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Modelling Indoor Environmental Performance of Pharmaceutical Factory Buildings in Nigeria

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ABSTRACT

Pharmaceutical factory buildings (PFBs) are expected to provide indoor environmental performance suitable to enhance workers' well-being and productivity. This study examined the indoor environmental performance of PFBs in Nigeria towards modeling an enhanced worker's well-being and productivity. Fourteen PFBs were purposively selected as investigation sites with a field survey conducted in Southwest Nigeria. Several types of equipment were used to obtain IAQ data (that is the air temperature, relative humidity, airflow velocity as well as the concentration of carbon dioxide (CO_2), particulate matter, TVOC, and HCHO) along with subjective evaluation of the perception of the factory workers to obtain information on their working environment within the factories. Findings showed that 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. However, the values obtained for CO_2, $PM_{1.0}$, $PM_{2.5}$, and PM_{10} were satisfactory. The study concludes by suggesting ways to improve the indoor environmental performance of PFBs and proposed a model to enhance the worker's well-being and productivity.

INTRODUCTION

The process of making drugs is specialized, as it also emphasizes security, serenity, and control of the built indoor environment of PFBs (Xiaoguang, *et al.*, 2011). In achieving this, the quality of air and thermal factors affect indoor environmental performance (IEP) significantly as a whole (Mahbob *et al.*, 2011). The IEP considers workplace conditions and helps minimize end-users' complaints (Catalina and Iordache, 2012; Saraoui *et al.*, 2018). Quang *et al.*, (2014) and Luu *et al.*, (2021) considered thermal comfort to be dependent on the individual indoor users' adaptation and that also concerning the geographical location, climate, age, and gender of the individual, (Nicol and Humphreys 2002 and Smolander 2002) had earlier agreed with the position too. The parameters considered by (Al Horr *et al.*, 2016 and Bawa *et al.*, 2021) included air temperature, mean radiant temperature, air relative humidity, and air velocity, while metabolic rates and clothing insulation were classified as personal factors.

Adejuyitan *et al.*, (2009) asserted that continual indoor stress reduces physical and mental well-being, eventually hinders human performance, and drains workers' productivity. The poor indoor environment can increase absenteeism to work due to respiratory infections and allergic diseases caused by biological contaminants inhaled or contracted or an adverse reaction to the kind of chemicals used in the factory. Most PFBs are not designed with windows (Zhuang and Wang, 2020). And the production workers of the PFBs are made to work in such an enclosed environment for 7 - 9 hours five or six days per week with only an hour for a break daily (World Health Organization, 2003 and World Health Organization, 2007).

In addition to the above, the indoor environmental quality (IEQ) of the production area of the PFB has another influence, and it is that it always contains chemicals as well as washing areas (World Health Organization, 2007; Kubba, 2016 and Tait, 2019). Statutory bodies both at the international level and local level mostly regulate best practices in drug production and to a degree environmental hygiene (World Health Organization, 2002; Williams, 2005; United States Pharmacopeia Drug Quality and Information Program and Collaborators, 2007; Gad, 2008; Marles, *et al.*, 2011; World Health Organization, 2011; World Health Organization (WHO) Expert Committee on Specifications for Pharmaceutical Preparations, 2011; Ameh *et al.*, 2012; Lartey *et al.*, 2018 and Mills, 2020).

Indoor air is known to have a large amount of impact a building has on inhabitants compared to outdoor air with both biological and chemical contaminants pollutants (Abdulaali, *et al.*, 2020). Smith and Pitt (2011) noted that chemical components of the contaminants include carbon monoxide (CO), carbon dioxide (CO_2), radon, nitrogen oxide (NOx), asbestos, respirable suspended particulates (RSPs), construction chemicals, and ozone (Smith and Pitt, 2011 and Bawa *et al.*, 2021), while the biological contaminants could be pests, dust mites, houseplants, molds, endotoxins, and pollen (Lewin & Baxter, 2007 and Abdulaali, *et al.*, 2020). Bornehag *et al.*, (2001) added that pollutants in buildings are usually related to respiratory health challenges with possible sources being the presence of moisture, water damage, and also microbiological pollutants.

Pilotto *et al.*, (1997) and Norback *et al.*, (2000) discussed nitrogen dioxide (NO2) as a source of the respiratory problem in a building; Menzies *et al.*, (1993) and Milton *et*

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al., (2002) accredited it to low ventilation rates. Lang *et al*., (2008) and Garrett *et al*., (1999) identified formaldehyde as an indoor gas that suspends in the indoor air and causes irritations and respiratory disorders when inhaled for a long time. McCoach *et al*., (1999) and Zock *et al*., (2001) worked on chemicals in cleaning products; while Wyler *et al*., (2000) also blame outdoor pollutants or exhaust of vehicles. The factors that influence workers' productivity as determined by the indoor environmental quality (IEQ) as related to indoor air quality (IAQ), therefore include; air temperature, relative humidity, TVOC, CO_2, HCHO, air velocity, airflow, and particulate matter ($PM_{1.0}$, $PM_{2.5}$, and PM_{10}) (Smith & Pitt, 2011; Kong *et al*., 2021 and Bawa *et al*., 2021). CO_2 increases in buildings with higher occupant densities, and is diluted and removed from buildings based on outdoor air ventilation rates.

Examining levels of CO_2 in indoor air can reveal information regarding occupant densities and outdoor air ventilation rates. Studies have found that high levels of carbon dioxide (CO_2) have a significant negative impact on cognitive ability and strategic thinking (Sireesha, 2017). HCHO is a common constituent of adhesives used in particle boards, carpeting, and furniture. The use of HCHO has been modified in recent years to reduce its release from these products. It is considered a carcinogen that causes cancer of the nasal cavity in workers exposed in their jobs at remarkably high levels of exposure (thousands of ppb or higher). Exposure to moderate levels of HCHO (hundreds of ppb or greater) can cause several irritant symptoms, including temporary burning of the eyes or nose, and sore throat (Salthammer *et al*., 2010).

Air velocity is another important factor that influences IAQ. It does not usually have any direct effects on human health but mostly promotes both positive and negative effects on other factors. Moving air can cause people to feel cooler if the moving air is cooler than body temperature (HSE, 2013). PM less than 2.5µm in size ($PM_{2.5}$) has been directly linked to respiratory illnesses and infections such as asthma, as well as cardiovascular and respiratory diseases, including lung cancer (WHO, 2013). PM_{10} refers to particles that are 10µm or less in diameter, they are less toxic than $PM_{2.5}$ and still cause symptoms of respiratory infections and irritations: If exposure is long enough, may cause pulmonary and cardiovascular diseases as well as lung cancer (WHO, 2013).

TVOC is a group of compounds that are usually present in emissions or ambient air with a wide variation in chemical properties that are essentially a complex mixture of potentially hundreds of low-level volatile organic compounds (VOC), the sum of all individual TVOCs provides a guide to determine whether chemical levels are elevated in air samples (Simpson and Driscoll, 1998 and Johnson 2018). These levels often reflect the potential for occupant irritation, and discomfort, to such toxicity levels that eventually lead to death (Simpson & Driscoll, 1998).

Meanwhile, pharmaceutical factories were expected to satisfy at least ISO 14644 class 7, where the ambient air quality of the factories must contain less than 352,000 particles (0.5um) in diameter per cubic meter of air. Therefore, maintaining indoor air quality between classes 7 and 8 of ISO 14644 is highly recommended. This study examined the indoor environmental performance of PFBs in Nigeria towards modeling an enhanced worker's well-being and productivity in the PFBs in Nigeria.

METHODOLOGY

Study location

Lagos State, Nigeria, is a coastal area with a capital at Ikeja. Lagos state is within approximate coordinates of 6.5227°N and 3.6218°E, DAT (Date and Time, 2021). The state has a common boundary with Ogun State, the Republic of Benin, and terminates in the Atlantic Ocean in the south; making it a coastal city where several long and attractive sandy beaches (like Bar Beach) are located. While Ogun State is located within an approximate coordinate of 6.9980°N and 3.4737°E, DAT (Date & Time, 2021). Ogun state is bounded on the west by the Republic of Benin and the east by Ondo State, to the north is Oyo state while Lagos State and the Atlantic Ocean are to the south, (pharmapproach, 2021). This study area contains the largest number of PFBs with Lagos state having 57, followed by Ogun state with 16 which are 45% and 13% respectively out of the total of 126 PFBs in Nigeria as registered by the Pharmacists Council of Nigeria (PCN) (pharmapproach, 2020).

Finally, fourteen (14) PFBs were purposively selected as investigation sites with field survey conducted in the study area after conducting a pilot study in the rainy season in October-November 2020 to test the research instruments and then the dry season (main fieldwork) in March 2021.

Materials

The equipment used to obtain IAQ data includes the multifunctional air quality detector (Plate I) that measured relative humidity, air temperature, air velocity, carbon dioxide (CO_2), total volatile organic compounds (TVOC), and formaldehyde (HCHO). Other instruments used to carry out the measurements included a Digital Laser Distance meter 100m (Plate III), Digital Lux Meter AS803, KXL-801 LCD CO detectors, HABOTEST HT625A digital Anemometer (Plate IV), Digital Sound Level Meter (Plate II), and Infinix Note 4 X626B Android phone camera.

The IAQ data was assessed as written below;

Where each Indoor Air Quality (IAQ) Data = x

x_1 = Average temperature (oC) measured in each PFB

x_2 = Average air velocity (m/s) measured in each PFB

x_3 = Average $PM_{1.0}$ (mg/m) measured in each PFB

x_4 = Average $PM_{2.5}$ (mg/m) measured in each PFB

x_5 = Average PM_{10} (mg/m) measured in each PFB

x_6 = Average TVOC (ppb) measured in each PFB

x_7 = Average CO_2 (ppm) measured in each PFB

x_8 = Average HCHO (ppm) measured in each PFB

To determine the IAQ from the data collected, the following calculations were made using the following

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

formulas:

The measurements from the 14 PFBs were calculated,

$$\text{Average of IAQ Data } (y_{1-8}) = \frac{\sum \text{IAQ Data } (x_{1-8})}{\text{Number of Samled PFBs (n)}}$$

$$\text{Percentage Difference between IAQ Data}(z_{1-8}) = \frac{(\text{each IAQ Data(x)} - \text{Average of IAQ Data } (y_{1-8}))^2}{(\text{Average of IAQ Data } (y_{1-8}))^2} \times 100\%$$

$$\text{Sum of Average IAQ data for each PFB} = \sum \text{IAQ Data } (x_{1-8})$$

$$\text{Average Percentage Difference between IAQ Data for each PFB(w)} = \frac{\sum \text{IAQ Data } (x_{1-8})}{\text{Number of IAQ Data for each PFB(v)}}$$

analysed, and presented on charts and discussed. The temperature readings were taken fifteen (15) times and the readings were taken at intervals of an average of three (3) minutes in each of the fourteen (14) PFBs. The air velocity was also measured at 15 points from the 14 PFBs. All the measurements for this study were taken in the production rooms of the 14 sampled PFBs.

Structured (systematic) questionnaires for the supervisors and workers to determine users' productivity by way of finding out whether or not workers met production targets. The questionnaire forms were administered to workers with questions structured to determine the work schedules of the workers and also obtain details of health challenges suffered as a result of working in the production section. The purposive sampling technique through homogeneous sampling was used in the selection of the fourteen (14) factories. Meanwhile, the population size for the workers using Yamane's (1967) formula was adopted to arrive at 400 respondents.

This was arrived at using some assumptions for an average number of production workers in large PFBs 300, medium 200, and small 100. This assumption was done largely because most PFBs did not have a definite record of the workers dedicated only to the production areas. The workers were mostly casual workers who were only invited when certain drugs were manufactured. Also, those that had permanent production workers, were not permanently assigned to work only in production. Sometimes they worked in packaging or maintenance or any other assigned duty.

The stratification of the PFBs into large, medium, and small, was done based on three reasons which are; the size of the building (production area); the number of workers, and the number of drugs produced.

Therefore;

Hence,

$$\frac{73 \text{ PFBs } (57 - \text{Lagos}, 16 - \text{Ogun})}{3 \text{ (Large, medium, small)}} \cong 23 \text{ large, 24 medium and 26 small sizes PFBs}$$

23 x 300 (large PFB) = 6,900

24 x 200 (medium PFB) = 2,800

26 x 100 (small PFB) = 2,600

Total population size of the workers 6,900 + 4,800 + 2,400 = 14,300

n= $N/(3+N(e)^2)$

Where:

N = Population (14,300)

n = Sample size

e = Constant (0.05)2

n= $14{,}300/(3+14{,}300(0.05)^2)$

n= 19400/48.5

Sample size (n)=370

The Sample Size (n) was approximated to = 400

RESULTS

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 one (1) Metre (M) height from the ground according to (Zhu *et al.*, 2021). Generally, the acceptable range of the indoor air temperature is between 22.5-26oC, and 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, and 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 below the allowable limit of 0.1ppm and 1.23ppm as the lowest and highest calculated averages. The average calculated CO_2 of 14 PFBs with 12 factories measuring below the ASHRAE threshold of 1009ppm. Only two (2) factories had higher than the recommended standard. The total average of CO_2 for the 14 PFBs was 773.56ppm.

DISCUSSION

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 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

Parameters measured	International Standard	Data obtained from Field Measurements
Temp. (°C)	24.25 [ASHRAE standard 55, 2010]	29.42
Air Vel. (m/s)	0.25 [ASHRAE standard 55, 2010]	0.99
PM1.0 (mg/m)	-	18.47
PM2.5 (mg/m)	-	33.92
PM10 (mg/m)		18.47
TVOC (ppm)	Below 3 [Dosh, 2005]	0.31
CO2 (ppm)	Below 1000 [ASHRAE standard, 2017]	772.99
HCHO (ppm)	Below 0.1 (Zhu et al., 2021)	0.86

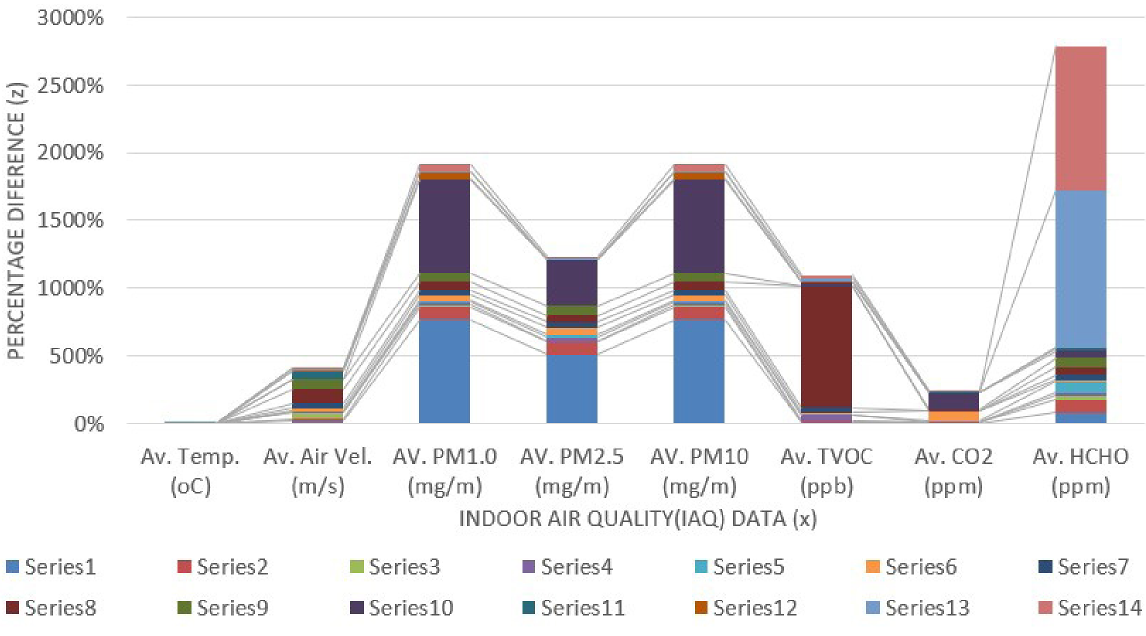

Figure 1: Percentage difference between IAQ data

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% different from the average measurement spread out through the 14PFBs, this is followed by the PM2.5 and PM10 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 PM2.5, PM10, and HCHO present in the PFBs.

The questionnaire result (Table 2) describes how the environmental performance variable affected the user's performance in the PFBs. The temperature, sometimes 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 and it is because mechanical ventilation is also needed to keep the drugs at a cool temperature. The rate about 57% agreed that they were able to meet the production target.

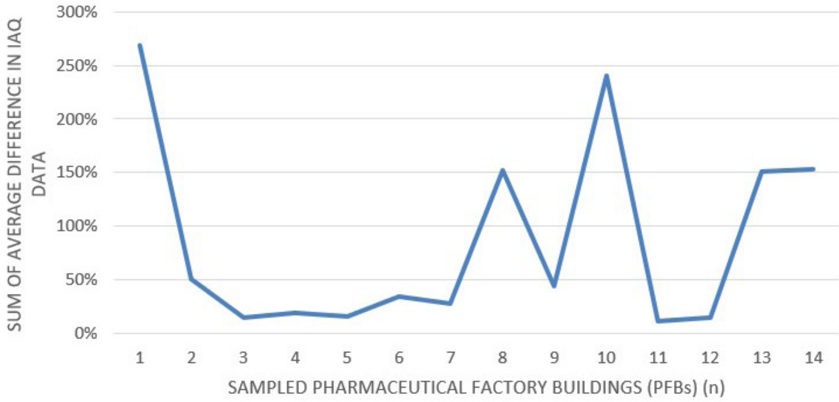

Figure 2: Average percentage difference in IAQ data from 14 PFBs

Table 3 explains the significance of the group mean in each of the predictor variables, as the group is significantly different in their mean score that is those that were productive are significantly different from those that were not productive.

From Table 3, it can be observed that except for relative humidity, average velocity, lighting, sound, CO_2, $PM_{2.5}$, PM_{10}, and airflow, all others show that there is no discriminant among the variables. The test result indicates that the significant value is less than 0.05 which implies an unequal variance among the group as in Table 4.

Table 2: comfort level of the Temperature and whether the hall is usually not airy enough

		Are you able to meet the production target?		Total
		Yes	No	
The temperature is sometimes uncomfortable during Production	Agree	149	152	301
	Undecided	37	21	58
	Disagree	127	67	194
The hall is usually not airy enough	Agree	71	102	173
	Undecided	20	13	33
	Disagree	222	125	347

Table 3: Tests of Equality of Group Means

	Wilks' Lambda	F	df1	df2	Sig.
Temperature	.774	16.630	1	57	.000
Relative Humidity	.960	2.355	1	57	.130
Average Velocity	.970	1.741	1	57	.192
Lighting	.998	.089	1	57	.766
Sound	.992	.444	1	57	.508
PM1.0	.922	4.815	1	57	.032
PM2.5	.965	2.061	1	57	.157
PM10	.970	1.759	1	57	.190
CO2	.993	.416	1	57	.522
HCHO	.148	329.062	1	57	.000
TVOC	.921	4.903	1	57	.031
Airflow	.971	1.690	1	57	.199

Table 4: Test Results

Box's M		548.368
F	Approx.	4.545
	df1	78
	df2	2292.828
	Sig.	.000

Tests null hypothesis of equal population covariance matrices.

This output generated in Table 5 shows the best predictors are the ones with the coefficient of 0.767, -0.172, -0.094, -0.093, and 0.065, which are the HCHO, temperature, TVOC, $PM_{1.0}$, and Relative humidity.

Table 5: Structure Matrix

	Function
	1
HCHO	.767
Temperature	-.172
TVOC	-.094
PM1.0	-.093
Relative Humidity	.065
PM2.5	-.061
PM10	-.056
Average Velocity	-.056
Airflow	-.055
Sound	-.028
Co2	-.027
Lighting	.013

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions.

Variables are ordered by the absolute size of correlation within the function.

The results of the structure matrix imply that each of the observed independent variables contributes to the dependent variable explanation in a significant way. The highest degree of relationship was indicated by temperature in the negative sense. This indicates that the lower the degree of temperature in a large pharmaceutical company the higher the probability that the workers will be productive. A similar relationship is recorded for $PM_{1.0}$ and TVOC.

The coefficient of PM_{10} is 0.000 which implies that PM_{10} affects workers' productivity also the presence of CO_2 is minimal in the large category factory as shown in Table 6.

Model Generated for Large PFBs

The model is developed in the order and amount of the parameters that determine productivity in the PFBs and from the analysis carried out with the data collected.

D(Y)=-0.266Temperature + 0.045 Relative Humidity -0.370 Average Velocity + 0.002 Lighting-0.001Sound-0.003$PM_{(1.0)}$ - 0.001$PM_{(2.5)}$ + 0.002CO_2 +1.691HCHO -2.091TVOC - 0.223Airflow

This model D(Y), can be verified by comparing each of the coefficients with the threshold value of each of the variables and using it to discuss in detail. For workers to be productive in a large category company the value of each of the variables should be considered and maintained to have good working conditions and better performance for the workers

Table 6: Canonical Discriminant Function Coefficients

	Function
	1
Temperature	-.266
Relative Humidity	.045
Average Velocity	-.370
Lighting	.002
Sound	-.001
PM1.0	-.003
PM2.5	-.001
PM10	.000
CO2	.002
HCHO	1.691
TVOC	-2.091
Airflow	-.223
(Constant)	.439
Unstandardized coefficients	

CONCLUSION

In modelling the IEP of PFBs, more research needs to be carried out in investigating the best way to consistently mitigate the high amount of PMs and HCHO in the atmosphere of the PFBs, as this research suggests that these could be the major reason for ill-health, discomfort, and reduced productivity in PFBs.

It is recommended that in large PFBs the parameters should be checked regularly to ensure that the developed standard or model is maintained for all the measured parameters to enable productivity.

The study also recommends that research can be conducted on the model for the productivity of workers in medium and small PFBs.

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