IOP Conference Series: Earth and Environmental Science

PAPER • OPEN ACCESS

Factors Influencing the Performance of Indoor Environmental Quality of Pharmaceutical Factory Buildings in Southwest Nigeria

To cite this article: J. A. Bawa *et al* 2022 *IOP Conf. Ser.: Earth Environ. Sci.* **1054** 012023

Factors Influencing the Performance of Indoor Environmental Quality of Pharmaceutical Factory Buildings in Southwest Nigeria

J. A. Bawa*, P. Ayuba and O. K. Akande

Department of Architecture, Federal University of Technology, Minna, Nigeria.

*Corresponding author's email: bawa.pg915484@st.futminna.edu.ng

Abstract. Pharmaceutical factory workers spend 37.5% of their daily time in the production hall manufacturing drugs used for human health needs. There is usually little or no time given to spend in the natural environment. This affects their sanity and well-being. The Pharmaceutical factory building (PFB) is classified as a specialized, controlled, or restrictive building; it provides little or no access to natural environmental conditions like ventilation and lighting, thereby increasing the financial implication of energy for the operation of production of drugs. Hence, the survey was conducted to identify the factors that influence the indoor environmental performance (IEP) of PFBs. The factors responsible for influencing the indoor air quality were measured through a survey conducted in Lagos and Ogun States, Nigeria on 14 PFBs to determine the value of these factors identified, using principal component analysis (PCA), Bartlett Test, and Kaiser-Mayer Olkin (KMO): the conditions for PCA were also observed. PCA is a factors or data reduction technique to select a subset of highly predictive factors from the larger group of factors identified from the study. Indoor environmental quality variables satisfied the condition for PCA while thermal performance variables did not meet the condition. PCA was conducted for Indoor environmental quality and the result showed 2 major factors explaining the variation in the original set of variables. Whereby CO_2, $P.M_{1.0}$, $P.M_{2.5}$, $P.M_{10}$, HCHO, airflow, AQICN, and AQIUS as component 1 and TVOC as component 2, the data set was also compared with the standards recommended for indoor environmental quality and thermal performance variables. It was found that at an average air velocity of 29°C and RH of 60%, the average CO, TVOC, $PM_{2.5}$, and PM_{10} were 0.25ppm, 0.31ppm, 33.92ppm, and 43.48ppm respectively for the PFBs. Because thermal performance includes several dependent variables, greater research on the indoor environment of PFBs in Nigeria is recommended to determine the impact of indoor environmental characteristics on thermal parameters.

Keywords: factors; indoor environmental quality; pharmaceutical factory buildings; principal component analysis; thermal performance

1. Introduction

A pharmaceutical factory building (PFB) is a specialized and controlled indoor environment where drugs are produced for various human health needs. The production area of the PFB is kept very clean for pharmaceutical goods to prevent pollution and contamination of the process and the products. Although the PFB is designed without windows and fenestrations to maintain the purity of the production process and products, heating, ventilation, and air conditioning (HVAC) systems are implemented to provide controlled interior air quality (IAQ) and indoor thermal conditions for the products, as well as an optimal indoor working environment for factory personnel, according to the report [1].

Most PFBs are not designed with windows [2]; while those that are have them constructed as fixed windows to permit only natural light into the indoor environment [3]. The uncertainty and unpredictability of the IEQ in the production area of these PFBs could be a reason for the possible exposure of the workers to health challenging situations [4]. It is therefore very unlikely that the dynamics of IEQ in PFB [2] will be the same as with other categories of buildings (such as schools, offices, gymnasiums, or factories): it has been studied that the external environment influences the IEQ of the internal spaces of the aforementioned categories of buildings (such as schools, offices, gymnasiums, or factories) due to their exposure to the outdoor climate [5]. This makes it thought-provoking, especially in its relationship with the productivity of the workers in the production area too.

2. Literature Review

Research conducted by [1] suggests that there is a high concentration or presence of total volatile organic compounds (TVOC) in the production areas of PFBs due to the chemicals and washing areas that are always present. The research also opined that there is a need for increased air velocity and airflow to dissolve and flush the harmful gaseous presence to keep the TVOC concentration within acceptable limits. When the harmful gases are not adequately controlled, it leads to the poor well-being of the workers. Poor indoor environmental quality (IEQ) has been shown in studies by [6] and [7] to have a negative influence on users' productivity, output, health, and mental development in the short and long term.

[8] suggested that there is insufficient research on the impact of combined factors such as the concurrent exposures of several chemicals as is found in the enclosed buildings such PFBs. This means that multiple dependent factors or variables are found to react with multiple independent factors, yet there is not adequate research describing this trend. As a result, this research was carried out to determine the factors that influence the IEQ of PFB production halls, as well as the factory workers' performance and well-being.

Poor IEQ has been linked to health hazards in previous research conducted on general buildings [9, 10, 7]. [11] has also shown that low IEQ affects workers' comfort, health, and productivity, and that IEQ is influenced by a variety of building-related factors. [12] and [13] also confirmed that the nature of the indoor environment has an impact on worker quality of life and productivity.

2.1. Factors Influencing the Indoor Environmental Quality of Buildings

The following factors or variables have been considered by other studies to influence the indoor environmental quality of buildings, with various categories established, as they largely influence the IEQ [14, 15, 16, 17, 18, 19, 20, 21, 22, 23], and these categories are fond to operate generally as;

i. Design and construction factors

These factors include the layout of the design, the quality of the lighting and ventilation systems, and ergonomics. Also, the design and construction technique of the building can add to building issues and challenges, especially heath. Other design and construction factors such as the location of the building, sun, rain shading devices, and views or orientation should also be considered in order to improve the indoor environmental quality [14, 15]. PFB is a peculiar building where detailed design and construction techniques and materials are used and greatly impact the quality of the indoor spaces.

ii. Perceptual and psychological factors

Phrenzy and psychological stress caused by a lack of concealment, a loss of control, or restricting effects owing to enclosed architecture are examples of these causes [16, 17]. The indoor area of the PFB is a sealed environment that can cause claustrophobic effects, largely because the building is usually without windows that give access to the natural environment;

iii. Cultural and organizational factors

These factors include cleanliness [17]. This is largely upheld by the PFB practice, as their regulatory bodies frown at uncleanliness, and it is dangerous to the practice of drug production. The quality of the internal space or environment is also influenced by the maintenance of equipment and the building envelopment. The IEQ is also influenced by management and their connections with manufacturing operators and workers.

iv. Services and Controls

Regulation and services of indoor environmental quality include lighting, air conditioning, thermal comfort, and control of indoor microclimate [18].

For the improvement of health quality in PFBs, the following conditions relating to water and its reticulation and use, heating and cooking of certain processes in drug formulation, cooling of the environment for human comfort, humidification, and general air quality should be carefully accounted for. Among the services available are:

a. Domestic water

The distribution system for domestic water, the storage type, and the containers, washing and drainage channel, water temperature design requirement and adequate control and checks strategy, system or automated monitoring, operational strategy, and disease or germs control technique should be considered in the PFB service delivery [19];

b. Heating

The heating system suitable for the efficacy control approach, greenhouse gas (GHG) emission standards, the position of the flue, working strategy, and maintenance is equally important [19];

***c.* Cooling**

The type of cooling system efficiency control checks and strategy for refrigerant type, refrigerant leakage detection technique, pump-down device position, and heat rejection, operational strategy, maintenance, and adequate access by the factory users [19];

***d.* Humidification**

The humidification method (spray, steam), condensation, cleaning, operational strategy, and maintenance method are necessary for proper IEQ [20];

***e.* Lighting**

The lighting type of system, lighting heights, switching effectiveness, and position of luminaires in the production area contribute largely to IEQ [21].

.

i. Workplace Design

This refers to the volume of space per worker, room heights, and building layouts. The categories mentioned below cover the variety of factors that contribute to the building-related comfort and productivity of the workers [22]:

- Insufficient floor-to-headroom height;
- massive unstructured open-plan rooms;
- lack of natural or day-light
- Insufficient sources of natural ventilation in the work environment.

ii. Occupants

Occupant activities, nature of work, clothing insulation and body metabolism or moisture, and an inlet of pollutants, cleaning agents in the indoor environment [23];

iii. Environmental Factors

The following environmental factors affect the thermal behavior of a building **[24]**;

- moisture and mold growth;
- noise;
- radon;
- odor and irritation;
- gas emissions;
- pollution from the outside.

iv. Factors Affecting Maintenance and Management

Maintenance and management factors influence the thermal behavior of a building. [25] These factors include;

- poor upkeep and administration
- incorrect or inadequate sanitation;
- insufficient communication;
- cultural dimension.

3. Materials and Methodology

This study examined literature related to this research, including reputable journals, books, proceedings from conferences, and available reports. Reputable internet databases such as Scopus journals, ResearchGate, Google Scholar, and ScienceDirect engines were utilized to search for relevant literature, using keywords: *factors, indoor environmental quality, performance, pharmaceutical industry, thermal performance.* IEQ works by researchers were reviewed and related factors were studied, analyzed, and discussed concerning PFBs.

Suitable hand-held instruments were acquired and a field experiment was conducted in Lagos and Ogun States in South-west Nigeria. The study was conducted twice in each of the 14 PFBs between October 2020 and March 2021, which spanned the rainy season and the dry season. The instruments that were used for the field survey included the Multifunctional Air Quality Detector (D9 model), which is ideal for measuring temperature, relative humidity, particulate matters ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), TVOC, formaldehyde (HCHO), and carbon dioxide (CO_2). A handheld digital sound level meter of 30–130 dB was used to measure the sound level. A digital laser distance meter of 100m was used to measure the length, breadth, and height of the production areas and the height, length, and breadth of the exterior 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 CO present in the production rooms. A HABOTEST HT625A digital anemometer was used to calculate the air velocity and airflow. An Infinix Note 4 X626B Android phone camera was used to photograph and record videos of the indoor environment to capture the equipment, activities going on in the production area, and the building components. An observation schedule was used to gather data on the architecture of the building, building materials, finishes, equipment, users' activities, and the operation within the production area, which was the focus of this study.

The findings were analyzed using factor analysis (FA), which is also known as principal component analysis (PCA). According to [26], PCA is the approach used for factor extraction in factor analysis. While factor analysis is an interdependence approach in which there is little or no division of parameters into dependent and independent parameters, it is an interdependence technique in which there is little or no division of parameters into dependent and independent parameters.

The goal of factor analysis is to define the relationship between the variables in the analysis. Furthermore, it is a type of analysis that uses the correlation between variables to describe the structural link between variables. The value of Kaiser – Mayer Olkin (KMO) of a group of parameters or variables to evaluate whether the fractional or partial correlations among variables are minor is one of the data necessary in the study, according to [26]. The correlation matrix is tested using Bartlett's test of sphericity [27].

4. Results and Discussion

The factors with higher eigenvalues were identified using Principal Component Analysis, which led to the identification of the right factors for the PFBs.

Table 1. Components Initial Eigenvalues

Component	Initial Eigenvalues		
	Total	% of Variance	Cumulative %
1	6.481	72.009	72.009
2	1.188	13.201	85.210
3	.785	8.721	93.931
4	.366	4.072	98.002
5	.164	1.826	99.828
6	.010	.110	99.938
7	.004	.049	99.987
8	.001	.009	99.996
9	.000	.004	100.000

Table 1 shows the components (factors or variables) that were tabulated, and the initial eigenvalues were determined, where the total values per component were stated. The percentages of the variance were given alongside the cumulative percentage. Then the component matrix was determined in Table 2, which was to extract the components.

Table 2. Component Matrix

	Component	
	1	2
$PM_{1.0}$	.979	.150
$PM_{2.5}$	.975	.159
PM_{10}	.976	.200
CO_2	.741	-.399
HCHO	.557	-.343
TVOC	-.174	.859
AQI CN	.981	.156
AQI US	.976	.161
Airflow	.903	-.190

Extraction Method: PCA.
a. 2 components extracted.

It was observed that two significant components were generated, which explained 85.2% of the variation in the data set. The first components are $PM_{1.0}$, $PM_{2.5}$, PM_{10}, CO_2, HCHO, and airflow, which account for 72% of the total variation, and component 2 is TVOC, which accounts for 13% of the total variation. This was then followed by the determination of the component plot in rotated space in *Figure 1*.

Figure 1 shows the concentration of HCHO is 0.557 in component 1 and -0.343 in component 2. This shows a high effect of HCHO, while CO2 has a high concentration of 0.741 in component 1 and a low concentration of -0.399 in component 2. Component 1 has more airflow than component 2.PM1.0, PM2.5, and PM10 have high concentrations of component 1 and low concentrations of component 2. The air quality index, Canadian standard (AQICN), and the air quality index, US standard (AQIUS) show more in component 1 than in component 2, while TVOC has a higher concentration in component 2 than in 1. This implies that the concentrations of the variables vary within the same production area as well as from factory to factory.

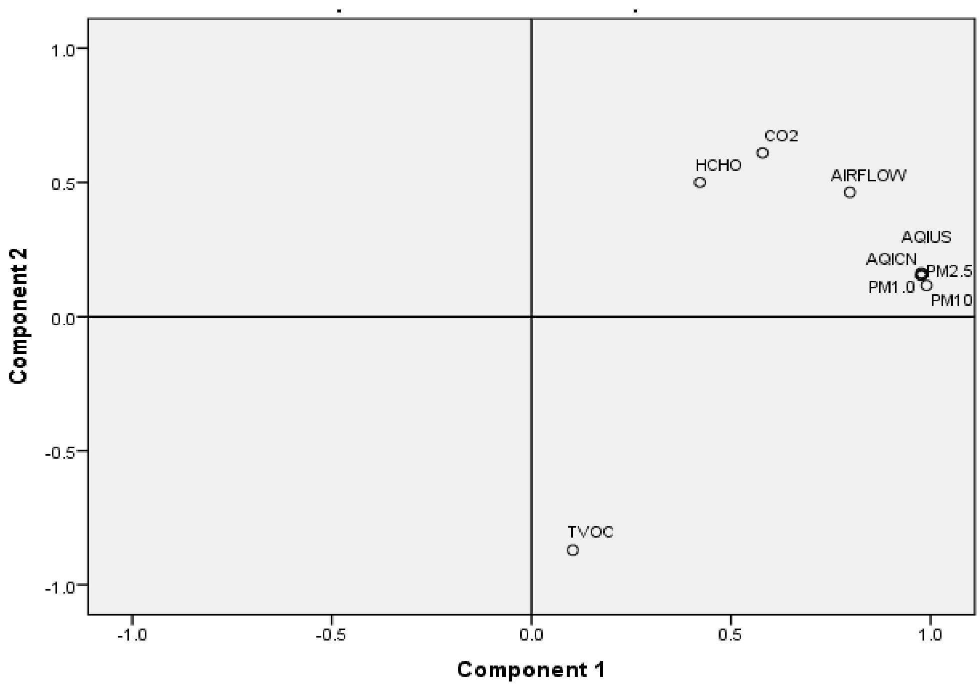


Figure 1. Component Plot in Rotated Space

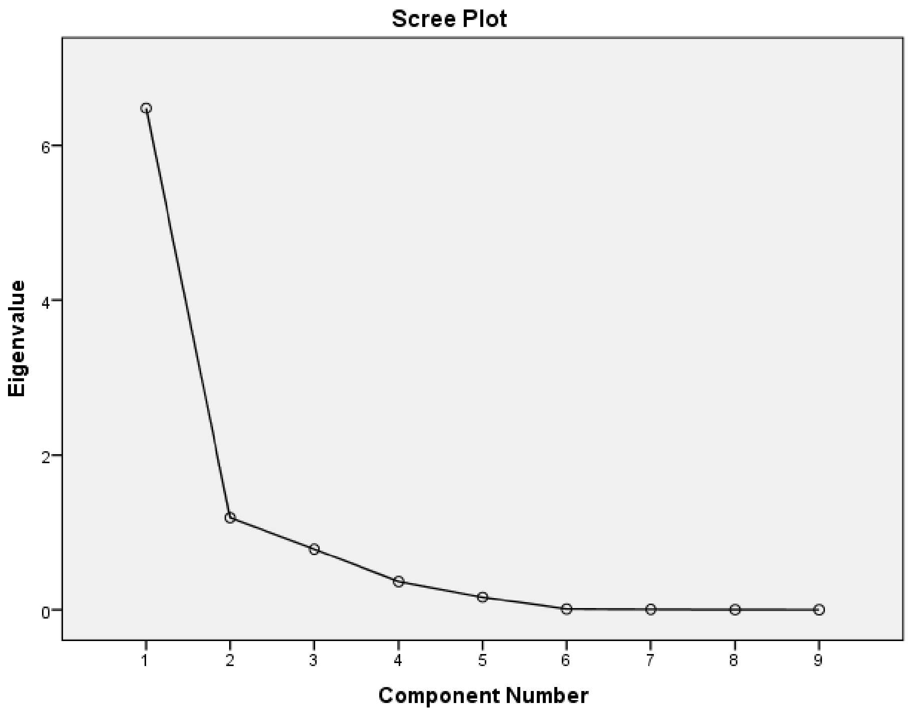


Figure 2. Plot of the Eigen Value

It is important to note that other dependable factors such as temperature, air velocity, and airflow were necessary for the overall study despite the factor analysis, largely because the study also seeks to recommend future studies to establish the permissibility of natural or hybrid means of ventilation in the production areas of PFBs, and these factors were very necessary to achieve this.

Certain gases constitute the major pollutants in the indoor environment. Some of such gases are more present in the PFBs largely due to the activities relating to the production of drugs that involve chemical mixes that goes on the PFBs. This is similar to studies conducted by [28], where four physical parameters (temperature, relative humidity, air velocity, and lighting) and seven chemical parameters (particulate matters ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), carbon monoxide (CO), formaldehyde (HCHO), carbon dioxide (CO_2), and total volatile organic compounds) are taken into consideration, and one mechanical parameter (noise/sound) was found to constitute the dependent and independent variables, respectively. The noise was equally added to the physical parameters.

For this study, indoor thermal quality or performance includes temperature, R.H, air velocity, lighting, and sound, which are the dependent variables. Chemicals can affect indoor air quality, but other factors that make up the independent variables include: CO_2, CO, $PM_{1.0}$, $PM_{2.5}$, PM_{10}, HCHO, and TVOC).

4.1. Discussion on the Effect of the IEQ Parameters on the Indoor Environment of PFBs

i. Air temperature

It is a relevant factor needed to sustain an applicable thermal comfort standard in the indoor space or environment of the PFB [29]. The inadequate temperature outside the standard values can affect the productivity of the factory users and their thermal comfort [30]. Air temperature within the acceptable standard in the PFB creates comfort for the workers and enhances their ability to achieve productivity and well-being.

Certain international standards include Malaysia endorsed a temperature which is from 23–26 °C [31], whereas Singapore has its recommendation from 22.5–25°C [32]. [33] also, recommend that between 22.5-27°C is adequate for factory building. For PFBs in Nigeria, a temperature of 20–27 °C is ideal, largely because there are heavy-duty workers who stand to lift and push loads and operate machines, and there are workers who sit and do light work such as packing drugs. The thickness of the clothing and the enclosed nature of the building alongside the geographical location of the PFB are other reasons for the range of recommended air temperature in PFBs in Nigeria.

The average air temperature of the 14 measured PFBs was 29.42°C. This is found to be beyond the generally accepted threshold [34]. Therefore, there will be cases of headaches, fatigue, and a general reduction in well-being and productivity [35].

ii. Relative humidity (RH)

This indicates the amount of moisture in the air. It's a factor that has an impact on a building's thermal comfort [18]. Low humidity causes a drop in mucus in the nose and eyes, which is irritating due to the drying of these organs. High humidity causes dust particles and airborne pestilences to be transferred into the respiratory organs. Diseases (like bronchitis) and irritation are caused by this process indirectly [36] [37]. High humidity also adds to the emission of pollutants from building materials, with HCHO and TVOCs as worthy mentions. This leads to poor IAQ [38].

[31] set a standard of 40–70%. For short–term exposure restrictions in both summer and winter, RH levels of 30–80 percent and 30–55 percent are required in Canada [39]. The total average RH of the 14 studied PFBs was found to be within the most acceptable limits, which was 60%. This is convenient for workers in a production factory.

iii. Air movement

Also called air velocity is another important influencer of IEQ [40]. Human health does not have a direct influence from air movement, yet it is affected both positively and negatively through its direct influence on other factors. Still air, for example, has an effect on air temperature and humidity for humans in the environment, creating thermal discomfort. Moving air can, on the other hand, make people feel cooler when their body temperature is higher than the moving air [41]. The average air velocity of the 14 PFBs studied was 0.98 m/s. This is far beyond the standard air velocity guideline value of 0.25m/s set by the

World Health Organisation (WHO) [42]. [31] endorsed different values of from 0.15 to 0.5 m/s and 0.25 m/s for outstanding and decent IAQ, respectively. No wonder the average air temperature of the PFBs was also found to be above the normal standards. This is largely because the air velocity influenced the air temperature.

iv. Carbon monoxide (CO)

CO is created by malfunctioning gear in the PFB manufacturing hall. The principal effect of CO on health is a reduction in the oxygen-carrying capacity of red blood cells, since it forms carboxy-hemoglobin by forming links with the oxygen carrier, hemoglobin. This impact causes a variety of symptoms, ranging from exhaustion to nausea to death by asphyxiation as a result of high concentrations [43]. CO poisoning is dangerous depending on the period of exposure, concentration, and general health status of the factory worker.

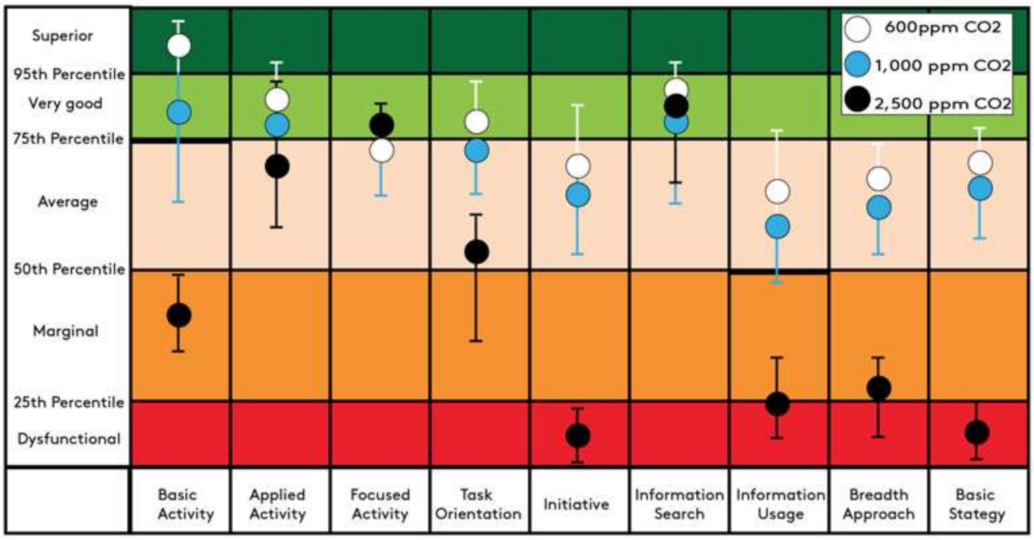
This study measured an average of 0.25 ppm CO, which is generally within the acceptable limit. This is possibly because of the controlled nature of the PFBs, where no outdoor pollutants or gases are allowed into the indoor environment of the PFBs.

Australian standard has 9ppm(10000µg/m3) as eight hours average 34000µg/m3 as eight hours working day, five days working week [44]. While the Canada/USA standard maintains 25ppm (29000µg/m3) as one hour average of 11ppm (13000µg/m3) at eight hours average [39, 45, 46, 47, 48, 49, 50].

v. Carbon dioxide (CO_2)

CO_2 levels rise as the number of people in a building rises, but are diluted and evacuated from buildings with higher air ventilation rates. For thermal comfort, it is established that workers' performance will fall by 6% if the room is too hot and 4% if the room is too cold. Moreover, studies [51] have shown that carbon dioxide (CO_2) in high quantities causes significant negative impacts on the strategic thinking and cognitive ability of humans, as *Table 3.0* below shows. The limit of the average measured in the 14 PFBs in Lagos and Ogun states was 773.56ppm, which is considered for the factory building because it is within the major thresholds.

Table 3. CO_2 impact on Indoor environment users



Source: www.swegon.com/en/, 2021

Standards adopted by Malaysia, Singapore and Canada are 1000ppm (Ceiling Level) [52], 1000ppm at 8h average [53] and 3500ppm for long-term exposure [45, 54], respectively. The limit for the USA is different at 5000 ppm (9000mg/m^3) for a 5-day working week at 8 hours for each working day [54].

IOP Conf. Series: Earth and Environmental Science 1054 (2022) 012023 doi:10.1088/1755-1315/1054/1/012023

vi. Formaldehyde (HCHO)

These are common adhesives applied to furniture, particle boards, and carpeting. This is thought to be a carcinogen that causes cancer of the nasal cavity in employees who are exposed to it at high levels in their employment (thousands of ppb or higher).

Moderate HCHO exposure (hundreds of ppb or more) might cause irritating symptoms such as a sore throat and transient nose or eye burning [55]. The average studied limit of HCHO of the 14 PFBs was 0.87 ppm. HCHO was found to be in excess in these PFBs and workers could be found to complain of ailments associated with the HCHO.

Standards adopted by Canada are 0.10 ppm (120μg/m^3) with a target level of 0.05 ppm (60 g/m^3) [45, 54, 56]. That of USA is 0.1ppm (123μg/m3) while ceiling level 0.016ppm (20μg/m3) with 10–h work day during 40h work/week 24540μg/m3 [54].

i. Total Individual Volatile Organic Compound (TVOC)

TVOCs, or the sum of all individual volatile organic compounds (VOCs), are commonly used to guide the chemical levels in air samples. The indications of TVOCs can range from a little irritation to toxicity levels that can lead to death [57]. Because of this, it is necessary to take special care to flush out abundant TVOC from PFBs as a precaution to avoid any casualties. The TVOC measured in the 14 PFBs was 0.31 ppm, which is still within the limit of the USA standard.

The comfort level for the UK, USA, and Canada is 300μg/m3 at an 8–h average [58]; 500μg/m3 for buildings [59] and [54]; and public works is 200μg/m3 [59] respectively.

ii. $PM_{2.5}$

Particulate matter less than 2.5 microns in diameter) has been linked to respiratory infections and illnesses, as well as cardiovascular and respiratory diseases, such as asthma and lung cancer [60]. Special notice must be made to avoid the suspension of $PM_{2.5}$ in the air for too long. Systems for flushing out the excess should be put in place in the PFBs. Cases of respiratory infections and illnesses cipher to the enduring existence of $PM_{2.5}$. 33.92ppm was the average measurement of the 14 PFBs surveyed. PM2.5, like PM10, is most regularly flushed from the indoor environment as the effect of inhaling an excess of it leads to lung cancer.

iii. PM_{10}

PM_{10} is less harmful in terms of toxicity to health than both $PM_{2.5}$ and $PM_{1.0.}$ It refers to particles with a diameter of 10 m or less. They induce infections and respiratory irritations, and long-term exposure can lead to pulmonary and cardiovascular problems, as well as lung cancer [60]. 10mg/m3 as 8–h average is the standard for PM10 in US [54, 61]. Although the average PM_{10} that was measured in the 14 PFBs was 43.48 ppm, Therefore, all particulate matter must be flushed out of the PFBs immediately. It is recommended that researchers explore automated ways of flushing out an excess deposit of these harmful gases automatically.

5. Conclusion and Recommendations

PFB is a restrictive indoor environment, where very little research is conducted to investigate the indoor environmental quality and performance of the building and its users' comfort, well-being, and productivity. It is an environment where several chemicals are combined and processed to produce drugs for human use, hence the large amounts of chemicals suspended in the atmosphere. These suspended compounds, in combination with other elements, have an impact on the performance of the pharmaceutical manufacturing buildings' interior environmental quality.

In this study, air temperature, relative humidity, CO_2, CO, $PM_{1.0}$, $PM_{2.5}$, PM_{10}, HCHO, and TVOC were discovered to be parameters that influence the performance of the production regions of the PFBs in Nigeria. Others include lighting and sound. Taking note of the dynamism of the presence of HCHO, CO_2, $PM_{1.0}$, $PM_{2.5,}$ and PM_{10} in the PBFs; their presence is largely at acceptable standards, though they still pose threats to the well-being of workers in the PFBs.

Meanwhile, it is recommended that more research should be conducted on the indoor environment of the PFBs in Nigeria in the following areas:

a. The impact of more than one dependent variable on more than one independent variable is the concurrent situation in PFBs;

b. The permissibility of natural lighting into the production hall of PFBs in order to possibly reduce the cost of energy consumption during production;
c. The permissibility of natural ventilation in the production hall of PFBs to enable workers to gain access to the natural environment and reduce energy consumption.
d. determining the comfort, well-being, and productivity of workers in the production halls of PFBs in Nigeria and
e. Establishing acceptable standards in Nigeria for PFBs' indoor environmental quality characteristics.

References

[1] H. Y. Yau, T. B. Chew, and A. Z. A. Saifullah, "Studies on the indoor air quality of Pharmaceutical Laboratories in Malaysia," vol. 1, pp. 110-124, 2012.

[2] C. Zhuang, *Uncertainty-Based Robust Optimal Design and Control of Cleanroom Air-Conditioning Systems*, 2020.

[3] World Health Organization(WHO), *Quality Assurance of Pharmaceuticals: A Compendium of Guidelines and Related Materials. Good Manufacturing Practices and Inspection*, World Health Organization, 2007.

[4] H. Abdulaali, I. Usman, M. Hanafiah, M. Abdulhasan, M. Hamzah and A. Nazal, "Impact of poor Indoor Environmental Quality (IEQ) to Inhabitants' Health, Wellbeing and Satisfaction," *International Journal of Advanced Science and Technology*, vol. 29, no. 3, pp. 1-14, 2020.

[5] F. Mancini, F. Nardecchia, D. Groppi, F. Ruperto and C. Romeo, "Indoor Environmental Quality Analysis for Optimizing Energy Consumptions Varying Air Ventilation Rates," *Sustainability*, vol. 12, no. 2, p. 482, 2020.

[6] A. Vardoulakis, C. Dimitroulopoulou and J. Thornes, "Review article Impact of climate change on the domestic indoor environment and associated health risks in the UK," *Environmantal International*, vol. 85, pp. 299-313, 2015.

[7] A. H. Yousef, M. Arif, M. Katafygiotou, A. Mazroei, A. Kaushik and E. Elsarrag, "Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature," *International Journal of Sustainable Built Environment*, vol. 5, no. 1, pp. 1-11, 2016.

[8] S. Coleman, M. F. Touche, J. B. Robinson and T. Peters, "Rethinking performance gaps: A regenerative sustainability approach to built environment performance assessment," *Sustainability*, vol. 10, p. 4829, 2018.

[9] A. C. K. Lai, K. W. Mui, L. T. Wong and L. Y. Law, "An evaluation model for indoor environmental quality (IEQ) acceptance in residential buildings," *Energy and Building*, vol. 41, no. 9, pp. 930-936, 2009.

[10] M. Frontczak and P. Wargocki, "Literature survey on how different factors influence human comfort in indoor Environments," *Build and Environment*, vol. 46, pp. 922-937, 2011.

[11] IOM (Institute of Medicine), *Climate Change, the Indoor Environment, and Health,* Washington, DC: The National Academies Press, 2011.

[12] M. Turunen, O. Toyinbo, T. Putus and A. Nevalainen, "Indoor environmental quality in school buildings, and the health and wellbeing of students," *International Journal of Hygiene and Environmental Health,* vol. 217, pp. 733-739, 2014.

[13] S. Langer, O. Ramalho and M. Derbez, "Indoor environmental quality in French dwellings and building characteristics," *Atmosphere Environment,* vol. 128, pp. 82-91, 2016.

[14] J. Miller, "Fungi as contaminants in indoor air," *Build Environment,* vol. 5, pp. 51-64, 1990.

[15] B. Walker, "A building aware of our needs," *Build. Services,* pp. 35-36, 1990.

[16] House of Commons Environment Committee, "Indoor Pollution, 6th Report," HMSO, London, 1991.

[17] K. A. Kuehn, R. Garrison, L. Robertson, R. D. Koehn, A. L. Johnson and W. J. Rea, "Identification of airborne microfungal populations from home environments within the Dallas Fort Worth (Texas) region," *Indoor and Build Environment,* vol. 1, pp. 285-292, 1992.

[18] ANSI/ASHRAE Standard 55 , *Thermal Environmental Conditions for Human Occupancy,* Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc., 2010.

[19] World Health Organisation (WHO), *Guidelines for Indoor Air Quality: Selected Pollutants,* Copenhagen: World Health Organization, Regional Office for Europe, 2010.

[20] HESE, *A European Study on Air Quality in Schools - Results. Health Effect of Schools Environment,* 2012.

[21] A. Karapetsis, "Case Study in School Buildings. MSc in Environmental Design of Cities and Buildings. School of Science and Technology," *Indoor Environmental Quality and Health,* 2016.

[22] F. Garcia, D. G. Shendell and J. Madrigano, "Relationship among environmental quality variables, housing variables, and residential needs: A secondary analysis of the relationship among indoor, outdoor, and personal air (RIOPA) concentrations database," *International Journal of Biometeorology,* vol. 61, no. 3, pp. 513-525, 2017.

[23] Y. Geng, W. Ji, B. Lin and Y. Zhu, "The impact of thermal environment on occupant IEQ perception and productivity," *Build and Environment,* vol. 121, pp. 158-167, 2017.

[24] J. Kim, M. Kong, T. Hong, K. Jeong and M. Lee, "Physiological response of building occupants based on their activity and the indoor environmental quality condition changes," *Build and Environment,* vol. 145, pp. 96-103, 2018.

[25] X. Shan, A. N. Melina and E. H. Yang, "Impact of indoor environmental quality on students' wellbeing and performance in educational building through life cycle costing perspective," *Journal of Clean. Prod.,* vol. 204, pp. 298-309, 2018.

[26] N. W. D. Ayuni and I. G. A. M. K. K. Sari, "Analysis of factors that influencing the interest of Bali State Polytechnic's students in entrepreneurship," *Journal Physics: Conf. Ser.*, vol. 953, 2018.

[27] E. Eyduran, S. Karakus and F. Cengiz, "Eyduran, E; Karakus, S; Cengiz, F 2009 Usage of factor scores for determining relationships among body weight and some body measurements," *Bulgarian Journal of Agricultural Science*, vol. 15, pp. 373-377, 2009.

[28] S. A. Abdul–Wahab, S. C. F. En, A. Elkamel, L. Ahmadi and K. Yetilmezsoy, "A review of standards and guidelines set by international bodies for the parameters of indoor air quality," *Atmospheric Pollution Research*, vol. 6, no. 5, pp. 751-767, 2015.

[29] A. P. Raman, M. A. Anoma, Z. Linxiao, E. Rephaeli and S. Fan, "Passive radiative cooling below ambient air temperature under direct sunlight," *Nature: Letter Research*, vol. 313, pp. 540-544, 2014.

[30] S. A. Abdul–Wahab, Sick Building Syndrome in Public Buildings and Workplaces, Springer, 2011.

[31] Department of Occupational Safety and Health (DOSH), *Industrial Code of Practice on Industrial Air Quality*, Malaysia: Department of Occupational Safety and Health, Ministry of Human Resources, JKKP DP(S), 2010.

[32] Institute of Environmental Epidemiology, *Guide for Good Indoor Air Quality in Office Premises, Ministry of the Environment*, Singapore, 1996.

[33] ASHRAE Standard 55, *Ventilation for Acceptable Indoor Air Quality*, Atlanta: American Society of Heating, Refrigerating and Air–Conditioning Engineers, INC, 2018.

[34] "Regulatory Requirements for Pharmaceutical Plants," in *Pharmaceutical Facilities: Design, Layouts and Validation*, pp. 1-30.

[35] C. Fehrmann and F. Depenbrock, "Recovery from Work-Related Stress: A literature review," *Maastricht Student Journal of Psychology and Neuroscience*, pp. 85-96.

[36] A. Ademakinwa and L. Rodrigues, "Building Resiloence fro Future Climate: An investigation of Fabric Optimisation to improve Thermal Comfort in Residential Buildinfs in Lagos, Nigeria," in *PLEA 2017 Conference: Design to Thrive*, Edinburgh, 2017.

[37] P. Wolkoff and S. K. Kjærgaard, "The dichotomy of relative humidity on indoor air quality," *Env. Int.* , vol. 33, no. 6, pp. 850-857, 2007.

[38] J. Jansz, "Theories and knowledge about sick building syndrome," in *Sick Building Syndrome in Public Buildings and Workplaces*, S. A. Abdul–Wahab, Ed., Springer, 2011, pp. 25-58.

[39] Federal–Provincial Advisory Committee, *Exp. Guide for Residential Indoor Air Quality: A Report of the Federal–Provincial Advisory Committee on Environmental and Occupational Health*, Ottawa, Ontario, 1989.

[40] Y. Al-Horr, M. Arif, A. Kaushik, A. Mazroei, M. Katafygiotou and E. Elsarrag, "Occupant Productivity and Office Indoor Environment Quality: A review of the literature," *Building and Environment,* vol. 105, pp. 369-389, 2016.

[41] Health and Safety Executive (HSE), *The Six Basic Factors,* 2013.

[42] TSI, *Indoor Air Quality Handbook, A Practical Guide to Indoor Air Quality Investigations*, 2013.

[43] M. A. Fierro, M. K. O'Rourke and J. L. Burgess, *Adv. Health Eff. of Exp. to Amb. Carb.Mon.,* Arizona: College of Public Health, The University of Arizona, 2001.

[44] The National Occupational Health and Safety Commission (NOHSC), *Exp. Standard for Atmospheric Cont. in the Occupied Environment,* Work safe Australia, 1995.

[45] Health Canada, *Exp. Guidance for Residential Indoor Air Quality,* Canada, 1989.

[46] R. Phipps, *Indoor Environment Quality Report*, 2007.

[47] R. Dales, L. Liu, A. J. Wheeler and N. L. Gilbert, "Public health: Quality of indoor residential air and health," *CMAJ*, vol. 179, pp. 147-152, 2008.

[48] R. Hedrick, *Ventilation for Acceptable Indoor Air Quality ASHRAE Standard 62.1*, 2010.

[49] S. Sebesta, *Indoor Air Quality in Commercial and Office Build,* 2011.

[50] A. Eweda, *An Integrated Condition Assessment Mod. for Educational Building Using BIM,* Monreal: Ph.D. Thesis, Concordia University, Montreal, Quebec, Canada, 2012.

[51] [Online]. Available: www.swegon.com/en/.

[52] H. Tang and D. Al-Ajmi, *Introdroduction to Air Policy and Air Quality Management,* Environment and Urban Development Division Kuwait Institute for Scientific Research, 2005.

[53] Institute of Environmental Epidemiology, *Guid. for Good Indoor Air Quality in Office Premises,* Singapore: Ministry of the Environment, 1996.

[54] ANSI/ASHRAE, *Ventilation for Acceptable Indoor Air Quality*, Atlanta: American Society of Heating, Refrigerating and Air–Conditioning Engineers, INC, 2004.

[55] T. Salthammer, S. Mentese and R. Marutzky, "Formaldehyde in the indoor environment," *Chemical Reviews,* vol. 110, pp. 2536-2572, 2010.

[56] Health Canada, *Residential Indoor Air Quality Guide: Formaldehyde,* 2006.

[57] European Commission (EC), *Air Quality Standards,* 2013.

[58] P. M. Bluyssen, *Understanding the indoor environment - putting people first, Daylight and Architecture*, vol. 13, 2010.

[59] Air Duct Cleaners, *Fact Sheet: Indoor Air Quality Standard*, 2013.

[60] World Health Organization (WHO), *Health effects of particulate matter. Policy Implications for Countries in eastern Europe, Caucasus and Central Asia,* 2013.

[61] K. Charles, R. J. Magee, D. Won and E. Lusztyk, *Indoor Air Quality Guide and Standard*, NRC Institute for Research in Construction, National Research Council Canada, PR–204.