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THE IMPROVEMENT OF ENERGY EFFICIENCY IN AVIATION AND AIR CARGO PUBLIC FACILITIES IN NIGERIA: A CALL FOR POLICY AND SUPPORTIVE REGULATORY FRAMEWORKS

Summary. This study explores the assessment of design strategies to improve energy efficiency in aviation facilities. The energy that Nigerian civil aviation sector facilities consume is substantial, with considerable implications for operational costs and environmental impact. This research investigates energy consumption patterns, evaluates the effectiveness of current design strategies and technologies, and identifies specific challenges hindering optimal energy efficiency. The study employs secondary data to study various aviation facilities. Findings reveal that while advanced building materials, passive design principles, and energy-efficient technologies have been adopted to some extent, significant variability exists in their implementation. The paper pinpointed major identifiable challenges that were not far-fetched from lack of awareness to high initial costs, and insufficient regulatory frameworks. The impact of these design strategies on

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indoor air quality and thermal comfort is also analyzed, highlighting improvements in occupant comfort and satisfaction in facilities with robust energy-efficient practices. The study concludes with recommendations for enhancing regulatory frameworks, increasing awareness and training, promoting financial incentives, and adopting integrated design approaches. These insights aim to guide industry stakeholders, policymakers, and researchers in advancing energy efficiency and sustainability in aviation facilities.

Keywords: air cargo, aviation facilities, energy challenges, design strategies, energy efficiency, policy frameworks

1. INTRODUCTION

Air transport system essential elements include airports, terminals, air cargo centers, taxiways, and runways. They are key in connecting people, goods, and services anywhere on the planet. This is because Kupfer, Meersman, Onghena and Van de Voorde (2017) stressed that air freight transport is expected to rise by a 3.51% annual pace until 2022 while the Boeing company (2016) and (2018) anticipated an annual progression of 2.3% to 4.9% until 2035. The expanding Asian market and the thriving e-commerce segment mostly drive these figures. Also, air cargo remains one of the major contributory factors to the aforementioned growth. It refers to the transportation of goods via aircraft and is also known as air freight (Hu, Lee, Chuang, and Chiu, 2018). Air cargo operations are a critical aspect of the aviation industry and are broadly classified into three major modes: belly-hold freight on passenger aircraft, all-cargo operations, and parcel services (Zhang, 2003). According to Gupta and Walton (2017), airlines have been transporting airfreight since 1911, when aircraft manufacturers started integrating cargo-holding flights with the airfreight necessitating aircraft design to customize airplanes with inbuilt cargo transport systems. Although custom-made cargo airplanes are now available, a considerable proportion of cargo transported by air is still carried aboard passenger planes in a containerized system (Meincke, 2022).

Suffice to posit therefore, that no nation in the world can attain greatness and also realize "the United Nation's Sustainable Development Goals (SDGs)" in the absence of "generating the necessary electric power needed to drive its small, medium and large-scale industries and economy." Further this, the aviation sector ingests a substantial amount of energy and contributes to environmental issues. According to the "International Air Transport Association" IATA (2020), the industry accounted for roughly 2 – 3% of worldwide carbon dioxide (CO2) emissions in 2019, and these emissions have been increasing. Heating, cooling, lighting, and specialized equipment all have considerable energy demands on aviation facilities. Reducing energy use at this institution is critical for economic savings and environmental responsibility (USDOE, 2017).

Airports play an important role in the air transportation business; hence, their efficient management is critical. Airports must be developed to meet sustainable standards in order to consume less energy, water, and heat (Korba, et al. 2022;). Furthermore, implementing sustainable airport practices can help airports improve their economic and social impacts while lowering their environmental impact (Eid, et al. 2022).

In the field of energy-efficient terminal building design, there are two approaches, namely, one involving increased energy generation and the other focusing on reduced energy demand. The usage of active systems plays a critical role in boosting energy supply and thereby decreasing external energy dependence. To meet the demands of heating, cooling, and illumination within airport terminal facilities, various systems, including solar, geothermal, wind, and biomass technologies, are combined either separately or in tandem (Zhou, 2022). From the above, this study shall evaluate the current energy consumption patterns and trends in Nigeria aviation facilities; critically assess the design strategies and technologies currently in use in aviation facilities to enhance energy efficiency; and identify the specific challenges and obstacles that hindered the achievement of optimal energy efficiency in the aviation sector in Nigeria.

2. THE RESEARCH PROBLEM

Aviation facilities, including airports, terminals, and air cargo centers, are essential components of the global transportation network. These facilities are characterized by significant energy demands due to continuous operations, passenger comfort requirements, and security measures. The International Air Transport Association (IATA) reported that the aviation industry was responsible for approximately 2-3% of global CO2 emissions in 2019, and these emissions have been on the rise (IATA, 2020). According to IATA (2018), the operation of an international air cargo terminal necessitates a significant amount of energy for lighting, temperature control, cargo handling equipment, and other operational requirements, which contributes to elevated operational costs and a significant environmental footprint.

The building envelope, which includes roofs, walls, windows, insulation, and ventilation systems, is critical in minimizing energy usage in aviation facilities (USDOE, 2013). It controls heat intake and loss, which has an immediate impact on “Indoor Air Quality,” thermal comfort, and overall power supply efficiency. Improved energy efficiency in cargo terminals contributes to economic sustainability by lowering operating costs. At the same time, it fulfills environmental responsibilities by reducing the terminal's carbon impact (ICAO, 2019).

Addressing this research problem is crucial to improving the sustainability, energy efficiency, and economic viability of Nigerian aviation and air cargo terminals and, by extension, cargo ports throughout the world. The findings have the potential to contribute to global environmental goals, local economic development, and cargo port employee well-being. Consequently, the questionable issues of this study are:

i. How are the current energy consumption configurations and trends in aviation and air cargo public facilities design?
ii. What design strategies and technologies are currently in use at aviation and air cargo public facilities to enhance energy efficiency?
iii. What are the specific challenges and barriers to achieving energy efficiency in aviation and air cargo public facilities in Nigeria?

3. SIGNIFICANCE OF THE STUDY

Assessment of design strategies to improve energy efficiency in aviation facilities addresses the critical challenge of optimizing energy consumption within the aviation sector in Nigeria. This research is justified by its potential to contribute to the sector's economic growth, environmental responsibility, and resource conservation. It addresses global and local issues, promotes cost reduction and operational efficiency, and has far-reaching policy and industry developmental output.

4. CONCEPTUALIZATION

As global concerns about climate change and sustainable practices intensify, the Nigerian aviation industry is under pressure to enhance its environmental performance. This conceptual clarification is targeted at providing a foundational insight for key terms and concepts inherent in this research topic.

i. Energy efficiency in aviation: Energy efficiency in aviation refers to the systematic effort to maximize the output, for example, transport services while minimizing the input of energy resources. In the context of aviation, this involves optimizing the energy consumption of aircraft, ground operations, and infrastructure (Corlu, et al., 2020).
ii. Design strategies: Design strategies are a collection of deliberate approaches and methods used during the planning and development stages to achieve certain goals (Bibri, & Krogstie, 2019). In this context, design strategies emphasize the development of aviation infrastructure and systems with low-energy consumption and environmental impact.
iii. Assessment: The systematic review and measurement of the efficacy, efficiency, and influence of various parts within the aviation system is referred to as assessment (Grépin, et al. 2021). In this study, assessment refers to determining the success of design strategies in enhancing energy efficiency.
iv. Aviation Sustainability: Aviation sustainability refers to the industry's ability to meet current requirements without jeopardizing future generations' ability to meet their own (Zhang, Butler, & Yang, 2020). The primary target of any lasting aviation business is to ensure a striking balance between commercialization sustainability, social responsibility, and environmental stewardship.
v. Operational practices: The term "operational practices" refers to the day-to-day activities and procedures in the aviation industry (Schweiger, & Preis, 2022). Energy-efficient operational practices entail minimizing energy use in procedures such as ground operations, air traffic management, and aircraft maintenance.

5. ENERGY EFFICIENCY IN AVIATION FACILITIES

i. The Usage of Power in Aviation Facilities

Energy consumption in aviation facilities is a critical factor that involves the use of energy for various activities, infrastructure, and support systems within airports and related facilities. The aviation industry consumes a substantial amount of energy, and regulating energy usage is critical for environmental sustainability, economic efficiency, and compliance with regulatory norms (Xu, & Xu, 2022).

According to Greer et al. (2020), energy is consumed in a variety of ways, including the illumination of terminal buildings, concourses, public spaces, runways, and taxiway edge lighting for safe aircraft movement, heating, ventilation, and air conditioning to maintain comfortable temperatures in terminals and hangars, energy consumed by ground support equipment used for aircraft servicing, radar systems, communication equipment, and control systems, and fuel transfer from storage to aircraft, among others.

ii. Factors contributing to high-energy consumption

A mix of operational, technological, and infrastructural reasons contribute to high-energy usage in aviation facilities (Gray, et al. 2021). Busier airports with more airplane arrivals and departures have higher energy requirements for air traffic control, lighting, and ground operations. Many major airports run continuously, resulting in continuous energy use (Lodewijks, et al. 2021).

Larger terminals with numerous amenities and intricate architectural designs frequently need more energy for lighting, "Heating, Ventilation, and Air Conditioning" (HVAC) (Razmi, Rahbar and Bemanian, 2022). Energy-intensive activities associated with aircraft maintenance and storage in big hangars add to overall consumption. Illumination for safe aircraft movement in all weather conditions and times of day necessitates a significant amount of energy (Orikpete, et al. 2023). The desire for well-lit and visually appealing terminal spaces adds to high-lighting energy consumption.

iii. Operational energy demands

Operational energy demands in aviation facilities encompass a wide range of activities and systems necessary for the day-to-day operations of airports, including terminals, air traffic control towers, hangars, surrounding communities, and associated infrastructure (Kalić, Dožić and Babić, 2022). These demands are critical to ensuring the smooth functioning of airport services, passenger handling, and aircraft operations (De Neufville, 2020). Key areas contributing to operational energy demands in aviation facilities are:

a) Terminal buildings and hangars: Heating, ventilation, and air conditioning (HVAC) systems are used to maintain comfortable indoor temperatures for passengers, cargoes, and staff. Also, illumination of terminal spaces, including public areas, gate lounges, retail spaces, and energy consumption associated with information technology systems, check-in kiosks, operation of maintenance tools, and baggage handling systems.
b) Air Traffic Control (ATC) towers: energy demands for radar systems, communication equipment, control systems, and systems required for air traffic controllers' workspaces.
c) Runways and taxiways: Energy consumption for runway and taxiway lighting to ensure safe aircraft movement, especially during low visibility conditions.
d) Fueling facilities and ground support equipment: Energy required for transferring fuel from storage to aircraft, vehicles and equipment used for fueling aircraft, and energy demands for conveyor belts and sorting systems.

6. LITERATURE REVIEW

The aviation industry, a significant contributor to global energy consumption, is increasingly pressured to enhance its energy efficiency and reduce environmental impact (Amankwah-Amoah, 2020). The review explores relevant works on the assessment of design strategies to develop prompt and stable power supply in aviation. The Nigerian aviation sector in particular has numerous hurdles in achieving energy efficiency. The growing demand for air travel, as well as the environmental impact of carbon emissions has, however, necessitated a paradigm shift in the industry's strategy (Dias, et al. 2022).

Design modifications in aircraft construction and technology are critical to increasing energy efficiency. Winglets, lightweight materials, and enhanced aerodynamics are being investigated for their potential benefits (Hasan, et al. 2021). Airports are essential parts of the aviation system. It is critical to design energy-efficient terminals, runways, and ground operations.

Sustainable architecture, smart lighting, and optimized layouts all help to save energy (Greer, Rakas and Horvath, 2020).

Efficient air traffic management is essential for minimizing fuel consumption. Research explores the impact of air traffic control procedures, routing strategies, and optimization algorithms on energy efficiency (Corlu, et al. 2020). Exploration of alternative fuels is an important step toward improving energy efficiency in aviation. The ability of sustainable aviation fuels derived from renewable sources to reduce carbon emissions is investigated (Cabrera and de Sousa, 2022).

Global attempts “to reduce the environmental impact of aviation activities” include regulatory frameworks. The literature investigates the effectiveness of policies such as emissions pricing and carbon offsetting in encouraging energy-efficient behavior (Rissman, et al. 2020).

Literature reveals a multifaceted landscape in the pursuit of energy efficiency in aviation. From aircraft design innovations to sustainable fuels and regulatory measures, a comprehensive approach is necessary. The assessment of design strategies involves a holistic consideration of technological, operational, and policy-related facets. As the aviation industry progresses, this review sets the stage for thoughts on the contemporary position of research and identification of gaps for advance investigation.

6.1 Empirical Review in Developed and Developing Countries

Hu, et al. (2018) study focuses on Taiwan's government-franchised air cargo terminal business, recognizing the industry's increasing competitiveness due to evolving cargo delivery methods. The research aims to enhance sustainable development and growth by improving service quality, customer satisfaction, and competitiveness. Through a literature review, exploration, and expert interviews, the study employs “the Decision-Making Trial and Evaluation Laboratory (DEMATEL) method and Analytic Network Process (ANP)” to design a framework for air cargo terminal service quality. Eight key criteria, such as new facilities, professionalism, and security, are assessed for their interrelationships and causality. Strategies are formulated based on the identified service quality demands, offering valuable insights for terminal operators.

On the other hand, Bauen, et al. (2020) paper reviews the future of aviation fuel, emphasizing the expected growth in demand and the reliance on kerosene in the United Kingdom. While efficiency improvements can reduce emissions, decarbonization necessitates low-carbon kerosene alternatives. Currently, alternative fuels form a small share, but commercialization is progressing. Hydrogen is a long-term option requiring design and infrastructure changes, and electrification is emerging, especially in small aircraft or hybrid modes for larger ones. The review assesses the status, challenges, and prospects of alternative fuels and electrification in aviation, providing insights into the evolving landscape of sustainable aviation fuel options.

According to the Özkanli and Demir (2023) study, it compares the energy efficiency policies of Turkey and Germany, tracing their development from the 1995 start of Turkey's efforts to Germany's pioneering Energy Conservation Law in 1976. Analyzing legal frameworks and updates, the research focuses on the impact of EU Directives on energy efficiency laws and examines differences in enacted laws and regulations. The study assesses the effects of Germany's renewable and emission-free energy targets against Turkey's domestic energy targets on energy efficiency initiatives. Through this comprehensive overview, the research aims to provide insights into the progress and disparities in energy efficiency policies between the two countries.

Dursun (2022) explores the long-run relationships among civil aviation, energy productivity, economic growth, and ecological footprint in France, Finland, and the United States from 1970 to 2020. Using "multivariate regression, Phillips Ouliaris, Engle Granger, Jarque-Bera Normality, and Cusum tests," the study finds that in France, the ecological footprint is impacted by energy efficiency, economic growth, and civil aviation, supporting the Environmental Kuznets Curve (EKC) hypothesis. However, in Finland, there is no significant impact, challenging the EKC hypothesis. Cointegration tests validate the model's long-run relationship in France and the United States, but not in Finland.

Harputlugil and de Wilde (2021) and Xianliang, et al. (2021) discovered that the buildings' infrastructure globally contributes to 40% of annual energy consumption, making them crucial for energy reduction efforts. Despite extensive study "on energy-efficient buildings since the 1970s," impact remains limited. This paper reviews building occupant behavior, a key factor influencing energy use. Two stages of review reveal a reliance on quantitative methods, with research predominantly in developed, high-income countries. Dominant topics include energy demand and thermal comfort. Current research focuses on technical aspects over socio-economic factors, often limited to single buildings. The study identifies gaps and issues for future exploration, emphasizing the need for broader, holistic perspectives linked to social and economic factors.

Cristino, et al. (2021) research discusses the challenges hindering the adoption of building energy efficiency (BEE) technologies in Brazil. Despite government efforts, the building sector contributes significantly to electricity consumption and greenhouse gas emissions. A systematic literature review identifies 27 barriers categorized into six groups affecting BEE technology adoption. The article conducts a survey of one thousand Brazilian professionals using cluster and factor analysis. Results validate the identified barriers, highlighting Governmental/ Political/ Regulatory and Financial/Economic categories as most significant. The findings indicate a societal expectation for more government involvement. The survey offers insights into technology and education aspects, guiding the development of strategies to overcome barriers. The study aims to assist government agencies, researchers, and experts in formulating effective guidelines for promoting building energy efficiency in Brazil.

Malhotra, et al. (2022) addresses the vital need from India perspective for capacity-building in developing countries to tackle environmental challenges, especially in managing technological change for climate mitigation and adaptation. Focusing on a qualitative case study in India, the research explores the dimensions of capacity-building. The study adopts a systemic and evolutionary understanding, examining how "the Bureau of Energy Efficiency developed and implemented" programs for energy efficiency. It emphasizes leveraging existing capacities and building new ones both within and outside the country, resulting in substantial energy savings. The outcome of the study contributed to the appreciation of the dynamics of capacity-building in the background of climate and sustainable development challenges.

Addressing UN Sustainable Development Goal 7, Adom, et al. (2020) examine the impact of energy efficiency improvements on commercial bank profitability in 43 African countries under different political regimes from South Africa. Using simultaneous System Generalized Method of Moments, the research fills a gap in the literature regarding financial indicators in developing economies. Results reveal that energy efficiency improvements tend to enhance bank profitability more in politically centralized regimes. The study suggests integrating clients' energy utilization behavior into the credit valuation process and emphasizes the importance of an aggressive pursuit of energy efficiency aligned with a political environment fostering sustainable practices.

Aldhshan, et al. (2021) discourses the imperative of sustainable energy systems, emphasizing that buildings globally consume 40% of total energy, projected to increase to 50% by 2030. Focusing on Malaysia, a major Asian energy consumer, the study conducts a detailed literature review on energy consumption and GIS methods for spatial energy efficiency assessment. Utilizing techniques like multiple criteria decision analysis, machine learning, and deep learning, the review underscores the significance of GIS in estimating energy consumption, exploring renewable sources, and assessing solar radiation. Notably, the fuzzy DS method is identified as reliable for optimal PV farm location determination, and 3D models prove effective in estimating solar radiation for various applications, including urban sunlight access and habitability analysis.

Munyehirwe, et al. (2022) survey micro and macro rebound effects following the introduction of energy-efficient biomass cooking stoves (EEBCs) in rural Africa, focusing on Rwanda. Using a model of biomass supply and demand, the researchers explore the impact of EEBCs, varying subsidy levels at the village level. While EEBC adoption reduces household firewood consumption, the study finds no significant local rebound effects. The research identifies conditions under which this finding may generalize to other settings, contributing valuable insights to the understanding of the effectiveness of energy-efficient interventions.

Basically, Coleman (2022) and Orikpete et al. (2023) comprehensive review focuses on energy consumption patterns in Nigeria's growing aviation and other sectors of the economy, recognizing its pivotal role in the country's economic landscape. Examining literature and global best practices, the study delves into various aspects, including flight operations, ground support, and maintenance. Identifying inefficiencies, it underscores the urgent need for "rigorous energy efficiency policies and enhanced regulatory structures" to address challenges like "inconsistent power supply and heavy reliance on non-renewable sources." The findings emphasize the importance of aligning energy management with Nigeria's fiscal aspirations for sustainable and ecologically responsible aviation sector growth. The insights provided are crucial for guiding stakeholders in navigating the complexities of energy management in burgeoning economies.

7. THE IDENTIFIED SPECIFIC CHALLENGES AND BARRIERS

The identified specific challenges and barriers that obstruct the achievement of optimal energy efficiency in the aviation sector in Nigeria are diverse, and they result in:

i. The implementation of energy-efficiency design strategies,
ii. The achievement of optimal energy efficiency, and
iii. The adoption of renewable energy sources.

7.1 The Implementation of Energy-Efficiency Design Strategies

We observed that the primary challenge in implementing energy-efficient design strategies in aviation facilities accordingly is high initial investment costs. This is followed by a resistance to change from traditional design practices 31%, lack of awareness about energy-efficient technologies 20% and regulatory barriers and compliance issues 9% (see figure 1). Overcoming these challenges is crucial for wider adoption of energy-efficient design strategies. High upfront costs can be a deterrent, and a lack of awareness can hinder the implementation of these strategies altogether.

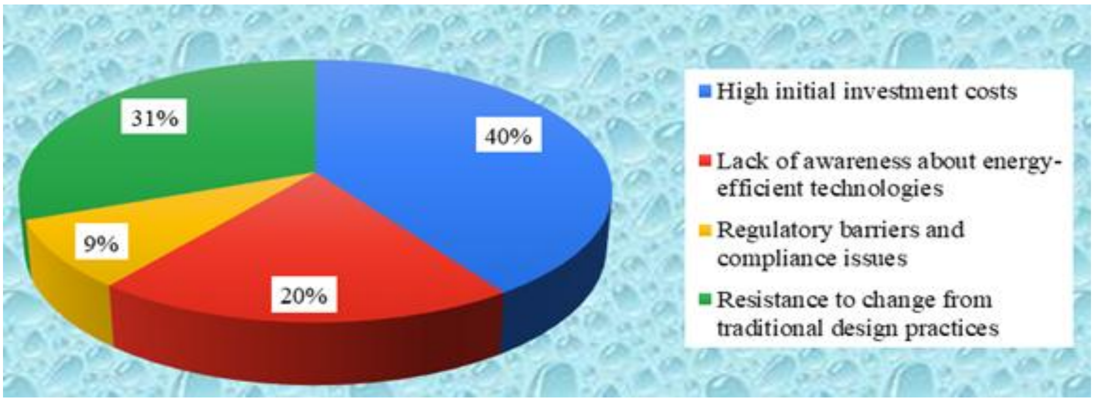

Fig. 1. Challenge in Implementing Energy-Efficient Design Strategies

7.2 The Achievement of Optimal Energy Efficiency

Figure 2 below presents the analysis of the achievement of optimal energy efficiency status. From it, we identified that limited technology availability of 23% suggests a lack of suitable options to implement, even with the desire to improve efficiency. Funding difficulties 32% highlight financial constraints that hinder investment in energy-saving solutions. Inadequate training and education on energy-efficient practices 29% highlights a knowledge gap that needs to be addressed. Employees may not be aware of the best practices to save energy. Lack of incentives for energy efficiency improvements 16% suggest financial incentives could encourage airlines and airports to invest in energy efficiency.

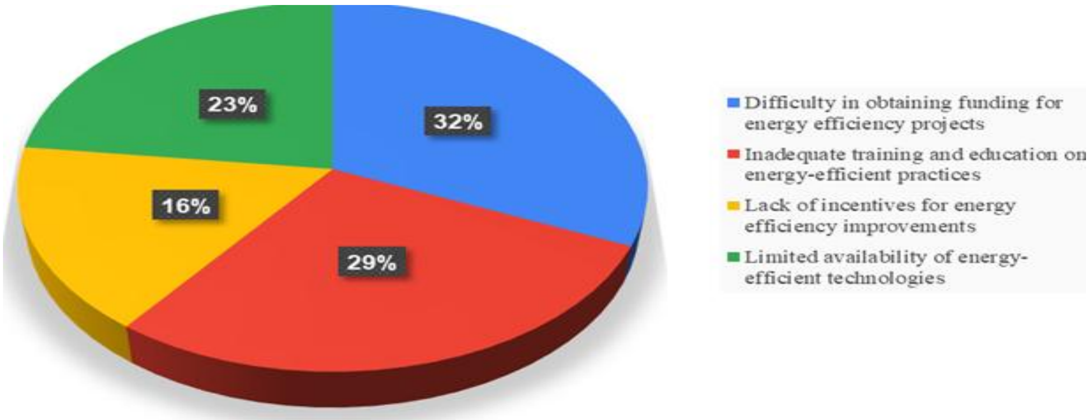

Fig. 2. Barriers Hindering the Achievement of Optimal Energy Efficiency

7.3 The Adoption of Renewable Energy Sources

Adoption of renewable energy sources is hampered to a percentage of 40% by the high upfront costs of renewable energy systems. It can be further noticed that 30% is a lack of renewable energy infrastructure. However, 20% is due to technological difficulties, while 6% is blamed on regulatory obstacles and permit concerns for the impediment to the adoption of renewable energy sources in aviation facilities (see figure 3).

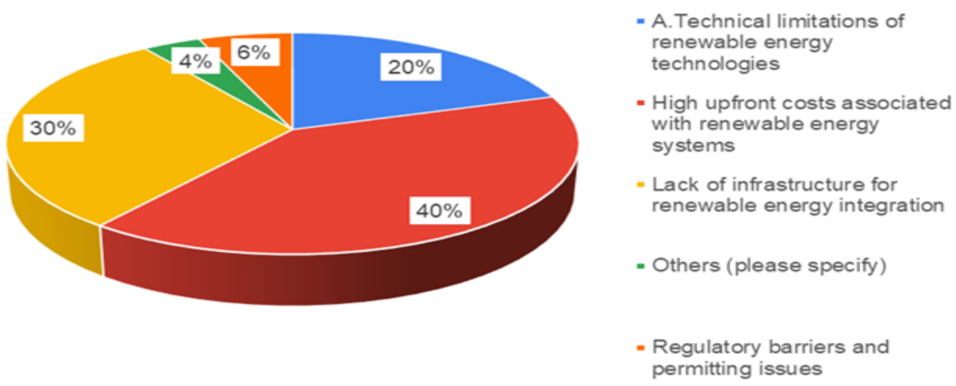

Fig. 3. Obstacle to the Adoption of Renewable Energy Sources

8. DESIGN STRATEGIES FOR IMPROVED ENERGY EFFICIENCY

The concept of Design strategies for improved energy efficiency underscores the vital role that thoughtful and intentional design plays in optimizing a building's energy performance (Karimi, Adibhesami, Bazazzadeh and Movafagh, 2023). This multidimensional approach involves a careful consideration of various architectural elements. From the choice of materials with high thermal mass to the implementation of effective insulation, the goal is to create a building envelope that minimizes heat transfer, reducing dependence on mechanical heating and cooling systems. The integration of energy-efficient windows and glazing systems, coupled with strategic solar shading, contributes to effective temperature regulation and lighting optimization (Alam, et al. 2020). Emphasis on air tightness and controlled ventilation ensures that the conditioned indoor air is preserved, promoting energy conservation (Jia, et al. 2021). Additionally, attention to building orientation and shape maximizes the utilization of natural light and passive solar heating (Kistelegdi, et al. 2022). In essence, it embraces a holistic and sustainable approach, recognizing that a well-designed building is a powerful tool for energy conservation, cost reduction, and environmental stewardship (Jaffe, et al. 2020).

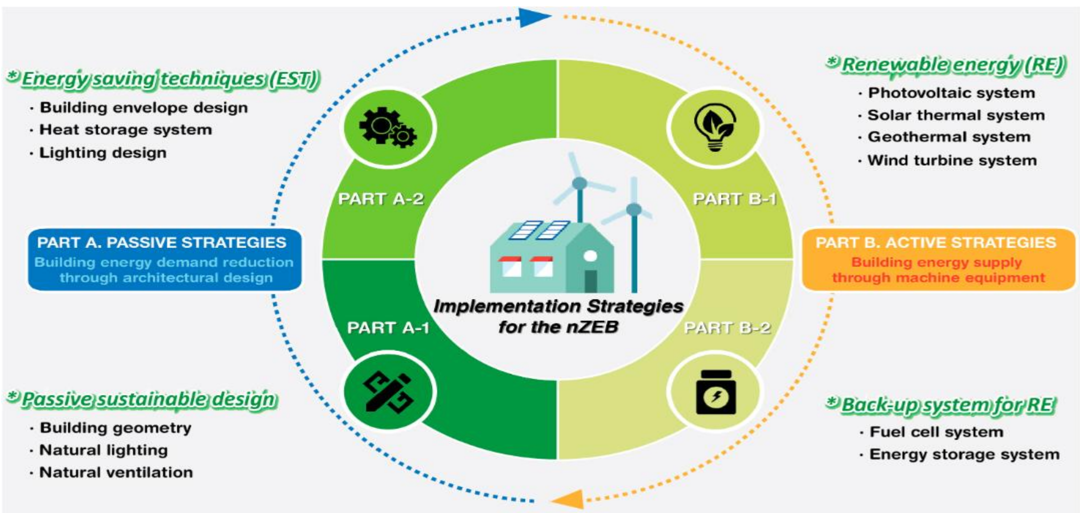

Fig. 4. Strategies for Net Zero Energy Building
Source: Oh, et al. (2017)

8.1 Sustainable Design Strategies in Aviation Facilities

This represents a pivotal paradigm shift in the aviation industry, aligning infrastructure development with ecological responsibility. This comprehensive approach addresses the unique challenges posed by aviation, emphasizing resource efficiency, environmental conservation, and long-term viability (Pinheiro Melo, et al. 2020). Incorporating cutting-edge technologies, such as energy-efficient lighting systems and renewable energy sources like solar panels, these strategies mitigate the carbon footprint of aviation facilities (Hoang, & Nguyen, 2021). Thoughtful site selection and landscaping not only enhance aesthetic appeal but also contribute to ecosystem preservation and biodiversity (Donati, et al. 2022).

Fig. 5. Strategies for Aviation Facilities Sustainability Planning
Source: Budget Truckee Tahoe Airport District (2023)

Water conservation measures, including advanced filtration systems and rainwater harvesting, underscore a commitment to responsible resource management. The use of eco-friendly materials in construction and a focus on waste reduction align with circular economy principles, reducing environmental impact (Wang, Zhu and Yang, 2020; Kılkış, et al. 2021). Moreover, sustainable aviation facilities prioritize passenger comfort and well-being through designs that maximize natural light, optimize thermal comfort, and incorporate green spaces. Integration with efficient public transportation systems fosters a holistic approach to sustainable mobility. It demonstrates how the airline sector can lead in environmentally sensitive practices while maintaining operational efficiency and passenger comfort (Greer, et al. 2020).

8.2 Passive Design Principles

Passive design principles in aviation facilities represent a potent weapon in the creation of sustainable infrastructure. These methods make use of natural materials and processes to improve energy efficiency and environmental harmony. Passive solar heating and cooling are optimized by intelligent orientation and building arrangement, decreasing dependency on mechanical systems (Rameshwar, et al. 2020). Temperature stability is ensured by high-performance insulation and thermal mass, reducing the need for excessive heating or cooling. Strategic window placement maximizes lighting while minimizing heat gain (Hesaraki and Huda, 2022).

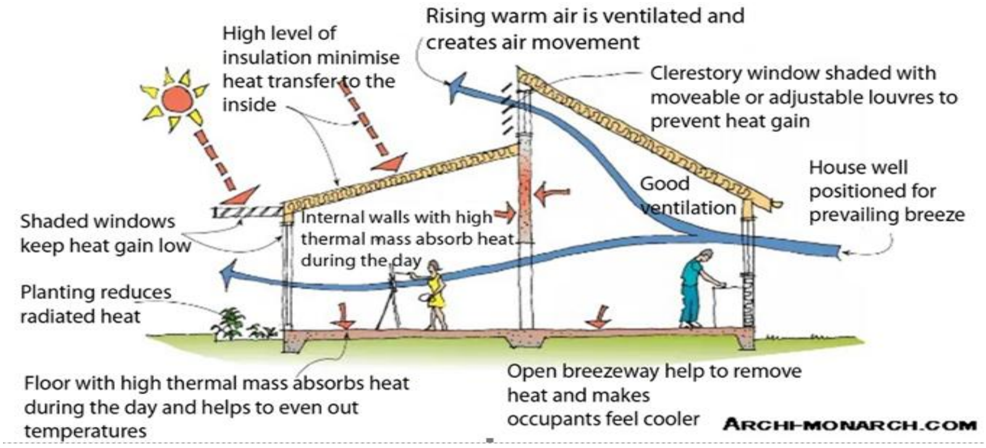

Fig. 3. Passive Design Strategies
Source: Archi Monarch (2024)

Furthermore, natural ventilation systems, when integrated intelligently, provide a fresh and comfortable indoor environment, reducing dependency on artificial climate control. Embracing passive design principles in aviation facilities not only aligns with eco-conscious practices but also positions these structures as exemplars of sustainability, demonstrating a commitment to energy conservation, reduced environmental impact, and enhanced operational efficiency (Rameshwar, et al. 2020; Whitmarsh, et al, 2020).

8.3 Use of Advanced Building Materials

The utilization of advanced building materials in aviation facilities epitomizes a progressive stride toward sustainable infrastructure. Innovative materials, such as high-performance composites and eco-friendly insulation, redefine the industry's environmental footprint. These materials boast superior strength-to-weight ratios, enhancing structural efficiency while minimizing resource consumption (Leao, et al. 2023). Additionally, their thermal properties contribute to energy conservation by reducing heating and cooling demands. Sustainable aviation facilities leveraging advanced materials exemplify a commitment to technological progress and environmental stewardship. This strategic integration not only fortifies structural integrity but also positions these facilities as beacons of sustainability, harmonizing operational excellence with ecological responsibility (Leao, et al.2023).

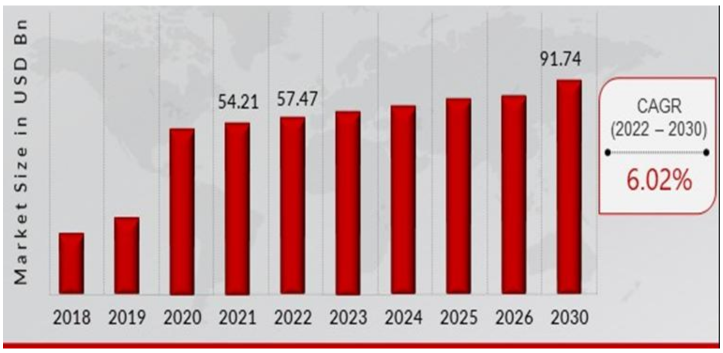

Fig. 4. The Size of Building Materials Market
Source: Market Research Future (2024)

8.4 Integration of Energy-Efficient Technologies

The integration of energy-efficient technologies in aviation facilities stands as a transformative leap toward sustainable design and operational excellence. Smart building systems, including advanced lighting controls, HVAC optimization, and energy management platforms, orchestrate resource-efficient operations. These technologies not only reduce energy consumption but also enhance operational precision (Mishra and Singh, 2023). Moreover, the incorporation of renewable energy sources, such as solar panels and wind turbines, augments energy resilience and slashes carbon footprints (Jain, 2023). Energy-efficient technologies not only align aviation facilities with green principles but also foster long-term cost savings and environmental stewardship. By harmonizing technological innovation with sustainable practices, these facilities pave the way for a greener aviation landscape, navigating towards a future where efficiency and environmental responsibility coexist seamlessly (Hassan, et al.2023).

9. SUMMARY OF FINDINGS

This study aimed to evaluate various design strategies employed in aviation facilities to enhance energy efficiency. The key findings include:

i. Energy Consumption Patterns: Energy consumption in aviation facilities is significantly influenced by factors such as HVAC systems, lighting, and operational practices, which the facilities cannot do without.
ii. Current Design Strategies: The study found that many aviation facilities in Nigeria have adopted advanced building materials, passive design principles, and energy-efficient technologies to reduce energy consumption. However, the extent of implementation varies significantly among facilities.
iii. Barriers to Energy Efficiency: The research identified several challenges hindering optimal energy efficiency in Nigerian aviation facilities to include high initial costs, lack of awareness, and inadequate regulatory frameworks. These have blocked serious-minded local and foreign investors.
iv. Impact on Indoor Air Quality and Thermal Comfort: The noticeable design strategies implemented have a noticeable impact on indoor air quality and thermal comfort, with some facilities reporting improvements in occupant comfort and satisfaction.

10. RECOMMENDATIONS IMPLICATION AND CONTRIBUTION OF THE STUDY

10.1 Recommendations

Based on the findings, the following recommendations are made:

i. Enhance Regulatory Frameworks: The Nigerian government(s) should strengthen regulatory frameworks to mandate the adoption of energy-efficient design strategies and technologies in aviation facilities.
ii. Increase Awareness and Training: Stakeholders should invest in training programs to increase awareness and knowledge of energy-efficient practices among facility managers and operators.

iii. Attraction of Investment and Transparent Deregulation: The energy generation and distribution policy for aviation facilities in Nigeria should be singled out and standardized by the government for investment, since it requires huge capital input.
iv. Promote Financial Incentives: Financial incentives and subsidies should be provided to offset the high initial costs associated with implementing advanced energy-efficient technologies.

10.2 Implications of the Study

The implications of this study are multifaceted. For industry stakeholders, the findings highlight the critical areas where energy efficiency can be improved, suggesting that targeted investments in specific design strategies can yield significant energy savings. For policymakers, the study underscores the need for supportive regulatory frameworks and incentives to encourage the adoption of energy-efficient technologies. Additionally, for researchers and academics, the study provides a comprehensive assessment of current practices and identifies gaps that require further exploration.

10.3 Contribution of the Study

This study contributes to the body of knowledge on energy efficiency in aviation facilities by:

i. Discussing issues on energy consumption patterns and the effectiveness of various design strategies.
ii. Highlighting the specific challenges and barriers to achieving energy efficiency in the aviation sector, thereby calling for a decisive policy and regulatory actions.
iii. Offering practical recommendations for industry stakeholders to enhance energy efficiency and improve indoor environmental quality.

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