Journal of Contemporary Research in the Built Environment ISSN: 2636-4468
Volume 6, Number 1, March 2022

EVALUATION OF AIR POLLUTANTS CONCENTRATION IN THE INDOOR SPACES OF PRINTING PRESSES IN ZARIA METROPOLIS

Olugbenga Ayeni[1], Emmanuel Chongcicimmi Ibrahim[1], Andrew Mhya Stanley[1], Dalhatu Abdulsalam[1], Ibrahim Isah[1], Fadila Muhammad Lawal[1] and Victor Onoja Agada[2]

[1]Department of Building, Ahmadu Bello University, Zaria, Kaduna State, Nigeria
[2]Department of Quantity Surveying, Ahmadu Bello University, Zaria, Kaduna State, Nigeria

ABSTRACT

Purpose: Indoor Air Quality (IAQ) is becoming an increasingly important building design consideration due to the growth in occupants' health and comfort problems attributed to indoor air pollution (IAP). This study evaluated the concentration of indoor air pollutants in the built spaces of printing presses within the Zaria metropolis with the view to improving the IAQ of this built environment.
Design/methodology/approach: The study adopted the quantitative research method. Twenty-two (22) printing presses were studied during active periods of printing to identify air pollutants. Concentration levels were measured and compared against the National Environmental Standard and Regulatory Enforcement Agency (NESREA) standard for excellent IAQ. Handheld Air quality meter, Carbon monoxide meter, and Ozone concentration meter were used to measure the mean concentration levels of nine (9) IAQ indicators; Temperature, Relative humidity, Carbon monoxide (CO), Carbon dioxide (CO_2), Total volatile organic compound (TVOC), Formaldehyde (HCHO), Particulate matter ($PM_{2.5}$ and PM_{10}), and Ozone (O_3). Data collected in this study were analysed using descriptive and inferential statistics.
Findings: The concentration of the air pollutants in the printing presses were in the range: Temperature (25-67-33.67ºC), RH (56.33-85.00%), CO (0.00-31.00ppm), CO_2 (533.67-1425.33ppm), TVOCs (0.113-9.999mg/m^3), HCHO (0.015-0.078mg/m^3), $PM_{2.5}$ (21.33-426µg/m^3), $PM_{10,}$ (28.00-568µg/m^3), and O_3 (0.00-0.05ppm). The mean concentration of temperature, RH, TVOC, HCHO, $PM_{2.5,}$ and PM_{10} exceeded the acceptable threshold of the NESREA standard in about 60% of the assessed presses.
Research limitations/Implications: Based on the air pollutant concentration levels recorded in this study, printing press operators and users in the Zaria metropolis are at risk of developing some health-related problems.
Practical implications: Regular IAQ assessment by press owners, inspection by regulatory bodies, and installation of IAQ monitoring or capture systems are recommended to achieve good IAQ levels as well as improve occupants' wellbeing in the assessed printing presses. **Originality/value** – The result of the study revealed the need to control the concentration of air pollutants in the printing presses in the Zaria metropolis as the measured concentration of air pollutants poses a major health threat to users of the facilities.

Keywords: Air Pollutant; Health; Indoor Air Quality (IAQ); NESREA standard; Printing press.

[1]*gbengabuilds@gmail.com*

1. INTRODUCTION

In recent years, indoor air quality (IAQ) has received a great deal of attention due to rising pollution levels and its associated health challenges in the built environment (Spiru and Simona, 2017; Atarodi, Karimyan, Gupta, Abbasi and Moradi, 2018; Abdullah, Abd-Hamid, Ismail, Ahmed and Mansor, 2019). It is one of the sub-domains of indoor environmental quality (IEQ) that affects human life inside a building where approximately 90% of daily time is spent (Silva *et al.*, 2016; Mujeebu, 2019). According to Slezakova, Peixoto, Pereira, and Morais (2018), as people spend this large percent of their daily time indoors either at home or in the workplace, the rising level of exposure to indoor air pollution (IAP) is a concern.

Annually, according to the statistic from World Health Organization (WHO) (2016), 4.3 million people die prematurely as a result of IAP. It is also mentioned that IAP is the "world's largest single environmental health risk" and as such, the importance of air quality in any indoor built space cannot be overemphasized as it greatly impacts the total well-being and productivity of users of a space or facility.

In the built environment, studies continue to evolve to characterize the indoor air by identifying parameters, harmful chemical species, pollutant composition, and concentration levels in the indoor space (Abdullah, Abd-Hamid, Ismail, Ahmed and Mansor, 2019; Omole, Mbamali and Abdulsalam, 2020). The key parameters responsible for the decline in the quality of air within the indoor environment have also been studied (Atarodi *et al.*, 2018). The parameters that determine the quality of air in the indoor space have been identified to include comfort parameters such as Temperature and Relative humidity (RH), harmful chemical species such as Carbon dioxide (CO_2), Carbon monoxide (CO), Particulate matter ($PM_{2.5}$ and PM_{10}), Total Volatile Organic Compounds (TVOCs), Formaldehyde (HCHO), Ozone (O_3) and Radon (Rn). These air pollutants in the indoor environment are either allergenic, irritants, carcinogenic, immunotoxic, neurotoxic, or sick building syndrome (SBS) indicative (Ismail, Deros1 and Leman, 2010). According to Atarodi *et al.* (2018), some of the factors that influence the concentration levels of these air pollutants in the indoor environment include the indoor pollutant source emission rate, the concentration of outdoor pollutants, ventilation rate, rate of removal of harmful chemical species and associated rate of transformation of pollutants.

The possible impact of these IAQ parameters on an individual's health and strategies for controlling pollutant concentration have also been reported (BCA, 2010; EPA, 2016; WHO, 2016; Adamovic, Pincjer and Adamovic, 2018; Levesque, Huppe, Dube and Fachehoun, 2018). Some of the short-term or long term health-related problems users of an indoor environment may likely suffer include discomfort, headache, shortness of breath, dizziness, sweating, restlessness, tiredness, mucous membrane irritation, fatigue, brain damage, heart problems, asthma attack, inflammation of the airway, lung irritation and diseases, cancer, liver, kidney or central nervous system damage.

The printing press is one of the prints and paper industries that suffer from poor IAQ (Kiurski *et al*., 2013; Adamovic *et al.*, 2018). It is well established that in the printing process, the release of harmful and hazardous substances takes place which often time, is a threat to human health. According to the Environmental Protection Agency (EPA) (2021), the printing industry's pollution is predominantly released into the air. In the year 1993, the printing industry released about 99 percent of its total Toxic Release Inventory (TRI) poundage to the air, while the remaining one percent of releases were split between water and land disposal. Emissions from printing operations result primarily from the evaporation of organic solvents contained in the inks. Most of the solvent contained in the ink evaporates during the process, although some solvent may remain with the printed product leaving the facility. The organic solvents used in the ink may be Volatile Organic Compounds (VOC) or Hazardous Air Pollutants (HAP). In general, the emissions points from a printing line (operation) include the ink fountain, the press, the drier, and the chill rolls. However, the actual emissions points vary by the type of printing operation (EPA, 2021). Typically, a large fraction of the emission is associated with exhausts from ink in the drying units (drier).

According to Kiurski *et al.* (2013), the health problems employees of printing presses suffer can be connected to the pollution of the printing indoor space, hence, making it imperative to evaluate the exposure levels to pollutants such as VOCs, formaldehyde, ketone, toluene, benzene, and ozone amongst others. These chemical contaminations emanate from different emission sources like printing inks, cleaning solvents, adhesives, coatings, and printing equipment/machines operations like washing, binding, finishing, and pre-pressing. However, as reported by Adamovic *et al*. (2018), the intensity of the chemical pollution within this facility may be affected by the type and quantity of chemicals used, conditions of the ambient air, type and capacity of aspirators, and the dimensions of the printing facility. The authors go on to say that the indoor environment in a printing facility, once polluted, could affect the health and total well-being of users of such a facility, contaminate other materials within the environment, increase odours, reduce the level of workers' productivity, discolour surrounding materials and electronic equipment, and cause poor work production.

While achieving good IAQ in different indoor spaces is an environmental and health problem in the built environment, there are just a few previous researches on the assessment and evaluation of IAQ in printing facilities in Nigeria. This study investigates the quality of the indoor air of selected printing presses in Zaria metropolis, Kaduna State. The concentration of Nine (9) air pollutants (temperature, relative humidity, CO_2, CO, TVOC, HCHO, $PM_{2.5}$, $PM_{10,}$ and O_3) in the indoor spaces of the printing presses in the study area were evaluated during the active printing operations. The study also establishes the air pollutants posing health risks to users of this indoor environment.

1.1. Research Hypothesis

The hypothesis investigated in this study is:

H_0: $\mu = \mu_0$ (There is no statistically significant difference in the mean indoor concentrations value of air pollutants across the printing presses in Zaria metropolis).

H_1: $\mu \neq \mu_0$ (There is a statistically significant difference in the mean indoor concentrations value of air pollutants across the printing presses in Zaria metropolis).

Where μ and μ_0 are population means corresponding to the mean concentration of air pollutants.

2. Literature Review

2.1. An Overview of Indoor Air Quality

Providing quality air that is adequate, sufficient, and free of contaminants for building occupants is one of the most important functionalities of a building. Indoor air quality (IAQ), one of the subdomains of indoor environmental quality (IEQ), is one of the essential factors that determine the quality of an indoor space (Mujeebu, 2019). Indoor air quality is defined in terms of the presence or absence of pollutants (unwanted odorous, irritating, toxic gases, particles, and microbes) in a space. In every indoor space, IAQ may be seen to be acceptable or unacceptable. Acceptable IAQ as defined by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is one void of known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction (ASHRAE, 2007). According to Muhamad-darus, Zain-ahmed, and Talib (2011), IAQ is a term that refers to the quality of air within and around a building in relation to the health and productivity of its occupants. Bluyssen (2009) describes the concept of IAQ from two (2) points of view (human and indoor air points of view). From the human perspective, IAQ of built space is the physical effect of exposure of people to the indoor air of the space they are in contact with. On the other hand, from the indoor air point of view, IAQ is expressed in a certain ventilation rate (L/s per person and/or L/s per m^2 floor area) or concentration for specific compounds.

Indoor air quality is now becoming an increasingly important building design consideration due to the growth in occupants' health and comfort problems attributed to poor IAQ. According to Pecingina and Popa (2014), among the serious health implications of poor IAQ are lung cancer, carbon monoxide poisoning, legionnaires' disease, allergy, and asthma. There are two fundamental reasons IAQ study is so important in the built environment: contaminant concentrations are generally higher ie indoors than outdoors; most people spend most of their time indoors. Various sources of contaminants that lead to IAQ problems in the indoor environment include but are not limited to volatile organic compounds (VOCs), formaldehyde, biological pollutants, oxides of nitrogen and carbon, and particulate matter, mold, smoke, radon, pesticides, and combustion products. IAQ problems often arise from the interactions of variables such as building materials, building activities, climate, and building occupants (Kike-Parsis, 2018). As put forth by EPA (2016), IAQ problems may arise as a result of inadequate temperature, poor ventilation systems, indoor air contaminants, or insufficient outdoor air intake into a space. However, the different categories of pollutants that may likely affect the IAQ of indoor spaces have been classified as biological (bacteria, fungi, pollen, and animal dander), chemical (adhesives, cleaners, solvents, combustion by-products, and emissions from floor or wall coverings) and particulate (solid and liquid suspended in air) pollutants.

According to ASHRAE (2007), there are two major approaches to tackling IAQ issues in the indoor space of buildings: one is to increase the ventilation rate of the outdoor air into the building, and the other is to minimize or control air pollution sources within and outside the building. Having said that, the first strategy would work only when the outdoor air is clean enough to improve IAQ. In general, good IAQ is achieved by providing air that is reasonably free of contaminants that are odorous, toxic, or irritating.

2.2. Indoor Air Pollution in Buildings

Indoor air pollution (IAP) is the chemical, biological, and physical contamination of the indoor air. In another clime, it is the presence of foreign substances in the atmosphere away from the normal or an important change in the proportion of its components seen to be harmful or of direct/indirect impact on health (Pecengina and Popa, 2014). This type of air pollution is observed to be more dangerous considering how concentrated air is in the indoor environment. According to Stanley, Mbamali, Zubairu, Bustani, Andrew and Joshua (2010), IAP is one of the challenges the nation of Nigeria is currently facing amidst other social, environmental and economic challenges beclouding the country such as insufficient electric power supply, poor waste disposal system, water pollution, political unrest, noise pollution, and unemployment.

In environmental research, IAP is now seen as a serious concern to deal with due to the rising number of death cases. WHO has it that polluted air has a link with varying health issues in the built environment ranging from irritations to diseases or death. In some instances, poor indoor air has been shown to exacerbate chronic respiratory diseases (WHO, 2016). The primary causes of IAP in buildings are found to include: high temperature; high humidity; toxic chemicals and building materials/products (e.g., Asbestos, Formaldehyde, Radon, Paints, Aerosols, etc.), and inadequate ventilation amongst others. In developing countries, the main source of indoor air pollution is biomass smoke which contains suspended particulate matter (PM_5), Nitrogen dioxide (NO_2), Sulphur dioxide (SO_2), and Carbon monoxide (CO), Formaldehyde and polycyclic aromatic hydrocarbons (PAHs). According to Ambu, Chu and Mak (2008), the causative factors associated with IAP in buildings with their respective levels of contribution are inadequate ventilation (52%); contamination from inside the building (16%); contamination from outside the building (10%); microbial contamination (5%); building material contaminants (4%); and others (13%).

2.3. Indoor Air Pollutants

At a global level, the pollutants that determine the quality of air in the indoor space are:

i. Carbon monoxide (CO): this is a colourless, odourless, tasteless, and highly toxic gas quite hard to detect by humans. It is one of the indoor air stressors for determining the quality of the air in a built space. It is produced from the incomplete combustion of carbon compounds in processes that involves smoking, burning of wood, chemicals, petrol, or coal. This gas is one of the leading causes of fatal poisoning in many industries. Prolonged exposure to CO may cause an individual to experience angina and heart problems. In severe cases, it may lead to brain damage or result in death (WHO, 2016).

ii. Carbon dioxide (CO_2): this is a naturally occurring gas which at room temperature is odourless, colourless, and non-flammable. It is a major by-product of human respiration often utilized as an important indicator for evaluating the indoor air quality of an indoor environment and the performance of the ventilation systems therein. The level of CO_2 should be maintained in spaces by careful assessment of the efficiency of ventilation systems in the built spaces. Increased levels of CO_2 in indoor spaces can be attributed to inadequate ventilation systems. Long exposure to CO_2 can give rise to several health effects that include dizziness, restlessness, needles feeling, headaches, difficulty breathing, tiredness, sweating, elevated blood pressure, increased heart rate, convulsion, and coma (EPA, 2016).

iii. Formaldehyde (HCHO): this is a colourless gas with a strong characteristic odour commonly found in chemicals and building materials such as pressed-wood products (fiberboard, plywood, and particleboard); paper coating products; adhesives and glues; insulation products; ceiling tiles and permanent-press fabrics amongst others. HCHO easily dissolves in water and is easily broken down in the air. Formaldehyde when inhaled in large quantity may cause adverse health effects that include sensory irritation, concentration distraction, lachrymation, coughing, and death. Some studies have also shown that large exposure to formaldehyde may cause cancer (American Cancer Society, 2014; WHO, 2016).

iv. Nitrogen dioxide (NO_2): this is a gaseous air pollutant formed when nitric oxide is oxidized. In the gas phase, it has a pungent odour and its colour is reddish-brown. It is also volatile in the gas phase. When nitrogen dioxide reacts with water, it forms nitrous acid which is one common pollutant indoors. In the indoors, it is formed when natural gas or fossil fuels like wood burns at high temperature. NO_2 causes a wide range of harmful effects on the lungs including reduced lung function; increased asthma attacks; increased inflammation of the airways and worsened wheezing and cough. A new study has also linked NO_2 to an increase in the risk of premature death, cardiovascular harm, and lower birth weight (EPA, 2016; WHO, 2016).

v. Volatile Organic Compounds (VOCs): these are compounds with low solubility in water and high vapour pressure often being evaporated at room temperature in the indoor environment. VOCs are mostly human-made chemicals used in the production of paints, lacquers, and refrigerants. They are mostly found and emitted from by wide array of products such as office equipment like printers and copiers, building materials, furnishings, carpets, adhesives, and many others. The concentration of VOCs is considerably higher indoors than outdoor. Its impact on health may be short-term or long-term and may include throat, nose, and eye irritation, headaches, shortness of breath, fatigue, skin problems, and dizziness. At high concentrations, it may cause lung irritation, liver, kidney, or central nervous system damage (BCA, 2010; EPA, 2016).

vi. Particulate Matter (PM): is a mixture of small particles and droplets in the air that can result in health problems when inhaled. Some PMs are visible while others are not, except under a powerful electron microscope. The most common sizes are $PM_{0.1}$ (< 0.1 micrometres), PM2.5 (< 2.5 micrometres), and PM10 (< 10 micrometres). Dust, dirt, soot, or smoke are the PM common to indoors. Activities in the Indoor environment that act as sources of PM include cooking, cleaning (sweeping or vacuuming, and burning (candles, smoking, incense) (Nazaroff, 2004). Smaller particles of PM have the greatest health concern because they can easily travel deep in the lungs and cause heart and lung disease (Oberdorster, 2000). The populations most affected by PM exposure are people with lung disease, children, and older adults (Liu, Box and Kalman, 2008).

vii. Ozone (O_3): this is a colourless gas that is naturally produced in the atmosphere with a characteristic odour at very low concentrations. It is an unstable gas at high concentrations and due to its strong oxidizing ability, it is seen to be hazardous to humans. Depending on the exposure levels to O_3, it can cause cough, scratchy or sore throat, difficulty when breathing, inflammation of the airways, lung infection, and lung diseases such as chronic bronchitis, emphysema, and asthma. Ozone contaminants are emitted via electrical discharges in printing equipment (EPA, 2016).

2.4. Health Problems associated with Indoor Air Pollution

As asserted by Levesque (2018), numerous health effects are often attributed to exposure to indoor air pollutants. They include a broad range of minor to life-threatening and rare to common health issues. Respiratory illnesses are often the greatest concern. Respiratory ailments often begin with the growth of a micro-organism in the respiratory tract as the organism is being inhaled. In most instances, the organism is thought to be airborne. Infectious agents may include viruses, bacteria, and fungi. The most common is the rhinovirus and adenovirus, believed to be responsible for the vast majority of these respiratory illnesses. Other IAP health problems include Building Related Illness (BRI) and Sick Building Syndrome (SBS).

BRI is an illness or disease caused by exposure to airborne building contaminants. Some well-known BRIs includes Legionnaire's disease; Pontiac fever; Hypersensitivity pneumonitis; Humidifier fever and Lung cancer from radon. The factors that contribute to BRI may include poor building design, structure deterioration, and interior finishes

(Calvert, 2011). Generally, avoidance of further exposure to BRI is often recommended by taking appropriate measures. SBS on the other hand is a certain set of symptoms, users of an indoor space experience that tend to abate when they leave a particular building (Joshi, 2008; Calvert, 2011). It is a condition that makes occupants of a building uncomfortable, irritated or ill (Burroughs and Hansen, 2008). The elevated prevalence of the symptoms in a building is considered a piece of evidence that the building is responsible for causing the problems. SBS symptoms include the following (Kamaruzzaman and Sabrini, 2011):

i. General symptoms: fatigue, headache, nausea, dizziness, and difficulties in concentrating.

ii. Mucous membrane symptoms: itching, burning, or irritation of the eyes; irritated, stuffy, or runny nose, hoarse or dry throat; and cough.

iii. Skin symptoms: dryness, itching, burning, tightness, or stinging of facial skin, erythema (reddening of the skin); scaling, itching scalp or ears; or, dryness or itching of the hands.

2.5. Indoor Air Quality Regulatory Body in Nigeria

National Environmental Standards and Regulations Enforcement Agency (NESREA) is the environmental agency in Nigeria saddled with the responsibility of ensuring a cleaner and healthier environment for Nigerians (NESREA, 2014). The agency was established in the year 2007 and is one of the parastatals of the Federal Ministry of Environment. NESREA has recorded several achievements in the area of environmental compliance, monitoring, and enforcement since its establishment, including the enactment of several regulations about environmental protection, monitoring environmental compliance, and enforcement actions. The agency in the year 2014 made a regulation "National Environmental Air Quality Control Regulation" to provide improved control of the nation's air quality to such an extent that would enhance the protection of the flora, fauna, human health, and other resources affected by air quality deterioration. The regulation made provision for the maximum permissible limit values for certain pollutants in the air, minimization of emissions from the point source, adequate information on emissions, ambient air concentrations of pollutants in the air, as well as air quality trends, measures for the enhancement of and improvement of indoor ambient air. According to this regulation, the maximum concentrations of indoor air contaminants for public buildings shall conform to the limits prescribed in Table 1.

Table 1: Indoor air quality values for public buildings based on 8 hours average

Parameter	Unit	Excellent Class	Good Class
Temperature	^{0}C	20-25.5	<25.5
Humidity	%	40-70	<70
Carbon Monoxide (CO)	μg/m^3	<2,000	<10,000
	ppm	<1.7	<8.7
Carbon Dioxide (CO_2)	Ppm	<800	<1,000
Particulates Matter ($PM_{2.5}$)	μg/m^3	<15	<35
Particulates Matter (PM_{10})	μg/m^3	<20	<180
Total Volatile Organic Compounds (TVOC)	μg/m^3	<200	<600
	ppm	<87	<261
Formaldehyde (HCHO)	μg/m^3	<30	<100
	ppm	<24	<81
Ozone (O_3)	μg/m^3	<50	<120
	ppm	<25	<61
Nitrogen Dioxide (NO_2)	μg/m^3	<40	<150
	ppm	<21	<80

Source: NESREA (2014)

2.6. Study Area

The study was carried out in the metropolis of Zaria, a major city in Kaduna State, Nigeria. It is located in the Northern part of Nigeria, with a geographical position between North latitudes 11° 02' 00" – 11° 12' 00" and East longitudes 7° 36' 00" – 7° 46' 00", with an altitude of 500-700 meters above sea level and a total area of 300km^2. The study area is the education center of northern states, a nodal point of road and rail transportation, and a major collecting point for peanuts, shea nuts, hides and skins, cotton, and tobacco. Zaria is characterized by a tropical savanna climate with warm year-round weather, a wet season lasting from April to September, a dry season from October to March, a monthly mean temperature ranging from 14ºC to 39ºC, and annual rainfall of 1092.8mm. It is a medium-sized city with an estimated population of 736,000 and growth of 3.5% per annum and a density of 1,360.7 km^2 (NPC, 2006). Major printing activities take place in a cluster known as printing village around Club Street, Benin street, Lagos Street, Warri Street, Hospital Street, and Yoruba Street in Sabo, a well-known place in Zaria. Another cluster of the printing press is formed in Samaru.

3. METHODOLOGY

This study adopted a quantitative research design approach. The population of the study includes all functional printing presses with any of the: Multilith; Kord; GTO; and Sord-Z machines within the Zaria metropolis. There are 30 functional printing presses within the study area having at least one printing machine. The following selection criteria were used to get the sample size in this study;

i. Printing press should only be engaged in the printing of paper-related materials.
ii. Press-related operation should be part of the printing press's major activity.
iii. Printing press should have at least printing equipment such as the KORD, Multilith, GTO, and/or Sord-Z machine.
iv. The printing press should be in an enclosed space built of materials other than steel.
v. Printing press should be operational and accessible during IAQ assessment.

To assess the quality of the indoor air of the printing presses in the study area and the acceptability of the IAQ within set guidelines, only 22 printing presses from the population of this study met the selection criteria (i-v). Hence, measurements and assessments were carried out only in these 22 printing presses identified in the study area. Alphabets (A_1, A_2 ---A_{20}, B_1, B_2) have been used to represent the selected printing presses for anonymity. Data for this study were collected using a checklist and measuring equipment. A well-structured checklist was used to obtain relevant information specific to each printing press's indoor location. The field measurement data were obtained using an Air quality meter (TUYA WIFI), Carbon monoxide meter (AS8700A), and Ozone meter (DM502-O3) as shown in Figures 1, 2, and 3 respectively. Data on IAQ parameters were collected by adhering to certain measurement procedures. An appropriate sampling location in the indoor space of the printing presses was first determined. A 1m distance away from the printing equipment was deemed fit and used throughout the assessment. It is within this distance that most operators of the printing equipment perform printing operations and the concentration of IAQ parameters is expected to be high around this region. During air pollutant measurements, the various handheld equipment was held at a height of 1.5m above ground level. Before each measurement was performed, each of the measuring equipment was calibrated according to the manufacturer's instructions after which the equipment was held 1.0m away from the printing equipment and IAQ measurements were performed.

Measurements of pollutant concentration were performed in the time window 9:00a.m – 6.00 p.m. At least three (3) measurements were taken for each sampling session of the printing operation. The results were read and recorded on a sampling form as displayed on the screen of the instrument. All measuring equipment was recalibrated before the start of any new measurement to ensure the accuracy of results according to the manufacturer's guide.

Figure 1: Air quality meter **Fig. 2:** Carbon monoxide meter **Fig 3:** Ozone meter
Source: Field survey (2021).

Descriptive statistics and Inferential statistics were used to analyse the data collected. These statistics techniques were used to compare the means and significant levels of the pollutants. The obtained means were merged into one SPSS file for analysis. Inferential statistics (One-Way ANOVA) were performed to test the set hypothesis in the study H_0: $\mu = \mu_0$ "There is no statistically significant difference in the mean indoor concentrations value of air pollutants across the printing presses in Zaria Metropolis". A Probability value ($p<0.05$) was used to decide on the acceptance or rejection of the hypothesis in this study.

4. PRESENTATION AND DISCUSSION OF RESULTS

4.1. Printing Press Characteristics

The indoor air quality of built space is sometimes a function of the general space build-up and characteristics. Hence, to characterize the printing presses assessed for IAQ, a checklist was developed and used to gather information on the general characteristics of the various press facility such as floor area, the volume of space, number of employees, average occupancy, and production volume (Table 2).

As observed in Table 2, about 7 printing presses have floor areas above 20 m^2 with printing press B2 having the highest floor area (168 m^2). Fifteen printing presses have floor areas in the range of 5-20 m^2 with A9 having the least floor area (5.4 m^2). In terms of the volume of space, printing press B2 dominates with a space volume of about 1,008 m^3 while printing press A6 has the least volume of space (13 m^3). The high floor areas and space volumes recorded in these presses may facilitate ample ventilation flows, as well as, give more room for some IAQ pollutants, such as TVOCs, to diffuse easily in the presses. On average, about 20 of the printing presses have at least 2 employees working in the facility. In addition, 17 of the presses have an average occupancy of 3 persons with printing press A3 having the highest number (15 persons) followed by press B2 with 12 persons. The impact of occupancy in these presses will become significant if the mean concentration levels of CO_2 are observed to be above the limit set by NESREA. It can also be seen that printing press B2 records the highest production volume with an average of 100,000 papers printed per day. This high average daily production volume may suggest more release of pollutants from equipment sources which may, in turn, cause the concentration levels of IAQ parameters such as temperature, RH, and O_3 to rise.

Table 2: Printing press characteristics

Printing Press	Floor Area (m^2)	Volume of Space (m^3)	No of Employees (persons)	Average Occupancy (persons)	Production Volume (papers/day)
A1	14	44.8	5	3	30,000
A2	18	54	2	2	1,000
A3	21.4	60	10	15	2,000
A4	8	24	3	2	20,000
A5	7.2	16.6	3	3	10,000
A6	6.1	13	3	3	5,000
A7	7.5	18.8	2	2	10,000
A8	22.1	60.87	5	10	5,000
A9	5.4	12.96	3	3	2,000
A10	8.3	26.21	1	2	50,000
A11	10.5	31.5	6	4	10,000
A12	25.2	75.6	16	10	35,000
A13	7	21	2	3	10,000
A14	8.64	21.6	1	2	2,000
A15	17.5	52.5	3	5	20,000
A16	18	45	8	4	30,000
A17	11.88	35.64	3	3	10,000
A18	31.5	94.5	6	5	15,000
A19	19.5	58.5	7	5	20,000
A20	108	324	2	3	500
B1	72	252	12	9	30,000
B2	168	1,008	20	12	100,000

Source: Field survey (2021)

In addition, the type of ownership of the selected printing presses and the different types of printing machines installed are presented in Figures 4 and 5 respectively.

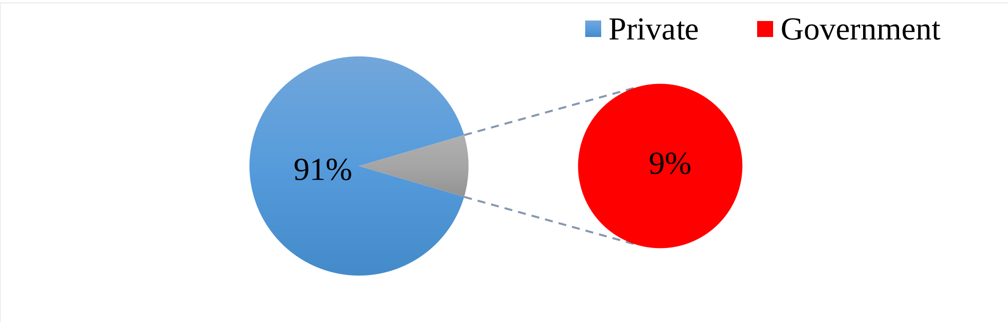

Figure 4: Ownership of Printing Press
Source: Field survey (2021)

From Figure 4, as it relates to ownership type, 91% of presses are privately owned while 9% are owned by the government. The ownership type may in some way influence the attitude of press owners towards IAQ management.

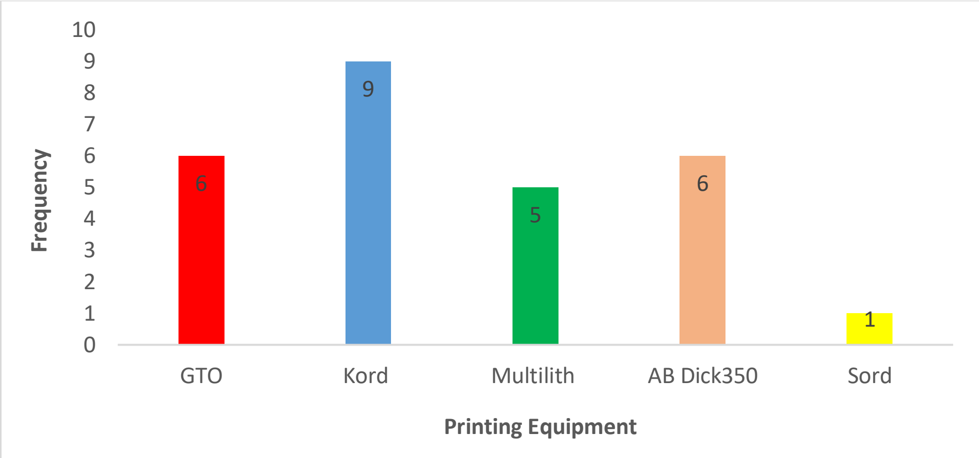

Figure 5: Printing Machines in Selected Printing Presses
Source: Field survey (2021)

As shown in Figure 5, the majority of the printing equipment installed across the printing presses are the Kord machines that print on A_2 paper. The GTO and AB DICK350 printing equipment were also installed across the selected printing presses which print on A_3 and A_4 paper respectively. Other printing machines as observed in the printing facilities are the Multiliths which print on A_4 and other smaller paper sizes.

4.2. Concentration Levels of IAQ Parameters in the Printing Presses

The mean concentration levels of temperature, relative humidity, carbon monoxide (CO), carbon dioxide (CO_2), total volatile organic compounds (TVOCs), formaldehyde (HCHO), particulate matters ($PM_{2.5}$, $PM_{10,}$), and ozone (O_3) of the 22 printing presses as measured using the well-calibrated IAQ handheld devices during the active printing activity times were evaluated and compared with limits as stipulated by NESREA and presented in Table 3.

4.2.1 Temperature and Relative humidity

From Table 3, it can be observed that the 22 printing presses have mean temperatures in the range 25.67-33.67 ^{0}C with presses A16 and A12 having the highest and least mean temperatures respectively. It is also evident that all the mean temperatures of the 22 printing presses did not fall within the acceptable temperature range as stipulated by the NESREA standard. The increase in the indoor air temperature may be attributed to heat generation or release from the various printing equipment. This increased temperature may cause press users to experience some form of dissatisfaction or discomfort when executing printing works.

For the relative humidity which is also a thermal comfort parameter of IAQ, increased values of R.H were seen across all the printing presses (A1-A20, B1-B2). Printing press B2 gave the least value for mean R.H while press A17 recorded the highest value of 85% which is the maximum value the handheld device can sense. In total, 13 printing presses (A6, A8, A9, A10, A12, A13, A14, A16, A17, A18, A19, A20, and B1) failed to meet the NESREA standard relative humidity range of 40-70%. As such, users of these facilities may likely experience some discomfort while the growth of molds in these presses may be promoted (Bluyssen, 2009).

4.2.2 Carbon monoxide (CO) and Carbon dioxide (CO_2)

Table 3 shows 8 printing presses (A1, A6, A7, A8, A9, A11, A12, and A14) having CO values (in the range of 5-31 ppm) exceeding the designated standard of NESREA for which CO value for an excellent class of IAQ should be <1.7 ppm. These recorded CO mean concentration levels in the printing presses could be attributed to outdoor CO pollutants sources such as generator and/or vehicular emissions. Prolonged exposure to these CO concentrations in the presses may cause users or operators of press equipment to experience fatigue, chest pains, angina, and/or heart problems (Kiurski, 2013). In severe cases, it may even lead to impaired vision, headaches, dizziness, brain damage, or result in death if concentration levels become high and exposure time lingers.

The 14 other presses (A2-A5, A10, A13, A15-A20, B1-B2) having 0 ppm CO values may be due to the availability of electrical power supply at the time of measurement, the distance of press facilities from vehicular emission sources or generators. Furthermore, it has been shown in Table 3 that the press with the highest and lowest mean concentration CO levels are A8 (31.0 ppm) and A1 (5.0 ppm) respectively. Looking at the mean concentration level of CO_2 across the printing presses as presented in Table 3, it is clear that 3 presses (A9, A11, and B1) with respective mean concentrations of 811 ppm, 1425 ppm, and 840 ppm did not meet the stipulated standard of NESREA where <800 ppm was stated as the ideal or allowable CO_2 concentration for an excellent class of indoor air. This high value of CO_2 recorded in these 3 presses may be due to inadequate ventilation and high occupancy density in the printing press. Impacts such as dizziness, restlessness, headaches, difficulty breathing, tiredness, sweating, and increased heart rate amongst others may be experienced by the users or operators of the various equipment in these presses (Kiurski, 2013).

4.2.3 Total volatile organic compounds (TVOCs) and Formaldehyde (HCHO)

As presented in Table 3, it is clear that 20 presses have mean TVOC concentration values exceeding the NESREA mark of <0.02 mg/m^3. Only 2 presses (A2 and A3) had values below the standard limit. In general, all the presses have mean values in the range of 0.113-9.999 mg/m^3. Maximum high concentrations of TVOCs (9.99 mg/m^3) as capable of being sensed by the handheld IAQ monitoring device were observed in presses A5, A8, A9, A11, A12, A17, and B2. The impacts of this extremely high mean concentration values of TVOC in the indoor space of the printing press may include short-term or long-term health risks such as throat, nose, and eye irritation, headaches, shortness of breath, fatigue, skin problems, and dizziness (BCA, 2010). At high concentrations, it may cause lung irritation, liver, kidney, or central nervous system damage.

According to the data captured in Table 3, the mean concentration values of HCHO were found to be high in 14 printing presses (A2-A6, A9, A11, A14-16, A18-A20). The formaldehyde (HCHO) levels of the printing presses evaluated for IAQ were in the range of 0.015-0.078 mg/m^3. The highest value of formaldehyde concentration was observed in press B2 with a recorded value of 0.078 mg/m^3. This exceeds the standard for HCHO specified by NESREA (<0.03 mg/m^3). Press A17 on the other gave the least HCHO concentration value of 0.015 mg/m^3. In addition, 8 printing presses (A1, A7, A8, A10, A12, A13, A17, and B_1) maintained low HCHO concentration values of 0.027 mg/m^3, 0.029 mg/m^3, 0.28 mg/m^3, 0.025 mg/m^3, 0.023 mg/m^3 ,0.023 mg/m^3, 0.015 mg/m^3, and 0.02 mg/m^3 respectively. Increased values of HCHO during the active times of printing may be attributed to emission sources such as printing inks, building materials, adhesives, and glues. Press users and operators may likely suffer sensory irritation, concentration distraction, lachrymation, or coughs during active printing times (Adamovic, Pincjer and Adamovic, 2018).

Table 3: Mean concentration levels of IAQ parameters in the printing presses

Printing Press	Variable/Pollutant								
	Temp. (^0C)	R.H (%)	CO (ppm)	CO_2 (ppm)	TVOC (mg/m^3)	HCHO (mg/m^3)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	O_3 (ppm)
A1	30.33	62.33	5.00	758.33	0.323	0.027	84.67	113.00	0.01
A2	32.33	69.67	0.00	658.33	0.113	0.031	42.00	46.00	0.00
A3	32.67	64.67	0.00	638.33	0.115	0.030	37.33	38.33	0.01
A4	32.00	62.33	0.00	661.00	0.788	0.034	29.00	36.33	0.00
A5	32.00	66.67	0.00	732.67	9.999	0.042	32.67	40.33	0.02
A6	33.00	74.00	19.00	746.33	4.707	0.050	78.33	92.67	0.00
A7	29.00	62.67	20.33	548.00	4.526	0.029	29.00	37.00	0.02
A8	32.33	71.67	31.00	558.33	9.999	0.028	36.67	41.33	0.03
A9	29.67	71.00	10.00	811.00	9.999	0.031	42.33	72.67	0.00
A10	30.33	80.00	0.00	603.33	0.551	0.025	31.00	43.67	0.00
A11	31.33	67.67	5.67	1425.33	9.999	0.033	50.67	63.67	0.02
A12	25.67	77.00	6.00	699.00	9.999	0.023	46.67	56.33	0.00
A13	26.67	83.67	0.00	630.33	6.831	0.023	58.33	53.67	0.00
A14	28.33	79.33	5.33	739.33	4.467	0.036	181.00	174.67	0.00
A15	32.67	69.67	0.00	540.33	2.454	0.036	43.33	37.00	0.05
A16	33.67	73.33	0.00	603.00	4.516	0.037	36.67	36.67	0.04
A17	31.33	85.00	0.00	586.67	9.999	0.015	25.33	32.67	0.00
A18	32.00	77.33	0.00	756.67	0.608	0.039	426.67	568.33	0.01
A19	30.00	84.00	0.00	646.67	0.564	0.031	67.33	92.67	0.03
A20	31.33	71.33	0.00	574.67	0.467	0.032	56.00	63.00	0.00
B1	28.00	74.67	0.00	840.00	0.741	0.029	36.00	44.67	0.01
B2	30.67	56.33	0.00	533.67	9.999	0.078	21.33	28.00	0.04
% exceeding Standard	100	59	36	14	91	64	100	100	0

NESREA Standard for excellent class IAQ: Temp. (20-25.5^oC), RH (40-70%), CO (<1.7ppm), CO_2 (<800ppm), TVOC (<0.20mg/m^3), HCHO (<0.030mg/m^3), $PM_{2.5}$ (<15µg/m^3), PM_{10} (<20µg/m^3), O_3 (<25ppm). Green – meets the NESREA Standard for excellent class, Red – did not meet the NESREA Standard for excellent class.

Source: Field Survey (2021)

4.2.4 Particulate matter ($PM_{2.5}$ and PM_{10})

Table 3 shows the mean concentrations of $PM_{2.5}$ and PM_{10} across all the printing press (A1-A20, B1-B2) assessed during active printing times where all measured and recorded values of $PM_{2.5}$ and PM_{10} were found to exceed respectively the <15 µg/m^3 and <20 µg/m^3 limits as captured in the NESREA standard. This was anticipated as mean concentration levels are expected to increase when printing equipment is in working condition as they are a potential source of particulate matter in the indoor environment. The highest recorded mean values of $PM_{2.5}$ and PM_{10} were observed in press A18 with respective values of 426.67 µg/m^3 and 568.33 µg/m^3. On the other hand, the press B2 gave the least mean concentration values of 21.33 µg/m^3 and 28.00 µg/m^3 respectively for $PM_{2.5}$ and PM_{10}. These observed high mean concentration values of particulate matter are detrimental to the health and total well-being of press users and operators. As these PMs are inhalable particles, they pose a high risk of being deposited on the airways or deeper parts of the lungs (Oberdorster, 2000). Based on these high values of PMs as shown across the 22 printing presses assessed, press users or operators may develop some health-related issues or risk factors such as respiratory symptoms, asthma attacks, and heart and lung problems. Other sources can be attributed to visible dust, dirt, printing machines, and the complex reactions in the built space of the printing press.

4.2.5 Ozone (O_3)

Across the 22 printing presses, it is revealed in Table 3 that about 12 presses had some degrees of ozone concentration as sensed by the IAQ ozone measuring device with concentration levels in the range of 0.01-0.05 ppm. No press had O_3 mean concentration values exceeding the <25 ppm limit as designated by the NESREA standard. Worthy of note also is the zero mean concentration levels of O_3 across 10 presses (A2, A4, A6, A9, A10, A12, A13, A17, and A20). With these O_3 values across the whole printing press during printing operation times, press operators or users may likely not have any health-related issues associated with high ozone concentration in the indoor space (Kiurski, 2011). However, caution must be taken or measures put in place to ensure values are kept as low as possible.

4.3. ANOVA of the Mean Concentration of IAQ Parameters during Active Printing Times

The hypothesis that was set in this study was tested using the one-way ANOVA. The result of the test is presented in Table 4.

Table 4: ANOVA of the mean concentration of IAQ parameters

ıp.			CO_2	TVOC	HO	.5	0	
53	86	49	6	1	3	3.56	1.34	9

Source: Field survey (2021)

As observed in Table 4, there were statistically significant differences between mean concentration levels of all IAQ parameters (temperature, relative humidity, CO, CO_2, TVOC, HCHO, $PM_{2.5}$, PM_{10}, and O_3) in the printing presses in the Zaria metropolis as determined by one-way ANOVA. The null hypothesis in this study is therefore rejected as all the respective p-values of the IAQ parameters were found to be less than the 0.05 alpha value.

5. Conclusion and Recommendations

In this article, the concentration of 9 air pollutants in the indoor spaces of 22 printing presses in the Zaria metropolis was evaluated. The study established that the concentration of the air pollutants in the printing presses were in the range 25-67-33.67°C, 56.33-85.00%, 0.00-31.00ppm, 533.67-1425.33ppm, 0.113-9.999mg/m^3, 0.015-0.078mg/m^3, 21.33-426µg/m^3, 28.00-568µg/m^3, and 0.00-0.05ppm respectively for temperature, relative humidity, CO, CO_2, TVOCs, HCHO, $PM_{2.5}$, PM_{10}, and O_3. The mean concentration of temperature, RH, TVOC, HCHO, $PM_{2.5}$, and PM_{10} exceeded the acceptable limits stipulated by the NESREA standard in about 60% of the assessed printing presses. The result of this study indicates that the concentration of these air pollutants in the indoor space of printing presses in the Zaria metropolis poses a major health threat to press operators and users and as such, they are at risk of developing some short-term or long-term health-related problems. Continuous monitoring of IAQ should be carried out regularly by printing press owners to enable them to receive real-time data on the levels of indoor air pollutants in their facilities as well as enable proper management of IAQ parameters in printing presses. More also, printing press owners in the study area should install at least an IAQ capture system such as ventilation hoods being that it controls IAQ in the indoor space to an extent as well minimize the impacts of IAP on users of the built space.

References

Abdullah, S., Abd-Hamid, F.F., Ismail, M., Ahmed, A.N., and Mansor, W.N.W. (2019). Data on indoor air quality (IAQ) in kindergartens with different surrounding activities. *Data in Brief*, 25, 1-5. https://doi.org/10.1016/j.dib.2019.103969.

Adamovic, S., Pincjer, I., and Adamovic, D. (2018). The impact of printing machines on indoor air quality. The University of Novi Sad. Pp 39-43 http://doi.org/10.2487/GRID-2018-p3.

Ambu, S., Chu, W., & Mak, J. (2008). Environmental Health and Building-Related Illnesses. *International e-Journal of Science, Medicine & Education (IeJSME)*(2), 11-18.

American Cancer Society. (2014). https://www.cancer.org/cancer/cancer-causes/formaldehyde.html Accessed on 6th June 2021.

Atarodi, Z., Karimyan, K., Gupta, V.K., Abbasi, M., and Moradi, M. (2018). Evaluation of indoor air quality and its symptoms in office building – A case study of Mashhaad, Iran. *Data in Brief*, 20, 74-79.

ASHRAE. (2007). *Ventilation for Acceptable Indoor Air Quality*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASHRAE. (2010). *Thermal environmental conditions for human occupancy*. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.

BCA. (2010). *Guidelines for Good Indoor Air Quality in Office Premises*. Building & Construction Authority: www.bca.gov.sg/greenmark/others/NEA_Office_IAQ_Guidelines.pdf.

Bluyssen, P. (2009). Towards an integrative approach of improving indoor air quality. *Building and Environment, 44*(9), 1980-1989.

Calvert, C. (2011). *Sick Building Syndrome & Building Related Illness.* Manchester: Fuss & O'Neill EnviroScience, LLC.

EPA. (2016). *Introduction to Indoor Air Quality*. https://www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality Accessed on 6th June, 2021.

EPA. (2021). Monitoring Information by industry Printing and publishing. Retrieved from https://www.epa.gov/air-emissions-monitoring-knowledgebase/monitoring-informationindustry-printing-and-publishing Accessed 6th June 2021.

Ismail, S.H., Deros1, B., and Leman, A. (2010). Indoor air quality issues for non-industrial workplace. International Journal of Research and Reviews in Applied Sciences: 5(3) Pp235-44.

Joshi, S. (2008). The sick building syndrome. *Indian Journal of Occupational and Environmental Medicine, 12*(2), 61-64.

Kamaruzzaman, S., and Sabrini, N. (2011). The effect of indoor air quality (IAQ) towards occupants' pscyhological performance in office buildings. *Design + Built, 4*(1), 49-61.

Kike-Parsis, A. (2018). *Indoor air quality*. Part 1- What is it: http://www.medscape.com/viewarticle/494503_4

Kiurski, J., Adamović, S., Oros, I., Krstić, J., and Đogo, M., (2011). Detection and quantification of ozone in screen printing facilities. *World Academy of Science, Engineering and Technology*, 51, 922–927.

Kiurski, J.S., Maric, B.B., Aksentijevic, S.M., Oros, I.B., Kecic, V.S., and Kovacevic, I.M. (2013). Indoor air quality investigation from the screen-printing industry. *Renewable and Sustainable Energy Reviews, 28 224-231.*

Liu, L., Box, M., and Kalman, D. (2008). Exposure assessment of particulate matter for susceptible populations in Seattle. *Environmental Health Perspectives, 111*(7), 909.

Levesque, B., Huppe, V., Dube, M., and Fachehoun, R.C. (2018). Impact of indoor air quality on respiratory health: results of a local survey on housing environment. *Journal of Public Health*, 163, 76-77. https://doi.org/10.1016/j.puhe.2018.06.015 Mujeebu, M.A. (2019). Introductory Chapter? Indoor Environmental Quality. In IntechOpen. Retr http://dx.doi.org/10.5772/intechopen.83612

Muhamad-darus, F., Zain-ahmed, A., and Talib, M. (2011). Preliminary Assessment of Indoor Air Quality in Terrace Houses. *Health and the Environmental, 2*(2), 8-14.

Mujeebu, M.A. (2019). Introductory Chapter? Indoor Environmental Quality. In IntechOpen. http://dx.doi.org/10.5772/intechopen.83612

Nazaroff, W. (2004). Indoor particle dynamics. *Indoor Air, 14*(7), 175-183.

NESREA. (2014). National Environmental Standard and Regulations Enforcement Agency (Nigeria).https://en.wikipedia.org/wiki/National_Environmental_Standards_and_Re gulati ons_Enforcement_Agency_(Nigeria) Accessed on 6th June 2021.

NPC. (2006). *Population. National Population Commission Census Report*. Nigerian Statistics Annual report:http://www.nigerianstat.gov.ng/nbsapps/annual_reports/CHAPTER%202.pdf

Oberdorster, G. (2000). Pulmonary effects of inhaled ultrafine particles. *International Archives of Occupational and Environmental Health, 74*(1), 1-8.

Omole, O.A., Mbamali, I., and Abdulsalam, D. (2020). Comparison of Indoor Air Quality in Eateries Within Zaria Metropolis. International Journal of Atmospheric and Oceanic Sciences; 4(1): 1-6. http://www.sciencepublishinggroup.com/j/ijaos. DOI: 10.11648/j.ijaos.20200401.11.

Pecingina, I.-R., and Popa, R.-G. (2014). Air Pollutants and the effects of on the human body. *Annal of "Constantin Brancusi" University of Tarju-Jui. Engineering series*, 213-218.

Silva, S., Monteiro, A., Russo, M.A., Valente, J., Alves, C., Nunes, T., Pio, C., and Miranda, A.I. (2016). Modeling indoor air quality: validation and sensitivity. *Springer*. Retrieved from https://doi.org/10.1007/s11869-016-0458-4

Slezakova, K., Peizoto, C., Pereira, M.C., and Morais, S. (2018). Indoor air quality in health clubs: Impact of occupancy and type of performed activities on exposure levels. *Journal of Hazardous Materials,* 359, 56-66.

Spiru, P., and Simona, P.L. (2017). A review on interactions between energy performance of the buildings, outdoor air pollution, and indoor air quality. *Journal of Energy Procedia*, 128, 179-186.

Stanley, A., Mbamali, I., Zubairu, I., Bustani, S., Andrew, S., and Joshua, I. (2010). Electric Power Generator Noise Level Characterization and Impact on Selected Commercial Areas of Zaria and Kaduna Nigeria, International Postgraduate Conference on Infrastructure and Environment. *The Hong Kong Polytechnic University*.

WHO. (2016). *WHO Guidelines for Indoor Air Quality: Selected Pollutants.* Copenhagen: WHO.