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Investigation of Indoor Air Quality of Residential Buildings in Enugu, Nigeria

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Abstract

Consideration of indoor air quality is a known practice in building and home design in developed Countries, and appropriate measures are taken during design for residential health. This is not so in developing economies. There is a dearth of research work on indoor air quality. Yet there is high level of exposure of the population to indoor air pollutants in residential buildings in these regions of the world. Building designers are yet to consider this problem in their designs. A major cause of indoor air pollution is the traditional method of cooking using dirty fuels. At present, no designs in these regions take cognizance of the use of these dirty fuels. This study addresses the problem of indoor air pollution of residential buildings in these areas. The study adopts 'International Environmental Protection Agencies' Evaluation Methodology, involving the use of Building Physics Equipment; Light House Laser Particle Counters; Carbon Monoxide and Extech DCO 1001, that measures particulates, carbon monoxide, indoor relative humidity, indoor temperature, and carbon dioxide quality respectively. Subjective assessment using questionnaire is also adopted. The data were analyzed with Statistical Package for the Social Sciences (SPSS). The results reveal that indoor air quality problem is common in the study area. The major pollutants identified in the study included: gases, steam, particles of dust and fibers, most of which are from internal indoor combustions. The result of the analysis also reveals that the factor loadings yielded a high cumulative percentage of the measured variables, in other words, a high concentration of the pollutants in the indoor air mass. The study recommends a new approach in residential buildings design that ensures immediate removal of indoor air pollutants from their source of generation.

Keywords: Residential buildings; Indoor air quality; Evaluation and testing methodology; Air pollutants

Introduction

Since ancient times, man had to contend with natural environment's hostilities, and the necessity to protect him from their effects. The protection measures resulted in shelter and building construction. One of the basic requirements of any building is the control of its internal environment and the satisfaction of the occupants' physical and physiological needs. Heerwagen and Markus posited that apart from comfort and performance, health is a major criterion for constructing buildings and residential environments [1,2]. Burbery and US Environmental Protection Agency (1980) reported that a growing body of scientific evidence has demonstrated that the air inside homes is typically more polluted than outdoor air, regardless of whether homes were in rural or industrial areas [3,4]. Hazards in indoor environments include biological and chemical contaminants as well as poor ergonomics, lighting, and physical design [5]. World Health Organization (2000) posits that indoor air pollution on a worldwide scale is responsible for more than 1.6 million annual deaths and is the biggest environmental contributor to ill health behind unsafe water and sanitation. United State Environmental Protection Agency (1980) concludes that the interior atmosphere is a critical design criterion for functional environments, more especially now that it is a known fact that people in modern societies spend more than 90% of their time indoors [5,6].

Gilbert asserts that we are exposed to chemicals and particulates in the air we breathe, which is mostly inside of buildings, where we spend almost all of our time. The fuels are often burned in homes without chimneys or proper channels for ventilation. Women and their infant children are often exposed to extremely high concentrations of particulates and other products of combustion for lengthy periods of time. The design of their buildings has not given any special attention to this problem. This is more serious in developing countries, where there are no studies and considerations in this regard [7].

The situation is made worse by the high humidity, high temperature and high dust concentration that characterize the climatic region over the South East geopolitical region of Nigeria. The attachment of the people to traditional food delicacies, its lengthy period of preparation/cooking with dirty fuels like wood, animal dung, kerosene and charcoal pose serious indoor pollution problems in residential buildings in the region. The result of this indoor air pollution is elevated levels of acute respiratory infections (ARI) and death in children. A number of studies, corroborated the results of indoor exposure to smoke [8,9]. The enormous bad effect is summarized by Anosike, (2015) when he asserted that about one thousand Nigerians die every year as a result of inhalation of toxic smoke from various household cooking and power generating appliances.

Unfortunately, residential design of buildings in the study area has always concentrated only on functional space organizations and relationships and on thermal comfort measures. There are no studies directed towards possible sources of indoor air pollution, and studies of the measure of indoor air pollution, the extent and dimension of indoor air pollution, and possible design measures to reduce and minimize indoor air pollution in residential buildings in the study area. This is what the study is seeking to investigate.

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Air and Indoor Pollution

Simply put, Air is a mixture of gases that surround the earth which we breathe. It is the space above the ground or that is around the earth and about things. According to Santosh, an average human being requires about 12kg of air each day, which is nearly 12 to 15 times greater than the amount of food consumed. From these, one can deduce that indoor air is that which surrounds us in any given enclosure or space, evidently very essential for human health and survival. Sometimes the purity of air can be impaired with refuse material, odors and some other noxious chemicals and particulates otherwise called pollutants [10].

According to Aerias, indoor air can be 100 times more polluted than outdoors. On their part, Institute of Medicine, (2000) asserts that hazards in home environments are the sites of a variety of biological, chemical, and other environmental hazards [11,12]. Biological hazards include infectious agents such as bacteria and viruses, molds, endotoxins, and antigens from house dust, mites, rodents and animal's dander. Chemical hazards include environmental tobacco smoke (ETS), nitrogen and sulfur oxides, ozone, particulate matter (PM), volatile organic compounds (VOCS), pesticides, formaldehyde, and plasticizers. Exposures to these agents are influenced by chemicals used in building materials, furniture, and other household items; everyday practices such as heating, cooking, cleaning and home repair; and spontaneous chemical reactions in the indoor environment [13,14].

According to Atkin, the term evaluation is an assessment of value, the act of considering or examining something in order to judge its value, quality, importance, extent or condition [15]. There are various definitions of the term, quality, by various Scholars as documented in literature, Crosby, Juran, Deming. From the documentation, one can deduce that quality deals with people's expectations and perception on how such expectations are satisfied within a predictable degree of uniformity and dependability. Thus the strong need for evaluation of indoor air quality of buildings and reliance on Air Quality Standards by American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE) standard 62-1989R; UK Health and Safely Executive Guidelines (EH40/95) and International Standard Organization (ISO 14644-1:1999) for moderation and implementation. Anything short of these set standards is regarded as non-satisfactory and hence poor. The result of non-adherence to these established standards within the study area is the major problem of building-related illnesses that leads to the 1.6 million deaths annually from poor indoor air quality as reported by World Health Organization, (2000) [16,17].

Study Area

The study area is Enugu State, Nigeria, with coordinate ranges, 6.20° N to 6°30'N and 7°25 E to 7°30'E. Enugu has a warm-humid climate characterized by two main seasons (Dry and Rainy Seasons). It experiences constant high temperatures and high relative humidity with low wind speed throughout the year. The temperature ranges from 23-27°C with maximum value of 30-34°C, and mean relative humidity value of 84%. The rainy season lasts from April to November, and dry season is from November to March. The 2006 census record has the population of Enugu as 722,664.

The Study Methodology

Convenience sampling method was employed because of experimentation (using instruments to test). The test was conducted on a sample from the building population. The sample characterized the building types as models, each of which assumes similar features with others in the same category. At least two buildings were selected from the building types obtainable in the study area. Other conditions include period of occupation (buildings occupied for at least twelve months to have operated for a full seasonal cycle); type of dwelling; materials of construction; floor-ceiling height; type of fenestration, volume and others. These are some of the variables for the study. For proportionate distribution of the buildings from the subsisting residential building types within the study area, Bowley, formular as used in Ogbuene, on a sample size for known population was adopted (Table 1).

Objective and Subjective assessments were used for data collection. This is to help balance the strengths and weaknesses inherent in the Study [18].

Objective Measurement using Equipment

The objective of the experimental design was that the field survey should be conducted under various indoor climatic conditions and spanned over a period of one full year. The field survey was designed in such a way to ensure accurate records. This is to provide an accurate and more representative evaluation of the population under study. Each house was visited for a minimum of two times [19,20].

Light house Laser Particle Counter and Extech DCO 1001 Building Physics Equipment were used to measure Particulates and concurrently indoor Relative Humidity, indoor Temperature and Carbon Dioxide respectively. The equipments were placed on a stool about 1.0 m above the ground to record the indoor variables. The Light House Laser Counter measures 0.03, 0.05 and 5.0 u particulate counts respectively at intervals of 60 seconds with a minimum of five trials done on a particular time and case, to produce a cumulative result. Each procedure was recorded in an in-built spread sheet format, and then retrieved and stored in a computer after every successive exercise. Handheld Carbon Monoxide Monitor was used to measure the level of carbon monoxide in any particular case. The Extech CO_2 Monitor was used to measure concurrently indoor carbon dioxide together with the physical data of indoor temperature and relative humidity with high sensory accuracy of ±5% of reading or ±75 ppm, ±0. ±0.5°C/0.9°F and ±5% respectively [21].

Subjective Assessment Using Questionnaire

This consists of a questionnaire administered to a group of residents in the study area addressing indoor relative humidity preferences and acceptability ratings as well as other factors playing roles in indoor air quality. The data from the questionnaire and survey and indoor environment characteristics were analyzed with Statistical Package for the Social Sciences (SPSS).

S/No	Building type	Total no	Distribution of buildings
1.	Flat	69593	2
2.	Traditional Building	28237	0.66
3.	Single Maisonette	309980	7.2
4.	Single Maisonette with Garage	154990	3.6
5.	Semi-detached Maisonette	28282	0.66
6.	Semi-detached Maisonette with Garage	14141	0.33
7.	Bungalow with Garage	32403	0.76

Source: Author's filed Study, (2015).

Table 1: Distribution of selected residential buildings in Enugu.

Data Analysis

The data analysis used Principal Component (PCA) on Carbon Monoxide (CO), Carbon dioxide (CO_2) and Particulate of 0.3, 0.5 and 5.0 micron count. The result of PCA includes descriptive statistics, Kaiser-Meyer-Olkin (KMO) and Bartlett's Test, Communalities, Total variance explained, Screen Plot and Component Matrix (Table 2).

The Table 2 above displays the descriptive statistics for the variables. The mean ± standard deviation for carbon dioxide is 121.146 ± 159.27, for carbon monoxide is 654.24 ± 173.68, for particulate 0.3 microns count is 269916.74 ± 5.00, for particulate 0.5 microns count is156364.71 ± 3.89 and particulate 5.0 microns count is 1797.80 ± 2254.23 (Table 3).

The Kaiser-Meyer-Olkin Measure of Sampling Adequacy is a statistic that indicates the proportion of variables that might be caused by underlying factors. A value of 0.563 generally indicates that a factor analysis is appropriate for the data. Bartlett's Test of sphericity indicates that the correlation matrix is not an identity matrix (P = 0.001), which means that the variables are related and therefore suitable for structure detection (Table 4).

Communalities indicate the amount of variance in each variable that is accounted for. Initial communalities are estimates of the variance in each variable accounted for by all components or factors. For principal components extraction, this is always equal to 1.0 for correlation analyses. Extraction communalities are estimates of the variance in each variable accounted for by the components. The communalities in this table are all high (greater than 0.5), which indicates that the extracted components represent the variables well (Table 5).

Variables	Mean	Std. Deviation	Analysis N
Carbon Monoxide	121.146	159.27069	41
Carbon Dioxide	654.2439	173.68143	41
Particulate 0.3 Microns Count	269916.739	5.00185	41
Particulate 0.5 Microns Count	156364.7146	3.87837	41
Particulate 5.0 Microns Count	1797.8	2254.2263	41

Source: Author's SPSS Principal Component Analyses, (2015).

Table 2: Descriptive statistics/data analysis.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.	8.863
Bartlett's Test of Sphericity Approx. Chi-square	42.978
Df	10
Sig	0

Source: Author's SPSS, Principal Component Analyses (2015).

Table 3: KMO and Bartlett's test.

Components	Initial	Extraction
Carbon Monoxide	1.000	0.718
Carbon Dioxide	1.000	0.579
Particulate 0.3 Microns Count	1.000	0.653
Particulate 0.5 Microns Count	1.000	0.843
Particulate 5.0 Microns Count	1.000	0.520

Source: Author's SPSS, Principal Component Analyses, (2015).

Table 4: Communalities and extraction method.

The total column gives the Eigenvalue, or amount of variance in the original variables accounted for by each component. The% of Variance column gives the ratio, expressed as a percentage, of the variance accounted for by each component to the total variance in all of the variables. So, factor 1 explains 53.122% of total variance while factor 2 explains 28.144%. The first factor explain larger amount of variance whereas the second factor explain smaller amounts of variance. According to Kaiser's criterion, retain all factors with eigenvalues above 1 and 0.6 average communality. Therefore all factors with eigenvalues greater than 1, were extracted which leaves only 2 factors.

The eigenvalues associated with these factors are again displayed and the percentage of variance explained in the columns labeled Extraction Sums of Squared Loadings. The cumulative percentage for the two components is 81%. This explains the 81% of the variability in the original 5 variables, so we can considerably reduce the complexity of the data set by using these components, with only a 19% loss of information. In the final part of the table (labeled Rotation Sums of Squared Loadings), the eigenvalues of the factors after rotation are displayed. Rotation has the effect of optimizing the factor structure; however some changes occurred after the rotation. The rotation maintains the cumulative percentage of variation explained by the extracted components, but that variation is now spread more evenly over the components. The changes in the individual totals suggest that the rotated component matrix will be easier to interpret than the unrotated matrix (Figure 1).

The scree plot helps to determine the optimal number of components. The eigenvalue of each component in the initial solution is plotted. Generally, the first two components on the steep slope were extracted. The components on the shallow slope contribute little to the solution (Table 6).

Finally, the rotated component matrix (also called the rotated factor matrix in factor analysis) which is a matrix of the factor loadings for each variable onto each factor shows factor loadings greater than 0.5 and sorted by order of size. The result reveals two factors (components) and variables load very highly onto only one factor with the exception of one. The variables that load highly on factor 1 are particulate 0.5, 0.3 and 5.0 microns count, while variables that load highly on factor 2 are carbon monoxide and carbon dioxide. The foregoing suggests that there is presence of high indoor air contaminants in these residential homes studied, and there is a pattern of indoor air quality within residential buildings in the study area.

Recommendations and Conclusion

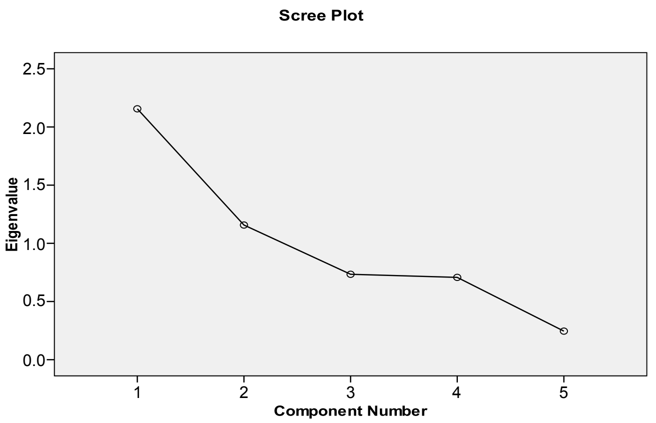
The study makes the following recommendations:

- Building occupants, management and maintenance personnel should endeavour to understand the causes and consequences

Component	Initial Eigenvalues			Extraction Sums of Squared Loading			Rotation Sums of Squared Loading		
	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%	Total	% of Variance	Cumulative%
1.	2.156	53.122	53.122	2.156	53.122	53.122	2.026	50.517	50.517
2.	1.157	28.144	81.267	1.157	28.144	81.266	1.287	30.749	81.266
3.	0.734	10.679	91.949	-	-	-	-	-	-
4.	0.707	4.146	96.092	-	-	-	-	-	-
5.	0.245	3.908	100.000	-	-	-	-	-	-

Source: Author's SPSS, principal Component Analyses (2015).

Table 5: Total variance explained.



Source: Author's SPSS, Principal Component Analyses (2015).

Figure 1: Showing the scree plot.

Component	Component factors	
	1	2
Particulate 0.5 microns count	0.892	
Particulate 0.3 microns count	0.808	
Particulate 5.0 microns count	0.721	
Carbon monoxide		0.844
Carbon dioxide		0.725

Source: Author's Component Rotated Matrix[a], (2015). SPSS, Principal Analyses (2015).

Table 6: Principal component analysis-rotated component matrix.

of indoor air quality problems, and then work together to prevent or reduce the problems;

- Kitchen and toilets in residential buildings need to be modified and flexible designs adopted to give occupants control over their interior environment for provision of healthy homes; removal of Pollutant source should be an effective approach to resolving indoor air quality problems, and
- Pollutant loads should be documented and considered part of residential building design process as well as building management process; Such documentation should be included among materials submitted for building approval process.

The deductions from this study are expected to lead to better understanding of the indoor air quality causative elements from cooking with dirty fuels in the study area. There is urgent need to develop new building design approaches to create healthy homes in South East Nigeria.

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