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Assessment of Factory Design Requirements of Pharmaceutical Factory Buildings in Southwest, Nigeria

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Abstract:- In pharmaceutical factory buildings (PFBs), numerous gaseous substances are suspended in the air due to poorly designed production areas. In most PFBs, fenestrations are limited, though they provide some ventilation and workers' access to the natural environment. This paper assessed selected PFBs designs to ascertain the adequacy of indoor airflow and air flush as well as lighting and sound needed for the removal of suspended gases largely harmful to human health. Using a quantitative approach, fourteen PFBs were audited by taking dimensions of the production area alongside data on the quality of air, sound, and lighting. Findings benchmarked against the global standard required for factory designs to maintain wellbeing revealed eight PFBs had unacceptable design features; It was found that a unit increase in HCHO was found to increase the temperature by 15.268ºC and 98.3% of the variation in air velocity is explained by airflow while only 0.5% is explained by $PM_{1.0}$, $PM_{2.5}$, PM_{10}. Workers' complaint of illnesses was traceable to these poor design features. The paper recommended a need for re-evaluation in the architecture of PFBs intending to provide a healthy working environment for PFB workers in Nigeria.

Keywords:- *Design Requirements, Indoor Air Flow, Pharmaceutical Factory Building, Ventilation, Worker's productivity.*

I. INTRODUCTION

The concept of providing a building is primarily considered for safety, and convenience (Smith and Pitt, 2011; Akadiri *et al.*, 2012; Ransom and WHO, 1988; Hanson, 2001; Scruton, 2013; Bawa *et al.*, 2022a), consequently the desire for its beauty and comfort would also come in, as these are parts of the enclosed spacing it provides for every inhabitant. The Pharmaceutical factory building (PFB) by extension is not omitted from this as notably, it is also a peculiar building, based on the circumstance that it stocks the process of drug production implies the need for safety, serenity, and control (Xiaoguang, Hong, and Long, 2011). A huge portion of the effect of Indoor air on the inhabitants of a building compared to that of outdoor air is a result of its composition of both chemical and biological contaminants; these are the indoor air pollutants (Abdulaali, *et al.*, 2020; Smith and Pitt, 2011). The Chemical components of the contaminants include asbestos, carbon dioxide (CO_2), carbon monoxide (CO), construction chemicals, nitrogen oxide (NOx), ozone radon, and respirable suspended particulates (RSPs) (Smith and Pitt, 2011). While the Biological contaminants could be dust mites, endotoxins, houseplants, molds, pests, and pollen (Abdulaali *et al.*, 2020; Ghodrati, Samari, and Shafiei, 2012; Mannan and Al-Ghamdi, 2021; WHO, 1979). Conditions such as asthma, sick building syndrome (SBS) and other respiratory allergies have been seen to causable by the above-mentioned contaminants. Important to the health and productivity of building users is Indoor air quality (IAQ) (Abdulaali *et al.*, 2020; Dubbs 1990; Lee *et al.*, 2009; Smith and Pitt, 2011; Wargocki *et al.*, 2000). This paper aimed to ascertain the adequacy of indoor airflow, air flush, lighting and sound required for the for sustaining the healthiness of the PFBs. This was done by assessing some selected PFBs designs for these suspended gases, unfit measure of light and sound which as mentioned by Abdulaali *et al.* (2020), Dubbs (1990), Lee *et al.* (2009), Smith and Pitt (2011), and Wargocki *et al.* (2000), are largely harmful to human health.

Researchers, (Abdul-wahab *et al.*, 2015; Jones and Molina, 2017; Paleologos, *et al.*, 2021; Taştan and Gokozan, 2020; Bawa *et al.*, 2022b) have agreed that globally, the biggest environmental health problem is air pollution. Air pollution hints at hostile implications on climate, ecosystems, and human health, it pollutes air by a high quantity of particulate matter and toxic gases in the atmosphere (Manisalidis *et al.*, 2020). Of the factors that describe the value of any building, the measure of high-quality indoor air ranks as first (Khazaii, 2014). Similarly, Korkmazer *et al.*, (2018) presented in what way light pollution can be hazardous, as it touches perception, leads to glare and even blindness. The wellness and productivity of people have a straight association with the quality of the design and maintenance of the indoor air and lighting of the building that they live and work in (Arif *et al.*, 2016; Vimalanathan and Ramesh Babu, 2014). Armstrong *et al.*, (2005), Bawa *et al.*, (2022c), Gawade *et al.*, (2020), and Khazaii (2014) have discoursed that for a healthier indoor environment, there is a need for efficient ventilation systems. From these, we see that air pollution is a major factor in the built environment. This makes parameters like air quality, and air speed of importance to any built environment, even the PFBs.

II. LITERATURE REVIEW

There are guidelines that have been established to standardize the rates of gases and other particulate matter in the air to aid in keeping the indoor air safe and good for the wellbeing of the occupants, this study reviewed some of these guidelines from WHO, TSI, DOSH, ASQIQ, HKEPD and the Institute of Environmental Epidemiology as well as reports and articles from Arens *et al.*, (2020), Dosh *et al.* (2005), Charles *et al.* (2005), Jeong (2008), Colbeck (2012), and Tangand Al–Ajmi (2006). The air velocity from the issued guidelines of The WHO was set at a value of 0.25m/s (TSI, 2013; Arens *et al.*, 2020). The mean airspeed for an indoor environment as recommended by The AQSIQ (2002) should be 0.3m/s in summer and 0.2m/s in winter. Airspeed, according to the HKEPD (1999), was set as <0.3m/s for good air quality and <0.2m/s for excellent air quality. Dosh *et al.*, (2005) and Singapore suggested diverse value ranges of 0.25m/s and 0.15–0.5m/s for good and excellent IAQ, respectively (Institute of Environmental Epidemiology, 1996). The unit of sound pitch is Hertz (Hz), as that of sound intensity is in decibels (dB) and the acoustic comfort range for humans is between 20 - 20,000Hz. The relative humidity indoors should be 30–60% in winter and 40–80% in summer was recommended by ASQIQ (2002) in China. Similarly, the standard of <70% for good air quality and 40–70% relative humidity needed for an excellent IAQ was set by HKEPD (1999). Federal-Provincial Advisory Committee (1989) set the stipulated values 30–55% and 30–80% as short–term exposure limits in both winter and summer In Canada. Whereas in Singapore, the Institute of Environmental Epidemiology (1996) set its standards at 70% for office premises and Dosh *et al.* (2005) also set a standard of 40–70%. Standards adopted for CO_2 in indoor environments as established by Japan, Korea, Singapore, and Malaysia is 1000ppm (Charles *et al.*, 2005; Jeong, 2008; Colbeck, 2012; Tangand Al–Ajmi, 2006; Institute of Environmental Epidemiology, 1996) and 3500ppm (Long-Term Exposure) Health Canada, (Health Canada, 1989; ANSI/ASHRAE, 2004), and in the USA is 5000 ppm at 9000mg/m3 as 8h working day; 5d working week (ANSI/ASHRAE, 2004). The restriction for the levels of exposure to HCHO was in Canada at Action Level, 0.10ppm (120µg/m3), at Target Level: 0.05ppm (60µg/m3)4b (ANSI/ASHRAE, 2004; Health Canada, 2006; Health Canada, 1989). And in the USA, 0.1ppm (123µg/m3) at ceiling level 0.016ppm(20µg/m3) at 10–h workday during 40h work/week (ANSI/ASHRAE,2004; US Building Centre, 2007). The limit for TVOCs in Canada was 200µg/m^3 at Comfort Level (Air Duct Cleaners, 2013), 500µg/m^3 at Building Standard, and in the UK 300 µg/m^3 as 8–h average UK (Bluyssen, 2010). There are variations in some of the limits set by some of the guidelines by different groups, it is suggested that these variations might be due to the peculiarity of the locations, such as the climate. This therefore, implies that guidelines could be useful for each region to help in ensuring productivity and improved accuracy in predicting the nature of the working environment in the PFBs and the possible physiological and psychological response of the workers.

PFBs maintain active control and restriction of the inflow of outdoor climatic elements (such as wind, water vapor, rain, and moist air) into the indoor environment of the production area so the chemicals, processes, and drugs produced are protected from contamination (World Health Organization, 2003; Bawa *et al.*, 2022a; Bawa *et al.*, 2022b). By design, windows are not placed in Most PFBs (Zhuang, 2020); while those with them, ensure they are built as as fixed windows to allow only natural daylight into the indoor environment (World Health Organization, 2007) despite their usefulness as access to nature, for well-being, and reduction in stress levels (Uwajeh and Ezennia, 2019). It was elaborated that the production workers of the PFBs are made to work in such an enclosed environment for 7 - 9 hours for five or six days per week with only an hour for break daily (World Health Organization, 2003; World Health Organization, 2007; Bawa *et al.*, 2022b). Al horr *et al.*, (2016) studied IAQ in two broad senses which included the strategies in building design that buttress on the improvement of IAQ by increasing ventilation rate, which will in turn act to reduce air pollution, and this position had earlier been advanced or supported by (Daisey *et al.*, 2003).

The second opinion suggested by the paper was by minimizing the source of the air pollution from both indoor and outdoor to reduce and if possible, eradicate air pollutants in the indoor space. This position is already being adopted and considered by the PFB operators that is why most do not have windows in the production area, and those that have, use the type of fixed windows. But the earlier suggestion of increasing ventilation rate to reduce air pollutants will be important to this PFB study when comparing the factory design requirements as against what is currently obtainable. Another significant factor that affects IAQ is Air movement or air velocity. It has effects on other factors on human health both positive and negative as it does not usually have any direct effect. An example is that moving air can cause people to feel cooler if the moving air is cooler than body temperature because air heightens the air temperature and humidity around people thus decreasing thermal comfort (HSE, 2014; Bawa *et al.*, 2022a).

III. MATERIALS AND METHODS

The quantitative approach was applied in this study to gather data from randomly selected 14 PFBs in south-western Nigeria. The Fourteen (14) pharmaceutical factories were selected based on two other reasons. These reasons included inclusive criteria for characteristics that the prospective subjects must have if they are to be included in the study and exclusive criteria for the characteristics that disqualified prospective subjects from inclusion in the study (Patino, 2018) and these characteristics includes permission bottleneck and difference in size.

This research considered variables due to the happenings relating to the manufacture of drugs that comprises chemical mixes that goes on the PFBs as labelled by Abdul-wahab *et al.*, (2015) namely; Air Velocity, Carbon dioxide (CO_2), Carbon monoxide (CO), Formaldehyde (HCHO), Light, Particulate Matters ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), Relative Humidity, Sound, Temperature, and Total volatile organic compound (TVOC)) were evaluated by the procedure of digital handheld devices such as multifunctional air quality detector that measured air quality index US and Canada (AQIUS, AQICN) standards, air temperature, air velocity, carbon dioxide (CO_2), formaldehyde (HCHO), relative humidity, and total volatile organic compounds (TVOC).

These variables were divided into two namely, the dependent and the independent variables. The Air Velocity, light, Relative Humidity, sound, and Temperature were measured as independent variables in this study, while the airflow, CO_2, HCHO, $PM_{1.0}$, PM_{10}, $PM_{2.5}$, and TVOC were measured as dependent variables. A handheld HABOTEST HT6254 Digital Anemometer (Environmental meter) device was employed to measure air velocity, airflow as well as the corresponding scales. All the readings were taken between 1-1.2m heights to maintain consistency; hence, high air velocity measurements were expected. The diffuser flow area was measured as 0.36m^2. The Air Velocity was also measured at 15 points in rooms and halls occupied by machines and workers doing productions of various kinds which included tablets, capsules, syrups, drips, and sterile productions. Therefore, the airflow rate was measured using m^3/h. And the readings were then converted to airflow velocity using the equation below;

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

Where,
v = air flow velocity
Q = air flow rate in m^3/h
A = cross section area of the diffuser

The ANOVA statistical tool was used to analyze the correlation and regression of the result ing data from the sampled PFBs.

IV. RESULTS AND DISCUSSION

From the results obtained, the correlation analysis between the dependent and independent variables demonstrated that there exists a significant and positive relationship between temperature and HCHO and also a strong and positive relationship between sound and HCHO (Table 1)). It was also discovered that there is a positive and strong relationship between light and airflow lastly a strong and positive relationship between air velocity and all independent parameters ($PM_{1.0}$, $PM_{2.5}$, PM_{10}, CO_2, and airflow) except HCHO and TVOC (Table 1). Only relative humidity was not found to react to any predictor.

A unit increase in HCHO was found to increase the temperature by 15.268^{o}C and the model is given as Temperature = 28.633 + 15.286HCHO. This implied that from the data collected, change in HCHO (0.10-0.03=0.07). Therefore, 0.07 x 15.286 = 1.07^{o}C. This can further be translated to mean that 0.07 units in HCHO increase the temperature by 1.07^{o}C. Furthermore, R (Correlation Coefficient) = 0.558 indicates a strong and positive association between temperature and HCHO. Also, R^2 is = 0.311 which implies the total variation in temperature being explained by HCHO. The Anova table indicates that the regression model fits the data well with a significance of 0.031 which is less than 0.05 (The benchmark for measuring significance). Again, a unit increase in HCHO was observed to increase the sound by 161.07dB and the model is given as Sound = 69.867+161.071HCHO. This means that from the data collected, the change in HCHO is 0.07, and 161.071 (the high variance shows there are outliers in the measured data). Hence, 0.07 x 161.071 = 11.27dB. This means that a 0.07 increase in HCHO will increase sound by 11.27dB. Where R = 0.553 indicates a strong and positive association between sound and HCHO. Also, R^2 is = 0.306 which implies the total variation in sound being explained by HCHO. The Anova column on the table indicates that the regression model fits the data well with a significance of 0.032 which is less than 0.05. Furthermore, a unit increase in airflow will increase the light by 1.811lux and the model is given as Light = 1875.507 + 1.811 Airflow. Meaning that 0.04 (difference in the data collected 0.48-0.44) x 1.811= 0.072. The correlation (R) = 0.568 which indicates a strong and positive association between them also R^2 is = 0.322 which implies the total variation in Light being explained by airflow. The Anova column on the table indicates that the regression model fits the data well with a significance of 0.027 which is less than 0.05.

It was also observed that a unit increase in $PM_{1.0}$, $PM_{2.5}$, PM_{10}, and Airflow will increase Air velocity by 0.013, 0.002, 0.000, 1.004 respectively and the model is given as; Air velocity = 0.196+0.013$PM_{1.0}$ + 0.002$PM_{2.5}$ + 0.000PM_{10} + 1.004 Airflow. R = 0.993 which indicates a strong and positive association between the dependent (air velocity) and the independent ($PM_{1.0}$, $PM_{2.5}$, PM_{10}, and Airflow) also R2 is = 0.987 which implies the total variation in Air velocity being explained by the independent variables. The Anova table indicates that the regression model fits the data well with a significance of 0.000 which is less than 0.05. Since the majority of the independent variables were not significant, there was the need to run the regression with the significant Airflow, and the regression is given as Air Velocity = -0.017+0.987Airflow with R = 0.992 which indicated a strong and positive association between them. Also, R^2 is = 0.983 which implied the total variation in Air velocity being explained by the airflow. This indicated that 98.3% of the variation in air velocity is explained by airflow while only 0.5% is explained by $PM_{1.0}$, $PM_{2.5}$, PM_{10}. The Anova table indicates that the regression model fits the data well with a significance of 0.000 which is less than 0.05.

Table 1. Correlation and Strength between dependent and independent variables

		Temperature	Relative Humidity	Air Velocity	Light	Sound
$PM_{1.0}$	Pearson Correlation	.083	-.305	.817**	-.402	.264
	Sig. (2-tailed)	.768	.268	.000	.137	.341
	N	15	15	15	15	15
$PM_{2.5}$	Pearson Correlation	-.023	-.339	.811**	-.391	.101
	Sig. (2-tailed)	.935	.216	.000	.150	.721
	N	15	15	15	15	15
PM_{10}	Pearson Correlation	.000	-.328	.826**	-.411	.186
	Sig. (2-tailed)	1.000	.232	.000	.128	.507
	N	15	15	15	15	15
CO_2	Pearson Correlation	-.016	-.340	.736**	-.437	.136
	Sig. (2-tailed)	.954	.215	.002	.103	.629
	N	15	15	15	15	15
HCHO	Pearson Correlation	.558*	-.278	.315	-.429	.553*
	Sig. (2-tailed)	.031	.315	.253	.110	.032
	N	15	15	15	15	15
TVOC	Pearson Correlation	.018	-.065	-.404	.028	.152
	Sig. (2-tailed)	.950	.817	.135	.922	.590
	N	15	15	15	15	15
Air Flow	Pearson Correlation	.154	-.218	.992**	-.568*	.188
	Sig. (2-tailed)	.585	.436	.000	.027	.502
	N	15	15	15	15	15

Table 2. Regression Analysis Result

Depend. Variable	Independent variable	R^2	R	Durbin Watson	Model	Sig.	Anova Sig.
Temp.	HCHO	0.311	0.558	2.102	28.633 + 15.286HCHO	0.031	0.031
Sound	HCHO	0.306	0.553	2.392	69.867+161.071HCHO	0.032	0.032
Light	Air Flow	0.322	0.568	0.241	1875.5+1.811Air Flow	0.027	0.027
AV	$PM_{1.0}$, $PM_{2.5}$, PM_{10}, Air Flow	0.987	0.993	2.433	0.196+0.013$PM_{1.0}$+0.002 $PM_{2.5}$+0.000PM_{10}+1.004 Air flow	0.405 0.543 0.963 0.000	0.000
AV	Air Flow	0.983	0.992	1.975	-0.017+0.987Air flow	0.000	0.000

V. CONCLUSION

The results from the 14 pharmaceutical factories for Air Velocity, Carbon dioxide (CO_2), Carbon monoxide (CO), Formaldehyde (HCHO), Light, Particulate Matters ($PM_{1.0}$, $PM_{2.5}$, PM_{10}), Relative Humidity, Sound, Temperature, and Total volatile organic compound (TVOC)) evaluated showed that the level of either temperature or sound can affect the HCHO in a PFB. Also, it was also discovered that both light and airflow, while air velocity does not affect either HCHO or TVOC. The results also indicated a relationship between Light and airflow.

Therefore, the data analysis showed a varied correlation between dependent and independent variables from factory to factory. The outcome was understandable because all factories were producing different drugs at the time of the study. For those that were probably producing a similar drug, for example, table as at the time of the study. It was very unlikely that it was the same tablet. And even if it was the same tablet, it was unlikely that other conditions were the same. Conditions such as the quantity of drugs being produced were not the same; hence the amount of chemicals mixed was not the same. And the independent variables such as HCHO, TVOC, and the three Particulate matters were a result of the chemical contaminants suspended in the indoor air; also, the quantity in use determined the rate of the contamination. The source of CO_2 was mainly as a result of the exhaled oxygen from the workers, and the more the number of workers using the production area, the more the rate of the CO2 that would be found in the indoor air. Therefore, the amount of the independent variables differed from factory to factory. Workers' complaint of illnesses was traceable to these poor design features.

It is therefore recommended that the design of PFBs should be deliberate about investigating how to use the relationships between the air flow, air quality, and lighting and sound variables to create a healthy working environment. There is also a need for further research into investigating the sources of the relationship and disparity between the variable that have been studied in this paper as it regards to PFBs.

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