

Evaluation of Cooling Strategies for Energy Efficient Low-Cost Housing Estate in Bauchi, Nigeria

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Abstract

This study evaluates the effectiveness of various cooling strategies in reducing thermal discomfort and energy consumption in low-cost housing estates in Bauchi, Nigeria. A mixed-methods approach combined field measurements, surveys, and simulations to evaluate the performance of passive and active cooling strategies in 50 housing units of Abubakar Tafawa Balewa housing estate. The strategies included natural ventilation, buffer space, building shape, external colour, texture of the building, optimum orientation, materials specification, insulation, shading devices, windows, thermal mass, landscaping etc. Results show that passive cooling strategies reduced indoor temperatures by up to 5°C and energy consumption by 30%. Evaporative cooling systems provided an additional 2°C temperature reduction. However, air conditioning remained the most widely used cooling method despite its high energy consumption. Occupant surveys revealed a preference for natural ventilation and shading devices due to their low cost and effectiveness. This study demonstrates the potential of integrated cooling strategies to improve thermal comfort and energy efficiency in low-cost housing estates in Bauchi. The findings inform policy and design recommendations for sustainable and affordable housing in Nigeria's residential sector.

Keywords: Cooling Strategies, Evaporative Cooling, Natural Ventilation, Shading Devices, Temperature Reduction.

Introduction

In Nigeria, the need for affordable housing is paramount, given the country's rapidly growing population and urbanization (Adedeji, 2023). Moreover, the rising cost of energy has made it crucial to consider energy-efficient design strategies, particularly in low-cost housing projects. It is estimated that around 150 million people are homeless, while approximately 1.6 billion people are living in inadequate dwellings worldwide (UN-Habitat, 2020). Reducing energy use and CO emissions to inhibit global warming and climate change are probably the greatest challenges now facing humanity (Berbie, 2018). Due to population growth and industrialization in developing nations, humanity's consumption of primary energy has reached unprecedented levels (Muzayanah, Lean, Hartono, Indraswari, & Partama 2022).

Housing ownership is an important life achievement but the cost of construction materials, technology and methods for affordable housing delivery is another big challenge, hence the exposition of Low-cost energy saving buildings have gained attention towards sustainable built environment (Ishola, 2023). Building belongs to the most fundamental human

preferences together with food, water and clothing (Camp, 2005). The building construction industry has significant influence on the natural environment as the main energy consumer of all end-use industries, comprising a third of total energy demand and for a huge part of greenhouse gases (GHG) emissions in all economies (Santamouris, & Vasilakopoulou 2021).

There is a high level of exposure to solar radiation in the tropical countries especially in Nigeria leading to the buildings being heated up (Obe, 2023). Therefore, building design should target minimizing heat gain indoors and maximizing evaporative cooling of the occupants of the spaces so as to achieve thermal comfort (Aluko and Aluko, 2013). Also, according to Ali (2021) buildings are the largest energy consuming sector in most developed countries, and offer the largest cost-effective opportunity for savings. Out of all the renewable energy sources such as wind, tide, geothermal, solar passive designs with solar architecture for increased energy efficiency in buildings has been widely used to achieve maximum comfort, reduced greenhouse gases, reduced energy cost and ensures available clean and sustainable energy in such homes (Elsaid, 2023). The varying manifestations of climate change are greatly impacting our lives and livelihoods principally due to the activities of industries that pollute the atmosphere and use up non-renewable resources to fuel our growth and development (Abbass, 2022). Energy efficiency technologies offer important economic and employment opportunities, improve energy security, and save more than it costs (Akindoyeni, 2012). The primary goal of building design is to enable construction of a comfortable and energy-efficiency internal environment and climate of a particular geographical location. Hence, buildings are regarded worldwide as one of life's essential needs and a necessity for man's existence Agboola, (2005). The amount of energy required to run this environment is excessively high, Buildings that promote good studies activities can be achieved through passive cooling. In achieving this, the architectural profession has a leading role to play in adopting passive cooling principles which are environmentally friendly and cost effective (Mainasara, A. T. and Ali, H. Z., 2019). Based on the deficiency in other studies, it was observed that the Federal Ministry of Power, Works and Housing (Housing) (FMPWH) in collaboration with the Nigerian Energy Support Programme (NESP) and relevant stakeholders in the building sub-sector have worked ceaselessly through meetings and workshops in putting together the building energy efficiency guideline (FMPWH, 2016).

Statement of the Problem

The primary challenge in integrating cooling strategies in the design of energy-efficient, low-cost housing in Bauchi, Nigeria, is balancing affordability with sustainable cooling solutions. In Bauchi, Nigeria, low-cost housing estates face significant thermal discomfort and high energy consumption due to inadequate cooling strategies. Residents rely heavily on air conditioning, which is expensive and unsustainable. Passive cooling methods are underutilized, and their effectiveness is unknown. There is a need to evaluate the performance of various cooling strategies in reducing indoor temperatures and energy

consumption. This study aims to investigate the effectiveness of natural ventilation, shading devices, green roofs, evaporative cooling systems, and air conditioning in low-cost housing estates in Bauchi, and provide recommendations for sustainable and affordable cooling solutions.

Research Questions

1. What is the level of cooling design integration in Abubakar Tafawa Balewa housing estate?
2. What is the relationship between of cooling design strategies on energy efficiency of in Abubakar Tafawa Balewa housing estate?
3. How can cooling design strategies be integrated for energy efficiency in Abubakar Tafawa Balewa housing estate?

Objectives of the Study

1. To identify the level of cooling design integration in Abubakar Tafawa Balewa housing estate.
2. To determine the relationship between of cooling design strategies on energy efficiency in Abubakar Tafawa Balewa housing estate.
3. To integrate the performance of cooling design strategy on the energy efficiency Abubakar Tafawa Balewa housing estate.

Literature Review

Some of the environmental and economic benefits in delivering energy efficient buildings are reduced running costs, reduced environmental impacts, improved ambient condition and increased equipment life (Abimaje and Akingbohunge, 2013). Strategies for Energy Efficiency in Buildings Strategies for Energy efficiency in buildings as described in CIBSE Guide (2012) are approaches through which the energy consumption of a building can be reduced while maintaining or improving the level of comfort in the building. Lechner (2014) illustrates the energy efficient strategies in form of "A Solar Fruit Tree" stating that efficiency is the low-hanging fruit as seen in Figure 1. The "Solar Fruit Tree" shows not only all the major solar strategies, but places them at various heights in relationship to the order in which they should be picked. "Some low-hanging-fruit strategies are free or can even save money by reducing the initial cost of a building" (Lechner, 2014).



Figure 1: The solar fruit tree chart showing the free and costly strategies Adopted from: Lechner (2014).

Passive cooling design is design that works with the environment to exclude unwanted heat or cold and take advantage of sun and breezes (Cairns Regional Council, 2011). The passive cooling design, overheating is prevented by trapping solar gains and ejecting internal heat gains. An important aspect of this method involves the significant reduction or total removal of the use of mechanical energy source (Akande, 2010). These strategies includes fixed/operable external shading, stacked windows, low window to wall area ratio, nocturnal cooling, passive ventilation, thermal mass, passive evaporative cooling, earth-tempering ducts. These passive design features in architectural design or planning component used to improve the thermal comfort of a building such as:

1. Site Orientation
2. Building Shape and Massing
3. Landscape consideration (Vegetation)
4. Openings (windows, courtyard and atrium)
5. Solar Shading and buffer spaces
6. Thermal Mass and insulation

Proper site selection and orientation of buildings can significantly reduce the need for artificial lighting and cooling/heating systems. The principles use to work on hot-dry climates are Solar and Heat protection, Heat Modulation, Heat Dissipation, Thermal Mass, and Super Insulation. (Figure 2) shows the Active Design and Passive Design.

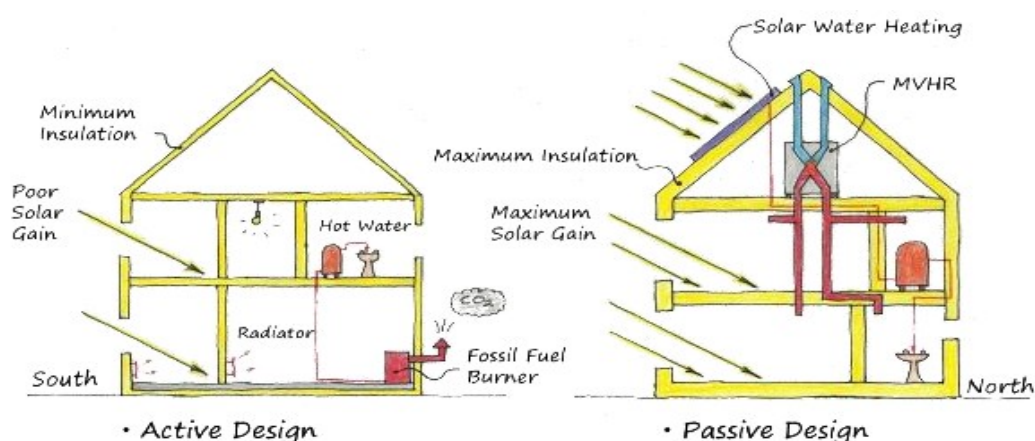


Figure 2: Principle of passive design Source: Passive design toolkit, (2005)

Landscape consideration is a good technique for achieving effective ventilation in a building, it can be used to protect the building from incessant heat and also used to divert cool and breezy wind into the building.

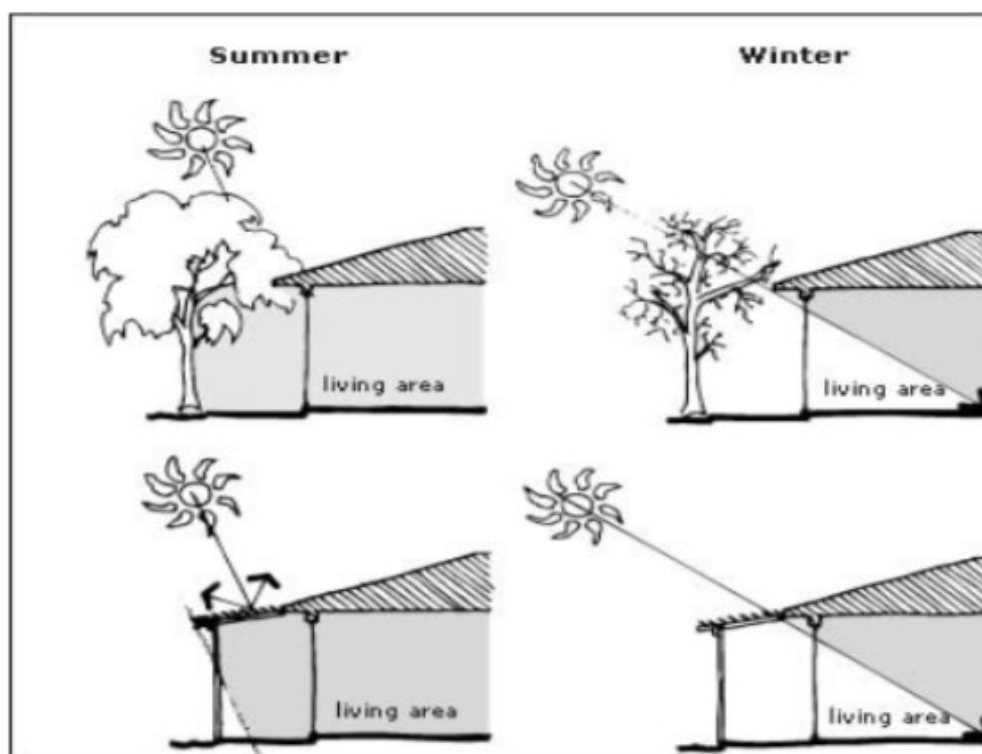


Figure 3: Landscape consideration for shading (Source: Chusid, 2015)

Installing shading devices like awnings, overhangs, or louvers to block direct sunlight, especially on windows facing east and west. Using reflective or tinted glazing to reduce heat gain through windows Shading is an important protective measure that can be used to lessen heat gain. These are shown in the Table 1.

Table 1: Shading types for building based on orientation (Chusid, 2015)

Orientation of building	Suggested Shading Types
North	Adjustable or fixed horizontal shading device above window and extending past it on both sides
East and West	Adjustable or fixed vertical louvers shading element: deep verandas or pergolas with climbers
NE and NW	Adjustable shading element or pergolas with climbers to allow solar heating or verandas to exclude it
SE and SW	Planting deciduous in cool climates, evergreen in hot climates

Use of materials with high thermal mass (such as concrete) inside the building to absorb and store heat during the day and release it at night, regulating indoor temperatures. Occupants wearing typical indoor clothing and carrying out near sedentary activity. According to ASHRAE STANDARD (2004), an environment is said to be an acceptable thermal environment if it at least at least 80% of the occupants of such environments finds it thermally acceptable. The comfort zone is, $22.8^{\circ}\text{C} < \text{ET} < 26.1^{\circ}\text{C}$ for summer, $20.0^{\circ}\text{C} < \text{ET} < 23.9^{\circ}\text{C}$ for winter. Utilizing light-colored or reflective roofing materials to reduce heat absorption. Design roof spaces to allow hot air to rise and escape, creating a cooling effect inside the building. Provision of education and training to builders, architects, and residents about passive design techniques and their implementation. Implementing passive design in low-cost housing projects in Bauchi State can significantly contribute to energy efficiency, making housing more affordable and sustainable for the residents while reducing the overall environmental impact (Ibrahim, 2018).

Research Methodology

Bauchi State as the study area is a state in the North-East geopolitical zone of Nigeria, bordered by Jigawa to the north, Yobe to the northeast, Gombe to the east, Taraba and Plateau to the south, Kaduna to the west and Kano to the northwest. It takes its name from the historic town of Bauchi, which also serves as its capital city. The careful selection of the site is with consideration for climate diversity, construction types, accessibility, and stakeholder engagement ensure that the research on passive cooling strategies for low-cost housing estates in Bauchi is both comprehensive and contextually relevant. Hence, the site is located at Abubakar Tafawa Balewa housing estate behind Ibrahim Babangida Square, Bauchi. The overall research strategic plan based on the research questions as shown in Table 2 below:

Table 2: Research strategy at a glance

S/n	Research Question	Research Objective	Method Of Data Collection	Method Of Data Analysis
1	What are the existing passive design strategies in the study area?	To identify the existing passive design strategies in the study area	Observation	Content Analysis
2	. What are the impacts of passive design strategy on energy efficiency in the study area?	To assess the impact of passive design strategy on energy efficiency in the study area	Observation	Questionnaire and Interview
3	How can passive design strategies be optimized for energy efficiency in the study area?	To optimize the performance of passive design strategy on the energy efficiency in the study area	Observation	Questionnaire and Interview

Source: Researchers' Field Work, 2024

The research approach to be adopted in this study is qualitative in nature, while the research method adopts data collection from primary and secondary sources. The primary sources involve mainly oral interviews, participant's observations, personal interviews, and physical investigations, checklists, photographs and sketches. While secondary sources include literature reviews of some secondary materials, questioners from field research work and feedback, data collected from published and unpublished materials, literary research, magazines and internet materials. Employ a mixed-methods research design, combining quantitative and qualitative approaches for a comprehensive understanding. Quantitative methods include climatic data analysis, thermal modeling, and cost-benefit assessments. Qualitative methods involve interviews, surveys, and stakeholder engagement to capture experiential and contextual insights. The population of this study covers 50 housing units within Abubakar Tafawa Balewa housing estate. In this study, the case study carried out shows how cooling design strategies enhance energy efficiency of various measures (both passive and active) that were used to save energy, the types and quality of the materials that were used to achieve energy efficiency, how issues on thermal comfort were resolved and the energy saving practices adopted in the selected study area.

Analysis and Findings

The qualitative analysis is presented below in Table 3.

Table 3: Analysis of the cooling design strategies at the study area at a glance

S/n	Design Elements	Application	Cooling Design Strategies			
			Heating	Cooling	Ventilation	Daylighting
1.	Building Shape	Extension, sunspaces, balconies	Average	Average	High	High
2.	Buffer space	Ventilated, textured skin, courtyard	Average	High	Average	Low
3.	High performance glazing	Clear glazing, tinted glazing	Average	Average	Average	High
4.	Operable windows	Size, placement, low conductance frames	Low	Low	High	High
5.	Solar shading (operable/fixed)	External sunshades, louvers, blinds, overhangs, vertical fins	Average	Average	Average	Average
6.	Thermal mass	aerated concrete	Low	Low	Low	Low
7.	Light colours	Exterior colour finishes	Average	Average	Low	Average
8.	High performance insulation	Insulation panels	Average	Average	Low	Low
9.	Air and moisture tightness	Sealing	Average	Average	Low	Low
10.	Natural lighting improvement	Reflective blinds, light shelves,	Low	Low	Low	High
11.	Wall window ratio (WWR)	Low (N/E), high (S/W)	Average	Average	Average	Average

Source: Adopted from Magdalena, 2016 and edited as researchers field work, 2024

The findings established in this work that adoption of some passive cooling techniques like the use of buffer space, building shape, external colour, texture of the building, optimum orientation, materials specification, insulation, shading devices, windows, thermal mass, landscaping etc. It is also important that buildings are designed with the thought of reducing energy consumption by optimized building siting, orientation and proper material selection to reduce total energy consumption and the need for air conditioning.

Also, passive cooling strategies reduced indoor temperatures by up to 5°C and energy consumption by 30%.

Evaporative cooling systems provided an additional 2°C temperature reduction. However, air conditioning remained the most widely used cooling method despite its high energy consumption.

The external colour, the texture of the building and the building shape (envelope) provide more effective considerable thermal comfort to the inner volumes.

The architectural contribution of this study has demonstrated that the application of elements of passive cooling and natural ventilation will reduce the energy consumption as well as carbon emission thereby reducing the effect of global warming.

Conclusion

In Nigeria, where affordable housing is a pressing concern and energy costs are on the rise, passive design strategies offer a sustainable solution. By harnessing the natural elements of sunlight and ventilation and incorporating them into low-cost housing projects, energy efficiency can be achieved without compromising comfort. To realize this potential, it is essential to raise awareness, provide education, and collaborate with local communities to ensure the widespread adoption of passive design principles in low-cost housing across Nigeria. Ultimately, this approach can lead to more sustainable, comfortable, and affordable housing options while reducing the environmental impact of the built environment.

Recommendations

- i. Buildings with passive cooling elements maintain the best environment for human habitation while minimizing the cost of energy.
- ii. Buildings with passive cooling elements are also meant to improve the comfort levels of the occupants and reduce energy for heating, cooling and lighting.
- iii. Architects have to continually work towards providing friendly environment for the occupants of these buildings, to encourage the use of architectural solutions based on natural principles of cooling and ventilating the buildings.

Areas for Further Studies

- i. Investigating affordable passive cooling techniques for low-cost housing in Bauchi.
- ii. Evaluating energy-efficient roofing materials for cost-effective cooling in residences.
- iii. Analyzing window design optimization for natural ventilation in low-cost houses.

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