Review of the Literature on the Evaluation of Indoor Environmental Quality in Pharmaceutical Factory Building

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Abstract: ***This study is a review of relevant literature to determine the extent to which indoor environmental quality (IEQ) performance evaluation in pharmaceutical factory buildings (PFBs) has been carried out. The purpose of the study is to better understand the areas covered while also identifying areas that need further study. The IEQ performance was evaluated based on the six parameters adopted in this study. Meanwhile, these appraised parameters have not been validated by this study as a measurement construct for the evaluation of IEQ performance in factory buildings. The combinations of subjective and objective methods of assessment of IEQ performance were used in gathering the data for the study. The study found out that most of the previous studies have not done systematic assessment of the performance of PFBs in terms of IEQ and the level of perception and satisfaction of the factory workers. And to promote a sustainable environment, the study recommends that the five components of the green house should be met.***

Keywords: Factory workers, Indoor environmental quality, performance, pharmaceutical factory building,

1. Introduction

The study of indoor environmental quality (IEQ) as one of the determinants of a sustainable environment has remained a major topic among researchers of IEQ because of its direct impact on the performance of the building and its end-users. The IEQ of a building contributes largely to the liveability or otherwise of such a building and the outcome and behaviour of its occupants. The primary objective of a building is to provide sheltered housing that is comfortable, convenient, safe, attractive, and contributes to the productivity of its users. Hence, the comfort of the occupant must be taken into consideration and made a priority. Therefore, ensuring improved IEQ in any building designed for human use should be a priority for all stakeholders of the built environment.

In addition to the physical elements, the interactions of the building's occupants with its physical features also affect the performance of the inside environment. The most important need for a building is to guarantee that it satisfies the demands and expectations of its residents as well as the criteria needed to create a healthy indoor environment. Regardless of their circumstances, people are always in an environment. Maintaining comfort and health is therefore quite difficult (Parsons, 2013). The physical environment and people's reactions must be considered while creating an environment for humans (De Giuli, et al. 2013). The occupants' reactions to the indoor environments of the building will determine whether they feel comfortable, happy, or dissatisfied with it. When building users rate a structure favourably, it is deemed to be working well. Moreso, and especially when it provides the users with healthy, and comfortable indoor environment that enhance their productivity and satisfaction.

People tend to prefer a setting where they have the freedom to change environmental conditions versus one where there are restrictions (Parsons, 2013). Building occupants' comments as building users led to the necessity for comfortable indoor environmental quality (IEQ) in buildings (Frontczak, et al. 2012). Therefore, if an indoor environment ensured that most of the building users were satisfied, it could be said to be doing well (Mui & Chan, 2005; Wong, et al. 2008). The preservation of health and comfort should never be disregarded for buildings such as pharmaceutical factories. A healthy environment has been shown to have significant effects on the workers' health and productivity.

A pharmaceutical factory building (PFB) is defined by Bawa (2022a) as a setting for the production of drugs that includes areas for training, research, and the production of medications for human use. In addition to improving society's well-being, a PFB environment that promotes human wellness also benefits the PFB's users of the manufacturing buildings and its support employees. In terms of indoor environmental quality, a PFB designated as a high-performance building would draw in and keep workers while also promoting wellness and productivity (Zborowsky & Kreitzer, 2008). Drug production for the treatment of various illnesses is the primary task of a PFB. The PFB must consequently be constructed to benefit its users as much as possible. It is crucial to pay close attention to a pharmaceutical facility's environmental conditions. Poor indoor air quality has an impact on residents' psychological as well as physical health (Mahbob, et al. 2011; Sadek & Nofal, 2013). IEQ issues can negatively affect how residents feel about their surroundings. IEQ's effect on users' pleasure can be measured by their psychological reaction and their bodily complaints (Sadek & Nofal, 2013).

The pharmaceutical manufacturing setting is a constrictive workplace, thus the push for a healthy and comfortable working environment in buildings is only slowly taking hold. The environmental impact of the constructed form has been given more weight in green buildings than the users' health and wellbeing, which has not yet gotten the attention it merits. However, researchers are starting to grasp the significance of emphasizing a sustainable occupant environment as a way to achieve sustainable development (Smith & Pitt, 2011). When the PFB interior environment is continuously evaluated for performance in order to address obvious issues, PFBs and the facility's quality and performance can be improved. The purpose of this study is to explore the underlying trends and advances regarding the idea of IEQ in PFBs in order to pinpoint places where its evaluation procedures are deficient as well as how it typically affects building occupants. This study will offer pertinent information on the procedures involved in evaluating the quality and influence of the pharmaceutical environment on its users to PFBs operators, owners, managers, and built environment professionals.

2. Building IEQ concept

Prior to recently, pharmaceutical plant workers' needs for a comfortable interior environment, particularly in developing countries, have not received the attention they require. A trend, meanwhile, has been toward creating a system that can offer a thorough building assessment on a global, local, and indoor environmental scale (Chiang, et al. 1999). Building owners are required by law in industrialized countries like the United Kingdom (UK) to show their energy performance certificate, which is counterproductive without also taking into account a statement of the indoor environment performance that has a considerable impact on energy use (Ncube & Riffat, 2012). It is important for everyone to be aware of the effects indoor environments have on people's health, safety, and comfort. Therefore, additional research is required to gain the essential knowledge of and a better understanding of the influence of the interior environment on PFBs in order to provide an ideal indoor environment for all inhabitants (Salonen et al. 2013). Additionally, there is a need to combine the demands of the many users of pharmaceutical production facilities and appropriately address both the present and future environmental sustainability demand. It is essential to create a suitable indoor environment for building inhabitants. Smith and Pitt (2011) stated that while the health and wellness of the occupants are given less attention, green building design has received increasing emphasis in the built form's environmental consideration. Individual IEQ factors, that the responses of individuals to IEQ, serve as the foundation for indoor environment standards and guidance as those in (BS, 2007). It has been strikingly observed that these factors interact to affect occupants' satisfaction and effectiveness (Huang, et al. 2012).

For instance, a study similar to this one that assessed the IEQ and how it affected medical activity in a hospital (Croitoru, et al. 2013) demonstrates that either standards are not followed in the design of hospital buildings or the standards do not satisfy the needs of the occupants, which is similar to what PFBs have experienced. It is necessary to re-evaluate IEQ standards in buildings if they are not meeting the occupants needs, taking into account both the physical environmental qualities and how the occupants perceive these attributes. However, even when requirements and recommendations for the various characteristics are followed, IEQ, as experienced by occupants, is frequently not satisfactory (Bluyssen, 2010). According to Croitoru et al. (2013), criteria for IEQ should be modified and tailored to the comfort of occupants in order to improve their utmost efficiency and comfort. This is due to the fact that rules and guidelines have consistently been shown to be in conflict with what building occupants would need.

On the indoor environmental quality of buildings and their occupants, numerous research have been done. Studies on factors relating to IEQ were conducted by Astolfi and Pellerey (2008), Humphreys (2005), Lai, Mui, Wong, and Law (2009), while studies on the incorporation of IEQ parameters into mathematical models as a quantitative indicator of IEQ performance were carried out by Mui and Chan (2005), Ncube and Riffat (2012), Wong et al. (2008), Heinzerling, et al. (2013). On the other hand, in their various investigations, Bluyssen et al. (2011), Schakib-ekbatan et al. (2010), and Veitch, et al. (2007) incorporated additional characteristics that are unrelated to IEQ.

In contrast, Frontczak et al. (2012) investigated the elements that make up comfort in Danish residential buildings and the methods that occupants like to use to achieve it. According to their survey results, the acceptability of the indoor environment as a whole depends on how well the inhabitants accept each indoor environmental characteristic on average at a given level of acceptability. The respondents agree that their level of comfort is impacted by environmental factors. Catalina and Iordache (2012) focused on the building design phase and the effects of the interactions between the IEQ factors on overall occupant comfort and energy use when analysing IEQ in schools. They created a mathematical technique that could be used to analyse IEQ when designing new buildings or remodelling existing ones. Children's responses to indoor environments are passive because instructors' preferences take precedence, according to De Giuli, et al. (2012) evaluation of students' perceptions of the quality of the indoor environment in a primary school. The study by De Giuli et al. (2012) described a technique for analysing school buildings that combined physical measurement with a survey of inhabitants' psychological perceptions of the impact of the indoor environment. A web-based survey of 351 office building inhabitants was conducted by (Frontczak et al. 2012).

The results of the survey show that people's satisfaction with their indoor environment is influenced by how much room, noise, and visual privacy they have in their houses. Overall satisfaction and workplace have a strong association, according to the analysis of the responder responses.

3. Overview of IEQ in healthcare facilities

The health and comfort of occupants, who spend more than 85% of their time indoors, are significantly influenced by a building's overall performance. However, in PFBs, the average amount of time spent indoors is 8 to 10 hours. With the exception of Sundays and, in some cases, Saturdays, some factories operate a 24-hour production schedule, which contributes to the PFB environment's high occupancy ratio. Residential structures may go empty for a while, workplace and school buildings may close for the day, but a pharmaceutical is often closed only at weekends and holidays. Only a few numbers of places, including hospitals and prisons, are constantly filled. Architects and PFB operators should concentrate on providing an atmosphere that matches the needs and expectations of occupants. To give employees and the products in PFBs a friendly and homely indoor environment, physical spaces, particularly the production areas or halls, should be built for improved IEQ.

Workers and the products, whose health, wellbeing, and sanctity are likely impacted by indoor air quality (IAQ), thermal comfort, privacy, temperature, visual comfort, noise level, and access to technical and social support, are the focus of designers and stakeholders who are working assiduously to promote the PFB environment. According to a study by Al-Harbi (2005), when all aspects or characteristics of indoor environmental quality are taken into account during the design of the structures, the quality of the indoor environment can be improved. Thermal comfort, acoustic comfort, visual comfort, and indoor air quality are some of these indoor environmental factors (IAQ). In assessing the indoor environmental quality of residential buildings, Yoon (2008) found that the attributes of both the residents and the environment have an impact on the relationship between them. In order to minimize IEQ issues in buildings, he also recommended an integrative approach to environmental quality, in which the environmental elements that affect occupant comfort and satisfaction are combined. It was also stressed and advised by ASHRAE Guideline 10-2011 (ASHRAE Standard, 2014) to conduct more thorough study to ascertain the degree of interaction among various IEQ components.

3.1 Indoor Environmental Quality indicators

Due to inaccurate or incomplete data, the performance indicators used currently to evaluate the indoor environment of buildings are far from being applicable (Bluyssen, 2010). These indicators really do not completely capture what makes up a building's indoor environment or the detrimental effects it has on its occupants. Bluyssen (2010) proposed a performance indicator that blends occupant comfort characteristics and building indoor environmental quality criteria in the description of a framework for an interior environment that promotes health and comfort. It also emphasizes the necessity of new building indoor environment performance measures that ensure residents' comfort and health.

According to Hellgren et al. (2011), a feeling of a stuffy and dry indoor environment is a sign that the air quality in a building is inadequate. For building users, a well-ventilated indoor environment frequently offers better air quality. Uncomfortable building occupants may be caused by environmental noise pollution from nearby construction sites or building services (Dascalaki, et al. 2009). Temperature, humidity, ventilation, light, and noise have all been listed by building occupants as indoor environmental elements that affect human comfort, wellbeing, and productivity (Dascalaki et al., 2009). Noise, illumination, ambient air temperature, and air quality were all mentioned as environmental factors influencing IEQ and stress in buildings by Rashid and Zimring (2008).

According to a study by Chiang et al. (1999), there are a number of physical indicators and weighting factors that can be used to evaluate the indoor environment of a building for the benefit of its users' health. Eight physical environmental variables, including acoustics, noise, lighting, thermal comfort, indoor air quality (IAQ), water quality, greenery, and electromagnetic fields, were identified through the weighting factors (EMF). On the other hand, according to Alzoubi, Al-Rqaibat, and Bataineh (2010), a building's indoor environmental quality (IEQ) is determined by factors like thermal comfort, acoustics, lighting, electromagnetic frequency levels, portable water surveillance, and indoor air quality (IAQ), which includes airborne pollutants in addition to other health, safety, and interior design concerns like aesthetic appeal. Al-Harbi (2005) divided the factory into various zones according to the significance of the IEQ criteria when establishing an IEQ assessment technique. The key factors that impact indoor environmental quality (IEQ) in buildings were identified as a result of this categorization as being thermal comfort, acoustic comfort, visual comfort, and indoor air quality (IAQ).

On the other hand, Salonen et al. (2013) identify nine crucial physical design elements in healthcare facilities—among which the study highlighted pharmaceuticals as one—that have an impact on occupants' health and well-being in a review of about 231 publications. These components of the building functional circulation organization, structure, and building environment make up these factors. Nonetheless, it is clear that the main factors used to evaluate a building's indoor comfort level in most studies on the inside environment of buildings were Indoor Air Quality (IAQ), lighting, thermal comfort, and acoustics (Al-Harbi, 2005; Catalina & Iordache, 2012; Croitoru et al., 2013; Dascalaki et al., 2009; De Giuli et al., 2013; Mahbob et al., 2011; Mui & Chan, 2005; Ncube & Riffat, 2012; Tarcan & Varol, 2004; Wong et al., 2008; Yoon, 2008).

3.2 Characteristics of IEQ and its influence on building occupants

The largest environmental health issue in the world, according to researchers Abdul-wahab et al. (2015), Jones and Molina (2017), Paleologos et al. (2021), and Taştan and Gokozan (2020), is air pollution. The health of people, the climate, and ecosystems are all negatively impacted by air pollution. The rising concentration of dangerous gases and particulate matter in the environment, poisonous gases released by industry, and automobile emissions all contribute to the contamination of the air. Humans who breathe polluted air may develop respiratory, cardiovascular, or skin disorders, among other major health issues. Since air pollution is now the biggest threat to environmental health, there is growing interest in air quality monitoring especially in the indoor environment of PFBs which is characterized by suspension of chemical gaseous content.

According to Mahboob et al. (2011), indoor environmental quality (IEQ) is significantly influenced by factors like air quality, thermal condition, lighting, and acoustics, but effective (IEQ) performance can enhance working conditions and reduce end-user complaints (Catalina and Lordache, 2012). In order to ascertain the comfort levels of pharmaceutical laboratories in Malaysia, Yau et al. (2012) used four (4) laboratories for a study on indoor air quality (IAQ). According to the study, in order to give laboratory workers adequate IAQ and maintain equipment performance, the HVAC system must be built to always be in standard operating condition. With the aid of measurement tools, the study measured the IAQ variables of dry bulb temperature, humidity, airflow velocity, and carbon dioxide (CO_2).

Information on the laboratory personnel' level of activity, thermal comfort rating, and clothing insulation was collected through subjective assessment. Using the ASHRAE standard recommendations, it was discovered that the measurement results varied from lab to lab, with some falling below standards, others above them, and some falling within the suggested range. Information on the laboratory personnel' level of activity, thermal comfort rating, and clothing insulation was collected through subjective assessment. Using the ASHRAE standard recommendations, it was discovered that the measurement results varied from lab to lab, with some falling below standards, others above them, and some falling within the suggested range. Finally, the study found that the thermal satisfaction showed that the air conditioning system in the examined pharmaceutical laboratories was performing on average (Brager and de Dear, 1998).

Yau et al (2012)'s investigation did not take into account the option of combining the mechanical ventilation system with natural or hybrid ventilation methods, which may help boost the ventilation rate if adjusted. In order to speed up the removal of any harmful gas deposits in the production area of the PFBs, the current study suggests an investigation into whether natural ventilation or a hybrid or the two is acceptable.
Abdulmujeebu (2019) conducted a study on indoor environmental quality and asserted that IEQ comprises the parameters that affect human life inside a building, these parameters included IAQ, lighting, thermal comfort, sound, water quality, ergonomics, electromagnetics, hygiene, odour, micro-organism and vibration. When these IEQs are strengthened, the quality of life of the building inhabitants can be improved, also the deteriorating economic value of the building and the fines on the building owners or maintenance needs can be mitigated. The study also found that poor indoor air quality (IAQ) has a considerable negative impact on users' productivity and health. IAQ is one of the main elements that depends on airborne contaminants inside a structure. Al horr et al., (2016) had previously endorsed this viewpoint, and Abdulmujeebu, (2019) asserted that there are two ways to address IAQ problems in buildings: first, by reducing indoor and outdoor sources of air pollution; second, by increasing the rate at which outdoor air is ventilated into the interior environment. IEQ factors that affect the PFB include those related to lighting, thermal comfort, sound, and IAQ, which are all covered below;

3.2.1 Thermal Comfort of a Building

Thermal comfort, according to Abdulmujeebu (2019), is a condition that is influenced by both environmental and human elements, such as physiological, physical, and sociopsychological aspects. The study focused on environmental variables such as air temperature, air velocity, humidity, radiant temperature, and relative humidity, while human variables such as garment insulation and metabolic heat were also considered. Additionally, aspects such as acclimatization, availability of food and drink, mental and physical health were taken into consideration. According to the study, a building has reached thermal comfort when at least 80% of its occupants are content.
A thermally comfortable atmosphere is necessary for workers or users to be productive and operate at their highest potential, hence Al horr et al. (2016) believed that thermal comfort was probably the most significant IEQ variable. According to Quang et al. (2014), thermal comfort is dependent on the individual adaptation of indoor users, which also takes into account the user's age, gender, geographic location, and climate. Nicol and Humphreys (2002), Van Hoof et al. (2010), and Smolander (2002) had previously agreed with this position. Al horr et al. (2016) took into account six variables, including air temperature, mean radiant temperature, air relative humidity, and air velocity. The classification of metabolic rates and clothing insulation as personal parameters.
Indoor air is having a large share of the impact a building has on inhabitants compared to outdoor air. This is made up of both biological and chemical contaminants indoor air as pollutants (Abdulaali, et al. 2020). (Smith and Pitt, 2011) The Chemical components of the contaminants include carbon monoxide (CO), carbon dioxide (CO_2), radon, nitrogen oxide (NO_2) asbestos, respirable suspended particulates (RSPs), construction chemicals, and ozone (Smith and Pitt, 2011). While the Biological contaminants could be pests, dust mites, houseplants, moulds, endotoxins, and pollen. International Organization for Migration (IOM) (2000) and Abdulaali, et al., (2020) have proven that these contaminants can cause asthma, sick building syndrome (SBS) as well as various respiratory allergies. Indoor air quality (IAQ) is important to the health and productivity of building users (Lee et al., 2009; Wargocki et al., 2000; Dubbs 1990; Abdulaali et al., 2020; Smith and Pitt, 2011).

3.2.2 Lighting (Visual) Comfort in PFBs

On lighting comfort, (Abdulmujeebu, 2019) found out that lighting has the properties of both waves and particles and as a wave property, lighting has a frequency that relays on the colour of the struck surface on walls, floor or ceiling of the indoor environment. This is observed in white surfaces that reflect the majority of the incident light.

Lighting impacts greatly on the physical and psychological health of the occupants of an indoor environment, which can affect their comfort, health and productivity (Abdulaali, et al., 2020, Hwang and Kim, 2011). The awareness of the right dimensions (light levels for illumination and lamination, glare control, light transmission and consistency) for optimal lighting in a built environment is important (Hwang and Kim, 2011; Abdulaali, et al., 2020). Too much lighting can lead to fatigue and blindness while too little of it can cause dry eyes, allergic reaction, eye irritation and headache (Boyce, 2010; Smith and Pitt, 2011; Abdulaali, et al., 2020).

Furthermore, lighting intensity in a building is dependent on the type of activity going on in the building, for example, operating theatres like the production areas of PFBs require a brighter contrast of lighting than a bedroom. The contrast in this instance refers to the legibility of even the smallest details. Natural lighting helps to improve the lighting condition of the PFB, although not all drugs produced in the PFB might require natural lighting. The study opined that visual comfort can be evaluated by establishing glare indices such as unified glare index (UGI), visual comfort probability (VCP) and CIE glare index (CGI) which are appropriate for artificial lighting (Carlucci and Pagliano, 2012; Xue et al., 2016; Suk et al., 2016 and Suk 2019) of which PFB belongs in this category where artificial lighting is used.

According to Leech et al., (2006); Serghides et al., (2015), and Al horr et al., (2016), visual comfort is critical for the well-being and productivity of users of a building. Other researchers have also evaluated the importance of lighting or visual comfort on workers performance, productivity, comfort and satisfaction (Veiteh, 2001).

3.2.3 Acoustic (Sound) Comfort in PFBs

On acoustic comfort, (Abdulmujeebu, 2019) explained that building acoustics has to do with controlling the quality of sound in the indoor environment. Acoustic comfort has two aspects which are room and building acoustics. Room acoustics deal with how sound is propagated clearly within the indoor environment, while building acoustics on the other end deals with the concerns of unsolicited sound such as outdoor environmental noise. Acoustic comfort in a building has a critical impact on the health, well-being, satisfaction, communication and productivity of the building workers. In considering acoustic comfort or noise, Al horr et al., (2016) agreed with Greek Legislation, (1989) that the acoustic comfort of any particular building is in its ability to protect its users from unwanted noise and deliver an acoustic indoor environment that is suitable for the building. And that there is a direct relationship that exists between the acoustic (noise) and the productivity of the workers or occupants of the building, (Landstrom et al., (1995) had earlier supported this same claim. ANSI, (2010) agrees that acoustic problems are generated from mainly airborne sounds or noise, outdoor environmental noise, noises that emanate from adjoining spaces, nearby facilities and more pronounced from the equipment.

Indoor spaces are also susceptible to both interior sources and external sources of noise due to bad acoustics (Abdulaali, et al. 2020). External noise must be stopped from affecting the indoor spaces to avoid Sound pollution which is harmful and has hearing implications (Abdulaali, et al., 2020). To avoid sound pollution, it is necessary to curtail prolonged load of noise to avoid hearing problems, permanent hearing damage and ensure unaverred personal motivation, efficiency and productivity of building users (Evans and Stecker, 2004; Smith and Pitt, 2011; Abdulaali, et al. 2020)

For the PFB, the concern is even more on the noise generated from the indoor activities within, through the machines used for production and communications among the workers. The acoustic comfort is usually affected by factors that may include the shape and size of the space, sound generated from within indoor and outdoor environments, airborne noise transmission, noise from impact and other acoustic characteristics such as absorption, transmission, echoes and sound reflections in the indoor environmental surfaces. The unit of sound intensity is decibels (dB), while sound pitch is Hertz (Hz) and the acoustic comfort range for humans is between 20 - 20,000Hz. Also, parameters used for evaluation of acoustic performance include reverberation time (RT), sound pressure level (SPL), early decay time (EDT), clarity (C50 for speech and C80 for music), speech intelligibility (D50) and speech transmission index (STI). Clarity has been defined as the ratio of the energy in the early sound (received in the first 80 mins) to that in the reverberant sound.

Noise from machines, if not properly checked in the production hall can lead to partial deafness which is sometimes indicative by continual talking loudly even when out of the production area. Noise can also lead to headache and fatigue among workers in the production area of PFB and this can ultimately lead to poor productivity. Therefore, production machines used in the PFB need to be as noiseless as possible. Hence frequent servicing and maintenance are necessary to keep them in their best working conditions. Other recent works on noise or acoustic comfort include (Tong et al., 2007) who researched noise in classrooms and laboratories in schools exposed to traffic areas. Jeony et al., (2018) studied acoustic design, an appraisal of musical concert theatre while Tan et al., (2006) were interested in the application of building information modelling to enhance the indoor acoustic comfort and performance. Other contributing researchers in this aspect included (Lam et al., 2018; Imran et al., 2018 and Ranterghem, 2018). For PFBs, the noise from the workers themselves can be added, while the movement of the workers and movement of products, chemicals and other goods within the production area equally generate noises that constitute an acoustic problem in the PFB, but the equipment or machines used for production are more pronounced.

Al horr et al., (2016) agrees with Bluyssen et al., (2011) that acoustic problems should be addressed at the design stages of the building and implemented at the construction stage. The architect must ensure this largely as they work with acoustic or sound engineers, (Passero and Zannin, 2012 and Shafaqhat et al., 2014) equally agreed with this method of solving acoustic problems and will be recommended for PFBs designs.

Earlier Al horr et al., (2016), worked on the impact of indoor environmental quality on occupant well-being and comfort, where the paper considers sick building syndrome, indoor air quality, thermal comfort, visual comfort and acoustic comfort as the parameters. This research on pharmaceutical factory buildings (PFBs) will not consider sick building syndrome because it is not the entire building that is being considered. It is only the production area, which is a carefully designed and built indoor space which is considered a delicate and most important section of the PFB because of the activity of producing drugs. There are several regulatory checks on this section of the building that building failure or sick building syndrome will hardly concern it without being noticed.

3.2.4 Thermal comfort and Indoor Air Quality (IAQ) in PFBs

ASHRAE 55, (2010) and standard, ISO 7730 (1994) defined thermal comfort as the state of mind that expresses satisfaction with the thermal environment in which it is located. Hence the outcome of the PFBs research seeks to achieve that condition where the production workers will find satisfaction working in the PFBs. And to achieve that, other variables too had to be considered.

Meanwhile, IEQ cannot be studied without deliberately studying IAQ, it is the most critical element of the PFB study. 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 the fixed window. 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.

3.2.5 Evaluation of IEQ performance in PFBs

It can be difficult to evaluate IEQ based on its various aspects. According to Parsons (2013), the Environmental Index value can be used as a single index value to determine an individual's optimal IEQ. This index value describes the connection between the strains an occupant experiences as a result of being under stress from the physical indoor environment characteristics. Priority should be given to correlating subjective responses from building occupants with objective physical data when assessing the efficacy of a building's IEQ (Frontczak et al., 2012). Building occupants' subjective assessments of IEQ provide insight into how people feel about the indoor environment (Bluyssen et al., 2011). Occupants are the most crucial instrument for evaluating the building environment, according to Gou and Lau (2012), despite the fact that it is challenging to calibrate humans. In various research, several techniques and instruments for a purely subjective assessment of building IEQ have been used. The Building Use Studies (BUS) approach (Leaman, Stevenson, and Bordass, 2010), a web-based survey with an online reporting tool (Zagreus et al., 2004), and BASE—building assessment survey and evaluation—are a few examples (US EPA, 2008). British Research Establishment Environmental Evaluation Method (BREEAM) was also recommended by Smith and Pitt (2011) as a tool for environmental assessment that might be used to enhance the quality of buildings for occupants.

The PFB operates an indoor environment of the production area that conforms maximally to the former opinion of this study, but the latter opinion is equally the opinion this current research hopes to integrate, where there can be openings in the production area that can increase air ventilation to increase the quality of the indoor environment, which can also enable the flushing of dangerous suspended gases. The PFBs study adopted air temperature, air relative humidity, air velocity, metabolic rates and clothing insulation as parameters and will be measured during the fieldwork, this is largely because these parameters are considered as the factors that can influence IAQ in PFB too.

Bawa (2021) performed a regression analysis on an objective indoor environment measure and subjective measurements as part of a study to improve a comfortable indoor environment in pharmaceutical companies. The findings showed that the indoor quality was rated substantially better by users than by objective metrics. However, Bawa (2021) came to the conclusion from the regression analysis that combining both measured and perceived variables produced the best prediction result. This study solely looked at which of the characteristics that could be assessed physically and those that could be rated subjectively was a better indicator of occupant comfort in a PFB. It was not taken into account to identify the variable that is the best predictor for each of the users. The relationships between IEQ's six key components play a role in how it is assessed.

Humphreys (2005) found that it is preferable to take into account each IEQ parameter separately rather than creating a single model that only accounts for an overall assessment of IEQ in his study to determine whether the combined indices of the indoor environment are practical in quantifying occupant's comfort.

On the other hand, Mui and Chan (2005) contend that it was necessary to investigate the interactions between the many IEQ variables in order to combine them into a single index that would define an acceptable IEQ. The design and maintenance of acceptable indoor environmental quality (IEQ) would take on a new dimension if the six indoor environmental quality (IEQ) variables were integrated into an indicator model that produces a composite IEQ index (Mui & Chan, 2005).

4. Discussion

Not so many studies have systematically assessed the performance of PFBs in terms of IEQ and the level of perception and satisfaction of the occupants. Studies on indoor environment in buildings generally in the last decade have focus mainly on the individual parameters such as thermal comfort (Azizpour et al. 2013; Khodakarami & Nasrollahi, 2012; Lomas & Giridharan, 2012; Melhado, et al. 2006; Pourshaghaghy & Omidvari, 2012; Skoog, et al. 2005; Bawa, et al. 2022), acoustic comfort (Xie, et al. 2009; Bawa, et al. 2022), visual comfort, and indoor air quality (Dascalaki, et al. 2008; Hellgren et al. 2011; Hellgren, 2012; Mendes, 2008; Bawa, et al. 2022). Sick building syndrome have been found to be connected with bad IEQ (Wong et al., 2009) and the impact on building occupants is even higher in PFBs largely because of the chemicals used to produce drugs. The level of environmental quality requirement for PFBs needed much more attention as compared to other building types. However, there has been no any consideration for an indicator for the overall IEQ of PFBs in terms of occupant's satisfaction with the environment.

The assessment of overall IEQ of buildings has always considered the perception and satisfaction of the occupants in ascertaining the level of performance (Mourshed & Zhao, 2012); however, for PFBs satisfaction and comfort levels of the occupants must be factored into the assessment. If the requirements of occupants in PFBs must be something to reckon with in creating standards, then, their different comfort levels must be put into consideration. It is easier to have a particular standard measure for IEQ in office and residential buildings; however, occupants in PFBs are often dissatisfied with their indoor environment based on requirements of standards as these are restricted and controlled environments. Standards for improving IEQ in buildings only define acceptable ranges for the IEQ parameters. If overall IEQ performance measures are to be incorporated into standards and guidelines, then studies must be conducted towards integrating all the contributing factors of IEQ into multiple models.

Some studies have already been conducted into integrating the four parameters of IEQ into a single model indicator of the indoor environment (Chiang et al., 2001; Heinzerling et al., 2013; Ncube & Riffat, 2012; Wong et al., 2008). However, no such study has been conducted in the context of PFB environment where the users work in a controlled indoor environment. As much as the comfort level of occupants in a hospital building could vary, they are always within the same environmental setting. Salonen et al. (2013) suggested a compromise to be made in the design and operation of hospital buildings such that the occupants are provided with an acceptable comfort level for all. Different evaluation framework models have been developed/proposed by different researchers in different building settings such as; school buildings (Catalina & Iordache, 2012), residential buildings (Yoon, 2008), office buildings (Choi, 2012; Mui & Chan, 2005; Ncube & Riffat, 2012; Wong & Mui, 2009), and care centre (Chiang et al., 2001). All these IEQ evaluation models, as proposed, cannot be effectively used in healthcare facilities because of the varied nature of the occupants. An IEQ model that could be fit for hospital buildings is the one that factored into the derivation of the model, the different comfort requirements of the occupants.

Heinzerling et al. (2013) carried out a thorough exploration of literature of studies on IEQ evaluation models in assessing buildings. Their review discussed the correlations between objective and subjective assessment methods of IEQ in buildings. Heinzerling et al. (2013) study reveals that there is no harmony on measuring protocols, IEQ weighting schemes and assessment class limits, and none accounted for inter-category relationships within the components of the model. They therefore, recommended that research on inter-category relationships should be carried out in future IEQ assessment models. Thermal comfort, acoustic comfort, visual comfort, and indoor air quality that have been seen as the four main factors or parameters of IEQ in buildings, have not been validated as an IEQ measurement construct.

IEQ Evaluation studies that used both subjective and objective assessment methods were also limited in ascertaining the degree of variation or equality in the measured parameters using the different methods. The above points raised can be corroborated from the appraisal of a review of IEQ assessment models done by Heinzerling et al. (2013), where no literature mentioned the validation of thermal comfort, acoustic comfort, visual comfort, and indoor air quality as parameters that determine the performance of IEQ in buildings. The overview of subjective and objective IEQ assessment methods in buildings as reviewed by Heinzerling et al. (2013) also shows that relationship between subjective measures and objective measures as assessment methods of IEQ in buildings have not been established. There is, therefore, a need to validate these parameters and also determine the relationship between the two assessment methods in the measurement of IEQ in buildings.

5. Conclusion and recommendations

The five main components of green buildings—Energy Efficiency (EE), Indoor Environmental Quality (EQ), Site Planning and Management (SM), Water Efficiency (WE), and Materials Resources (MS)—which have significant effects on building occupants and environmental degradation—should be met by buildings in order to promote a sustainable environment. One of the difficulties or fundamental issues that architects encounter when constructing PFBs is how to create a healthier environment as opposed to one that limits it. Little has been done in evaluating the built environment's impact on these facilities' users despite the existence of various publications on evidence-based design of PFBs. The performance indicator chosen by the consumers should be the ideal one for a structure or environment. As a result, in addition to physical measurements and regulations, occupant satisfaction should be a key factor in determining a building's indoor environmental quality.

The findings the reviews conclude as follows:

The validation of thermal comfort, acoustic comfort, visual comfort, and indoor air quality as parameters of IEQ measures in PFBs has not been attempted. Therefore, the validation of the IEQ measurement parameters is required before an integrated IEQ performance evaluation model can be created.

To determine the degree of variation or equality in their measured variables, a relationship between subjective occupant surveys and objective physical measurements as IEQ assessment methods in buildings needs to be developed.

Few efforts have been made to isolate each user type in pharmaceutical factory buildings in order to identify the variations in their IEQ needs and satisfaction. Determining a good IEQ comfort level that is acceptable to all occupants in a PFB will be of the utmost importance in light of the aforementioned factors. This established degree of comfort can be taken into account when creating a PFB's IEQ performance indicator model.

The most important need for a building is to guarantee that it satisfies the demands and expectations of its users as well as the criteria needed to create a healthy indoor environment. Therefore, a model that represents the effectiveness of IEQ in buildings should be comprehensive and focused on the satisfaction of the users with the IEQ.

The development of an integrated IEQ performance and occupant satisfaction as an evaluation framework for PFBs may be based on the validation of IEQ parameters and assessment methodologies. Studies aimed at creating a single index that quantifies the performance of IEQ in buildings (Parsons, 2013) may serve as inspiration for a future evaluation of standards that considers the interior environment as a whole rather than just its individual aspects. For PFB operators, managers, and designers, this review research established a baseline of knowledge that would help them make the much-needed changes to the environmental design of PFB facilities.

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