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Effects of Renovation on Ventilation and Energy Saving in Residential Building

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Abstract

Renovation usually increases the aesthetic and market value of buildings. Consequently, with the rapid growth of the city's population and skyrocketing demand for decent housing, the current trend of building conversion and renovation of existing and dilapidated property stock within city centres has become rampant. The rise in demand has pushed beyond the boundaries that every real estate investor wants to maximize profit, and it has resulted in the prevalence of uncontrolled building development, land use conversion, and non-compliance with building requirements, etc. Renovations that involve changes in building elements (especially the window system) that can influence energy saving and ventilation efficiency have thus become very common. However, the effects of building renovations on ventilation and energy efficiency have not been fully examined, particularly in Enugu (Nigeria), a rapidly growing colonial metropolis. This research employed a qualitative research approach to investigate the effects of building renovation on ventilation and energy saving in Achara layout, Enugu City, Nigeria. Four blocks of flat residential buildings were the derived sample size using a judgmental sampling technique. Physical measurements, an observation schedule, and oral interviews with site workers centred on window size, area, property, and fenestration type were used to collect empirical data involving the window system. The result reveals a very significant difference between the as-built and renovated window design systems of all studied variables. Its conclusion hinged on the fact that a renovated structure does not encourage effective natural ventilation and hence will consume more energy in cooling and lighting. It recommends the re-introduction of appropriate window systems and construction techniques for the tropical environment to reduce heat stress build-up within building units.

Keywords: Building Renovation; Window Design; Residential Building; Energy Saving; Thermal Comfort.

1. Introduction

With the expanding global population, cities, especially urban centres in third world countries, are confronted with a myriad of challenges, ranging from a rapid rise in the population of city dwellers, caused by a high level of rural-urban migration, to affordable housing deficits and also climate change-induced thermal heat stress. The increasing demand for decent housing to accommodate the teeming population and other associated modern city challenges has given rise to old residential building/property owners attempting to salvage what is left of their old apartment buildings. This gave birth to the current trend of residential house renovation and remodelling being experienced in most cities in the sub-Saharan region. In fact, the study of Ogunmakinde et al. [1] stated that some of the identified reasons why some house

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owners remodel, renovate, or retrofit their buildings are to maintain a certain standard that will suit current taste and demand and also to get higher rent from the building. Scuderi [2] noted that retrofitting is necessary in buildings so as to upgrade them to current technological standards and current realities. On the contrary, in developed cities, housing renovations are employed to meet decarbonization goals, and their approach is shifting towards industrialised solutions that combine a variety of active and passive components, increasing the cost and complexity of implementation [3].

Housing, like food and clothing, is a basic human necessity and, to a large extent, defines an individual. Therefore, it is a primary predictor of a person's place and standard of living in society [4, 5]. Studies have revealed that an increasing number of people in the modern world spend up to 85% of their time indoors, especially since the COVID-19 pandemic. Thus, the quality of interior space, which is impacted by a variety of elements, including good ventilation, should be adequately planned. In developing countries like Nigeria, poor housing delivery has been an age-old issue attributed to many factors like poor mechanisms, system of land use, lack of funds, inadequate mortgage institutions, poor planning, etc. [6]. As a result of this, the cost of securing a decent living apartment in cities is skyrocketing, especially given the large number of migrants to cities in search of better living conditions [7]. Despite the fact that cities are witnessing a massive development of new structures erected daily in their urban centers, the cost of renting an apartment in these new buildings is frequently far beyond the means of the average urban dweller. In order to fill the gap and accommodate the low and medium-income earners who make up the major fraction of city dwellers, owners of old building properties in the city resort to the option of retrofitting, renovating, or remodelling their old structures so as to meet the standard or appearance of the newly erected structures. More often than not, the retrofitting, renovation, or remodelling entails a basic change of some external elements or parts of the building, so as to give it a face lift. They mainly change the windows, roof structure, repaint the building and upgrade the electrical and plumbing fittings. This peripheral change gives the building a new façade because exterior fenestration has been affected. Evidence in the literature, substantiated by anecdotal experiences, establishes that conventional planning and design strategies for buildings in Nigeria rely heavily on active means to attain a conducive environment for cooling and lighting [8, 9]. This plan causes thermal discomfort owing to the accumulation of heat stress and a temperature rise in the indoor air, particularly during power outages, and contributes to a decline in environmental quality.

Building facades and fenestration are considered the biggest challenges designers encounter in achieving higher levels of energy efficiency and thermal comfort in building design [10], since buildings have evolved from being essentially passive systems to having some amount of control over their internal conditions. This is mostly owing to the increased use of artificial means of ventilation and illumination of the interior space, which is the core purpose of building fenestrations [11]. Hence, in the conceptual design phase of any project, the selection of façade type, fenestration system, and size play a very crucial role in determining how the building will function and also the air flow rate to keep the internal space comfortable enough for the occupants. The studies of Naderi et al. [12] stress the importance of the appropriate window size to be used in any building, also putting into consideration the climatic condition of the area. This is consistent with Ayoosu et al. [13], who opined that window size and placement are critical to the quality of daylight and ventilation that gets into a building, especially in the tropics, where trying to let in more natural air into the building for the purpose of thermal comfort is essential. Therefore, fenestrations are not just to be used in buildings for aesthetic purposes alone or to just complement the façade, but should be tools in the hand of the designer to make the internal spaces of the building conducive for the occupants.

Studies have demonstrated specifically, that an increase in ambient temperature has an adverse impact on occupant's health [14]. Hence as noted by Bluyssen [15], thermal comfort and health in housing units, are continuously being used as a yardstick to measure wellbeing in the built environment. As a result, investigations of thermal comfort and housing satisfaction in the built environment are becoming increasingly popular [16]. Previous studies such as [17-21] have focused on the various aspects of conducive environment and housing satisfaction. Natural ventilation appears to be a key variable in determining satisfaction according to the aggregate findings of these studies. These investigations have also revealed that it has some physical, psychological, and physiological impact on occupants. Thus, the efficiency of natural ventilation is influenced by both internal and external features. External considerations such as the residential development's location, orientation, prevailing wind speeds, and building forms are all constrained by elements outside the control of building designer and architects. Internal features such as opening configurations and window types, on the other hand are to the discretion of clients and design architects.

In an attempt to proffer a lasting solution to this heat stress buildup within contemporary building unit in sub-Saharan region and most especially southeast Nigeria, researchers have investigated some aspects of building design in urban areas. Examples are the studies on climate responsive design strategies for contemporary low-rise residential buildings in tropical environment of Enugu [9], effects of wall openings on effective natural ventilation for thermal comfort in classrooms of primary schools in Enugu metropolis [22], Adoption of appropriate technology for building construction in the tropics [23], Health implications of conventional planning/design strategies on occupants of contemporary residential building in the hot‑humid tropical environment [24], Bioclimatic design strategies for residential buildings in warm humid tropical climate of Enugu [25], Evaluation of the effectiveness of design strategies for passive ventilation of student hostels, in hot- humid tropical environments [26], Evaluating the perception of thermal environment in naturally ventilated schools in warm and humid climate of Imo state [27], Evaluation of thermal comfort in schools of environmental technology complexes in selected government owned universities in the south east Nigeria [28], A derivation of passive guidelines for achieving thermal comfort in the design of residential buildings in warm humid climate of Abia State [29], Air Quality in Private and Public Offices in Abakaliki [30]. A close examination of these studies revealed that in the southeast Nigeria, emerging scholarship on thermal comfort studies, is largely monopolized by engineers and building designer (architects) with focus on facility and residential building, having prominence on experimental research method combined with statistical models and simulations whose computational analyses are difficult to grasp from a social science perspective. Hence, to the best of the author's knowledge, no study has investigated effects of building renovation on ventilation and energy saving in Enugu urban with particular reference to window (fenestration) systems and design. Thus, the underpinning necessity of this study to examine the various implications to both client and building occupants.

In light of the foregoing, this study argues that the search for solutions to building a conducive indoor environment from passive means must begin with the building elements that admit light and air. This study aims to investigate the effects of the current building renovation trend on ventilation and energy efficiency as windows size and design are affected in Nigeria's urban areas using Achara layout, Enugu as a case study. The study pursued the following research objectives: (i) to identify the main reason behind the renovation trend experienced in the study area; (ii) to determine the reduction in size of the windows; and (iii) to examine the effects of change in fenestration design on the understanding of a building occupant. This study is considered valuable to the current trend of sustainable buildings and the rising statistics of global warming, which have compelled designers to now seek ways through which energy consumption in buildings can be minimized. It is based on the assumption that the as-built structure underwent a standard design process and was erected to meet acceptable indoor climate requirements. Therefore, the findings of this study are expected to inform architects, builders, and property owners in the south-east of the ill effects of the renovation trend in residential building stock within the metropolis. It further recommends and advocates for the reintroduction of appropriate window systems and construction technology for the tropical environment so as to effectively achieve thermal comfort in residential buildings using natural ventilation.

2. Martials and Methods

The study concentrated on the southeastern Nigeria and was carried out in the capital city of Enugu state, more precisely Achara Layout one of the oldest residential areas of the metropolis (see Figure 1). Because of the existence of the seat of power of the colonial administration, state rule and three local municipalities, Enugu serves as an administrative center. These are thought to have influenced real estate investments in the city, transforming it into a hub for numerous business activities. It has also boosted demand for living and working space, resulting in an avalanche of mass housing projects from individuals, the state government and corporate sector [31].

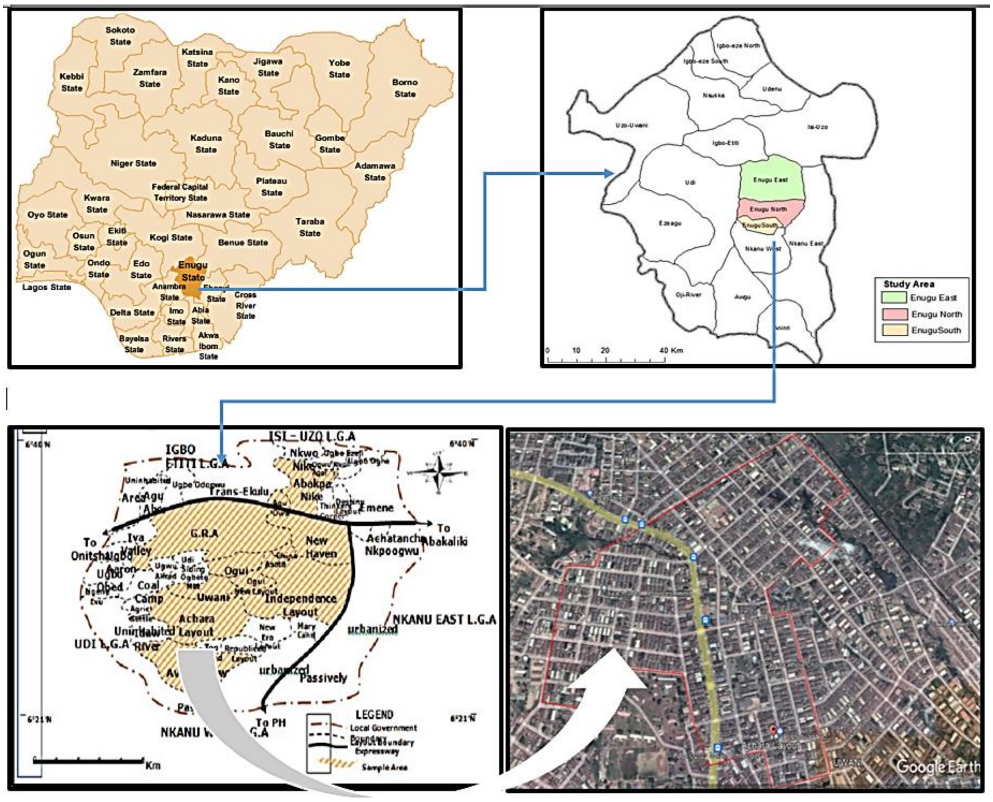

Figure 1. Maps showing the study area

From Figure 1, the selected neighbourhood was considered for the study because it is a grid-pattern planned medium density district, housing majority of middle-income class residents [32]. This neighbourhood have survived successive government administrations and is heavily built up with blocks of flat residential apartments (see Figure 2). According to the Nigerian head count of 2006, it has a population of 76,306 people and a projected figure of 112,321 in 2020 covering an area of 955ha [33]. From statistics, this is the most populated medium density neighbourhood in the city aside Abakpa and Emene districts that are both high density residential areas.

Figure 2. A typical Street view of Achara Layout in Enugu, Nigeria

Figure 3 shows a graphic representation of the research methodology flow chart. It demonstrates that the research process can be broken down into six key stages, starting with the perceived problem and review of literature then concluding with recommendations.

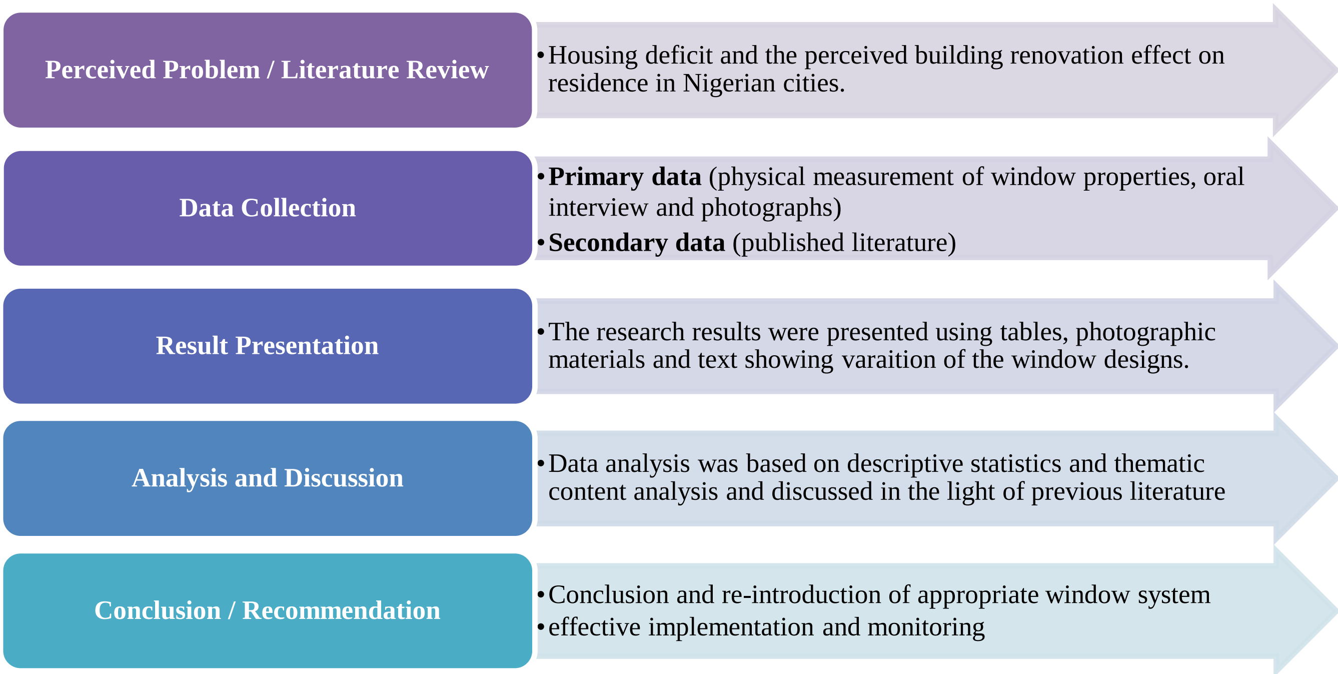

Figure 3. Flowchart of the research methodology

In order to achieve the stated objectives of the study, this research employed a combination of case study and survey research design. Out of eighteen neighbourhoods in Enugu city, Achara Layout was conveniently chosen for the study as it is a well-planned medium density residential neighbourhood existing since the colonial rule and accessible from various parts of the city. It is heavily built up with blocks of flat residential apartments and accommodate fairly large proportion of the city's inhabitants. The sample population involved all residential building in Enugu urban and the sampling frame consist of 520 blocks of flat residential building type existing within the neighbourhood. Using judgmental sampling technique, four blocks of flat residential building was the derived sample size labelled as building block A-D (see Figure 4).

Figure 4. Map of Achara Layout and the case studies-Source; Researcher's field work

This was obtained by an inventory of existing building stock in the layout as at the period of conducting the research, and only buildings under renovation were considered for the study. Though situated in different locations within the neighbourhood, observations, oral interviews, and empirical data collected were centred on physical measurement of window size and window area, while observations and oral interviews of four site workers provided details on the property and fenestration type of all sampled building blocks. Measurement was done using a 30m glass-fiber tape. Further instruments for data collection are photographic images as evidence for the study. Secondary sources of data include published journal papers, conference proceedings, and building standard documents available on electronic databases. Due to the qualitative nature of data collected, analysis was based on thematic content. The research results were presented using tables, photographic materials, and text. The fact that snap shots of interior spaces were not allowed was a problem in this study.

3. Results and Discussion

Table 1 reveals the four variables that were considered in the study to draw a comparison between the As-built designs and the renovated structure. It is evident that all studied variable exhibits marked significant difference.

Table 1. Comparison between the colonial and contemporary building designs of Enugu, Nigeria

Buildings	Variables studied	As-built design	Renovated design	Remark
A	Fenestration type	Louvre window	3 panel Casement windows	very significant difference
	window size (Length × width)	1.35 × 2.4 m	1.2 × 1.5 m	very significant difference
	Window property	Wooden framed with protective window hood.	Aluminium framed with decorative window hood.	very significant difference
	window area (m^2)	3.24	1.8	very significant difference
B	Fenestration type	Louvre window	2 panel sliding window	very significant difference
	window size (length × width)	1.5 × 1.8 m	1.5 × 1.2 m	very significant difference
	Window property	Wooden framed with protective window hood.	Aluminium framed with decorative window hood.	very significant difference
	window area (m^2)	2.7	1.8	very significant difference
C	Fenestration type	Louvre window	2 panel Casement windows	very significant difference
	window size (Length x width)	1.5 × 1.8 m	1.2 × 1.1 m	very significant difference
	Window property	Wooden framed with protective window hood.	Aluminium framed with decorative window hood.	very significant difference
	window area (m^2)	2.7	1.32	very significant difference
D	Fenestration type	Louvre window	3 panel Casement windows	very significant difference
	window size (Length x width)	1.5 × 2.0 m	1.35 × 1.5 m	very significant difference
	Window property	Wooden framed with protective window hood.	Aluminium framed with decorative window hood.	very significant difference
	window area (m^2)	3.0	2.025	very significant difference

Subsequently, other findings of this study are presented in the form of photographic images depicting the architectural building cases that were analyzed as evidence in support of the discussion in the next section. All four sample are undergoing renovation works. Figure 5-A, is a 3-bedroom block of flat residential building along Egbo Nnaji street; Fgure 5-B, is a 3-bedroom block of flat residential building along Jonah Agbo Street; Figure 5-C, is a 2-bedroom block of flat residential building along Amah Street; Figure 5-D, is a 2-bedroom block of flat residential building along Nnaji Nwede street all in Achara layout illustrating the dominant housing type in the metropolis.

Figure 5. The building case study Discussion

According to Bessoudo et al. [34] windows can be considered as the most important component of the building envelope, considering their impact on both the thermal comfort and energy use in spaces. Therefore, the first objective of this study sought to investigate the reason behind the renovation trend (involving change in window system) experienced in the study area. As gathered from the oral interview and a close inspection of building blocks A-D shown in Figure 5, the renovation works cut across changes in window system, roof structure, repainting of building and upgrade of the electrical and plumbing fittings. It has no structural implication neither did it affect the load bearing component of the building. This implies that the building was only given a "face lift" to improve the aesthetic value and enhance its market net worth to measure up to the assumed contemporary building designs in the area. As reviewed in literature, aside the aesthetic and structural importance of windows in building design, it also has to fulfil certain functional requirements, such as weather protection, day lighting, fresh air supply, connection to the outdoors, sound and thermal insulation. These according to Nwalusi et al. [9] defines the quality of the interior space and further enhance the market value.

The findings of this study, which were reported in the previous section of this paper, reveal a marked difference in the studied variables. The four previously studied cases previously had Louvre systems as their fenestration type. This window type originated in the tropics to cater to their peculiar climatic conditions and improve a building's energy efficiency by providing natural ventilation and airflow to the building. It ensures that the air is exchanged whenever it is necessary and can achieve up to 95% ventilation efficiency regardless of wind direction [35]. This view was corroborated by Chiang et al. [36], who stated that the proper horizontal louvres can be used to improve indoor air quality by means of increasing air change rate, especially at sites with lower wind velocity. However, the contemporary design (renovated structure) has deviated from the original intent of the tropical window design to sliding and casement aluminium windows, as evident in Figure 5, which cannot offer the desired thermal comfort level. Furthermore, in comparison with other variations of the renovated window types (casement and sliding), louvre windows have the following merits:

- Window can be left open for ventilation during light rain
- The window can be automated (Motors are integrated into, and fully concealed by, the window frame)
- Louvres seldom project beyond the wall, and when they do, generally by less than 60mm. This do not create hazard for those walking past
- It has the ability to maintain privacy while allowing ventilation
- Ability to be easily screened to the outside or inside. (Insect, security or bushfire screens)
- It can be used for both internal and external ventilation and still perform optimally.
- Multiple openings give best ventilation even when openings are restricted to comply with fall prevention requirements of the National Building Code.
- For air infiltration, unlike draughty old fashioned louvre windows, modern trend of louvre windows seals tightly and exceed Building Code requirements.
- In combination with building technology, Louvre Windows can also be integrated into an alarm system.
- The assembly of louvre windows is technically very simple and also its maintenance is cost effective.

It becomes pertinent to wonder why the renovated structures within the study area choose to forego the numerous importance accruing to louvre window to other versions of window types.

Subsequently, findings on window sizes (length & width) of the studied buildings show a significant difference between the as-built and the renovated building design. The largest variance is visible in the width of the windows, as the highest width reduction is 900 mm and the least 500 mm. Hypothetically, the size or area covered by a window in a building is an important factor affecting the level and amount of natural ventilation experienced in that building, and this directly translates to how thermally comfortable the building will be [37]. Thus, the implication of the decrease in window size is a lower natural ventilation efficiency, which will result in a heavy reliance on mechanical means to achieve thermal comfort in the renovated structures. This renovation trend of buildings in the studied area does not support the building energy efficiency guidelines for Nigeria [38], as it notes that the window size of a building determines the amount of energy consumed in that particular building, as using the proper size of window and omitting air conditioners in a way directly reduces the amount of energy consumed in the building. Also, this finding is in consonance with the assertion of Mba et al. [22] that the size of openings (windows and doors) does significantly affect the ventilation coefficients of buildings. It also agrees with Wang et al.'s [39] findings that the size of the window/fenestration in residential spaces has a significant impact on the thermal comfort level of the interior living space. To achieve this thermal comfort level and determine the optimum window area in relation to the façade dimension, studies on the aspects of daylight level, energy needs, and ventilation needs of that specific area must be considered [40].

The findings on window property demonstrate that the as-built window designs have wooden frames with protective window hoods. While the renovated structures incorporated aluminium frames with decorative window hoods, showing a significant difference in the functional requirements of windows. Although the wooden frames have good thermal insulating properties but require maintenance, the aluminium frames are light and almost maintenance free but conduct heat very rapidly, which makes them a poor insulating material. The implication of this finding is that the interior spaces with aluminium window frames get heated up easily and require additional energy to maintain thermal comfort. Furthermore, window hoods, which are architectural details placed above a window and used as an accent in the tropics, serve mainly protective purposes, i.e., against driving in rain and as solar shading devices [41]. However, as evident in the renovated structures, they have been converted for only aesthetic purposes. It invariably exposes windows to direct heat from the sun and other elements of the weather, with the implications of higher cooling loads. This is in line with the studies of Pathirana et al. [42], who opined that in most tropical countries, achieving thermal comfort within their living spaces without the use of air conditioners is becoming hard; this is due to the poor building/window design found in most houses. Also, the submission agrees with a previous study by Nwalusi and Okeke [23], which found that the use of local building materials and appropriate technology that people in developing countries think is more satisfying, convenient, and prestigious is going down.

Lastly, the natural comfort requirement of a habitable room to obtain a naturally minimum comfort level specifies that a minimum of one or more ventilation openings whose total area is equal to not less than one tenth of the floor area of the room is required [43]. All studied cases had a significant reduction in window size that resulted in making the room fall short of the standard for a habitable room. Buildings A-D have at least a 0.9m2 reduction in total openable area, resulting in a decrease in wall-to-window ratio. This has great implications for the airflow rate and may give rise to sick building syndrome during occupancy. This finding buttresses the argument of Odum and Ezezue [24] that residents of conventional planning and design strategy buildings exhibited more symptoms of the various health challenges associated with the buildings. Furthermore, Awada et al. [44] hinted that when indoor environmental quality is compromised, residents are more susceptible to a variety of ailments, which are compounded by social and economic factors. Thus, the thermal comfort of an internal space has a significant impact on the health and the productivity level of the occupants within a space. Sanders [45] has shown that there is always a percentage drop in the rate of productivity and active life once there is a notable deviation or decline from the optimum room temperature of a space. From the findings of his studies, it implies that thermal comfort is one of the most important indoor environmental quality factors a designer needs to get right in every living space and can conclude that the major factor that leads to poor thermal comfort is low-performing fenestrations. In other words, using technology to improve the efficiency of natural ventilation in buildings that don't have mechanical support from the outside is a way to reduce health risks and save energy in a building.

4. Conclusion and Recommendation

In line with the aim of this research, which is to investigate the effects of building renovation on ventilation and energy saving in Enugu metropolis, the conclusion of the study shows that the primary function of a window as an opening in a building designed to let in air or light, or both, has been overthrown by the aesthetic function of beauty. This conclusion was arrived at because the findings of this current study have revealed a significant reduction in window sizes and area with changes in fenestrate type and properties for renovated residential buildings. The demand for housing experienced in the developing city has stretched beyond supply and the thermal comfort of building occupants in renovated blocks of flat residential buildings is jeopardized.

In a tropical climate, the target is to let in fresh air to keep the indoors cool, consequently requiring large openings. However, as previously designed, all the large window openings of buildings in the study area have been shrunk to accommodate a different window type not appropriate for the climate. This encourages high energy use within the building and limits effective natural ventilation; therefore, it is not an energy efficient approach. Although building occupants/end users do not know the cost and health implications of renting such an apartment. It is recommended that, despite population growth and global warming concerns, the reintroduction of appropriate window systems and construction techniques for the tropical environment be adequately implemented in all building renovation works and enforced by local town planning authorities to alleviate heat stress build-up in cities.

Despite the fact that the current study appears to have achieved its goal, however, it suffers from flaws associated with qualitative research. Surprisingly, the study's research strategy was largely based on the subjective opinion of the researcher and the respondents' bias. This means that the conclusions are exclusively based on the biases of subjective data and responses available at the time of the study. So, more research needs to be done to figure out how to combine a few simulation models to get better results that are easy to apply for a typical Nigerian building occupant to understand.

5. Declarations

5.1. Author Contributions

Conceptualization, F.O.O. and P.I.O.; methodology, C.O. and I.A.E.; Performed the experiments, E.C.E. and I.A.E.; Formal analysis, F.O.O. and C.O.; data curation, F.O.O. and I.A.E.; writing—original draft preparation, I.A.E. and E.C.E.; final writing and editing— F.O.O. and P.I.O. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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