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The Relationship Between Indoor Air Quality and the Incidence of Health Complaints by Residents of Residential Buildings in Nigeria

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Abstract
Nigeria is plagued by high endemic rates of infectious diseases unintentionally caused by poor housing quality. This study investigated the relationship between housing quality and health complaints of the residential occupants in Nigeria. The objective is to establish a resident-centred quality of life through quality housing provision in Nigeria. A quantitative approach to data collection, comprising household surveys and indoor environment monitoring in Bauchi metropolis, was conducted. The average CO_2 emission indicates acceptable ventilation in the buildings, while the mean IAQ values (i.e., particulate matter) exceeded the WHO recommendation. A broader approach to healthy housing that incorporates the significance of building design was suggested.

Keywords: Housing quality; Quality of life; Public health; Nigeria

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1.0 Introduction

The quantitative deficiencies of housing are one of the major needs to support the rapidly growing population in Africa's cities. This varies in magnitude between developing and developed countries. Meanwhile, the current housing supply's qualitative deficiencies provide a greater difficulty to meeting the expanding demand of housing. Housing, as a fundamental factor of health and quality of life, should be designed to provide for and enhance physical and mental health, as well as the quality of life of individuals and households. A city's design, development, and the citizens' quality of life is a reflection of the quality of their housing. The World Health Organisation (WHO, 2018) defines healthy housing as one that promotes whole physical, mental, and social well-being. Poor housing conditions and exposure to environmental hazards constitute risk factors for severe health outcomes such as respiratory, cardiometabolic, and mental health problems, as well as a reduced life expectancy (WHO, 2018).Housing quality is strongly tied to quality of life, hence, improving housing quality is a major concern, particularly in developing countries. Housing in Nigeria is generally, but notably qualitatively, insufficient (Akande, 2021). Currently, Nigeria has one of the most pressing housing concerns, with a large number of very low-quality

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dwellings.

The majority of the country's population is exposed to housing-related health concerns as a result of low-quality residences. Poor indoor air quality, indoor allergens, pests and noise are all examples of housing-related health risk factors (Braubach, 2021). Researchers such as Udofia *et al.,* (2014) have demonstrated that decent home conditions are critical to enhancing household health. Inadequate housing and environmental conditions might predispose to health problems such as respiratory disorders, stress, and depression. According to Fullilove & Fullilove (2000), poor and deteriorating housing conditions can cause a variety of ailments, including lung disease, neurological disorders, and mental and behavioural dysfunction, all of which disproportionately affect children.

The combined influence of indoor and outdoor sources, building design and conditions, the existence and operation of ventilation systems, and residential activity patterns all contribute to exposure to housing health hazards (Adamkiewicz *et al.,* 2014). Furthermore, the characteristics of the living space contribute to the health, well-being, and quality of life of residents [WHO, 2018]. In Nigeria, there has been little published research on the precise drivers of housing quality. Similarly, there is a scarcity of indices at the national level that cover several domains of housing quality and indoor environmental risk factors. Furthermore, data is not often consistently collected, making it difficult to assess housing and environmental conditions over time.

This study aimed to investigate the relationship between housing quality and health complaints of the residential occupants with a view to establish a resident-centred quality of life through quality housing provision in Nigeria. Thus, the study seeks to answer the following questions (i) what factors within the residential indoor environment influence and/ or promote incidence of health complaints and outbreak of infectious diseases? (ii) Is there a correlation between houses with poor indoor air quality ($PM_{2.5}$, PM_{10}), poorly ventilated (CO_2) houses and incidence of health complains?

2.0 Literature Review

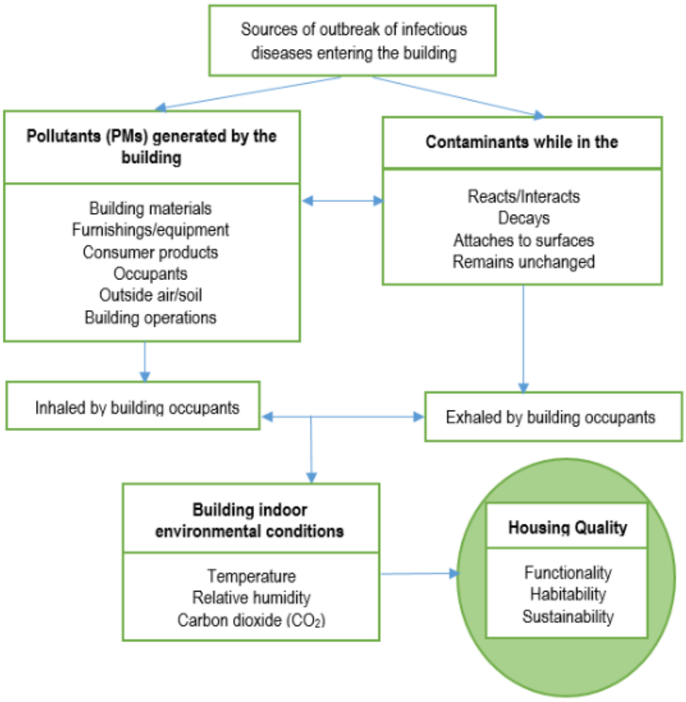

Figure 1: Conceptual framework for investigating housing quality
Source: Authors research work

Recent research (Amatkasmin *et al.,* 2022; Rice & Drane, 2020; Mahdi & Al-Kaissi, 2020; Zhang *et al.,* 2018) has demonstrated a link between building and physical health consequences. Previous research has also focused on the elements that influence housing quality (Amao, 2012; Mallo & Anigbogu, 2009). These studies show that the factors influencing housing quality varies depending on location. The literature on housing quality evaluation in Nigeria identified the most often used housing quality indicators. Structure adequacy, community quality, people' perceptions of neighbourhood safety, room density, and housing affordability are among the indicators evaluated. While the findings on these indicators are instructional and necessary for suitable housing provision, the studies' shortcomings are that the measures utilised were insufficient to reflect the occupants' health and well-being in housing delivery. Lanrewaju (2012) examined and reported on four factors utilised in measuring housing quality in other places. Beauty, convenience, health, and accessibility were among the characteristics considered. Similarly, while the research addressed a wide range of other measures of housing quality, the study's missing link was the lack of the element that directly links housing to the health of its occupants.

Other studies conducted in Nigeria highlighted the terrible state of housing. According to Awe and Afolabi (2017), building elements including as roofs, doors, windows, floors, ceilings, and walls in Ado-Ekiti's urban centre are in poor condition, causing the buildings to be in poor condition and, in most cases, unfit for human habitation. Adeoye (2016) found that the majority of the houses surveyed had substantial flaws and were overcrowded. Lanrewaju (2012), citing Neilson (2004), stated five basic criteria that should be followed to ensure housing quality: the house must be in tolerable condition, free of serious disrepair, energy efficient, equipped with modern facilities and services, and it must be healthy, safe, and secure.

Despite the above-mentioned studies on housing quality in Nigeria, the hazards of poor housing quality and its relation to health complaints by the residents of residential buildings in Nigeria is limited. The significant gaps in the current literature highlighted the importance of this research serving as a foundation for future developments. The research is guided by the authors' conceptual framework (Figure 1).

3.0 Research Methodology

To obtain data from household respondents, this study used a quantitative research approach that included a structured questionnaire survey.

3.1 Study location, population and sampling

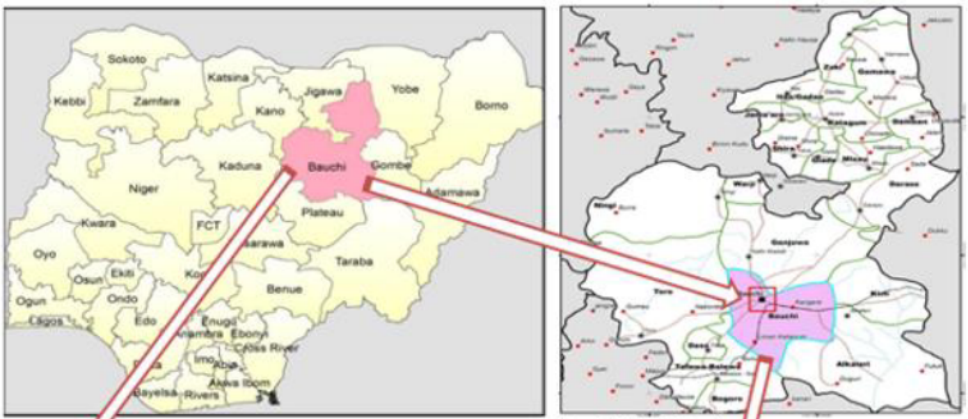

Figure 2a: Map of Nigeria showing Bauchi   Figure 2b: Map of Bauchi State showing the towns

Figure 2d: Google map of Bauchi city showing the study   Figure 2c: Map of Bauchi city showing the selected ward

Source: Muhammad et al., 2018

This research was carried out in Bauchi metropolis, Nigeria having a population of 421,187 persons (NPC, 2014). Bauchi lies between latitudes 90 00' and 90 30" north of the equator and longitudes 100 25" and 110 20" east of the Greenwich meridian (Figure 2a - 2d). The predicted number of dwellings in Bauchi, according to Kawu (2016)'s Geometric Progression Population Projection Formula is between 30,000 and 45,000, with an average household size of 8 to 12. The study used purposive, stratified, and systematic sampling approaches to choose 8 residential areas from southern part of Bauchi having an estimated 37,500 dwelling stock and 300,000 household population. Because the housing types are diverse, the study used maximum variation sampling, also known as heterogeneous sampling, as a purposive sampling strategy. The study area was divided into strata using stratified sampling, and participant households were recruited from each stratum.

3.2 Sample size and response rate

The sample size calculation and formulas proposed by Creative Research Systems (2003) and Czaja and Blair (1996) for this study are as follows:

$$ss = \frac{Z^2 * (p) * (1-p)}{C^2}$$

Where:

Z = Z value (e.g. 1.96 for 95% confidence level)
P = percentage picking a choice, expressed as decimal
(.5 used for sample size needed)
C = confidence interval, expressed as decimal

In surveys, it is usual practise to strive for a 95% confidence level or a precision level of 5%. As a result, a 95% confidence level was adopted, as is typical in other studies, z = 1.96 for 95% confidence level (i.e., significant threshold of = 0.05). A confidence interval (c) of 10% was found adequate for this inquiry. Czaja and Blair (1996) advocated that the worst-case percentage of picking a choice (p) be assumed to compute the sample size and attain some degree of accuracy. As a result, the sample size was approximated using the following assumptions:

$$ss = \frac{1.96^2 \times 0.5\ (1 - 0.5)}{0.1^2}$$

$$ss = 96.04$$

The questionnaire survey will have a sample size of 96 respondents. However, for small populations, the computed value must be adjusted further. As a result, the following formula for computing finite populations was adapted from Czaja and Blair (1996):

$$\text{new ss} = \frac{ss}{1 + \frac{ss - 1}{pop}}$$

Where: Pop = population

$$\text{New ss} = \frac{96.04}{1 + \frac{96.04 - 1}{300{,}000}}$$

$$\text{New ss} = 96.00$$

This formula can be used to calculate the finite populations, and it can be seen that 96 samples are the bare minimum. It was critical to adjust the sample size to account for nonresponse. This was computed using Akadiri's (2011) technique, as shown below, with the goal of achieving a trustworthy response rate of greater than 85%, as advocated by Botani (2021) for in-person (F2F) surveys:

$$\text{Survey ss} = \frac{\text{New ss}}{\text{Response rate}}$$

$$\text{Survey ss} = \frac{95}{0.85} = 113$$

A minimum of 113 respondents with a response rate of more than 85% was required to conduct the survey. The trained questionnaire administration staff collected 116 completed surveys out of 140 total, yielding an 86% response rate. This response rate is adequate to back up this empirical study.

3.3 Research instruments, data collection and analysis

Air quality and other environmental parameters (e.g., temperature, relative humidity, carbon dioxide (CO_2), volatile organic compounds (VOC), particle matter (PM) $PM_{2.5}$ & PM_{10}) were measured using environmental active samplers (e.g., Airnode visual sensor). These were monitored in real time within the homes at 60-second intervals. The use of scientific equipment to monitor indoor environmental parameters is justified as this has been used in other studies (Rim-Rukeh, 2015; King *et al.,* 2018; Akande *et al.,* 2018 and Akande *et al.,* 2023) to investigate indoor air quality in residential buildings. The indoor environmental data were collected at a height of approximately 1.2 m in the living room and bedroom. The samplers were calibrated and tested before being deployed in the field. The authors created a structured questionnaire for data gathering from respondents based on WHO (2018) housing and health domain recommendations. The researchers adopted the prioritised domains of environmental health threats and bad housing conditions linked to poor health. This procedure has also been used by King *et al.,* (2018); Akande *et al.,* (2018) and Akande *et al.* (2023) who also adopted the use of questionnaire to obtain responses from residential households in their studies.

The questionnaire was divided into five sections: demographic information, occupant health and interior environment, building operation, and ventilation characteristics. Participants were asked to rate the level of influence their interior dwelling had on their health. The domains included in the data collection are (i) indoor air quality, (ii) indoor temperature, (iii) household number, and (iv) ventilation. The acquired data was analysed using the Statistical Package for the Social Sciences (SPSS) version 23 to create and present the items utilised in the descriptive analysis, inferential statistics, and response frequencies and/or percentages. A Pearson's correlation test with p=0.05 was used to see whether there was an association between dwelling attributes and respondents' health complaints. Cronbach's alpha values, which should range between 0.70 and 0.95 (Yount, 2006), were determined for the analysis of the internal reliability of the questions, with a cut-off value of 0.80 assumed for this study.

4.0 Findings

A total of 140 questionnaires were distributed, with 116 returned (i.e., response rate of 86%). A reliability value of 0.826 was achieved, as well as 65.8% male and 34.2% female responses. The study's reliability rating of 0.826 and response rate percentage were rated adequate. The majority of responses are over the age of 25. Approximately 20% of the respondents live in leased housing, whereas 79%reside in owned housing. Well over half (67%) earned $52 each month. The mean indoor temperature for all of the dwellings ranged from 22°C to 40°C, with the majority of the buildings recording temperatures over the ASHRAE comfort limit. The relative humidity (RH) was between 29% and 82%, with around half of the dwellings meeting the threshold. The mean PM concentrations ranged from 10 µm/m³ to 231 µm/m³ ($PM_{2.5}$) and from 20 µm/m³ to 1667 µm/m³ (PM_{10}) which is greater than the WHO (2014) recommended value of 25 µm/m³ and 50 µm/m³. The CO_2 values ranged from 403ppm to 2201ppm, with a mean of 584 ppm. Some important findings relating to infectious disease outbreaks are described below.

4.1 Residential PM Exposure

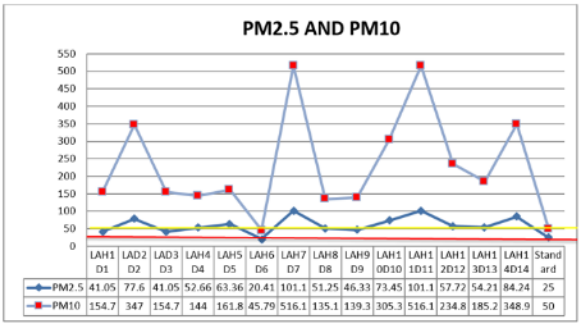

Figure 3: PM exposure of occupants in neighbourhood LA

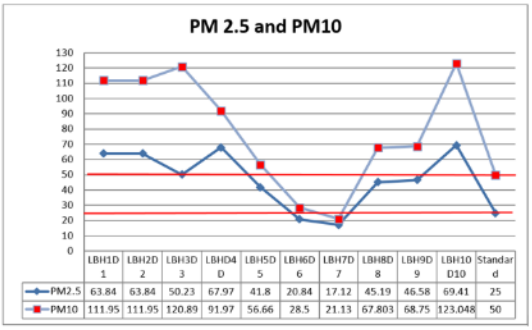

Figure 4: PM exposure of occupants in neighbourhood LB

Readings were taken from houses in different residential areas to establish the level of the occupants' exposure to the PMs within the building and their potential impacts to induce infectious illnesses. The neighbourhoods, houses, and days were classified for easier identification as LAH1D1 to LDH1D1, which stands for "Location A House1 Day 1 and so on." The results provided for each residential neighbourhood are shown in Figures 3 to 6. The equipment readings were compared to the internationally recognised standard acquired from WHO and shown on the figures. The yellow line in the figures represents the acceptable threshold for PM_{10}, while the red line represents the standard for $PM_{2.5}$. Figure 3 shows that LAH6D6 was the only building with PM_{10} and $PM_{2.5}$ readings below the permissible standard. Meanwhile, the values of other residences were much over the permitted level, with house LAH11D11 recording the highest $PM_{2.5}$ of 101.1 and PM_{10} of 516.1.

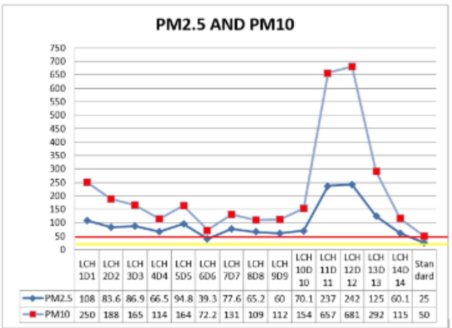

Figure 5: PM exposure of occupants in neighbourhood LC

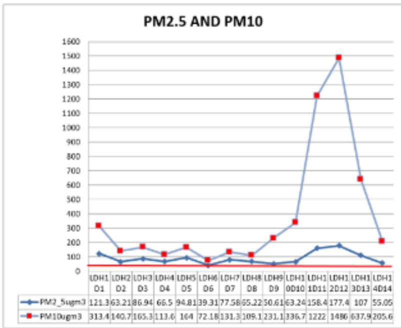

Figure 6: PM exposure of occupants in neighbourhood LD

Figure 4 shows that the $PM_{2.5}$ and PM_{10} levels in houses LBH6D6 and LBH7D7 are below the standard while others are significantly above, implying that the majority of the dwellings are not conducive due to the detrimental effects of $PM_{2.5}$ and PM_{10} on human health.

The findings corroborate those of recent research by Gurley *et al.* (2013) and Gurley *et al.* (2014), which found an elevated risk of acute lower respiratory infections as a result of indoor PM exposure.

Figures 5 and 6 show that the values observed in all of the residences were significantly higher than the WHO-required level for $PM_{2.5}$ and PM_{10}. It was discovered that LCH12D12 and LDH12D12 have the greatest value, implying that the houses are unfit for human habitation due to the detrimental effect of PMs on human health. This data supports WHO's (2014) conclusion that diseases related with PM as a major air contaminant cause nearly half of all premature deaths.

4.2 Influence of indoor environment in promoting the incidence of health complaints

To address the question, "What factors within the residential indoor environment (RIE) influence and/or promote the incidence of health complaints"? The effect of indoor factors on the incidence of health problems was investigated using ordinal logistic regression. Table 1 displays the outcome. Table 1 results demonstrate that the effect of PM_{10} on health incidence is significantly positive, with a coefficient of 0.004 and a p value of 0.04 less than 0.05, implying that a unit increase in PM_{10} increases the incidence of health.

Table 1: Factors within the residential indoor environment influence and/ or promote incidence of health complaints

							95% Confidence Interval	
		Estimate	Std. Error	Wald	df	Sig.	Lower Bound	Upper Bound
Threshold	[Q10 = 1.00]	17.140	12.570	1.859	1	.173	-7.497	41.776
	[Q10 = 2.00]	19.270	12.638	2.325	1	.127	-5.501	44.041
Location	PM2.5	-.019	.034	.304	1	.582	-.085	.048
	PM10	.004	.002	4.192	1	.041	.000	.009
	AQI	-.022	.026	.700	1	.403	-.072	.029
	TEMP (°C)	.582	.400	2.117	1	.146	-.202	1.366
	HUMIDITY	.050	.040	1.536	1	.215	-.029	.128
	CO_2	.004	.003	2.339	1	.126	-.001	.009

Table 2: Correlation between houses with poor indoor air quality (PM2.5, PM10), poorly ventilated (CO2) and health complains.

			PM2.5	PM10	CO2
Kendall's tau_b	Has the quality of the indoor environment ever affected your health or health of the any member of the family	Correlation Coefficient	-.159	-.018	-.096
		Sig. (2-tailed)	.146	.866	.379
		N	52	52	52
	Influenza	Correlation Coefficient	**-.228***	-.200	-.155
		Sig. (2-tailed)	**.031**	.058	.144
		N	**52**	52	52
	Malaria	Correlation Coefficient	-.109	-.092	**-.232***
		Sig. (2-tailed)	.308	.394	**.031**
		N	52	52	52
	Pneumonia	Correlation Coefficient	-.031	-.056	.008
		Sig. (2-tailed)	.782	.622	.942
		N	52	52	52
	Asthma	Correlation Coefficient	-.052	-.189	-.184
		Sig. (2-tailed)	.651	.101	.111
		N	52	52	52
	Meningitis	Correlation Coefficient	.105	.079	.203
		Sig. (2-tailed)	.359	.488	.077
		N	52	52	52
	Measles	Correlation Coefficient	.047	-.033	.106
		Sig. (2-tailed)	.681	.771	.351
		N	52	52	52
	Chickenpox	Correlation Coefficient	**-.277***	-.181	**-.231***
		Sig. (2-tailed)	**.014**	.106	**.040**
		N	**52**	52	**52**
	Tuberculosis	Correlation Coefficient	-.003	.074	.030
		Sig. (2-tailed)	.981	.521	.794
		N	52	52	52

To determine the implications of the occupants' exposure to high PMs, the correlation between houses with poor indoor air quality (PM2.5, PM10), poorly ventilated (CO2) houses and incidence of health complains was examined. The results as shown in Table 2 suggest that there is a significant association between Influenza and $PM_{2.5}$, as well as Malaria and CO_2. There is also a p-value less than 0.05 which shows there is a relationship between $PM_{2.5}$ and Chickenpox and CO_2.

4.2 Air quality index (AQI) of the houses

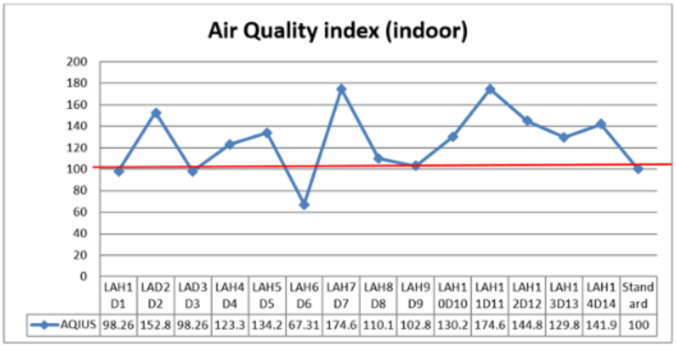

Figure 7: AQI of houses in neighbourhood LA

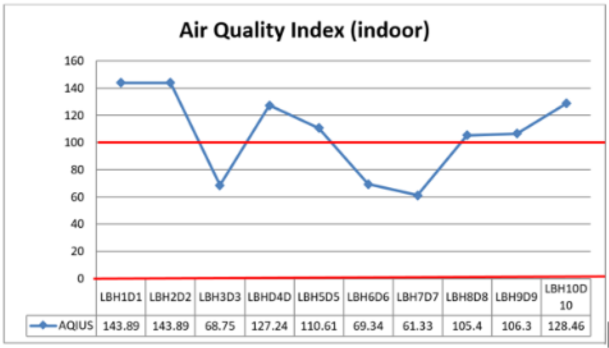

Figure 8: AQI of houses in neighbourhood LB

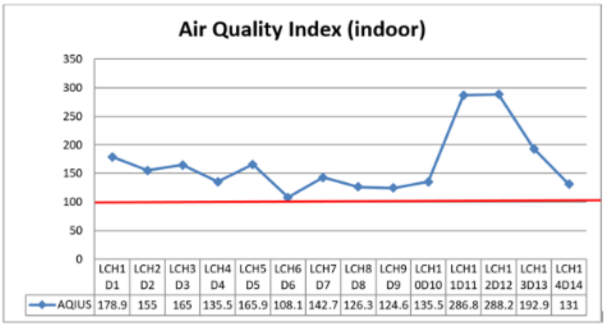

Figure 9: AQI of houses in neighbourhood LC

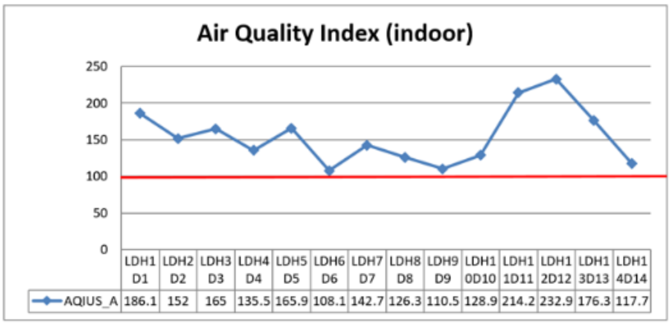

Figure 10: AQI of houses in neighbourhood LD

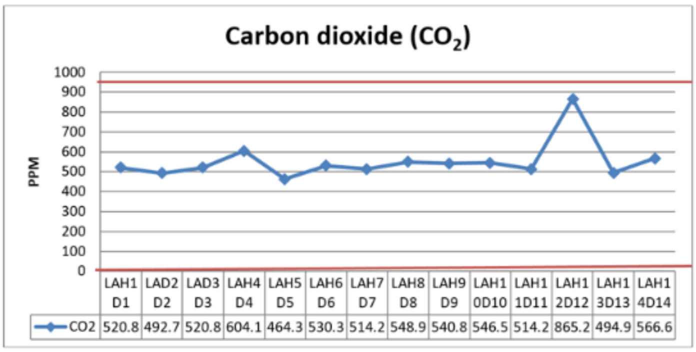

Figure 11: CO_2 recorded for houses in neighbourhood LA

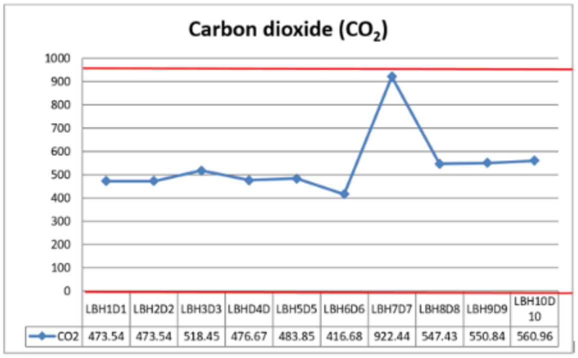

Figure 12: CO_2 recorded for houses in neighbourhood LB

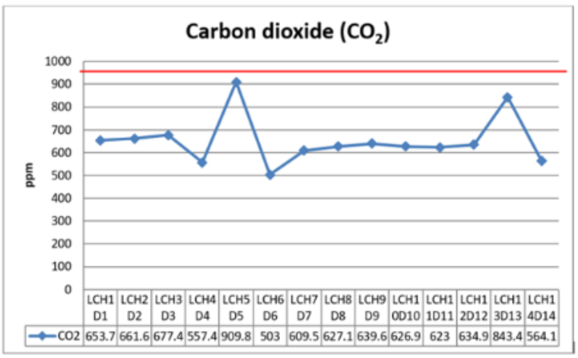

Figure 13:CO_2 recorded for houses in neighbourhood LC

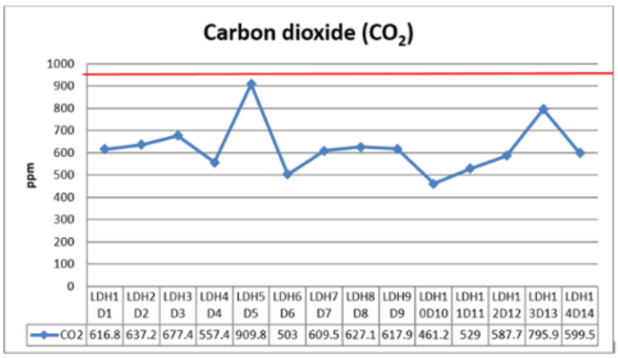

Figure 14: CO_2 recorded for houses in neighbourhood LD

The air quality index (AQI) of the houses was measured to estimate the daily air quality inside the analysed houses. The AQI of the houses indicates the health impacts that the residents may feel after breathing dirty air for a few hours or days. The AQI acquired from the Environmental Protection Agency (EPA) index for reporting air quality in the United States utilises a yardstick ranging from 0 to 500. The higher the AQI value, the worse the air pollution and the greater the health risk. Figures 7–10 show the AQI achieved in the investigated dwellings. The AQI standard values are shown in red and range from 0-50 (good), 51-100 (moderate), and 101-151 (unhealthy and dangerous). Figure 7 shows that houses AH1D1 (98.26), LAH3D3 (98.26), and LAH6D6 (67.31) are within moderate acceptable limits, whereas other houses are unhealthy for building occupants, particularly the sensitive group (active children and adults, and people with respiratory diseases such as asthma).

Figure 8 shows that the AQI in house LBH6D6 (69.34) and LBH7D7 (61.33) are below tolerable limits for human health, whilst others are significantly above. This statistic implies that the vast majority of dwellings are unfit for human habitation.

Figures 9 and 10 show that all of the houses' AQI values are far over healthy levels, with values more than 101 being unhealthy for building occupants. Figures 10–13 gave the findings on the values acquired from the amount of CO_2 in the building.

International acceptable levels are measured in parts per million (ppm) and range from 0 to 650ppm (healthy), 650-950ppm (acceptable), and 950-1250ppm (unacceptable). Figure 11-14 shows that all of the dwellings' CO_2 levels are below safe limits.

5.0 Discussion

This study included quantitative measurements of exposure to fine particulate matter (PM) and carbon dioxide (CO_2) in participating families, as well as elevated indoor PM concentrations in the residences assessed. The high amounts of PMs found in this study could be attributed to the energy sources used by the homes for cooking (firewood, charcoal, and kerosene). Other significant particle sources could have resulted from unpaved roads and a lack of green space surrounding the structures. The findings of this study correspond with those of Gurley *et al.* (2013), who found that exposure to indoor $PM_{2.5}$ levels greater than 100 µm/m³ increased the incidence of acute lower respiratory infections, particularly in newborns. This is consistent with the findings of this study, which found that the average mean raised PM concentrations exceeded the WHO guideline. PMs have been identified as a prominent component of indoor air pollution. For instance, the result obtained in Table 1 clearly demonstrate that the effect of PM_{10} on health incidence of the residents is significantly positive with a coefficient of 0.004 and a p value of 0.04 less than 0.05, implying that a unit increase in PM_{10} increases the incidence of health complaints of the resident. This finding is aligns with the study of Gurley *et al.,* (2014) which showed that the accumulation of PMs in the indoor environment can cause respiratory problems, particularly in children. Because of the nature of its tropical climate, open windows are relatively popular in northern Nigeria, where harmful gases from burning wood or kerosene used for cooking indoors may be reduced by natural airflow.

Within the study location, it is common for families to keep their doors and windows open due to exposure to hot and dry temperatures, which explained the reason for the result of recording lower CO_2 in most of the houses surveyed, despite the fact that many had insufficient windows for adequate ventilation in their houses to bring in fresh air into the building. Surprisingly, the findings of this investigation indicate that the buildings are properly ventilated, with average CO_2 levels in bedrooms rarely exceeding 1000 ppm. This could be due to a combination of factors, such as how the occupants operate their dwellings or the fact that several residences were built around a courtyard. This enables households to leave their windows open for extended periods of time, both at night and during the day. This is a regular occurrence, particularly among residents in naturally ventilated housing. It worthy of note that this study with the exception of chicken pox and influenza, there was no significant connection between exposure to PMs, CO_2, and infectious disorders reported by respondents. This is consistent with Bruce's (2000) results that most research from underdeveloped nations failed to reveal a substantial link between indoor air pollution and specific illnesses. This is due to a variety of factors, including methodological constraints and a small sample size to identify a substantial correlation between the variables studied. In the current study, this is regarded as the case.

6.0 Limitations and Future Research

Certain limitations emerged in the conduct of the present study due to the inability to monitor indoor air quality and CO2 beyond 8–12 hours, in contrast to the 24 hours recommended by the WHO. This is due to resource and time constraints, and the inability to get a continuous power supply for 24 hours to power the scientific equipment used. Thus, these limitations resulted in failing to include the complete range of possible indoor PM levels throughout the day. In addition, other air pollutants, including nitrogen oxides (NOx), which could have enhanced the assessment of possible indicators of infectious diseases, were not measured in the current study. This could have provided the platform for the association between infectious diseases and/or their symptoms and indoor air pollution. Furthermore, due to the limitations of time, resources, and space, all the variables identified in the conceptual framework and investigated could not be reported within this study. Hence, further studies need to take into consideration the above limitations by embracing a more holistic approach and expanding research on the impact of residential housing on the health and well-being of building occupants beyond the study area in Nigeria.

7.0 Conclusion

The present study explored and assessed the potential association between housing quality and residents' health complaints in Bauchi, Nigeria. This study provides substantial support for the notion that if house quality were improved, household health problems would decrease. The primary factors observed in the house's indoor environment that promote the prevalence of health complaints in this study were high amounts of PMs. However, there could be many additional factors leading to poor indoor air quality that need to be examined in future studies. Houses intended to create adequate indoor environmental factors that improve occupants' wellness and health are determinants of housing quality. As a result, the government has to strive hard to ensure that the quality of housing being built for citizens improves. This would be informed by the appropriate building orientation, selection of window type, wall material, and other finishing materials, among others. This study suggests a synergistic framework that integrates the roles of architects, government, and public health experts, as well as taking into account the cultural background of building occupants when designing and providing housing that contributes to addressing the conundrum of unhealthy housing.

8.0 Paper Contribution to Related Field of Study

This paper will help future researchers have a starting point from which to develop measures to reduce inequalities in housing by making them healthier, more resilient, and salutogenic. It provides the platform for architects and engineers to reimagine and redesigned residential buildings that are healthy for the populace.

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