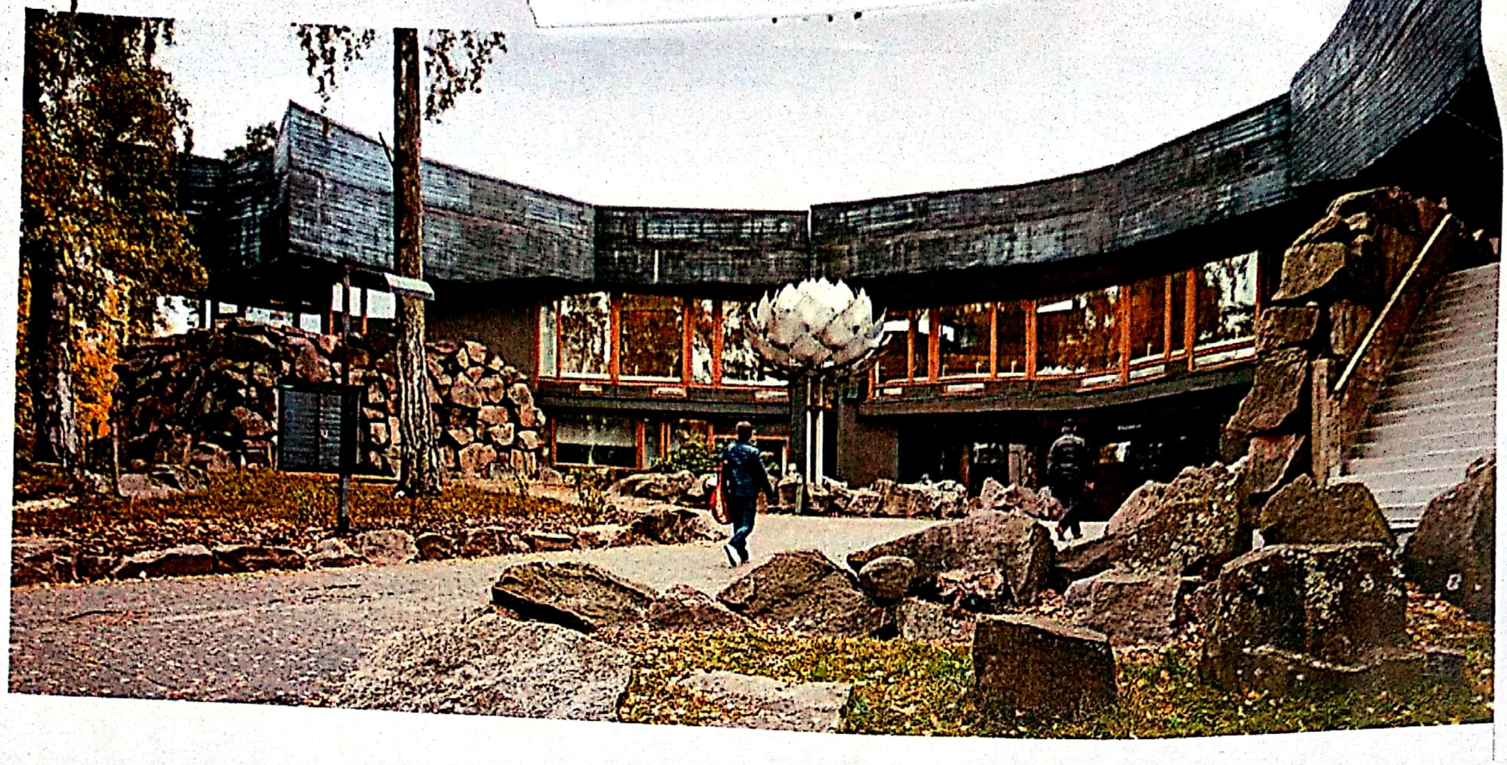

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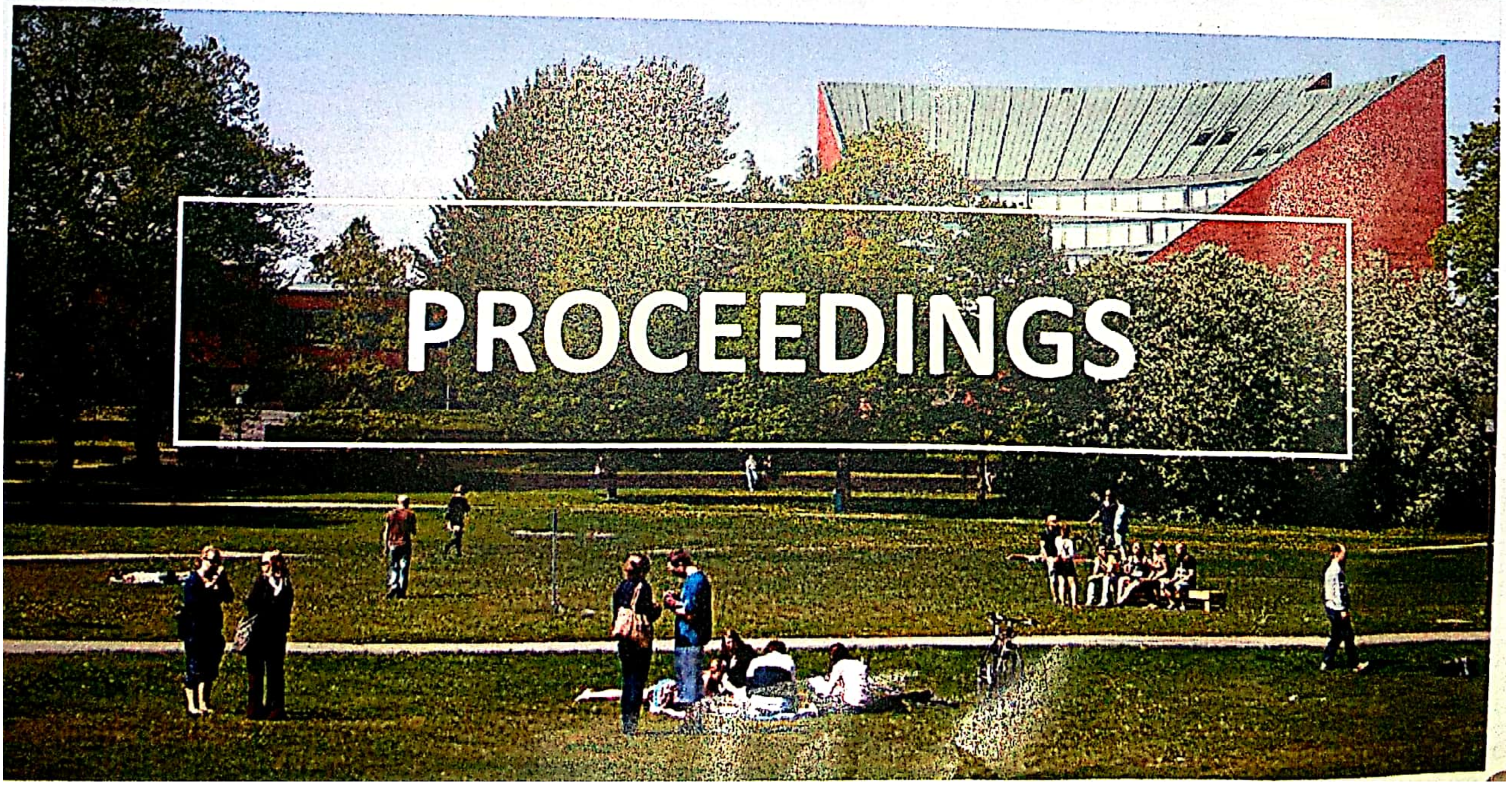

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INDOOR AIR QUALITY AND HEALTH IN NATURALLY VENTILATED RESIDENTIAL BUILDINGS IN NIGERIA

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SUMMARY

Bacterial Meningitis is a large-scale health problem in Sub-Saharan Africa, with up to 200,000 cases every year across 14 countries including Northern Nigeria (Bassey et al 2009). There are suggestions that poor air quality, including in houses where numerous family members both congregate and sleep contribute negatively to infection transmission. According to the World Health Organisation, cities in Nigeria are considered the most polluted in the world with PM10 values regularly over thirty times recommended levels (WHO, 2016). The objective of this study is to investigate relationship between indoor air quality parameters, housing design and reported health of local residents.

Health questionnaires and overnight monitoring of CO_2, temperature, PM2.5 and PM10 were conducted in 115 houses separated into eight districts in Bauchi, central north-eastern Nigeria. Air quality parameters were measured using Airnode sensors (Airvisual, USA) whose CO_2 values were calibrated against a Rotronic CL11 (Rotronic, BSRIA, Bracknell, UK). Questionaires included demographics, reported health issues and symptoms and operation of the building. A building audit recorded room and window sizes, location and orientation and aspects such as cooking fuel sources.

Preliminary results suggest that buildings tend to be well ventilated, with average CO_2 levels in bedrooms rarely surpassing 1000ppm over an eight-hour period. Houses were often in fenced compounds or a courtyard design so inhabitants could safely leave their windows open. On the other hand, PM10 values often surpassed 1000μm/m^3 and PM2.5 ranged from 10 to 1800μm/m^3. Analysis will be reported to correlate the indoor air measurements to the occupant survey. Pending health survey analysis, a simplified tick-box style questionnaire framework could, in future, provide a meningitis risk analysis tool for local healthcare workers based on building type and window size assessment. This could potentially dispense with lengthy health questionnaires or environmental monitoring.

Keywords: indoor air quality, health, natural ventilation, residential buildings, meningitis

1 INTRODUCTION

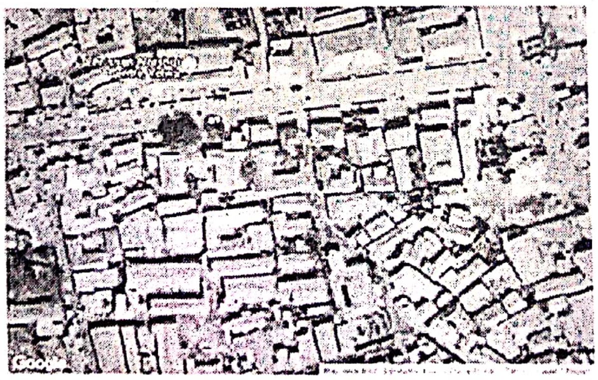
Urbanization is a global phenomenon rapidly occurring in developing countries such as Nigeria; a lower-middle-income and Africa's most populous country (approximately 193 million). Within these populations, the poorest socioeconomic groups of about 50.2 per cent of its urban populace disproportionately suffer from inadequate supply of urban housing thereby living in slums (UN-Habitat, 2016). Consequently, this has led to growing millions of sub-standard/poorly design houses resulting in ill-health of most occupants. Natural ventilation and indoor air quality in millions of the houses are often poor, resulting in the prevalence of airborne disease transmission. Among the health related problems is the prevalence and incidence of increasing meningitis outbreaks. The World Health Organisation (WHO) estimates that at least 1.2 million cases of bacterial meningitis occur each year out of which 135,000 are fatal (Rouphael *et al.*, 2012; Jafri *et al.*, 2013). In 2017, a total of 14,513 cases with 1,166 deaths were reported particularly in Northern Nigeria. Although part of the efforts to prevent meningitis outbreak was reactive vaccination however, the immunization strategy for meningitis control is insufficient to reduce the burden of the disease. Further, the prevention of the disease is also faced with challenges of insufficient funding for vaccine supply and unaffordability of multivalent conjugate vaccines making them not routinely available (McVernon *et al.*, 2004a, b; Segal and Pollard 2004). Despite significant advances in vaccine administration and the gains achieved from meningitis control through immunization strategy interventions, little still is known about the dynamics of the indoor environment and building characteristics influencing the transmission of meningitis leaving an enormous unmet public health's need.

According to Kembel *et al.*, (2012) buildings are complex ecosystems that house trillions of microorganisms interacting with each other, with humans and with their environment. Previous work on indoor air in buildings shows that poor indoor air quality contain various bacteria, viruses, and fungi leading to increase the risk of infections (Emmenlin, 2007; Kovesi, *et al.* 2007; Ishihama *et al.*, 2009). WHO (2005) identified indoor air quality as the eight most important risk factor and responsible for 2.7% of the global burden of disease. Similarly, poor ventilation, accumulation of biological pollutants, and infection potential have been reported to seriously deteriorate indoor environments (Graudenz *et al.*, 2005). The indoor air quality causes more concern as places are crowded with people are at risk of spreading diseases caused by airborne bacteria. Although several studies demonstrates the significant health impact of housing and socioeconomic characteristics on the burden of meningitis and other diseases in developing countries; most studies failed to investigate association between indoor air pollutants and building characteristics and infectious diseases risks such as meningitis outbreak. This paper seeks to address this knowledge gap; it aims to investigate relationship between indoor air quality parameters, housing design and reported health of local residents living in naturally ventilated residential buildings (NVRBs) in Nigeria.

2 METHODS

2.1 Study design and population

This study employed a cross -sectional study design that reflected in the data collection methods. It involves a household survey, building audit, PM and CO_2 monitoring. The study took place in a low income urban setting of area of Bauchi metropolis, Northern Nigeria (Figure 1). One hundred and fifty (150) households were invited to participate and 115 agreed to take part in the study. All the 115 consented for indoor air quality monitoring. Approval for the study was granted by the University of Leeds Research Ethics Committee, United Kingdom and a signed informed consent was obtained from each participating household. The cross-sectional survey was conducted between 13th and 31st October 2017.



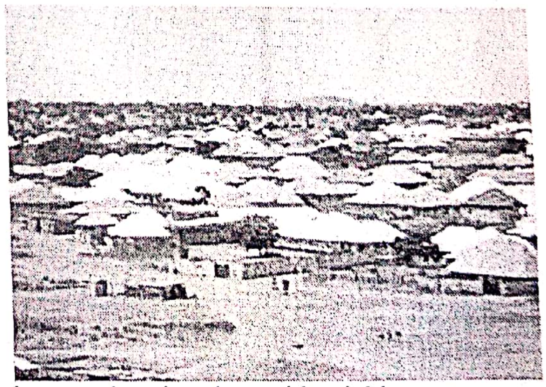


Figure 1. *Area map and photographic view of the study area* showing the residential layouts

2.2 Data collection

Households were randomly selected and a health questionnaire developed by the researchers was administered to the head of the household. The survey was carried out with the help of local community health workers and architectural technologists recruited and trained to administer the questionnaire in English and local language. The questionnaire consisted of two sections. Section one collected demographic data and information on household's health such as their experience of Tuberculosis (TB), Meningitis, Measles, and Chicken pox, Influenza, Asthma, Pneumonia and Malaria along with their symptoms in the last 5 years. Section two gathered information related to the building design characteristics (e.g. room and window sizes, window location and orientation etc.) and operation of the building by the occupants such as cooking fuel sources, indoor smoking and alternative source of lighting at night in the absence of electricity. Overnight monitoring of CO_2, temperature, $PM_{2.5}$ and PM_{10} were conducted in all the houses from eight neighborhoods. Air quality parameters were measured using Airnode sensors (Airvisual, USA) whose CO_2 values were calibrated against a Rotronic CL11 (Rotronic, BSRIA, Bracknell, UK). The environmental samplers were placed from a height of 1.3 m above the floor. Microsoft Excel 2010 was used to record, store, and organize all survey results and PM measurement data.

2.3 Statistical methods

In this study, incidence of occupant's health complaints were the main outcomes and were recoded as binary variables (1 = Yes for diseases/symptoms, 0 = No for disease/symptoms). Independent variables such as including housing design characteristics, building operation, PM and CO_2 variables were analysed using descriptive statistics generated for the outcome and independent variables. Bivariate analyses, including cross- tabulations and chi-squares tests, were performed for assessing unadjusted associations between the independent variables and the reported diseases/symptoms as outcome variables. As the current study is cross- sectional with common occurred health outcomes, a multivariable regression analysis to examine the adjusted association between diseases/symptoms and housing design characteristics and operation and PM and CO2, were conducted. The multivariable modelling was carried out reporting in the paper variables found to be significantly associated with the health outcomes in the univariate analysis with $p < 0.05$. In each model, the goodness of fit (Nagelkerke R2 value) and significance were evaluated. A Fisher exact or χ^2 test was used for categorical variables. Further analyses of significant results involved calculating raw odds ratios (ORs) and 95% CIs. Statistical analysis was performed using the IBM SPSS Version 23.0 for windows. The critical level of significance of 5% for all statistical tests (two-tailed) was used in this study.

3 RESULTS

The majority (47.6%) of the respondents in this study had a monthly income less than N20, 000 ($50) (i.e. about $ 1.25 per day) for a household with an average size of four family members in Nigeria. About 50% of the households use kerosene (0.7%), firewood (24.6%), charcoal (2.6%) and combination of the three (14%) for cooking purposes in the house. These produces more toxic fumes than other energy types (e.g. electricity and gas). Elevated concentrations of PM were observed in most (79.5%) of the houses. The mean concentrations of $PM_{2.5}$ (63 μm/m^3) and PM10 (228 μm/m3) ranged from 10 μm/m^3 - 231 μm/m^3 (PM2.5) and 20 μm/m^3 - 1667 μm/m^3 (PM_{10}). This result demonstrates that the majority of the households were exposed to higher than the WHO guideline value of 25 μm/m^3 and 50 μm/m^3. The mean concentrations of CO_2 (584 ppm) indicated that the ventilation was adequate having a range from 403ppm - 2201ppm. The mean temperature (28.9 °C) slightly exceeded the ASHRAE (2014) recommended guideline values (21°C - 26°C) and while the relative humidity (40.7%) is within recommended guideline values (30%–70%). Results from the analysis carried out found weak positive correlations between $PM_{2.5}$ the main building orientation and orientation of window opening). Meanwhile, weak negative relationship was found between $PM_{2.5}$ and the type of housing unit, type of window, window size and other variables such as type of cooking fuel, main source of lighting and size of household. In the case of PM_{10}, weak positive relations were observed with only the main building orientation, orientation of window opening and other variables such as type of cooking fuel and main source of lighting. For CO_2, weak positive relationship were only noted for main building orientation and type of housing unit. $PM_{2.5}$, PM_{10} and CO_2 were subjected to Point Biserial Correlation with the reported ailments (Table 1). Findings shows that $PM_{2.5}$ was negatively correlated to the occurrence of most of the ailments but was positively correlated to TB, meningitis and chicken pox. However, none of the relationship has p-value less than 0.05; thus not significantly correlated to $PM_{2.5}$.

Table 1: Correlation between $PM_{2.5}$, PM_{10}, CO_2 and incidence of health complaints.

Variables	Participants' Responses	F	%	$PM_{2.5}$		PM_{10}		CO_2		Remarks	
				R_{pb}	Sig	R_{pb}	Sig	R_{pb}	Sig	No response	Total
Tuberculosis	No	63	45.3	0.093	0.452	0.097	0.431	-0.047	0.703	48	116
	Yes	5	4.3								
Pneumonia	No	52	44.8	-0.080	0.510	-0.044	0.714	0.136	0.257	45	116
	Yes	19	16.4								
Asthma	No	63	54.3	-0.074	0.541	-0.068	0.577	0.085	0.482	46	
	yes	7	6.0								
Meningitis	No	52	44.8								116
	Yes	16	13.8	0.050	0.683	0.003	0.982	-0.008	0.948	48	
Measles	No	48	41.4								116
	Yes	19	16.4	-0.35	0.777	-0.114	0.360	0113	0.362	49	
Chickenpox	No	49	42.2								116
	Yes	24	20.7	0.177	0.133	0.285	0.014	0.081	0.494	43	
Influenza	No	28	24.1								116
	Yes	55	47.4	-0.115	0.299	0.055	0.622	-0.161	0.146	33	
Malaria	No	3	2.6								116
	Yes	100	86.2	-0.072	0.470	0.022	0.827	-0.008	0.939	12	

Similarly, PM_{10} was negatively correlated to the occurrence of Pneumonia, Asthma and Measles but positively correlated to the incidence of other reported ailments. In most of the cases none of the relationship has its p-value less than 0.05 except for chicken pox where $R_{pb} = 0.285$, $p < .05$. This implies that most of the disease occurrences are not significantly correlated to PM_{10} except for Chicken pox. The result for CO_2 is also similar to $PM_{2.5}$. The occurrences of some of the ailments were negatively correlated with CO_2 while others were positively correlated with none of the correlation values possess values less than 0.05 and hence are not significant. The building characteristics were cross-tabulated with the incidence of the reported diseases to explore the association between them; Chi- square values and Fishers' exact test were computed at 0.05 level of significance. The results show that that the main building orientation is significantly associated with the incidence of Measles ($p<0.02$), Meningitis ($p< 0.03$) and TB ($p< 0.04$). Meanwhile the building floor materials are significantly associated with Meningitis ($p<0.01$), Measles ($p<0.02$) and influenza ($p<0.002$) the materials used for floor covering. Their odds ratio are less than 1 implying that as the floor material improves from earth, wood, cement and to rug, the odds of incidence of the three ailments are reduced. Meanwhile, logistic regression analyses of the diseases along with indoor air quality shows no relationship with CO_2. However, PM10 shows significant relationship with chicken pox (Wald = 4.029, p = .045) and Influenza (Wald = 4.002, p = .045); while $PM_{2.5}$ (Wald = 6.263, p = 0.012) is significantly related to Influenza. Similar result was found with the number of bedrooms available in the building. PM_{10} shows significant relationship with chicken pox (Wald = 3.890, p = .049) and Influenza (Wald = 3.987, p = .046); while PM2.5 (Wald = 5.726, p = 0.017) only show significantly relationship with Influenza.

4 DISCUSSION

This cross-sectional survey is a pilot study employed to uncover the prevalent factors in NVRBs design associated with PM, CO_2 and occupant's health with particular reference to meningitis and other diseases. In this study, elevated indoor concentration of PM was recorded and the possible explanation for this could be as a result of source of energy used by the households for cooking (i.e. firewood, charcoal and kerosene). Other major particle sources could also have been from the use of candles for lighting, unpaved roads and lack of green areas around the buildings. Although this study did not measure PM over a long-term period, however, the levels of PM within the buildings exceeded the WHO Guidelines (i.e. 24-h mean) for PM2.5 (25μg/m3) and PM10 (50μg/m3) respectively. Surprisingly, this study did not find any significant association between the elevated PM in the indoor environment and several reported illness except for Chicken pox and influenza. This agrees with the findings of Bruce (2000) that most studies from developing countries failed to demonstrate a significant association between indoor air pollutants and certain illnesses. This is due to some reasons such as methodological limitations and small sample size to detect a strong association between the variables investigated; this the authors believe is the case in the current study. Other possible limitations that could have also affected the results is the fact that indoor air quality and CO_2 was monitored between 8-12hr in contrast to 24hr recommended by WHO. Further, findings in this study also suggests the buildings tend to be well ventilated, with average CO_2 levels in bedrooms rarely surpassing 1000ppm. This reason for this could be as a result of multiple interacting factors such as the way the occupants operated their buildings, many houses are within a secured fenced and around a courtyard. This allows households to leave their windows opened for long hours both night and day. This behaviour is common especially with occupants of NVRBs in Nigeria due to its tropical climate. Hence, PM from biomass and kerosene used in the buildings could become easily diluted by natural ventilation thereby reducing its effect on occupant's health. While at the same time the ambient air pollution from the surroundings could adversely impact indoor air quality.

5 CONCLUSIONS

This pilot study demonstrates association between certain building characteristics (i.e. the building orientation, wall and floor materials, housing type and number of rooms) as potential risk factors in NVRBs for certain diseases (i.e. Meningitis, Measles, Chicken pox and Influenza). Meanwhile, the PM were associated with Chicken pox and Influenza. Findings from this study can be used for future intervention studies. However, a large-scale with large sample size is recommended along with continuous measurements of indoor PM and CO_2. This is essential to capture the full range of air quality measurements and their association with occupant's health outcomes over time and space. Intervention studies have proved that poor indoor air quality can be improved significantly by using different intervention strategies such as improved ventilation through enlarged windows and introducing chimneys and smoke hoods into the kitchen design. Such intervention studies could improve scientific basis for developing a simplified tick-box style assessment framework, which in future could provide a meningitis risk analysis tool for local healthcare workers based on building type and window size assessment. This could potentially dispense with lengthy health questionnaires or environmental monitoring.

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