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Effect of Indoor Operational Environment on Workers' Well-Being in Industrial Buildings: The Case for Pharmaceutical Factory in Nigeria

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Abstract
In 2021, the worth of the pharmaceuticals market across the globe was estimated and projected to $1.17 trillion resulting in increasing pharmaceutical factories. Yet, less attention is given to the indoor operational environment of these buildings and the impact on the workers' well-being. To address these emerging concerns, this study investigated the indoor operational environment of pharmaceutical buildings. A field survey was conducted on purposively selected 14 pharmaceutical factory buildings in Southwestern Nigeria. Measurements of indoor environmental parameters were taken from the buildings with the aid of multifunctional air quality, and other handheld instruments. Findings show the presence of gaseous substances in the air within the production area and inadequate ventilation to dissolve and evacuate the gases which could negatively impact workers' well-being. The study concludes that a multidisciplinary approach encompassing the stakeholders in the pharmaceutical industry is critical to developing optimal design solutions for a well-designed pharmaceutical factory in Nigeria.
Keywords: Indoor Environment; Industrial Buildings; Nigeria; Pharmaceutical Factory; Workers' Well-Being.

1. Introduction

The primary objective of a building is to provide sheltered housing that is comfortable, convenient, safe, and attractive to its users (Ransom and WHO, 1988; Hanson, 2001; Smith and Pitt, 2011; Akadiri et al., 2012; and Scruton, 2013, Aziz Amen & Nia, 2017). Although the pharmaceutical factory building (PFB) is not just like any other building, the fact that it houses the drug production process means it has to be secure, serene, and controlled from contaminated air (Xiaoguang et al., 2011). Indoor air has a large share of the impact a building has on inhabitants compared to outdoor air due to its composition of both biological and chemical contaminants, as suggested by (Smith and Pitt, 2011; Abdulaali et al., 2020; and Bawa et al., 2022). Carbon monoxide (CO), carbon dioxide (CO2), radon, nitrogen oxide (NOx), asbestos, respirable suspended particles (RSPs), construction chemicals, and ozone are chemical components of the pollutants (Smith and Pitt, 2011,Amen,2021). Pests, dust mites, houseplants, molds, endotoxins, and pollen are examples of biological pollutants (WHO, 1979; Ghodrati et al., 2012; Abdulaali et al., 2020; and Mannan and Al-Ghamdi, 2021).

It has been proven that these contaminants can cause asthma, sick building syndrome (SBS), as well as various respiratory allergies that affect the users of the building. The importance of indoor air quality (IAQ) to the health and productivity of building occupants has been discovered (Dubbs, 1990; Wargocki et al., 2000; Lee et al., 2009; Smith and Pitt, 2011; Abdulaali et al., 2020; Bawa et al., 2022). Air pollution is the world's most serious environmental health concern, according to researchers (Abdul-wahab et al., 2015; Jones and Molina, 2017; Taştan and Gokozan, 2020; Paleologos, et al., 2021; and Bawa et al., 2022). Air pollution has negative consequences for human health, the climate, and ecosystems because it pollutes the air with a large amount of hazardous gases and particulate matter (Manisalidis et al., 2020).

One of the most essential criteria in determining the quality of any structure is having high-quality indoor air (Khazaii, 2014). Similarly, Korkmazer et al., (2018) and Ukpong et al., (2022) showed how hazardous lighting pollution can be as it affects perception, causes glare and even blindness.

The quality of the interior air and lighting in the building where people live and work has a direct impact on their health and productivity (Vimalanathan and Ramesh, 2014 and Arif et al., 2016). Armstrong et al., (2005), Khazaii (2014), and Gawade et al., (2020) opined that there is a need for efficient ventilation systems that can provide a healthier indoor environment.

2. Workers' Well-being and Productivity

Workers' productivity is defined by Sreekumar et al., (2018) and Mahamid (2013), in agreement with Al-Saleh (1995), as the amount of goods and services produced by a worker in a given amount of time, taking into account the availability of raw materials, appropriate tools or equipment, construction methods, political factors, project financing, and environmental factors. All these factors will be carefully reviewed because some equally constitute the variables of indoor environmental quality, according to Abdulmujeebu (2019). Carrasquel (2019) studies the three (3) factors that contribute to workers' productivity in the workplace, and workers' engagement was found to be the greatest tool required to increase productivity. Since worker productivity is a vital element to organizations, the work environment is a key contributor to workers' productivity where the environment describes the people and the people describe the environment. The study noted that when the work environment is tense and filled with negativity, employee management, and productivity levels obviously decrease significantly, thereby affecting the company's output as well as workers' motivation.

This is a typical description of production workers of PFBs. The Chartered Institute of Personnel and Development (CIPD) (2017) asserted that among the factors that can influence the work environment are morale among colleagues, increased stress, increased racial discrimination, or race-related harassment and bullying at work. Another important factor to consider is the design of the factory, also known as the construction method. If the spaces are proportionate to the sizes of the equipment and the number of workers and permit ease of circulation and seating to work and walk around effectively while having sufficient natural lighting and ventilation, then workers will be productive, and the productivity of the workers means an adequate design requirement. Carrasquel (2019) also described the use of technology as a factor that contributes to the well-being and productivity of a worker. The research argued that the latest and adequate technological tools could be employed to make the job easier for the workers, which could increase their productivity. This could equally improve the way workers interact with work and each other in the PFB.

3. Materials and Methods

This study used a mixed-method approach to achieve its goal (Tashakkori and Teddlie, 2003; Creswell and Plano, 2010). According to Johnson and Onwuegbuzie (2004), mixed methods research is a type of study in which the researcher employs both quantitative and qualitative research methodologies. This method ensures that the results of both data sets can be used as a check against conclusions drawn solely from one of the approaches. As a result, the data collection in this study included both numerical and textual information, ensuring that the final database has both quantitative and qualitative data (Creswell, 2012). This study aimed to provide a more comprehensive grasp of the research issue than could be obtained by using only one of the methodologies (Morse, 2005, Creswell and Plano, 2010). The research considered two (2) broad characteristics for the selection of the pharmaceutical factory: the pharmaceutical factory must be manufacturing a drug at the time of the survey and it must be in one of the stratified categories (Large, Medium, or Small PFBs). The characteristics of the three categories are described in Table 1.

Table 1. The Criteria for the inclusiveness in a category of a sample

Categories of PFBs	No. of Workers	No. of Drugs Produced	Size of production Hall
Small PFBs	1-100	5-10	100-250sqm
Medium PFBs	101-200	11-15	251-400sqm
Large PFBs	201-300	16-20	401-550sqm

This study surveyed 14 PFBs in Lagos and Ogun state, Nigeria, between October 2020 and November 2021, which extended into three climatic seasons, with the rainy season studied two times, and so the survey was carried out three times with the firs being a pilot study. The handheld digital laser distance meter was used for the measurements of lengths, breadth, heights, and perimeters of the production area and all the various production rooms in the 14 PFBs. The other handheld devices used included a multifunctional air quality detector that was used to measure temperature, relative humidity, air velocity, particulate matter $PM_{1.0}$, $PM_{2.5}$, and PM_{10}, formaldehyde (HCHO), a digital sound level meter to measure the sound level generated by the machines, and the workers, The LCD CO Gas carbon monoxide detector measured CO and the digital anemometer measured air velocity and airspeed. Each of the 14 PFBs was measured 15 times at various points, and the measurements were done within 3–5minutes interval. Questionnaire forms were administered to the production workers as well as the management staff in each of the 14 PFBs surveyed.

3.1 Research Site

The choice of the location of the study area was based on the number of pharmaceutical factory buildings. The Southwest was chosen because it has a higher concentration of PFBs in Nigeria, thereby having a larger workforce in the pharmaceutical industry. Lagos State had the highest number of PFBs in Nigeria with 57, which was followed by Ogun with 16 ou of the 16 recognised PFBs in Nigeria, (pharmapproach, 2021).

3.2 Description of the Equipment

The instruments that were used for the field survey included the Multifunctional Air Quality Detector D9 model (Plate I), which is ideal for measuring temperature, relative humidity, particulate matter ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), Total Volatile Organic Compound (TVOC), formaldehyde (HCHO), and carbon dioxide (CO2). A handheld digital sound level meter of 30–130dB (Plate II) was used to measure the sound level in the 14 PFBs. A Digital Laser Distance meter of 100m (Plate III) was used to measure the length, breadth, and height of the production areas of the PFBs. The Digital Lux Meter AS803 was used to calculate the illumination of the production rooms. A KXL-801 LCD CO detector was used to measure the amount of carbon monoxide (CO) present in the production rooms. The HABOTEST HT625A digital anemometer (Plate IV) was used to calculate the air velocity and airflow. While an Infinix Note 4 X626B Android phone camera was used to take photographs and record videos of the indoor environment to capture the equipment, spatial arrangement, circulation spaces, the activities going on in the production areas, and the building components.

Plate I: Multifunctional Air Quality Detector

Plate II: Digital Sound Level Meter

Plate III: Digital Laser Distance Meter 100M

Plate IV: HABOTEST HT625A Digital Anemometer

4. Results

Some of the variables present in the PFBs are due to the activities relating to the production of drugs that involves chemical mixes that goes on in the PFBs as described by (Abdul-wahab et al., 2015) namely; temperature, relative humidity, air velocity, lighting, sound, particulate matters ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), carbon dioxide (CO_2), carbon monoxide (CO), formaldehyde (HCHO) and total volatile organic compound (TVOC)) were assessed by the use of digital handheld devices as presented on Plates I-VI. The temperature, relative humidity, air velocity, lighting, and sound were assessed as independent variables in this study, while the $PM_{1.0}$, $PM_{2.5}$, PM_{10}, CO_2, airflow, HCHO, and TVOC were assessed as dependent variables.

Fourteen (14) pharmaceutical plants were chosen for two reasons, including both inclusive and exclusive criteria: Inclusive criteria are qualities that prospective units (PFBs) must possess in order to be included in the study. Exclusive criteria are traits that disqualify potential participants from participating in the study (Patino, 2018) and the permission bottlenecks faced in the field were the second reason. All the readings were taken between 1-1.2m in height to maintain consistency; as a result, high air velocity readings were expected. The airflow rate was calculated using m^3/h since the diffuser flow area was $0.36m^2$. Using the equation below, the values were converted to airflow velocity.

$$v = \frac{Q}{3600A}$$

Where,

$\mathrm{v} = \text{air flow velocity}$

$\mathrm{Q} = \text{air flow rate in } m^3/h$

$\mathrm{A} = \text{cross section area of the diffuser}$

The air velocity was also measured at 15 points in production rooms or halls occupied by machines and workers doing the production of various kinds of drugs, which included tablets, capsules, syrups, and sterile. A handheld HABOTEST HT6254 Digital Anemometer (environmental meter) device was employed to measure air velocity and airflow as well as the corresponding scales.

5. Discussion

The indoor air quality data obtained from the 14 PFBs includes the temperature, air velocity, particulate matter ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), total volatile organic compounds (TVOC), and formaldehyde (HCHO). The Air temperature was measured at about 1m height from the ground according to Zhu et al., (2021). Generally, the acceptable range of the indoor air temperature is between 22.5-26ºC, the maximum limit of air velocity recommended by Amens et al., (2020) is $0.25ms^{-1}$. The acceptable limit of TVOC of below 3ppm was used as consistent with the recommendation of Dosh (2005). ASHRAE Standard 2017 recommends levels of 1000ppm in the case of continuous exposure to CO_2. Zhu et al. (2021) asserted that headaches, sore throat, breathing difficulty such as asthma can result in occupational exposure to HCHO which is above 0.1ppm.

The average air temperature (29.42°C); air velocity (0.98 m/s) and formaldehyde (0.87ppm) were beyond the acceptable and recommended threshold by ASHRAE and WHO. All the 14 PFBs measured for TVOC had far low below the allowable limit 0.1ppm and 1.23ppm as the lowest and highest calculated averages respectively. The total average was calculated at 0.31ppm as seen in Figure 2.0. The average calculated CO_2 of 14 PFBs with 12 factories measuring below the ASHRAE threshold of 1009ppm. Only factories 006 and 010 had higher than the recommended standard. The total average of CO_2 for the 14 PFBs was 773.56ppm. It could be observed from Figure 2.0 that 11PFBs out of 14 had largely exceeded the suggested limit with the total average of HCHO giving about 0.87ppm.

The IAQ data with the highest difference was the HCHO measurement with a variation of about 199% in difference from the average measurement spread out through the 14PFBs, this is followed by the $PM_{2.5}$ and PM_{10} as the measurements were seen to vary by 137% from the average measurements for the PFBs, this showed the magnitude of the differences in the $PM_{2.5}$, $PM_{10,}$ and HCHO present in the PFBs, the Table 1 presents that the IAQ data with the least difference is between the individual PFBs and the average measurement from all the PFBs for each of the IAQ data. The average air temperature (29.42°C); air velocity (0.98 m/s) and formaldehyde (0.87ppm) were beyond the acceptable and recommended threshold by ASHRAE and WHO.

Figure 1 illustrates that the total average variation of the temperature reading of all the PFBs in the study was found to be sum up to about 5% away from the average air temperature reading of 29.42ºC from Table 1. This showed that the air temperature levels were consistent. The variation in the carbon dioxide and air velocity at 239% and 412% respectively, were the other two IAQ variables in these PFBs that had total average variations that were less than 500%, though there were PFBs that had readings varying from a carbon dioxide level as high as 126% above the 772.99ppm as well as an air velocity level of about 100% above the 0.99m/s average readings. The variations of the HCHO, $PM_{1.0}$, $PM_{2.5}$, PM_{10}, and TVOC were the most dispersed of all having this total average variation at levels between 1000% and 2500% from the readings of 18.47mg/m for $PM_{1.0}$, 33.92mg/m for $PM_{2.5}$, 0.31ppm for TVOC and 0.86ppm for HCHO (Table 1 and Figure 1).

Table 1. Average IAQ data from the 14PFBs

	Av. Temp. (ºC)	Av. Air Vel. (m/s)	AV. $PM_{1.0}$ (mg/m)	AV. $PM_{2.5}$ (mg/m)	AV. PM_{10} (mg/m)	Av. TVOC (ppm)	Av. CO_2 (ppm)	Av. HCHO (ppm)
Standard [source]	Average of 24.25 [ASHRAE standard 55, 2010]	0.25 [ASHRAE standard 55, 2010]	Nill	Nill	Nill	Below 3 [Dosh, 2005]	Below 1000 [ASHRAE standard, 2017]	Below 0.1 [Zhu et al. (2021)]
14PFBs Av. IAQ data	29.42286	0.989286	18.46929	33.915	18.46929	0.305714	772.9893	0.860786

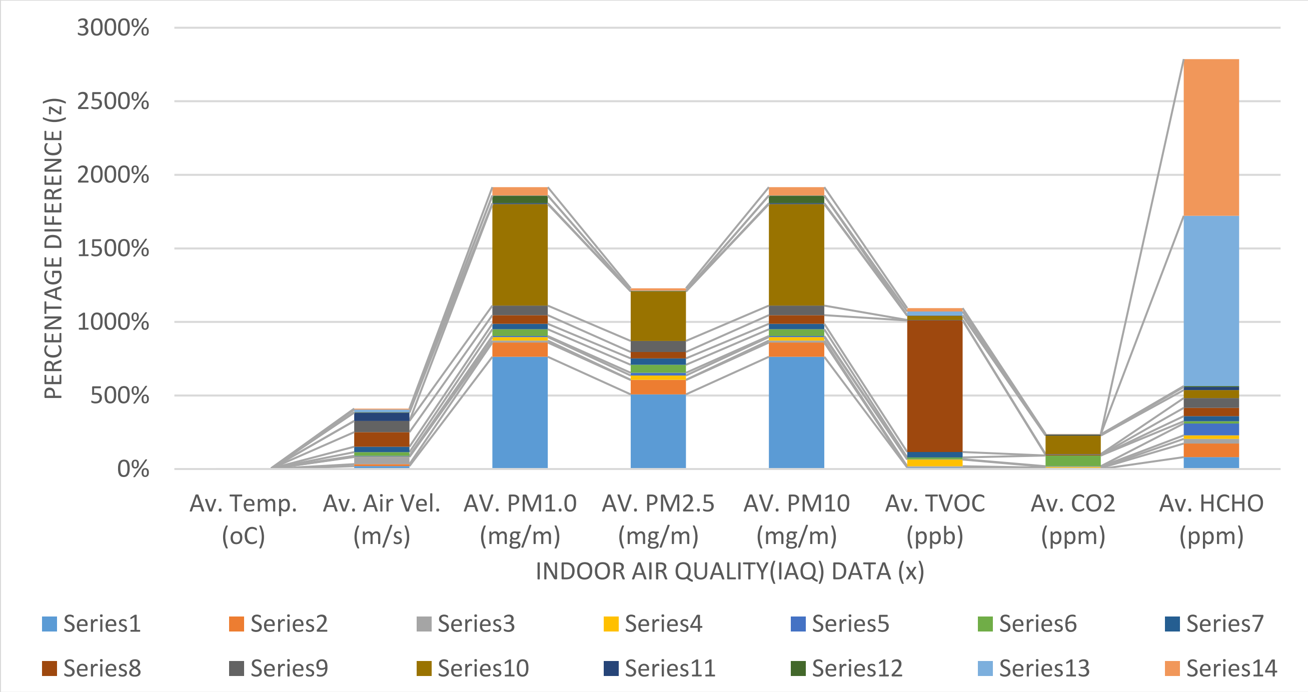

Figure 1. Percentage difference between IAQ data

Figure 2 demonstrates the performance of the different PFBs in these IAQ performances with about nine (9) of them having an average difference in IAQ data summing up to about 50% or less while five were between 150% and 300%. It could be observed from Figure 2.0 that 11PFBs out of 14 had largely exceeded the suggested limit with the total average of HCHO giving about 0.87ppm. The IAQ data with the highest difference was the HCHO measurement with a variation of about 199% in difference from the average measurement spread out through the 14PFBs, this is followed by the $PM_{2.5}$ and PM_{10} as the measurements were seen to vary by 137% from the average measurements for the PFBs, this showed the magnitude of the differences in the $PM_{2.5}$, $PM_{10,}$ and HCHO present in the PFBs,

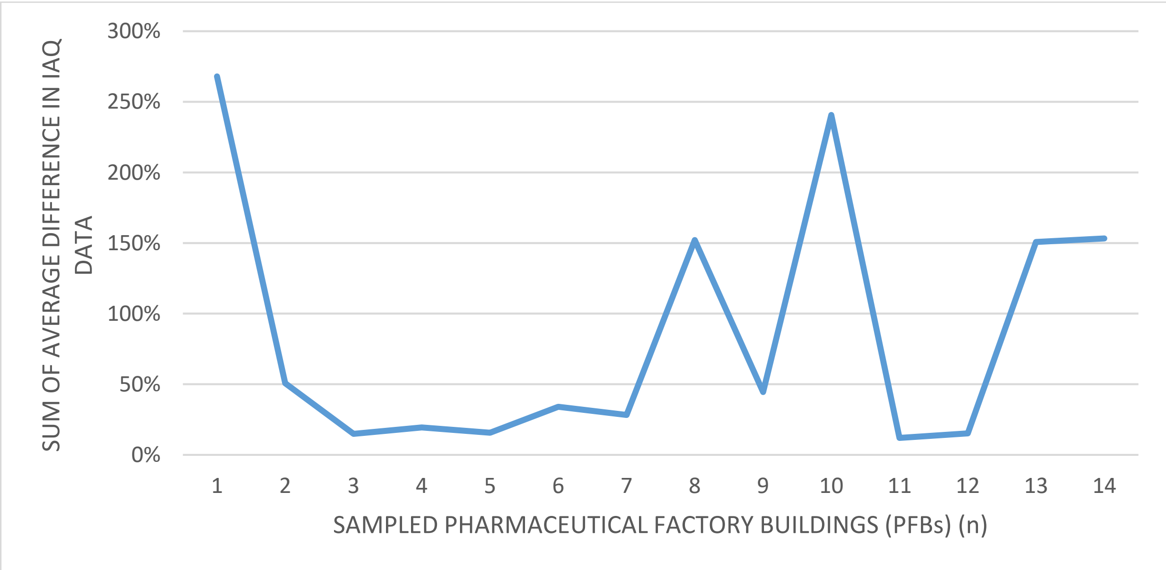

Figure 2. Average percentage difference in IAQ data from 14 PFBs

The questionnaire result (Table 2) described how the environmental performance variable affected the user's performance in the PFBs. The temperature, sometimes being uncomfortable during production, had a significant influence with low impact. The perception of 54% of respondents was that the temperature is sometimes uncomfortable during production. The air velocity impact was fair, as 63% disagreed that the hall is usually not airy enough. At the rate of about 57% agreed that they were able to meet the production target.

Table 2. Crosstab on the comfort level of the Temperature and whether the hall is usually not airy enough

			Are you able to meet the production target? Yes	No	Total
The temperature is sometimes uncomfortable during Production	Agree	Count	149	152	301
		Expected Count	170.4	130.6	301.0
	undecided	Count	37	21	58
		Expected Count	32.8	25.2	58.0
	Disagree	Count	127	67	194
		Expected Count	109.8	84.2	194.0
The hall is usually not airy enough	Agree	Count	71	102	173
		Expected Count	97.9	75.1	173.0
	Undecided	Count	20	13	33
		Expected Count	18.7	14.3	33.0
	Disagree	Count	222	125	347
		Expected Count	196.4	150.6	347.0

6. Conclusion

However, the values obtained for CO_2, $PM_{1.0}$, $PM_{2.5,}$ and PM_{10} were satisfactory. The IAQ of the PFBs is consistently challenged by the HCHO which is though seen at different rates through the samples PFBs, is constantly one of the factors exceeding the set standard for its presence. In determining the wellness of workers of indoor environment of PFBs, more research needs to be carried out to investigate the best way to consistently mitigate the high amount of PMs and HCHO in PFBs, as this research suggests that these could be the major reason for ill-health, discomfort, and low-production in PFBs.

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