of Deborah Hall](image2.png)
4. Results and Discussion

4.1 Data analysis

Figure 4 and 5 show the demographic characteristics of the respondents. The analysis of the gender of respondents revealed that 55.6% were females and 44.4% were male respondents. It was also deduced from the characteristics of the respondents that the postgraduate hall of residence had the most respondents with 49.2%, 34.9% of respondents were either from Joseph, Danial, Lydia, or Dorcas hall, 12.7% were from either Mary or Deborah hall, and the rest were distributed between Peter, Esther, Paul, and John halls. These results show that the response gotten were evenly distributed amongst the various undergraduate and postgraduate halls within the study area.

![Figure 4. Gender of respondents](image-url)
4.1.1 Method relied upon for thermal comfort. It was observed that a larger percentage of the respondent (77%) preferred to rely on mechanical methods of ventilation to achieve thermal comfort as compared to the 23% of respondents who preferred natural ventilation as their preferred method.

Figure 6. Level of ventilation preference

4.1.2 Factors influencing overall comfort within spaces. This section of the questionnaire sort to analysis the various factors that determined the overall comfort of users within the spaces. This was done by selecting common factors that played a major role in spatial comfort. It was discovered that 85.7% of respondents considered ventilation of a space a major influencer of overall comfort within spaces, 57.1% considered the internal lighting of a space as having an influence of the overall comfort, 54% selected cooling as having an overall influence on the comfort of internal spaces, 52.4% selected personal control over the various factors has influenced the overall comfort within spaces, and 30.2% of the respondents selected noise has had an influence on the overall comfort within spaces.
4.1.3 Availability of various features within internal spaces. In this section of the questionnaire, the respondent was asked to identify which of the features listed on the table below were readily available in their internal spaces. It was discovered that the majority of them had all of these features present in their space, with a few identifying the absence of these features. However, it was observed that a substantial amount of respondent was not completely sure of the availability of these features, maybe because it was not adequate at all times.

4.1.4 Satisfaction with Comfort Parameters within Spaces. In trying to understand how people felt within spaces, this section of the question sort to understand the level of satisfaction experienced by respondents from the various student halls of residence. It was however observed that the majority of respondents were fairly satisfied, with the level of satisfaction majorly ranging between the 2-4. This showed that residents of the student halls of residence were not completely dissatisfied neither are they completely satisfied but rather stuck in between. It could then be deduced that satisfaction level based on the parameters outline varied at different times.
4.1.5 Control over Comfort Parameters. Through the questionnaire, respondents have been asked their level of satisfaction with comfort parameters, factors that influenced comfort within their spaces, the method relied upon for comfort, and also the availability of certain features within spaces, this section of the questionnaire then sort to identify which of the comfort parameters respondents would like to have control over at any point in time. It was discovered that the majority would like to have control over all comfort parameters highlighted, however control over certain parameters were not desired. Amongst such comfort parameters that control was largely not desired was artificial cooling, followed by natural lighting, natural ventilation. More respondent desired control over natural ventilation and artificial lighting.

![Figure 9. Satisfaction with Comfort Parameters within Spaces](image-url)
5. Conclusion
Passive design strategies offer the potential to improve energy efficiency in buildings. From the study conducted in this paper, lighting and ventilation are very important as they are major factors that influence the building users’ comfort, a significant number of users consider ventilation to have the most influence on comfort and would prefer to have control over these factors. Passive design strategies should be adopted from the initial design phase of a building. Orientation and building shape provide a significant influence on how natural ventilation and natural lighting would have access to the building while minimizing solar heat gain, solar glazing and shading devices also reduce solar heat gain and can allow adequate natural light into spaces in the buildings, while natural ventilation helps reduce the constant use of artificial ventilation. These passive design strategies if properly adopted can greatly promote energy efficiency in residential buildings and also reduce energy consumption. Buildings should be designed to provide adequate natural lighting and ventilation while giving building users’ control over these factors.

References
[1] International Energy Agency (IEA) 2009 Energy Efficiency Retrieved September 9, 2018 from https://www.iea.org/topics/energyefficiency/
[2] Li X, Bowers C P, and Schnier T 2010 Classification of energy consumption in buildings with outlier detection. IEEE Transactions on Industrial Electronics 57 (11) 3639–3644.
[3] Allouhi A, El Fouih Y, Kousksou T, Jamil, A. Zeraouli Y and Mourad Y 2015 Energy consumption and efficiency in buildings: Current status and future trends, Journal of Cleaner Production 109 118-130
[4] Shukla A, and Sharma A 2018 Sustainability through Energy-Efficient Buildings ed A Shukla, A Sharma (Miami: CRC Press) p150
[5] Sadik O W 2015 Energy Crisis in Nigeria: sustainable option using nanotechnology as the way forward director of the center for advanced sensors & environmental International Journal of Energy Economics and Policy 5
[6] Chad-Umoren, Y E and Ebiwonjumi, B F 2013 Nigeria’s nuclear power generation project: current state and future prospects Journal of Energy Technologies and Policy 3 (7) 10–21
[7] Nwofe P A 2014 Need for energy efficient buildings in Nigeria International Journal of Energy and Environmental Research 2 (3) 1–9
[8] Santamouris M 2016 Cooling the buildings – past, present and future. Energy and Buildings 128 617–38.
[9] Pacheco R, Ordóñez J, and Martínez G 2012 Energy efficient design of building: A review Renewable and Sustainable Energy Reviews 16 (6) 3559–3573
[10] Kamal M A 2012 An overview of passive cooling techniques in buildings: design concepts and architectural interventions Acta Technica Napocensis: Civil Engineering & Architecture 55 (1) 10-12
[11] Oikos 2008 Passive Cooling Strategies Oxford: Elsevier Architectural Press 15
[12] Geetha, N V 2012 Impact of planted areas on urban environmental quality: a review Atmospheric environment 25 (3) 289-99
[13] Givoni B 1994 Passive Low Energy Cooling of Buildings New York: John Wiley & Sons. Van Nostrand Reinhold Co
[14] Hirst, E., and Brown, M., 1990. Closing the Efficiency Gap: Barriers to the Efficient Use of Energy. Resources, Conservation and Recycling 3; 267-281