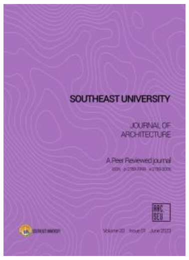

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Impact of Airflow Pattern in Urban Residential Buildings in Kubwa, Nigeria

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ABSTRACT

Fenestration sizes, in relation to room capacity, orientation, headroom, and aspect ratios from site planning are the main factors that affect the airflow and air flush pattern of any neighbourhood. However, many Nigerian urban residential neighbourhoods rarely take these factors into account. This research examined the airflow pattern's effects on residents' comfort, health, and well-being as well as the ventilation characteristics that are most common in Kubwa, Nigeria. A structured questionnaire was developed to obtain information from 152 respondents using a quantitative research method. To determine the actual size of openings on buildings, physical measurements of their characteristics were made. The majority of window types frequently used by occupants, according to the research, were sliding windows, which act as the primary airflow entry point inside the structure. Considering that sliding windows might only provide 50% ventilation, the number of windows that are currently available is generally too little. Results indicate that windows are not always placed to take advantage of the direction of the prevailing wind and that building orientation is not always taken into consideration. Furthermore, it is uncommon for buildings to have an appropriate setback of more than one metre from either the perimeter fence or other buildings. Inadequate airflow into the buildings and a lack of suitable air flush within the buildings prevent the residents from having a healthy indoor environment. These are two consequences of these flaws in the construction of these buildings. More than ever, appropriate residential planning is required, together with strong enforcement of and adherence to local construction rules, in order to design buildings with adequate airflow while taking into account the climatic zones in which they are to be located.

1. Introduction

Heat transfer, water vapour, and other scaler factors in urban streets are all driven by airflow within the urban canopy, just as it is for the indoor ventilation of urban buildings. Human comfort is impacted by climate change, such as urban heat island and global warming, in addition to local and regional pollution, particularly in high-density urban residential areas located at mid or low latitudes, which has become a serious problem. (Azli et al., 2012) The spatial arrangement of buildings is a crucial component of urban forms that significantly affects the local energy dynamics in any neighbourhood (Chen et al., 2011). Most building stocks (the total number of buildings in a region) in developing countries like Nigeria are still under construction, necessitating meticulous energy planning in order to achieve sustainability (Bardhan & Debnath, 2016a; Debnath & Bardhan, 2016b).

Natural ventilation is used to meet the space-cooling needs in low-income housing, particularly in urban slums like Kubwa, Nigeria. Natural ventilation is unpredictable and greatly influenced by site factors such as building or site obstructions, site elevation or altitude, wind direction,

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and building orientation (Karava et al., 2007). An essential component of building design and construction is providing occupants with an adequate supply of outdoor air that meets their needs. Both natural and artificial forces can be used to improve the airflow pattern and ventilation (the movement of air into, through, and out of a building). Understanding this process is essential since it has an impact on a building's internal environment as well as its energy usage. In the winter season, excessive ventilation will place an undue burden on the building's heating system, while insufficient ventilation might result in issues with the quality of the air inside the building, potentially putting users in danger (IEA, 1991).

Many developing nations, including Nigeria, have struggled for years with poor air quality due to inefficient air flow patterns caused by fast, unchecked urbanisation and growth. Environmental deterioration has been a result of economic and social development policies. Rapid industrialization has resulted in economic growth and development that has been prioritised, with less attention paid to the environmental effects of urbanisation. In areas like Kubwa, Nigeria, the effects of air pollution on public health and the environment continue to worsen; these effects vary from chronic illnesses due to air pollution to semi-permanent environmental deterioration (Timothy, 2018). Today, one of the primary needs for a low-energy building design is natural ventilation (Awbi, 1996).

The objectives of this study are to: (i) investigate the impact of the airflow pattern of residential buildings on the health of residents; and (ii) identify strategies to improve airflow in residential buildings. This study seeks to investigate problems associated with poor airflow patterns in residential buildings with a view to improve airflow for a healthy indoor environment of residential buildings in Nigeria.

2. Literature Review

In terms of envelope space and expression, windows play a crucial role in building envelopes. They are made primarily to let sunlight enter the building and ensure optimum ventilation. Air can move between inner and outside regions when a window is able to be opened. (Hau, 2011). Therefore, a key component of architectural engineering and building design is comprehending and managing the airflow pattern between indoor and outdoor areas (Mikkelsen, et al., 2019). For understanding flow conditions, air exchange rates, and their effects on thermal comfort, previous studies of window design concerning airflow have primarily focused on single-sided conditions (Wang, 2015) and simple openings (Prakash & Ravikumar, 2015; Heiselberg et al., 2016; Masood, et al., 2018).

The airflow patterns and spatial phenomena produced by the dynamic movement of windows were studied by Alexis & Isak in 2020. The simulation experiment uses nine distinct window types. These types were selected because they encompass the vast majority of window designs that are commercially accessible on the market and, thus, have the greatest implementation in the built environment. Single Hung, Double Hung, Awning Transom, Hopper Transom, Single Placement, Double Placement, Gilder, Vertical Pivot, and Horizontal Pivot are among the several types of windows.

In December 2019, a new epidemic began in Wuhan City, and as it spread along with various varieties, it alarmed the entire world. Later, the condition was known as COVID-19 (Li et al., 2020). Because properly built spaces can help with the prevention, containment, and treatment of infectious diseases, including COVID-19, architecture plays a special role in COVID-19 disease preventive strategies. There are worries that the coronavirus is aerosolized, which means that, like the bacteria that causes tuberculosis, it could linger in the air for a short period before being breathed by someone else. As a result, inadequate airflow develops into a problem that may be fixed by good airflow design. The ability to open windows to a certain extent, boost airflow, and add filters could mean the difference between health and safety (Murphy, 2020).

Seven million premature deaths worldwide occur each year as a result of air pollution, according to the United Nations Economic Commission for Europe (2021). The poorest and most vulnerable populations around the world suffer the most negative effects on their health from air pollution. In developing countries, there is a greater degree of exposure in terms of the number of persons exposed, the intensity of the exposure, and the length of the exposure. In the developing world, indoor air pollution from particle matter accounts for around 76% of all air pollution. Air pollution is becoming a major threat in the majority of Nigerian cities. Urban poor are most concentrated in metropolitan centres and slum areas (Ukemenam, 2014). The classification of air contaminants is shown in Table 1 below.

Table 1: Classification of Air Pollutants (Otti et al., 2011)

Class	Subclass	Member of Substance
Particulate	Solid	Dust, Smoke, fumes
	Liquid	Mist, Spray
	Hydrocarbon	Methane, Ethylene, Butane
Gases (Organic Gasses)	Oxide of carbon Oxide of sulphur	Carbon monoxide, Carbon monoxide, carbon dioxide, Sulphuric dioxide, sulphuric trioxide Nitrogen dioxide, Nitric oxide Hydrogen sulphide,

Inorganic	Oxide of Nitrogen Others	Hydrogen fluoride, and ammonia

Awbi (1996) demonstrated using computational fluid dynamics (CFD) that natural ventilation systems, such as atriums, with open doors and roof extract openings built to meet the local climate and weather circumstances, may achieve appropriate ventilation rates. Buoyancy was shown to be capable of collecting solar heat gain and reducing carbon dioxide levels to a comfortable level and acceptable air quality in the absence of wind. The effectiveness of green infrastructures in raising air quality is demonstrated by Pugh et al. (2012). Additionally, it asserts that putting plants in urban canyons can cut street-level concentrations of NO2 and PM by up to 40% and 60%, respectively. Green canyons are now the simplest and most effective approach (Giulia & Luca, 2018).

According to Muhammad et al. (2014), 63% of Kubwa residents live in rented homes, which are typically crammed with people and have poor ventilation and sanitation, which is bad for their health. Numerous people sometimes share a single room because of the high cost of rent in the neighbourhood, thus putting pressure on the housing amenities that are available as a result. Additionally, 14% live in government housing, and 17% live in their own homes. A pressure difference between two places and a continuous flow path or opening linking them are necessary for airflow to occur (John, 2016).

The pressure differences necessary for air flow within and through buildings are produced primarily by three mechanisms: wind, stack effect, and mechanical air handling equipment. All structures are affected by wind forces, which normally produce positive pressure on the windward face and negative (suction) pressure on the walls. To determine the pressure placed on a building as a function of wind speed, utilise Bernoulli's equation. The pressure generated by a flow that has slowed to a standstill is known as stagnation pressure. Most of the time, the forces on low-slope roofs are negative (uplift), especially near the leading edge (Figure 1). Positive pressures are felt on the windward face of roofs with slopes more than roughly 25 degrees, whereas suctions are felt on the leeward (John, 2016).

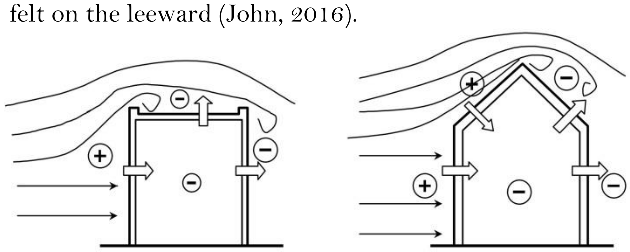

Figure 1: Wind Pressure Effects on Representative Buildings (John, 2016)

Hot air rises and cool air descends, causing changes in air density that result in stack effect pressures. In the winter, the air within a building behaves like a bubble of hot air in a sea of cold air. The situation is inverted during the summer, albeit air temperature variations are typically smaller. Air moves through enclosures and inside buildings due to fans and blowers. They are able to create significant pressures in this way. A net negative pressure is created when a building exhausts more air than it is supplying, and the opposite is also true (John, 2016).

3. Methods

3.1 Study Area

The study area is located in Abuja, the Federal Capital Territory (FCT) of the Federal Republic of Nigeria (Figure 2a) Kubwa is a residential district in Bwari, one of the councils in the Federal Capital Territory, and one of the major suburbs within the city (Figure 2b). Originally inhabited by the Gbagi people, Kubwa as it is now, came into existence in 1990 and is considered the biggest satellite town in West Africa.

3.2 Data Collection Method

The quantitative research methodology was employed to investigate the problem for this study. A structured questionnaire was distributed to people in Kubwa, Nigeria, to gather primary data. According to Luthans and Davis (1982), choosing a survey methodology is justified by its advantages for identifying characteristics of a large group of people as well as its economy of design and rapid data-gathering method. Tables and charts are used to analyse and show the responses received. The portions of the structured questionnaire employed in this study's objectives served as the basis for the questions that were asked. Residents of Kubwa, Abuja, were given the questionnaire survey. The employment of a questionnaire was found to be the best approach for obtaining the needed data because it was the easiest, most effective, and most widely used way to get in touch with the respondents.

3.3 Study Population and Sampling

Kubwa has an estimated population of 12,183, according to the National Population Commission (NPC), 2006 data. The population is currently estimated to be around 55,000. For a known population size between 50,000 and 74,999, 381 questionnaires must be distributed, according to Krejcie and Morgan (1970). 30% of the genuine, fully completed questionnaire responses must be sent back for review. 30% of 381 is 114. For this survey, a minimum of 114 valid replies are required.

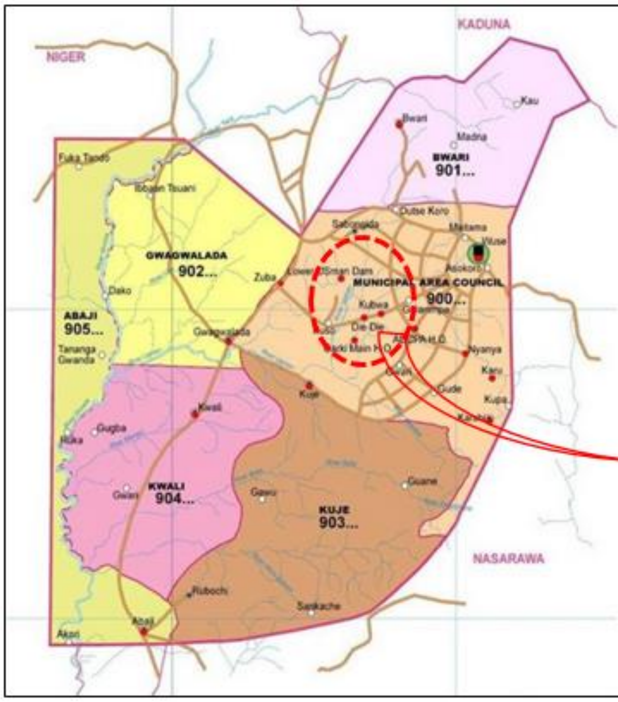

Figure 2a: Map of Abuja showing Kubwa

Figure 2b: Map of Kubwa,the study location

4. Results and Discussion

One hundred fifty-two (152) valid questionnaires were distributed to respondents in Kubwa, Abuja, Nigeria, who were chosen at random for the study. Out of the 385 questionnaires sent out, 152 responses were gotten which is higher than the 114 minimum requirements according to Krejcie & Morgan (1970). This produced a response rate of 39.4%. This rate is greater than the one obtained in a similar study by Emuze (2011) having a 25.4% response rate. The questionnaires administered had 94% valid responses having a reliability value (Cronbach's Alpha) of 0.77 indicating that this is reliable. Table 2 shows the age distribution of respondents. 66.4% of them are between the ages of 16 to 29. This is to be expected given that the questionnaire was primarily given online and that this age group, which includes Millennials and Generation Z, uses the internet the most. not just in Nigeria but also everywhere else. The majority of the responders (56.6%) agreed their residences are designed by professionals. However, 34.9% of the houses are designed by artisans while 8.6% of the respondents agreed they designed their houses by themselves. This shows almost half of the houses are not designed by a professional.

Table 2: Summary of Occupant's Data

Characteristics	Percentage	Characteristics	Percentage
Gender of respondents		Designers of respondents' houses	
Male	67.8	Professional	56.6
Female	32.2	Artisan(Bricklayer /Mason/Carpenter)	34.9
		Self	8.6
Age group of respondents		Breakdown of professional designers of respondents' houses	
16 – 29 years	66.4	Architect	77.1
30 – 44 years	28.9	Urban Planner	5.5
45 – 59 years	3.3	Civil Engineer	9.2
60 – 79 years	1.3	Student/ building/ owners/ unknown	8.2
Type of buildings respondents live in		Duration of stay of residents in their current residences	
Traditional (compound houses)	5.3		
Flat	53.9	Less than a year	24.3
Detached	17.8	1 – 3 years	32.9

Semi-detached	13.2	4 – 6 years	12.5
Rooming accommodation (commonly known as face me – I face you)	6.6	7 – 9 years	7.9
		10 years and above	22.3
Improvised (Informal + others)	3.3		

In the study area, sliding windows were the most common type of window, as shown in Figure 3. 50.7% of the houses make use of this window type. However, sliding windows only permit up to 50% airflow and air flush (Alexis & Isak, 2020), making them a poor choice for hot climates like Kubwa (Akande, 2010).

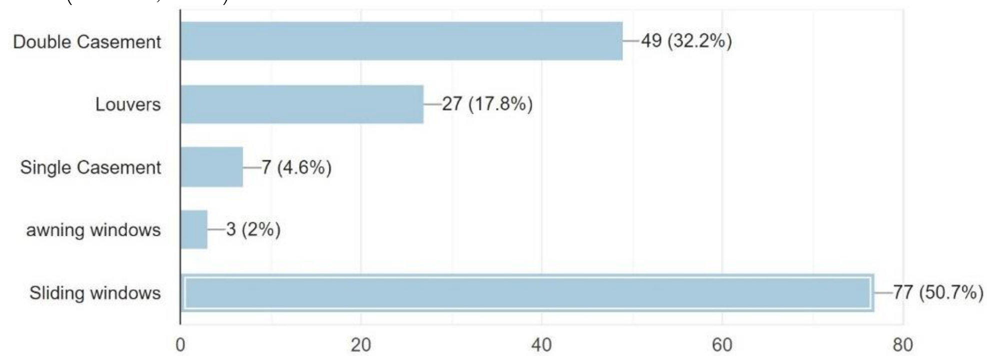

Figure 3: Types of windows in the study area

The optimum option for airflow is double casement, which is used by about 32.2% of people (Alexis & Isak, 2020). Louvers are used by 17.8% of people, which is also a smart choice because they provide more versatility in terms of opening size (Anunobi et al., 2015). 4.6% use single casement windows, while only 2% use awning windows. With 39.9% of homes having this type of ventilation in their living rooms, Figure 4 demonstrates that adjacent ventilation, in which windows are positioned on walls at 90-degree angles to one another, is the most prevalent ventilation style.

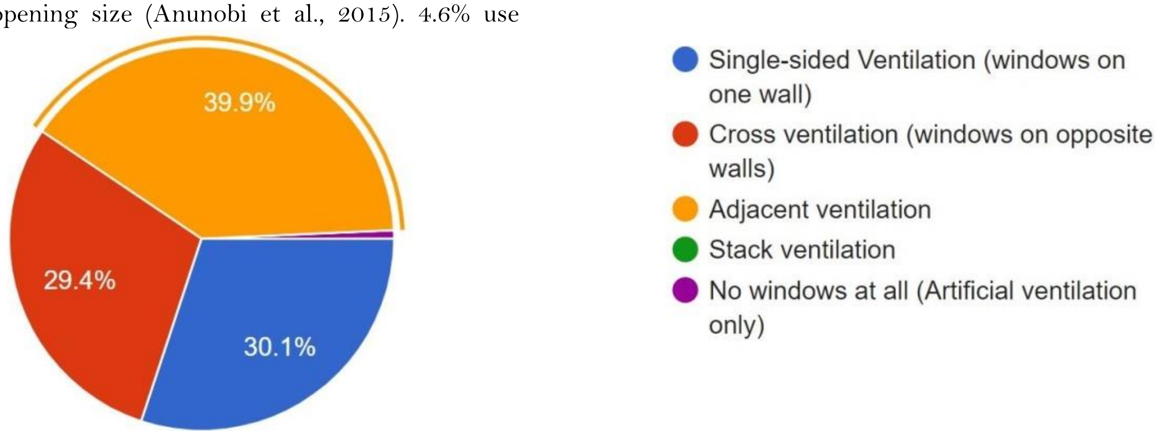

Figure 4: Position of windows/ Ventilation style in respondent's living room

Only 29.4% of living rooms accomplish cross ventilation, the optimal type of ventilation, while 30.1% use single-sided ventilation, and 0.7% have no windows in their living room. However, there have been no cases of stack ventilation observed or noted in the study area. Figure 5 demonstrates that only 27% of bedrooms have cross ventilation, the best type of ventilation, while 32.2% have single-sided ventilation, 0.7% have stack ventilation, and 0.7% have no windows in their bedrooms.

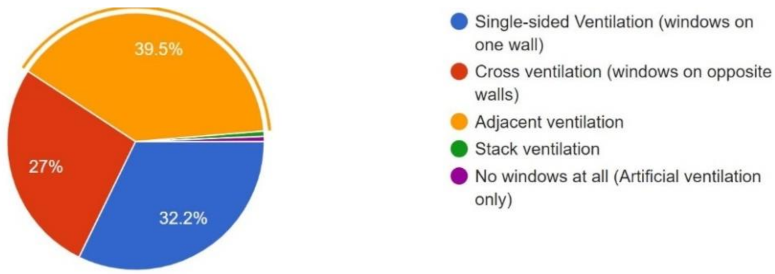

Figure 5: Position of windows/ Ventilation style in respondent's bedroom

It can therefore be deduced from these responses that windows are typically improperly located on walls in the study area. Figure 6 displays the ventilation level ratings for several rooms in respondents' homes. Generally, most respondents evaluated ventilation to be medium (moderate) throughout the living room, bedroom, kitchen, toilets, and bathrooms.

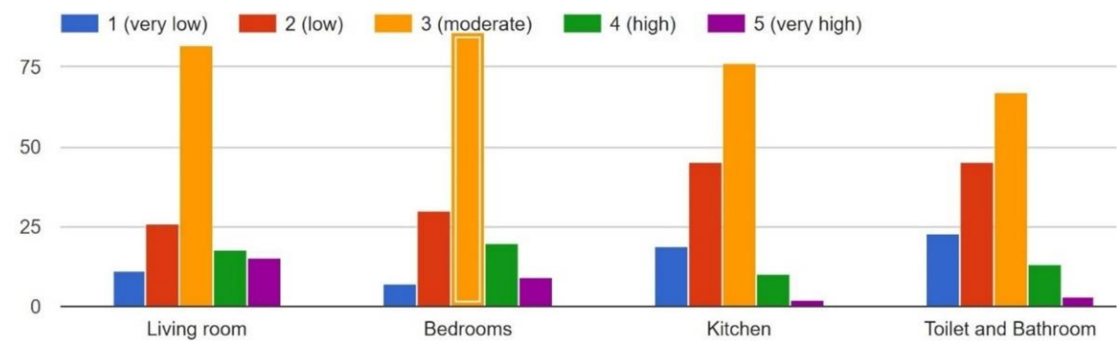

Figure 6: Ventilation ratings by respondents for different spaces in their house.

A deeper glance at the graph reveals that more people give their ventilation in living rooms and bedrooms excellent marks than in kitchens, bathrooms, and toilets combined. Figure 7 shows most respondents rate natural ventilation in their house as average (moderate).

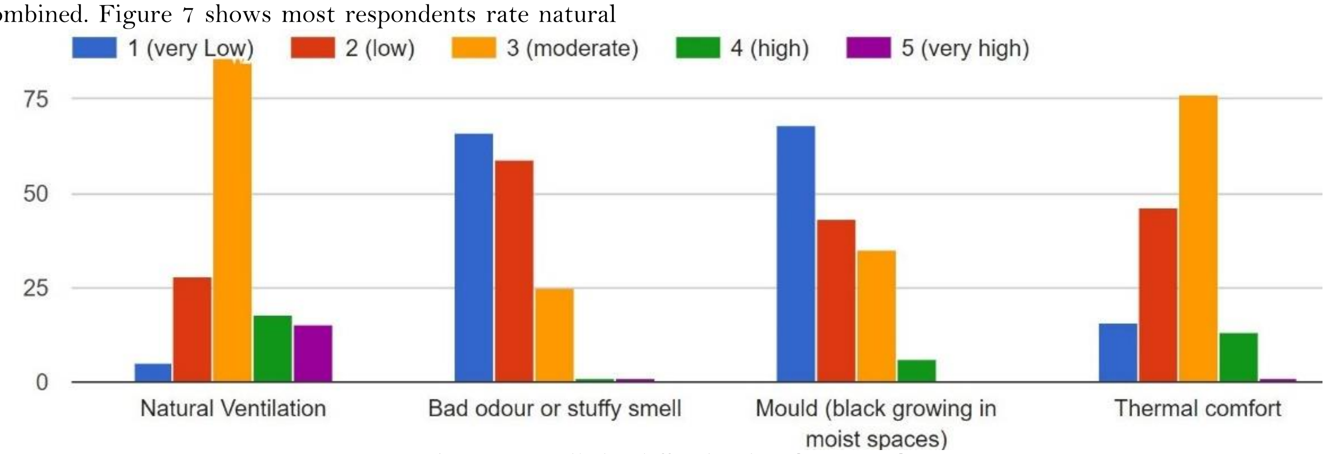

Figure 7: Ventilation (effects) ratings by respondents

More than 50% agree there is a low stuffy smell inside their houses while approximately 25-30% also agree there is a low-moderate presence of mould growing in some places of their house. The rating for thermal comfort is fairly average. Figure 8 depicts how the study room's windows are oriented. In comparison to windows facing south, west, or east, the living room has more windows facing north. The predominant average hourly wind direction in Kubwa, Abuja, varies throughout the year, according to Weather Spark (2021). However, for 4.4 months (February 11–June 22), the wind is primarily from the south. From June 22–August 30 the wind is primarily from the west. For the remaining 3.5 months, the wind is primarily from the east (October 26 to February, 11). This demonstrates that placing windows facing north is the least beneficial for ventilation. The best orientation for inflow is south and east, and the best orientation for outflow is north and west (air flush).

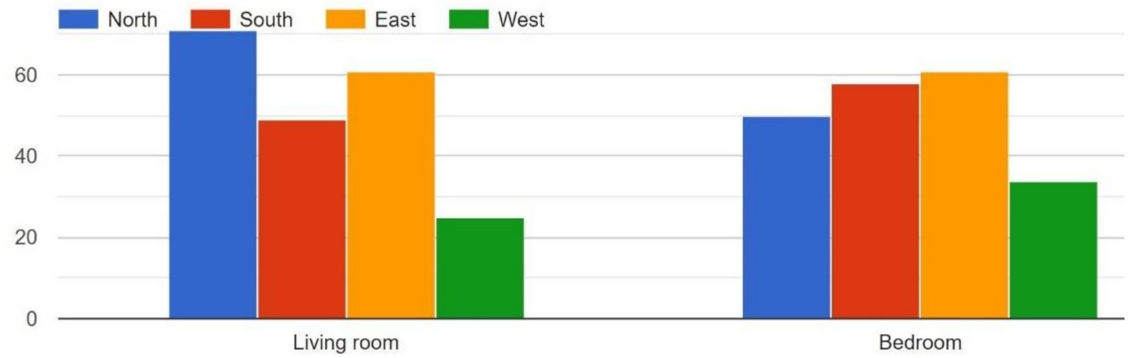

Figure 8: Orientation of windows in the living room and bedroom

Table 3 shows that respondents with one window in their living room typically have very low to moderate ventilation levels, while respondents with two windows typically have low to high ventilation levels. Additionally, it was observed that individuals with three or more windows in their living room have high and extremely high ventilation.

Table 3: Comparing total fenestration area to rate of ventilation in the living room

		How many windows do you have in your living room				Total
		1	2	3	4	
Rate the ventilation level in the following spaces in your house (1 is very low, 5 is very high) [Living room]	Very low	7	4	0	0	11
	Low	11	12	3	0	26
	Moderate	11	47	15	9	82
	High	0	7	3	8	18
	Very high	0	5	7	3	15
Total		29	75	28	20	152

The typical window size in the study area, 1200mm × 1200mm, as shown in figure 9, validates the number of windows chosen here. Hence the bigger the number of windows, the higher the total opening area. More specifically, Table 4 shows that respondents with one window in their bedroom typically have between very low and moderate ventilation, while respondents with two windows typically have between low and high ventilation.

Table 4: Comparing total fenestration area to rate of ventilation in bedrooms

		How many windows do you have in the following spaces in your house? (Bedroom)				Total
		1	2	3	4	
Rate the ventilation level in the following spaces in your house (1 is very low, 5 is very high) [Bedrooms]	Very low	6	1	0	0	7
	Low	14	15	1	0	30
	Moderate	17	57	9	3	86
	High	6	14	0	0	20
	Very high	1	8	0	0	9
Total		44	95	10	3	152

According to Table 5's findings, respondents who have three or more windows in their bedrooms receive moderate ventilation. The argument for using this many windows is supported by the fact that, as shown in Figure 9, the typical window size in the research area is 1200 mm by 1200 mm. Therefore, the total opening area increases as the number of windows increases.

Table 5: Relationship between fenestration area and bad odour or stuffy smell

		How many windows do you have in the following spaces in your house? (Bedroom)				Total
		1	2	3	4	
Please rate the level of the following in your house (1=very low, 5=very high) [Bad odour or stuffy smell]	Very low	17	44	5	0	66
	Low	19	36	2	2	59
	Moderate	8	14	2	1	25
	High	0	0	1	0	1
	Very high	0	1	0	0	1
Total		44	95	10	3	152

The majority of respondents who have between one and two windows in their bedrooms concur that their rooms smell musty or foul. However, respondents with three or more windows report very infrequently having an unpleasant or stuffy odour in their rooms. Meanwhile, Table 6 reveals that respondents with one or two windows in their bedroom have between low and moderate natural ventilation in their houses while respondents with three or four windows have considerable ventilation in their houses.

Table 6: Comparing total fenestration area to rate of natural ventilation

		How many windows do you have in the following spaces in your house? (Bedroom)				Tota l
		1	2	3	4	
Please rate the level of the following in your house (1=very low, 5=very high) [Natural Ventilation]	Very low	4	1	0	0	5
	Low	11	15	2	0	28
	Moderate	21	54	8	3	86
	High	3	15	0	0	18
	Very high	5	10	0	0	15
Total		44	95	10	3	152

Figure 9 demonstrates that the window size most frequently used in the study area's living room and bedroom is 1200 mm x 1200 mm. Meanwhile, a size of 900mm by 1200mm size windows are also extensively utilised for bedrooms in the study area.

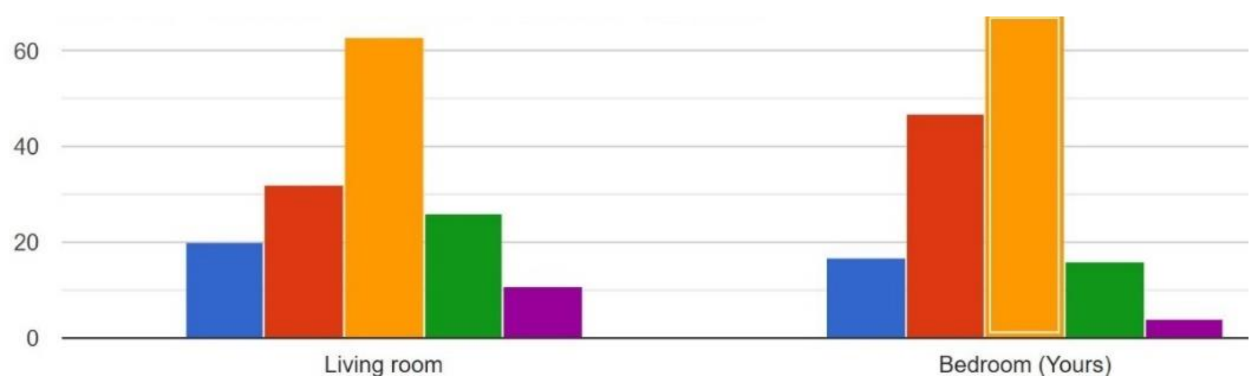

Figure 9: Sizes of windows in living room and bedroom

According to the results in Table 7, respondents who only have one or two windows in their bedroom report low to moderate thermal comfort levels in their homes, whereas those who have three or more windows report moderate thermal comfort levels.

Table 7: Comparing total fenestration area to rate of Thermal comfort

		How many windows do you have in the following spaces in your house? (Bedroom)				Total
		1	2	3	4	
10. Please rate the level of the following in your house (1=very low, 5=very high) [Thermal comfort]	Very low	7	7	2	0	16
	Low	18	25	2	1	46
	Moderate	16	52	6	2	76
	High	3	10	0	0	13
	Very high	0	1	0	0	1
Total		44	95	10	3	152

The argument for using this many windows is supported by the fact that, as shown in Figure 9, the typical window size in the study area is 1200mm by 1200mm. According to Table 8's findings, respondents with one or two windows report more mould growth than those with three or four windows.

Table 8: Comparing total fenestration area to the presence of mould

		How many windows do you have in the following spaces in your house? (Bedroom)				Total
		1	2	3	4	
Please rate the level of the following in your house (1=very low, 5=very high) [Mould (black growing in moist spaces)]	Very low	21	44	3	0	68
	Low	15	25	2	1	43
	Moderate	5	24	4	2	35
	High	3	2	1	0	6
Total		44	95	10	3	152

According to Table 9, 19.1% of the dwellings have setbacks between three and four metres from the access road, while 45.4% have setbacks of more than five metres. Houses with extremely poor setbacks include 13.8% of homes with setbacks of less than 1 metre and 21.7% of houses with setbacks between 1 and 2 metres. Large amounts of dust will accumulate in these homes as a result of the nearby unpaved roads and major health risks associated with the airflow pattern.

Table 9: Setbacks around the building

Characteristics	Percentage	Characteristics	Percentage
Setbacks from the access road		Side setbacks for buildings	
Less than 1m	13.8	Less than 1m	16.4
1 – 2m	21.7	1 – 2m	34.2
3 – 4m	19.1	3 – 4m	26.3
5m and above	45.4	5m and above	23.0

At the research location, 16.4% of the houses had a side setback of under one metre. The majority of the houses have a one- to two-meter side setback. This demonstrates that even though these dwellings have windows on the side walls, the fence or a nearby building will still impede the airflow due to the bad aspect ratio. Hence, inadequate site planning as regards airflow requirements is frequent in the research area. A poor pattern of airflow to provide adequate ventilation has been linked to a number of illnesses, most notably respiratory illnesses by Akande (2021). For maximum thermal comfort, this is in addition to the requirement for appropriate circulation and air flush. The analysis of the data shown above clearly demonstrates that bedrooms, which range in size from 10 to 12.96m^2 (3000mm by 3000mm to 3600mm by 3600mm), and living rooms, which range in size from 9 to 19.64m2, are the most common spaces in which sliding windows of a size of 1.44m^2 (1200mm by 1200mm) are used. Floor-to-ceiling heights is typically between 2.7 and

3.0 metres, which is adequate. However, given that sliding windows may only allow for 50% ventilation, the number of windows is generally too low. Data demonstrates that windows that are not properly positioned to take advantage of the prevailing wind direction are not always taken into consideration when a building is being oriented. Furthermore, it is uncommon for buildings to have an appropriate setback of more than one metre from either the perimeter fence or other buildings. All these results in an overall inadequate design for airflow which in turn has compromised the well-being, comfort, and health of the residents. As an illustration, 80% of the survey participants ranked the general thermal comfort in their buildings as either low or average.

5. Conclusions

This study examined the effect of airflow patterns in several residential buildings in Kubwa a Nigerian metropolitan area. The study's findings revealed certain flaws in the design of a safe and comfortable internal space for the residents of these housing developments. Inadequate airflow into the buildings and a lack of appropriate air flush within the buildings prevent the occupants from having a healthy indoor environment are two consequences of these buildings' design flaws. In addition to the need for adequate airflow for maximum thermal comfort, poor airflow pattern has been related to several diseases, most especially respiratory diseases. To mitigate this, more than ever, there is a need for effective residential planning, stringent enforcement of local building rules, and adherence to building codes to design structures with adequate airflow while taking into account the climates of the locations of those buildings. For efficient airflow and air flush within the building, the following recommendations are made: (i) Adequate residential neighbourhood planning, stringent enforcement, and adherence to local building codes should be carried out by the government and development control. (ii) Building designs should be adequately checked for fenestration sizes in relation to the dimension of spaces as well as an orientation before they are approved by the authorities. (iii) Architects and other built environment professionals should always be involved to provide appropriate designs for adequate airflow patterns for occupants' health and well-being.

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