Evaluate Indoor Air Quality in Selected Kwara State University Senate Buildings, Considering Window-To-Floor Ratio with The National Building Code

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ABSTRACT

The aim of this study was to evaluate the indoor air quality in various Senate buildings of universities in Kwara State, Nigeria, specifically focusing on the window-to-floor ratio (WFR) as mandated by the National Building Code of Nigeria and insights gleaned from relevant literature. The study encompassed the Senate buildings of the University of Ilorin, Landmark University, Kwara State University, and Al-Hikmah University. To assess indoor air quality, observations, measurements, and calculations were employed, taking into account indoor air quality parameters including window area, floor area, window type, and headroom. The findings revealed that both the University of Ilorin and Landmark University Senate Buildings met the minimum standards of the National Building Code, attaining average WFR scores of 7.56% and 7.79%, respectively. Conversely, the Kwara State University and Al-Hikmah University Administrative Buildings fell short of compliance, scoring WFRs of 4.59% and 3.82%, respectively. Moreover, research by Olufowobi and Adenuga in 2006 and Ayinla in 2011 highlighted the acceptable range for indoor fresh air quality to be between 0.5 to 1.5 m/s air velocity. The analysis revealed that the University of Ilorin and Landmark University Senate Buildings merely exceeded the minimum specified 0.5 m/s air velocity 0.504 m/s and 0.519 m/s respectively, whereas the Kwara State University and Al-Hikmah University Administrative Buildings has velocities of 0.306 m/s and 0.255 m/s, respectively, indicating they did not meet the desired air velocity standards. Further analysis indicated a positive correlation between WFR and indoor air velocity, suggesting that a higher window area leads to better indoor air circulation. This underscores the importance of adhering to recommended window proportions in building codes not only to comply with regulations but also to enhance indoor air quality.

Keywords: *Indoor air quality, National Building Code, Window-to-Floor ratio.*

INTRODUCTION

Despite being a vital aspect of the indoor environment, indoor air quality (IAQ) often receives limited attention in research and practice. Furthermore, the National Building Code's guidelines on the window-to-floor ratio, specifically designed to ensure adequate natural ventilation and improve IAQ, have not been systematically evaluated or enforced in many Nigerian educational institutions. An inadequately studied aspect of indoor air quality in Nigerian academic environments is the correlation between the window-to-floor ratio (WFR), a key architectural design element, and indoor air pollutants and ventilation rates. In Senate buildings at selected universities in Kwara State, Nigeria, this research aims to systematically evaluate and analyze the IAQ parameters, their associations with WFRs, and the degree of adherence to the National Building Code through established acceptable standards as benchmark.

According to The World Health Organization (WHO) guidelines for indoor air quality 2010, Indoor air quality (IAQ) is a complex amalgamation of various pollutants that can adversely affect the health, comfort, and well-being of individuals. Such pollutants can include particulate matter, volatile organic compounds (VOCs), carbon dioxide ($CO2$), and biological contaminants such as bacteria, mold, and viruses. The primary sources of indoor pollutants are both indoor and outdoor environments, and building design plays a crucial role in the quality of the indoor air. The World Health Organization (WHO) identifies several factors that can affect IAQ, including inadequate ventilation, lack of humidity control, poorly maintained HVAC systems, and improper construction materials. The relationship between building design, specifically the window-to-floor ratio (WFR), and IAQ has been an area of focus in modern building design practices, especially considering its potential impact on natural ventilation and occupant health. The National Building Code serves as a critical reference for architects and engineers in Nigeria, providing guidelines for building construction, including those related to ventilation, natural light, and indoor air quality. However, the degree to which these guidelines are implemented and followed in practice, particularly concerning WFR and IAQ, has not been comprehensively studied. In this context, the evaluation of IAQ in selected University Senate buildings at Kwara State, Nigeria, considering WFR according to the National Building Code, is a pertinent research endeavor. Understanding the relationship between WFR, IAQ parameters, and ventilation rates in the university environment can contribute to improved building design practices, promoting occupant health and comfort. Furthermore, this study could potentially lead to recommendations for enhanced compliance with the National Building Code and the development of tailored strategies to optimize indoor air quality in academic institutions in Nigeria and beyond.

LITERATURE REVIEW

In the warm and humid climate of Nigeria, numerous homes lack sufficient indoor air quality due to a window-to-floor area ratio that significantly falls short of the 20-30% benchmark necessary for effective natural airflow. This observation aligns with the claim that a substantial portion (30 to 60 percent) of the population in Third World nations, Nigeria included, lives in inadequate conditions marked by congested and inadequately ventilated urban residences, as noted by Brew-Graves (1995), Arayela (2000), and Diogu and Okonkwo (2005).

Sustainable design key: According to Oikos (2008),the key to sustainable construction is passive design. Passive design is designed to respond to the local climate and the site conditions to provide maximum comfort and health to building users while reducing energy consumption. Passive design can help to reduce temperature variations, enhance indoor air quality and make a home dryer more pleasant to live in. Passive design works by using free, renewable energy sources such as solar and wind to supply household heating, cooling, ventilating and lighting, reducing or eliminating the need for mechanical heating or cooling (Oikos, 2008).It can also reduce energy consumption and environmental impacts such as greenhouse gases issues. Interest in passive design has increased, especially in the last decade as part of the trend towards more comfortable and resource-efficient buildings. Passive solar design can provide cooling and ventilation even in summer convective air currents arising from the natural tendency of warm air to rise(Oikos, 2008).The key elements of passive design are: building location and orientation on the site; building layout; window design; insulation (including window insulation); thermal mass; shading; and ventilation. Each of these elements works with others to achieve comfortable temperatures and good indoor air quality. (Stamas, 2008).

Indoor air quality, Natural ventilation and National Building Code (NBC): In the ever-evolving landscape of sustainable architecture, the integration of natural ventilation has emerged as a pivotal aspect of promoting indoor air quality and creating environmentally conscious and energy-efficient buildings. As the world grapples with the challenges of climate change and the imperative to reduce energy consumption, the synergy between natural ventilation and building codes becomes increasingly critical. This article explores the intersection of natural ventilation principles and the National Building

Code, shedding light on the role codes play in shaping sustainable design practices (Atolagbe, A.M.O. and Fadamiro, J.A. 2005).

Understanding Natural Ventilation and indoor air quality: Natural ventilation involves the controlled flow of fresh air into a building and the expulsion of stale air without the aid of mechanical systems. It harnesses natural forces such as wind and temperature differentials to create a required indoor air quality needed for comfortable and healthy indoor environment. This approach not only reduces dependency on energy- consuming mechanical ventilation systems but also enhances occupant well-being and minimizes a building's environmental footprint (Oikos, 2008).

The National Building Code and Guidelines for indoor air quality: The National Building Code serves as a comprehensive regulatory framework governing construction practices, safety standards, and sustainability considerations. Within its provisions, specific guidelines address ventilation requirements to ensure adequate indoor air quality and occupant comfort. These guidelines typically encompass parameters such as the minimum ventilation rates, air exchange rates, and the design and placement of openings to facilitate natural airflow (National building code 2006).

Relevance of University Senate Buildings: University Senate buildings are vital hubs for academic and administrative activities. Evaluating natural ventilation in these spaces is crucial due to their high occupancy levels and diverse usage patterns. Compliance with the National Building Code ensures that the indoor environment is conducive to learning, decision-making, and collaboration. Thus, the evaluation of natural ventilation in university Senate buildings using the National Building Code as a benchmark holds significant relevance for several key reasons such as: demonstration of best practices, energy efficiency and operational cost, sustainable campus development etc.

RESEARCH METHODOLOGY

Data collection involved the selection of four university senate buildings out of a total of eight, employing a combination of simple random and quota sampling methods. The selection criteria were based on the university ownership, aiming to represent the three senatorial districts in Kwara State. The chosen university senate buildings encompassed diverse institutions, namely the University of Ilorin Senate Building, Kwara State University Administrative Building, Landmark University Senate Building, and Al-Hikmah University Administrative Building.

Sample size and selection criteria.

UNIVERSITY SENATE BUILDING	OWNERSHIP	SENATORIAL DISTRICT
University of ilorin	Federal government	Kwara central
Kwara state university	State government	Kwara north
Al-Hiqmah university	Private ownership	Kwara central
Landmark university	Private ownership	Kwara south

Source: Field work, (2023).

The study gathered data by observing, measuring, and calculating indoor air quality variables such as Window area, Floor area, Window type, and Headroom. The analysis relied on benchmarks and relevant literature, utilizing calculated values to draw conclusions in alignment with established standards and scholarly insights.

Analytical tools used:

Window to Floor ratio (WFR) = (Operable window area / Floor area) * 100%

Indoor air velocity = (WFR / Range of WFR benchmark) * (Range of velocity benchmark)

Compliance Percentage = (WFR / Range of WFR benchmark) * 100%

Note: WFR benchmark is 5% - 20% (National building code, 2006) and

Indoor air velocity is 0.5 m/s – 1.5 m/s (Olufowobi, M.B. & Adenuga, 2006) and (Ayinla, 2011).

RESULTS AND DISCUSSION

The pre-designed Tables 1-4 provided below have been specifically crafted to showcase the data that has been collected and measured from the senate buildings of selected universities, namely the University of Ilorin Senate Building, Kwara State University Administrative Building, Landmark University Senate Building, and Al-Hikmah University Administrative Building. The data presented in these tables is in accordance with the predefined sample size for the study. The primary focus of the collected data revolves around key parameters such as Window Area, Window Type, and Floor Area. The objective is to conduct a comprehensive evaluation of the natural ventilation systems within these buildings, ensuring compliance with the relevant provisions of the National Building Code of Nigeria.

The selected university senate buildings serve as the focal points for this study, with meticulous attention given to the specified parameters. The Window Area, Window Type, and Floor Area have been identified as crucial factors in assessing the natural ventilation effectiveness of the buildings. This evaluation is undertaken with a specific reference to the National Building Code of Nigeria, which outlines provisions related to the Window-to-Floor Area Ratio (WFR). Additionally, the study aims to gauge the fresh air quality within the buildings, drawing upon insights and conclusions derived from pertinent literature in the field.

The choice of these universities, including the University of Ilorin, Kwara State University, Landmark University, and Al-Hikmah University, is strategic, ensuring a diverse representation of educational institutions. By focusing on their respective senate and administrative buildings, the study aims to provide insights that can be generalized and applied to similar structures across the country.

Tables 1-4 act as a visual aid, presenting the meticulously collected data in an organized manner. These tables serve as a comprehensive repository of information related to the Window Area, Window Type, and Floor Area of the selected university buildings. The presentation is in line with the established sample size, ensuring statistical relevance and reliability of the findings.

Table 1: Indoor air quality evaluation of University of Ilorin Senate building through Window openings in compliance with the National Building Code (2006) as benchmark.

Institution	Floor Level	Floor Area (m^2)	Window sizes (m)/ (m^2)			Window Area (m^2)	Operable Area (m^2)	Window Type	Headroom (m)	Window to Floor Ratio (WFR) Observed (%)	(NBC) Window to Floor Ratio (WFR) (%)	Remark
			2.4x1.8 / 4.32	1.5x1.8 / 2.70	0.6x0.6 / 0.36							
UNILORIN	Ground floor	1008.45	36/ 155.52	08/ 21.60	05/ 1.80	178.92	77.22	Sliding/ Fixed	3.60	7.66	5-20	Good
	First floor	1008.45	34/ 146.88	08/ 21.60	05/ 1.80	170.28	73.38	Sliding/ Fixed	3.60	7.28	5-20	Good
	Second floor	1008.45	34/ 146.88	08/ 21.60	04/ 1.44	169.92	73.20	Sliding/ Fixed	3.60	7.26	5-20	Good
	Third floor	815.41	29/ 125.28	08/ 21.60	04/ 1.44	148.32	63.60	Sliding/ Fixed	3.60	7.80	5-20	Good
	Forth floor	815.41	29/ 125.28	08/ 21.60	04/ 1.44	148.32	63.60	Sliding/ Fixed	3.60	7.80	5-20	Good
	Fifth floor	815.41	29/ 125.28	08/ 21.60	05/ 1.80	148.68	63.78	Sliding/ Fixed	3.60	7.82	5-20	Good
	Sixth floor	815.41	27/ 116.64	08/ 21.60	06/ 2.16	140.40	60.12	Sliding/ Fixed	3.60	7.37	5-20	Good
	Average percentage of Window-to-Floor ratio WFR ---									7.56%		

Standard Indoor air velocity range at 5-20 percent of WFR ----- 0.5-1.5 m/s (Olufowobi, M.B. & Adenuga, 2006) and (Ayinla, 2011).
Average observed fresh air velocity at 7.56 percentage of WFR ----- 0.504 m/s
Compliance to NBC 2006 provision for WFR ----- 50.40%

Sources: Field survey (2023).

Table2: Indoor air quality evaluation of Kwara state university Administrative building Malete, Nigeria through Window openings in Compliance with the National Building Code (2006) as benchmark.

Institution	Floor Level	Floor Area (m^2)	Window sizes (m)/ (m^2)				Window Area (m^2)	Operable Area (m^2)	Window Type	Headroom (m)	Window to Floor Ratio (WFR) Observed (%)	(NBC) Window to Floor Ratio (WFR) (%)	Remark
			1.5x1.2/ 1.80	1.2x1.2/ 1.44	1.2x0.9/ 1.08	0.6x0.6/ 0.36							
KWASU	Ground floor	1194.75	04/ 7.20	42/ 60.48	02/ 2.16	10/ 3.60	73.44	48.96	Sliding	3.60	4.10	5-20	Fair
	First floor	1194.75	05/ 9.00	46/ 66.24	02/ 2.16	10/ 3.60	81.00	54.00	Sliding	3.60	4.52	5-20	Fair
	Second floor	1194.75	05/ 9.00	54/ 77.76	02/ 2.16	10/ 3.60	92.52	61.68	Sliding	3.60	5.16	5-20	Good
	Average percentage of Window-to-Floor ratio WFR ---										4.59%		

Standard Indoor air velocity range at 5-20 percent of WFR ----- 0.5-1.5 m/s (Olufowobi, M.B. & Adenuga, 2006) and (Ayinla, 2011).
Average observed fresh air velocity at 4.59 percentage of WFR ----- 0.306 m/s
Compliance to NBC 2006 provision for WFR ----- 30.60%

Sources: Field survey (2023).

Table 3: Indoor air quality evaluation of Landmark university Senate building Omu-Aran, Nigeria through Window openings in compliance with the National Building Code (2006) as benchmark.

Institution	Floor Level	Floor Area (m^2)	Window sizes (m)/ (m^2)				Window Area (m^2)	Operable Area (m^2)	Window Type	Headroom (m)	Window to Floor Ratio (WFR) Observed (%)	(NBC) Window to Floor Ratio (WFR) (%)	Remark
			0.75x3.6/ 2.7	0.75x1.2/ 1.44	0.75x0.6/ 0.72	R-0.375/ 0.44							
LANDMARK	Ground floor	995.18	64/ 172.8	08/ 7.20	12/ 15.00	64/ 28.16	223.16	74.39	Projected/ fixed	4.50	7.48	5-20	Good
	First floor	995.18	00/ 00	70/ 63.00	14/ 17.5	00/ 00	80.50	80.50	Projected	3.30	8.09	5-20	Good
	Average percentage of Window-to-Floor ratio WFR ---							7.79%					

Standard Indoor air velocity range at 5-20 percent of WFR ----- 0.5-1.5 m/s (Olufowobi, M.B. & Adenuga, 2006) and (Ayinla, 2011).
Average observed fresh air velocity at 7.79 percentage of WFR ----- 0.519 m/s
Compliance to NBC 2006 provision for WFR ----- 51.93%

Sources: Field survey (2023)

Table 4: Indoor air quality evaluation of Al-Hikmah University Administrative building Ilorin, Nigeria through Window openings in Compliance with the National Building Code (2006) as benchmark.

Institution	Floor Level	Floor Area (m^2)	Window sizes (m)/ (m^2)				Window Area (m^2)	Operable Area (m^2)	Window Type	Headroom (m)	Window to Floor Ratio (WFR) Observed (%)	(NBC) Window to Floor Ratio (WFR) (%)	Remark
			1.5x1.2/ 1.80	1.2x1.2/ 1.44	1.2x0.6/ 0.72	0.6x0.6/ 0.36							
AL-HIKMAH	Ground floor	667.11	00/ 00	20/ 28.80	00/ 00	07/ 2.52	31.32	20.88	Sliding	3.30	3.13	5-20	Poor
	First floor	667.11	03/ 5.40	25/ 36.00	01/ 0.72	08/ 2.88	45.00	30.00	Sliding	3.30	4.50	5-20	Fair
	Average percentage of Window-to-Floor ratio WFR ---							3.82%					

Standard Indoor air velocity range at 5-20 percent of WFR ----- 0.5-1.5 m/s (Olufowobi, M.B. & Adenuga, 2006) and (Ayinla, 2011).
Average observed fresh air velocity at 3.82 percentage of WFR ----- 0.255 m/s
Compliance to NBC 2006 provision for WFR ----- 25.47%

Sources: Field survey (2023)

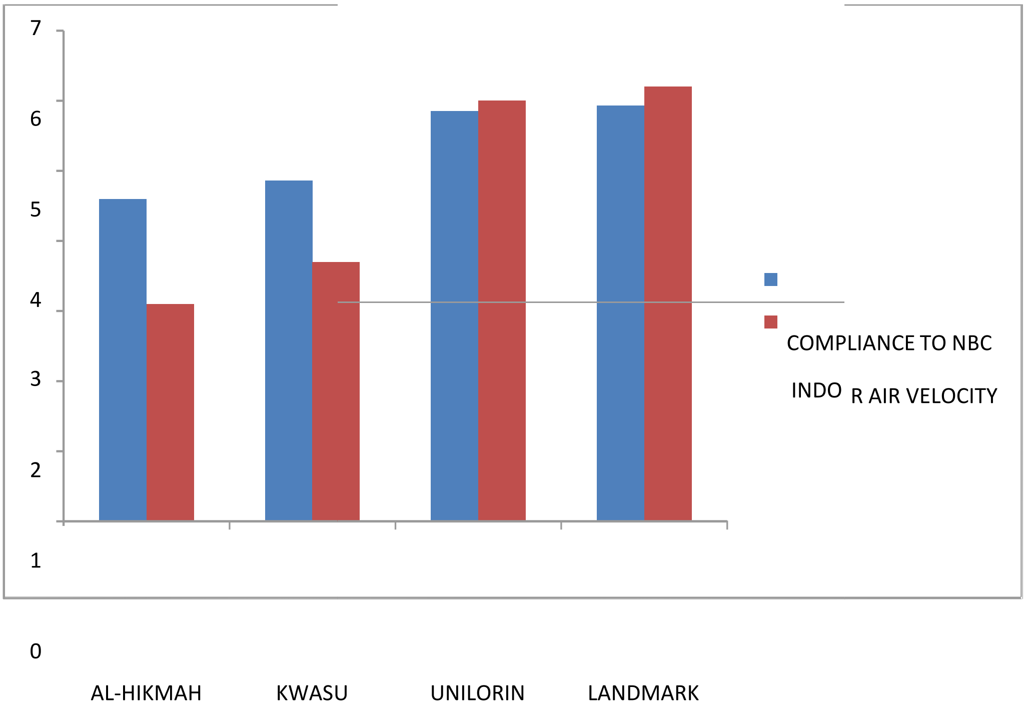

Figure 1: Bar chart showing level of compliance to National building code (2006) provision for Wall to Floor ratio (WFR) to enhance Natural ventilation and indoor air quality through indoor air velocity.

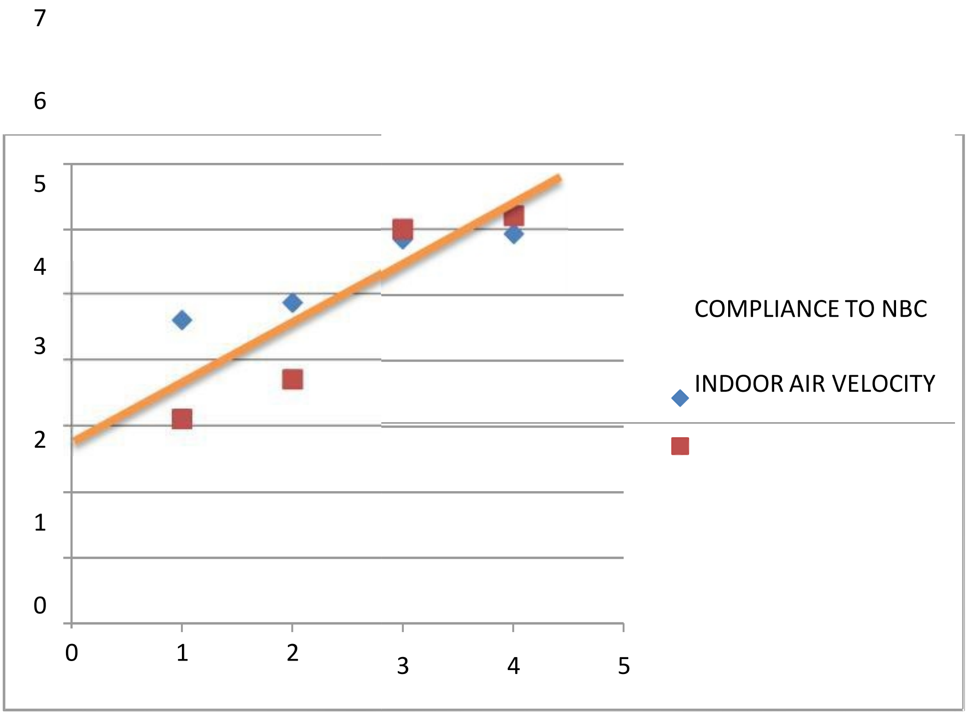

Figure 2: Scatter point correlation; Shows Perfect positive relationship between Wall to Floor ratio (WFR) and indoor fresh air quality through indoor air velocity.

DISCUSSION

The findings presented in Table 1 and Table 2 clearly indicate that both the University of Ilorin Senate Building and Landmark University Senate Building marginally meet the minimum requirements stipulated by the National Building Code of Nigeria, scoring an average Window-to-Floor Area Ratio (WFR) of 7.56% and 7.79%, respectively. In contrast, Table 3 and Table 4 reveal that Kwara State University Administrative Building and Al-Hikmah University Administrative Building fall short of compliance with the prescribed 5% WFR, registering scores of 4.59% and 3.82% WFR, respectively.

In accordance with the research conducted by Olufowobi and Adenuga in 2006, and Ayinla in 2011 the acceptable benchmark for indoor fresh air quality ranges from 0.5 to 1.5 m/s air velocity. Analyzing the obtained results, it becomes apparent that Table 1, 2, 3, and 4 shows the calculated air velocities of 0.504 m/s, 0.306 m/s, 0.519 m/s, and 0.255 m/s, respectively. This implies that the University of Ilorin Senate Building and Landmark University Senate Building merely surpass the minimum specified 0.5 m/s air velocity, while Kwara State University Administrative Building and Al-Hikmah University Administrative Building fall short, having velocities of 0.306 m/s and 0.255 m/s, respectively.

The correlation drawn from these results indicates that a perfect positive relationship between the Window-to-Floor Area and indoor air velocity as shown in figure 2. Specifically, the higher the window area, the greater the speed of indoor air velocity. This observation underscores the significance of adhering to recommended window proportions as outlined in building codes, not only for regulatory compliance but also for optimizing indoor air circulation.

Further scrutiny reveals an interesting insight into the impact of window types on natural ventilation. It is discerned that the operable window area of sliding windows is lower in comparison to their corresponding total window area. Conversely, the operable area of projected windows matches the area of their respective windows. This observation leads to the inference that the use of sliding window types may not be conducive to enhancing natural ventilation in senate buildings. Instead, the adoption of projected or casement window types is recommended.

This conclusion aligns with the findings of Ayeni, Ayinla, and Ajayi in 2018, who advocate for casement window types as the optimal choice for office building design and thermal

Comfort. The recommendation emphasizes the importance of selecting window types that facilitate effective natural ventilation, contributing not only to energy efficiency but also to the occupants' comfort and well-being.

In summary, the discussion of the results underscores the critical role of the Window-to-Floor Area Ratio in determining indoor air velocity. Compliance with the National Building Code of Nigeria's provisions is crucial for achieving optimal natural ventilation in senate buildings. The correlation between window types and their impact on ventilation further emphasizes the significance of architectural choices in influencing indoor environmental conditions. The insights gained from this study can inform future building design practices, encouraging the adoption of window types that align with both regulatory standards and principles of thermal comfort.

CONCLUSION

In conclusion, the examination of Tables 1-4 has provided valuable insights into the compliance of selected university senate buildings with the National Building Code of Nigeria's provisions regarding Window-to-Floor Area Ratios (WFR) and indoor air quality. The University of Ilorin Senate Building and Landmark University Senate Building demonstrated marginal adherence to the prescribed standards, scoring WFR averages of 7.56% and 7.79%, respectively. On the contrary, Kwara State University Administrative Building and Al-Hikmah University Administrative Building fell short of compliance, recording WFR scores of 4.59% and 3.82%, respectively.

The correlation established a perfect positive relationship between Window-to-Floor Area and indoor air velocity highlights the critical role of architectural choices in influencing natural ventilation. The observed trend, where higher window areas correspond to greater indoor air velocities, underscores the significance of maintaining recommended window proportions outlined in building codes. Moreover, the study delves into the impact of window types on natural ventilation, suggesting that the adoption of projected or casement window types, as opposed to sliding windows, is more conducive to enhancing airflow in senate buildings.

These findings align with the recommendations of Ayeni, Ayinla, and Ajayi (2018), emphasizing casement window types as optimal for office building design and thermal comfort. The study's implications extend beyond compliance, emphasizing the broader influence of architectural decisions on indoor environmental conditions. This research serves as a valuable resource for informing future building design practices, encouraging the adoption of window types that not only meet regulatory standards but also contribute to energy efficiency and occupants' well-being. Ultimately, the insights gained contribute to the ongoing discourse on sustainable building practices and the creation of healthier, more comfortable indoor environments.

RECOMMENDATION

The primary suggestion is to embrace a comprehensive strategy in designing buildings, ensuring adherence to regulatory guidelines, especially the National Building Code of Nigeria, and giving priority to effective natural ventilation. This includes making strategic modifications to the Window-to-Floor Area Ratio, taking into account the selection of window types. The implementation of these guidelines in upcoming university senate buildings can not only fulfill regulatory standards but also enhance indoor air circulation, thereby promoting energy efficiency and the health of occupants.

REFERENCES

Atolagbe, A.M.O. and Fadamiro, J.A. (2005); "Energy Policy for Building Materials Technology: A Global Imperative for Sustainable Architecture". Jurnal Sains Dan Teknologi; Electro Mesin Arsitektur Sipil (EMAS) Vol. 15, No. 3 Pp. 45-58.

Ayeni C. A, Ayinla A. K and Ajayi O (2018) Evaluating ventilation efficiency of windows insenate buildings: a case of Nigeria universities. For Engineering Sciences International Research Journal Published by IMRF Journals - Sep 2018.

Ayinla A. K (2011) Effect of Natural ventilation on Residents' comfort in the house of the tradintional core of Ogbomoso, Nigeria. An unpublished work for the degree of Master of philosophy at the Obafemi Awolowo University (OAU), Ile-Ife, Nigeria

Brew-Graves, S.H. (1995); Shelter: The Implications for Health. AARCHES J.A. Journal of the Association of Architectural Educators in Nigeria 1(2); September, Pp. 10, 40, 41, 42.

National Building Code (2006); Federal Republic of Nigeria.

Oikos (2008) passive cooling strategies. Elservier Architectural Press Jordan Hill, Oxford.

Olufowobi, M.B. & Adenuga, (2006) O.A Towards The Specification Of Windows Sizes For Journal Published by IMRF Journals - Sep 2018.

Stamas, M. & Sanford, M. (2008). The revival of passive design. Build Environment Rocky Colorado.