Review

A Literature Review of Indoor Air Quality and Sick Building Syndrome in Office Building Design Environment

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Abstract: Building indoor spaces requires constant access to fresh air for occupants' health, well-being, and performance. Clean breathing air can be achieved through the removal of pollutants from within the building's interior by ensuring a sufficient outdoor air exchange rate. This review set out to create a clear understanding of recent developments in indoor air quality (IAQ) studies and their relationship to sick building syndrome (SBS) impacts on occupants' health and well-being, as well as the role architectural design plays in promoting a healthy indoor environment. It also provides support information as well as existing state-of-the-art practices in IAQ and SBS in office buildings, with a particular focus on monitoring, assessment, and space configuration. The information available here would provide building professionals, particularly architects, with the potential for incorporating design and the development of guidelines for the control of SBS-related environmental parameters in order to create a healthy and comfortable office indoor environment.

Keywords: indoor air quality, sick building syndrome, building design, indoor environment, space configuration

1. Introduction

Indoor building spaces are required to have constant access to fresh air for occupants' health, well-being, and performance. Clean breathing air can be achieved through the removal of pollutants from within the building's interior space by ensuring a sufficient outdoor air exchange through ventilation. Proper ventilation in buildings, therefore, acts by diluting air contaminants and removing them from the indoor space, thereby improving the quality of air for building users [1]. A building design without adequate ventilation would have a great impact on indoor air quality (IAQ), temperature, humidity, and airflow as a result of inherent pollution. These indoor air pollutants cause sick building syndrome (SBS), which affects the health of building users. Consequently, a building can be termed healthy if, on its own, it can uphold health, reduce environmental impacts, and ensure both the physical and psychological comfort of its occupants [2]. The role of IAQ in creating a healthy environment is critical, as humans spend most of their quality time indoors. The air in an indoor space can be contaminated by either natural or artificial agents. As such, its design configuration is critical. An indoor environment with a free flow of air and a limited occupancy level improves the quality of indoor air as the concentration level of carbon dioxide (CO_2) is low [3]. A study in the United States by Watson [4] has shown that a greater population of citizens acknowledged the importance of a healthy IAQ during the COVID-19 pandemic. Because of the adverse effect of poor IAQ, different international organizations have developed guidelines and standards to meet the requirements for acceptable air quality for occupants' comfort [5]. In Nigeria, there

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are no such existing regulations on IAQ. As such, building environment design and maintenance are carried out without consideration of IAQ standards and regulations. Studies on IAQ are faced with challenges resulting from the assessment and monitoring methods adopted. These challenges range from differences in monitoring periods, data reporting, IAQ variables and pollutants measured, and the unavailability of worldwide thresholds [6]. As such, a critical evaluation and comparison of related studies on IAQ and SBS are difficult. There is, therefore, a need to provide adequate monitoring capabilities of air quality in buildings as a means through which occupants' health, well-being, and productivity can be improved. Consequently, Ghaffarianhoseini et al. [7] suggested an appraisal of buildings from a health perspective to identify crucial obstacles and the way forward. Indoor air contaminants have been rated as one of the top environmental risks to building occupants' health and well-being [8]. The most common range of air pollutants within buildings' indoor spaces includes odors, smoke, metabolic CO_2, volatile organic compounds (VOCs), and particulate matter (PM). VOCs are IAQ elements or pollutants resulting from building furnishings, building structures, or the building ventilation system. The quality of air within building indoor spaces varied according to building types, occupancy, and the different sources of inherent contaminants, such as their variation in concentration levels. The atmospheric quality of the indoor air (temperature, humidity, ventilation rate, air particles, etc.) can pose some health challenges to building occupants. Where office building users are increasingly requesting sick leave as a result of some medical claims, it is an indication of the impact of SBS, which needs to be investigated. When there is a consistent occurrence of symptoms related to SBS over a period of time among building occupants, such a building can be said to have a "risk factor" impact. A report by the World Health Organization (WHO) has shown that about 30% of existing and new buildings in the world have been ascertained as being susceptible to SBS [9]. Building occupants' well-being is greatly impacted by SBS occurrence, resulting in identifiable symptoms, as evident in different studies on office buildings [10-14]. Apart from the impact on health, SBS is also related to human mental well-being [7]. Due to the negative impact of SBS on building occupants, the need for designing healthy buildings has grown in importance. Understanding the significant relationship between IAQ, SBS prevalence, and building design features, as well as harnessing this relationship at the early building design stage, is a sure way of achieving a comfortable and healthy work environment in an office building. Available information reveals that even with the austere impact of poor IAQ in buildings, developing countries such as Nigeria have shown little interest in exploring these impacts on building users' health. In order to develop more beneficial IAQ policies in developing nations, the forms of IAQ contaminants and their impacts on health and well-being should be researched more often [15]. There is, therefore, a need to encourage IAQ-directed studies, especially in Nigeria and other developing nations of the world. This study carried out an overview literature review to summarize existing knowledge and highlight design solutions and roadmaps for future office building indoor environments. The review set out to create a clear understanding of recent developments in IAQ studies and their relationship to SBS impacts on occupants' health and well-being, as well as the role architectural design plays in promoting a healthy indoor environment. Furthermore, it attempts to bring to the fore the complex nexus between sustainable design and the development of office buildings as it relates to their IAQ and impact on occupants' health. This study aims to create more awareness about the need for office buildings to accommodate the health and well-being of their occupants through adequate provision for IAQ and its attendant effects. After discussing IAQ and SBS impacts and assessments in buildings, the main parameters that typically relate to office space design and the promotion of a healthy work environment were summarized.

2. Methodology and selection criteria

For this study, a random search was done on accessible databases such as Google Scholar, ResearchGate, Academia, Science Direct, Scopus, etc. The search was facilitated by filtering a comprehensive number of journals and conference publications. Articles found on other databases and the web that are relevant to the study were also reviewed. The database search was carried out using a combination of keywords such as IAQ, SBS, IAQ monitoring and assessment, SBS assessment, SBS-related symptoms, office buildings, passive building design, ventilation, and IAQ impact on building occupants. The first search of databases returned about 1,626 articles from peer-reviewed journals and other papers and reports. After careful screening, only 306 articles were chosen, which was in line with the study design. Further screening of the 306 articles was carried out to eliminate articles that did not fall within the study keywords and the period under review (the last two decades, 2002 to 2022). This thorough filtration process resulted in 92 papers being adopted for the final review. A clear understanding of the selection process as per the flow diagram is provided in Figure 1. The review focused on papers published in the last 20 years (Figure 2) to establish the periodical progress that has been made in the design of office building environments for air quality and mitigation of SBS.

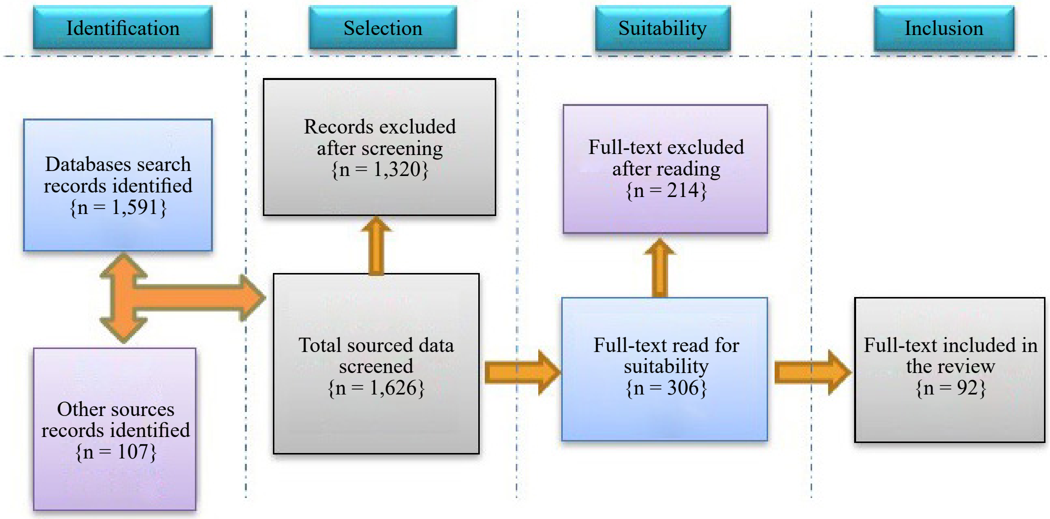

Figure 1. Flow chart of the review selection process

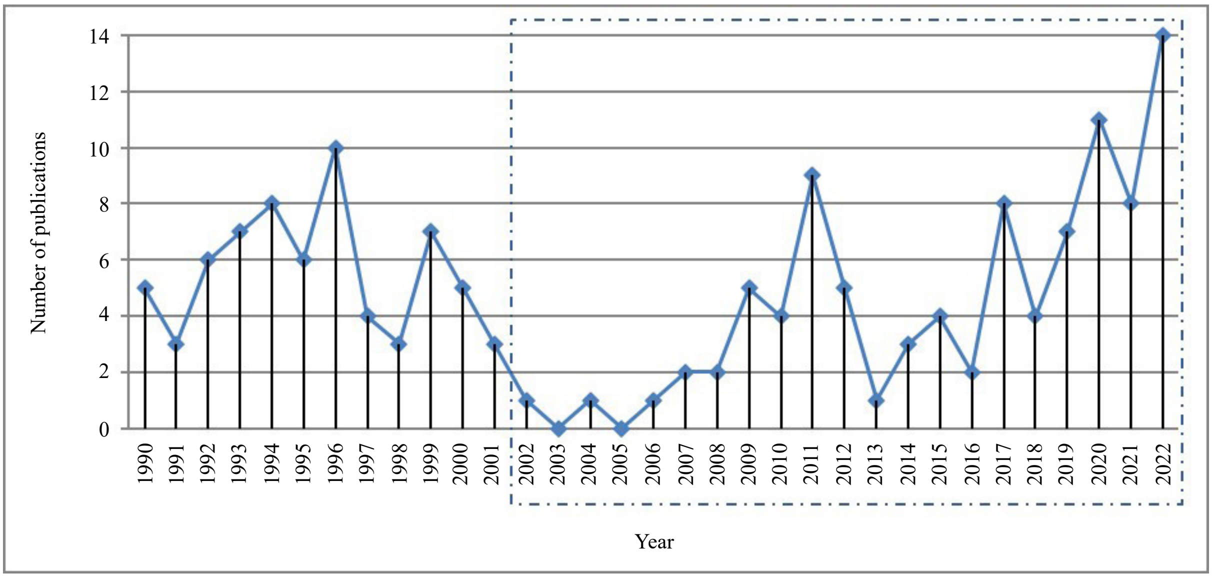

Figure 2. The number of full-text articles per year that's considered suitable for the study. The highlighted range marked by spotted lines (year 2002 to 2022) characterizes the outline of this study

3. SBS

SBS is a kind of building disorder that is used to describe a situation in which building occupants experience acute health and comfort effects that appear to be linked to time spent in a building. Occupants of a building may experience SBS while in the building, and it may occur immediately [16]. It is termed SBS because the symptoms tend to fade away as one leaves the building. According to the WHO and the Environmental Protection Agency (EPA), what causes these symptoms is not known, but their impact is enormous. There is a difference between SBS and building-related illnesses.

For building-related illnesses, the cause is known and affects a person in the building. Another point of departure is that the building-related illnesses are more serious, such that the illnesses do not subside as one leaves the building. SBS is a symptom exhibited mostly by occupants of poorly ventilated buildings.

According to a proclamation by the WHO in 1983, SBS has been viewed as a collection of certain superficial symptoms observed among building occupants, especially in offices. Other researchers have defined SBS as feelings of malaise among building occupants [17], as a concern about a particular symptom raised by 30% of building occupants within a cycle of not less than 14 days [18, 19], etc. Because of the building syndrome, there is no specific illness or cause that can be identified.

A study by Ghaffarianhoseini et al. [7] has identified five different parameters as key agents of SBS in buildings. These include physical, biological, chemical, psychological, and individual parameters that negatively influence building users. Physical contributors include parameters such as the variables of indoor environmental quality (IEQ; temperature, humidity, illuminance, noise, and air quality), as well as electromagnetic radiation. Biological contributors, on the other hand, are molds, fungi, and mites found in buildings, which can affect the quality of the air, ventilation, and building structural fabric [20]. Chemical contributors, on their part, are associated with PMs and chemical substances such as VOCs, formaldehyde, and plasticizers, whose associations have been linked with the presence of SBS symptoms [21]. While psychological contributors are related to feelings of nervousness, depression, environmental uneasiness, and job pressure, individual contributors have to do with the personal characteristics of the building's occupants. Several factors are responsible for SBS, which include:

- Building materials: Certain microorganisms can be found growing on building materials used for buildings, as well as chemical elements that are irritating to humans
- Poor sanitation
- The equipment and furnishings
- Volatile organic substances and atmospheric elements
- Poor ventilation, whether natural or artificial
- Poor maintenance and cleaning
- Bad IAQ and lighting for ease of task performance
- Environmental elements such as air temperature and humidity

VOCs, formaldehyde, and PM are some of the basic stimulators of SBS that are influenced by the IAQ. VOCs are the totality of organic compounds within a defined boiling range of between 50 °C and 260 °C [22]. VOC concentration varies even within the same indoor space, which depends on the nature of the space and its constituents. Some of the commonest VOCs found in office buildings are benzene, ethyl benzene, toluene, xylene, and limonene. Formaldehyde emissions as a chemical compound constitute a major problem in different indoor environments. The source of this emission is mostly wooden materials and paints. Some of these emissions have resulted in SBS associated with asthma and allergies. A study carried out in some public buildings has shown that the main contributor to indoor PM is the infiltration of outdoor pollutants [23]. These outdoor pollutants, in the form of ultrafine airborne particles within an indoor environment, can be removed using ionizers and air filters, mostly in unventilated rooms [24]. However, the effectiveness of this method depends to a large extent on the size of the room. Other stimulators of SBS occurrences in buildings include mold and dampness [25, 26]. Dampness in buildings as a result of capillarity rise can cause the emission of certain organic chemicals from the building's construction materials.

4. Building ventilation system

Ventilation and IAQ are two related variables that, if not carefully considered, especially at the building design stage, would influence the prevalence of SBS. The impact of the COVID-19 pandemic has showcased a new requirement for ventilation in indoor spaces to include the elimination of airborne pathogens [27]. Poorly ventilated office building spaces could provide a breeding space for molds, which are biological agents contributing to SBS. Furthermore, shared ventilation systems in buildings allow for the recirculation of microorganisms within the shared spaces. Providing proper ventilation and the correct choice of materials within an indoor space can inhibit the occurrence of SBS. In light of this, the provision of adequate ventilation within the occupied spaces of a building would improve infection control. In like manner, adequate ventilation in a building would reduce the incidence of SBS [28].

The need for air ventilation in buildings is to provide the required oxygen for occupants' well-being, dilute and neutralize polluted air, and ensure the removal of excessive heat as well as moisture within a space [1, 29]. Building ventilation is employed in buildings to achieve the building's heating and cooling tasks [30]. It is worthy to note that the application of proper ventilation in buildings is an effective measure towards the control of air quality [31]. Proper ventilation in a building's indoor space could be achieved through the following:

- The clean oxygen provided for humans is considered to have poor IAQ if it contains a high concentration of CO_2, which has been found to greatly impact one's thoughts and concentration [29].
- Ventilation dilutes and neutralizes the air within a building space, thereby removing air contaminants and/or pollutants.
- It regulates air exchanges, thus maintaining thermal balance and comfort.

A building with poor ventilation can be evident in an occupant's body odor [29]. A stuffy, closed or stale environment is an indication of poor air quality; as such, the building's occupants tend to experience body odors. A feeling of having body odors within a building space is a sign that the indoor space is not properly ventilated [32]. The level of CO_2 concentration in an indoor space is also an indication of the indoor space ventilation rate under certain conditions that are not normal. CO_2 is generated within the indoor space through human metabolism. Another common indoor air contaminant that is a result of the improper exhaustion of combustion gases being re-introduced into the building's indoor space is carbon monoxide (CO). An indoor space with a good ventilation rate is likely to have a low concentration of CO_2 within the space, which is affected by location and level of occupancy as well as the time of the day [33]. Under those circumstances, natural ventilation is considered a reasonable tool for reducing CO_2 emissions or concentration levels in buildings [34].

The level of concentration of PM within an indoor space is significantly affected by the occupancy level within that space [23]. This is a clear indication that the indoor PM concentration is, in most cases, higher than the corresponding outdoor levels. It has been ascertained that at a very low exhalation rate, a building occupant's thermal plume assists in restricting pollutants within a short distance while sitting [35]. To assuage this, the required ventilation flow rate of fresh air into a building space is recommended at 15 liters per second (lps) per person [36]. For office task performance, the minimum acceptable ventilation rate, particularly in the western world, is recommended at 10 lps per person [37]. There is therefore a need to improve ventilation rates, especially in office buildings.

Natural ventilation in buildings can be analyzed using analytical, empirical, or network models, whose application depends on specific geometries and driving forces [38]. A steady-state ventilation equation has been derived in a study carried out by Kurnitski et al. [27]. This ventilation equation is capable of complementing current ventilation systems by determining the required ventilation rates to design indoor spaces with less contagion threat. Natural ventilation in buildings can be optimized using computational fluid dynamics (CFD). The CFD simulation applies to three different aspects of a building (the site plan, building shape, and building envelope [39]), which have the potential to significantly improve the building's energy performance [40]. Furthermore, optimization of ventilation systems in buildings can be achieved by using or adopting Internet of Things (IoT) or artificial intelligence (AI)-based control measures [41]. The optimization of passive design principles in office buildings can significantly improve the ventilation system while maintaining a good or comfortable indoor environment [42].

The ventilation rate in a building environment is influenced by the prevailing wind conditions, window types, and window orientation [43]. Increasing the cross-ventilation rate in a naturally ventilated building is possible with openings of different sizes [44]. The ventilation rate in an open-plan office building is greatly affected by its window opening ratio. Large open-plan office spaces are more effective at achieving improvements in airflow rate, IAQ, and thermal comfort [45]. In contrast, an efficient level of ventilation that would facilitate appropriate indoor air circulation is not favorable with the indoor space having just one opening on its external wall.

The air quality in buildings can be improved by adopting vernacular architecture concepts as a means of providing natural ventilation. Apart from its ability to improve the air quality in an indoor space, natural ventilation is also a passive technique whose adoption reduces energy demand for cooling [46]. Cáceres-Araya's [47] study shows that the application of natural ventilation may not necessarily improve IAQ in buildings located where outdoor pollutants' concentrations are high. This adversely affects the occupant's health. The condition of natural ventilation within a building's indoor environment is greatly influenced by window sizes and incident wind angle variation. According to Sacht and Lukiantchuki [38], the wider the window size, the more air passes into a building's indoor space at a higher air exchange rate per hour. Conversely, the character of the adjoining built environment of a building significantly impacts its cross-ventilation drift due to the fluctuation that occurs in the velocity and air flow rate [48].

5. Impact of IAQ on SBS

Several studies have established the relationship between IAQ and certain SBS symptoms in humans [49]. These include respiratory airway effects, mucosal membrane irritation, headaches, infections of the eyes, Legionnaires' disease, and other allergies that cause dizziness [50, 51]. Likewise, the air temperature of indoor spaces correlates with SBS, where a higher temperature has been found to increase related symptoms. This, incidentally, would affect work output as well as increase the risk of accidents within a building space [22]. General office spaces or offices with multiple occupants tend to have a higher temperature as a result of the higher metabolic rate. Higher temperatures imply that the occupants are more susceptible to SBS symptoms when there are other contributing factors. Therefore, the need to improve the air quality in an office building's indoor spaces cannot be overemphasized. The relationship between health symptoms and buildings IAQ required consistent examination to develop proper precautionary measures [52].

How an office building is operated or used could impact its exposure to indoor air contaminants [53]. Certain office equipment, such as photocopiers, printers, and other machines, can give off pollutants and odors within an indoor space. Human contact with these indoor pollutants allows for the occurrence of SBS symptoms. These syndromes have the capability of negatively affecting the health and well-being of building occupants [7]. A study has shown the impact of CO_2 (as one of the indicators of poor air quality) on building occupants' reported thermal comfort as a result of stimulation in their respiratory systems [54]. Consequently, having a higher concentration of CO_2 within a building space has acute health effects [55, 56] as well as reducing the blood pH value [57]. On the other hand, the most compelling evidence establishing the effects of VOCs on SBS-related issues is not available. VOCs are chemicals that have been found to have a higher concentration indoors than outdoors [58]. It is therefore not advisable for people with allergies to be in an indoor space with a high concentration of VOCs to avoid being sick. Some VOCs emitted from building materials have been linked to irritation, nausea, respiratory problems, increased blood pressure, and contributing to diabetes [59]. By all means, these chemical compounds or elements with varying irritable properties have shown a significant relationship to SBS symptoms.

Different studies have also established an association between certain variables of IAQ and the common cold [60]; however, its association with work fatigue and performance is limited. Altogether, there is an association between the common cold and PM within the environment. Another sickness, allergy or symptom that is associated with the quality of air within an indoor space is dry eyes. A study carried out by Idarraga et al. [61] has revealed that short-term exposure to poor air quality has a severe adverse effect on dry eye symptoms.

6. IAQ and SBS impact on health and well-being

Poor IAQ has been identified as one of the factors contributing to SBS in buildings, which has negatively affected the building occupants' work output [7]. Additionally, poor quality of air in an indoor space is associated with SBS, which can also induce the appearance of psychological symptoms such as stress, anxiety, and aggression in building occupants [62]. SBS are symptoms experienced by building occupants that are related to the nature of the building's indoor environment. The impact of SBS on building occupants is individualistic, as people react differently to environmental conditions and air pollutants. To put it differently, the adverse effect of SBS on building occupants depends to a large extent on the amount of time spent in the building. As a result, it may be more visible among clerical staff, who spend more time at their desks than management staff.

The impact of SBS on building occupants can be categorized into four categories; symptomatology, psychological effect, economic impact, and job output or performance [7]. Manifestations such as nasal, ocular, itchy eyes, etc. are symptomatic effects, while stress, anxiety, and the occupants' level of satisfaction are psychological. Staying away from work, low productivity, and energy demand to maintain comfort, on the other hand, are cost-related to SBS occurrence. Additionally, building occupants experience the negative impact of building design and quality in the form of either biological or psychological problems. Health effects such as headaches, itching, irritation, nausea, dizziness, etc. are biological problems, while attention disorders, tension, anger, anxiety, etc. experienced within a building's indoor space are the psychological problems of SBS. The impacts of IAQ variables, which are a result of SBS in office buildings, must be considered by all players and professionals in meeting the building's occupants' requirements for comfort, healthy living, and productivity.

There is a positive and substantial relationship between the occurrence of building-related symptoms and the occupants' medical history of allergies. Those who have pre-existing medical ailments could be adversely affected when exposed to SBS. Moreover, there are specific illnesses in people that are caused by their exposure to certain elements of buildings' indoor spaces. A step into such a space would expose you to feelings of nausea, dampness, dust, and poor air quality. Notably, symptoms and signs of SBS experienced by building occupants include, among others, skin irritation, eye irritation, nasal and airway blockage, headaches, fatigue, etc. SBS impact or effect on people's health can occur basically in six different dimensions of human physiology [37]:

- Respiratory: Being sensitive to odor, nasal blockage, runny or bleeding nose, dry cough or sore throat, sinus congestion, throat irritation and wheezing when breathing.
- Eye irritation: Visual disturbance, watery eyes, eye itching, dryness of the eye, and a burning eye sensation.
- Dermal irritation: Dry skin, itchy skin, rashes on the skin, iris dryness, erythema.
- Cognitive complaints: A headache that affects mental concentration, mental confusion, migraine headaches, swollen mucus membranes, and feeling tense.
- Lethargy: Forgetfulness, lack of concentration, fatigue, drowsiness, and not thinking clearly.
- Gastrointestinal symptoms such as nausea.

The above symptoms, when experienced by building occupants, are an indicator of such a building's having SBS. In essence, the impact of air pollution can be seen in how people's health is affected and its potential contribution to global warming. One of the top-ranked environmental threats to community health is IAQ contaminants [63]. Building occupants' exposure to these chemical compounds has resulted in SBS symptoms [26]. Occupants' exposed to higher concentrations of CO_2 would have a higher risk of dry cough and rhinitis [64]. Again, the concentration level of PM within a building's indoor space is also a factor affecting IAQ and the occupants' health [65]. Exposure to PM, such as PM2.5, has been found to affect the corneas, which leads to ocular surface damage in the eyes of both humans and mice [66, 67]. Overall, the presence of PM10 and PM2.5 in the atmosphere has a significant impact on people's health and well-being. However, the particular chemical element particles that are responsible for this have not yet been identified. There is therefore a need to develop measures of control to reduce the concentration levels of air pollutants that are above required standards. The concern of every architectural design is to meet the physical, biological, and psychological balance needs of the building's occupants. The building's design therefore must be such that its configuration and components do not cause discomfort or health challenges to the building's users.

7. Solutions to IAQ problems

The origin of poor IAQ can be traced to the growth of some microbial elements, damaged inorganic fiber planes or materials emitting chemical substances [68]. Bennett et al. [23] have suggested further studies towards identifying mitigation measures that could improve the IAQ for occupants' health and well-being. These measures could include improving ventilation or taking structural-based measures toward air cleaning. To achieve a healthy living space, a building's indoor environment must have acceptable ventilation, comfortable temperature and humidity, and pollution control [63]. When these are implemented during a building's lifetime, the IAQ will surely be improved.

A study by Morawska et al. [69] has suggested the application of engineering control in public buildings as a global measure to reduce the likelihood of airborne transmission. This would reduce the burden of isolation and quarantine, social distancing, and hand hygiene. Engineering control has to do with the enhancement of ventilation systems and control in buildings. Ventilation in buildings has been largely acknowledged as an approach to airborne transmission reduction in a building's indoor environment. In the absence of mechanical ventilation, natural ventilation must be enhanced to reduce the CO_2 concentration in an indoor environment. Both mechanical and natural ventilation can be utilized as complementary strategies for the control of CO_2 concentration in buildings.

Plants that act as natural purifiers have also been identified as potential elements that, when introduced into an indoor environment, may improve the IAQ of the building while reducing energy demand [70]. Comparatively, the level of VOCs in an indoor environment can be eliminated or reduced with the installation of certain indoor plant species [71]. For high levels of air PM in an indoor space, photo-catalytic air purifiers can often be run during the period in which the building occupancy is zero [72]. The positive impact and improvement that plants bring, especially in an office environment, have been ascertained to increase office workers' motivation and productivity [73, 74].

8. Assessment of IAQ and SBS

A dynamic assessment procedure for IAQ and SBS needs to be developed to provide a clean environment for building users. The essence of IAQ assessment or monitoring is to identify trends and problematic areas and then take remedial action [4]. The assessment or monitoring of IAQ in buildings depends to a large extent on the different parameters adopted. The important indoor air pollutants for consideration include CO, CO_2, ozone (O_3), VOCs, formaldehyde, PM, etc. Other factors to be considered include the air exchange rates, building design and ventilation characteristics, thermal variables (temperature and relative humidity), as well as the level of concentration of external pollutants and outdoor climatic conditions. Notwithstanding, about 65% of IAQ studies considered CO_2 to be the most vital parameter [75]. Since building spaces are occupied by humans who emit CO_2, a high concentration of it is an indication of poor ventilation. Furthermore, pollutants within an indoor space can be determined by the amount of CO_2 concentration [76]. The effectiveness of ventilation systems in buildings is evaluated using some indicators of IAQ, such as air exchange rate, air exchange efficiency, CO_2 concentration, and contaminant removal [30].

Assessment protocols for IAQ have been set by several international organizations such as WHO, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), EPA, and other related health and environmental agencies in different countries (China, Hong Kong, Denmark, Singapore, etc.). Consequently, a framework for the assessment of IAQ impact in buildings would include pre-assessment and risk analysis. The healthiness of a building depends largely on how risk-free its IAQ is. Assessment of IAQ can be carried out using threat analysis and assessment methods, as well as a survey of users' perceptions. The assessment of the impact of IAQ through the occupants' perception is however affected by certain parameters such as gender, age, previous medical history, and the occupants' habits [77].

The level of indoor air contaminants within an indoor environment is somehow not easily ascertainable as its assessment and monitoring are not carried out within a fixed period, not using the same apparatus and sample techniques, and at different indoor spaces [15]. This can, however, be taken care of if monitoring is carried out following consistent protocols. It is also very important for IAQ in buildings to be monitored in actual time at spatial and time-based data resolutions for proper control and application [5]. To determine the impact of building design on IAQ and occupants' health, data monitoring should be conducted for no less than two weeks [6]. On the other hand, the choice of equipment for IAQ parameter monitoring is determined by cost, standardization requirements, and the required hardware for field operations [75].

Since mobile technologies have already become part of human daily life, smart application systems for IAQ monitoring need to be adopted in office building design and operations, although not without some challenges. These challenges associated with automation in the monitoring of a building's IAQ and ventilation performance can be mitigated by undertaking additional initiatives, such as the development of control systems for both artificial and natural ventilation [75]. Similarly, office building spaces, especially those with multiple occupancy rates, can be transformed into living labs by adopting the IoT strategy of monitoring their IAQ to determine their performance. The IoT can be customized and spread across all offices. This can also be used in describing different spatial office configurations' variability in IAQ.

IAQ monitoring processes require hardware, software, as well as services geared towards resolving any related health issues [4]. Open-source technologies' preference for the implementation of IAQ monitoring has taken center stage in most studies conducted by researchers [75]. As a result, computational analysis through building simulations has been encouraged as a strategy for building performance monitoring. Computer simulation is a tool employed in today's world for analysis in different fields of endeavor, ranging from games to science and engineering development, and also to military combat intelligence [78]. In buildings, simulation has been employed in evaluating building thermal performance, heat and mass transfer, air flow movement, daylighting, building systems and component identification, etc. [40]. The application of computational building simulation at the building design stage can solve both the requirements for thermal comfort and air quality. This is because the systems of equations used in evaluating thermal comfort and IAQ variables are the same [30]. The simulation of buildings to determine their performance has both direct and indirect benefits to the stakeholders in the building industry and to the environment as well.

It has been shown that due to the vast and varying nature of samples related to the problems of IAQ in buildings, there is no remedy or organized sampling strategy to adopt for monitoring. This can be remedied to an extent by adopting a multidisciplinary approach where specialists in IAQ, building physics, and ventilation systems work together in harmony [68]. Additionally, the assessment of building IAQ and SBS for improvement can be carried out by obtaining more parameters and data through onsite monitoring [8]. This will provide an in-depth understanding of the characteristics of the air pollutants that are detrimental to occupants' health. Note that the failure of IAQ measurement in a building to detect the presence of IAQ-related problems does not signify the absence of such problems [33].

9. The role of architecture in promoting a healthy work environment

For a man to meet his personal needs, certain natural environmental conditions must be harnessed and designed through different forms of manipulation. For this reason, building design and construction should be such that they do not create adverse health effects. One of these adverse health challenges is created by SBS. Building design configuration and features, as revealed in different studies, are of greater significance in influencing SBS symptom appearance [7, 16].

Building space design has been found to play a vital role as a determinant of indoor environmental performance [79]. Therefore, the spatial configuration of building indoor space is deserving of greater attention during the design process. To reduce the adverse effects of SBS contributors in buildings, such as the variables of IAQ, the configuration and design features of the building must be carefully considered at the conceptual and design stages to avert or reduce their impact during its usability stage. Building users, the building, and their environmental elements have different levels of interaction as they impact both occupants and building quality. Figure 3 shows the interaction of buildings with their occupants and their relationship with SBS.

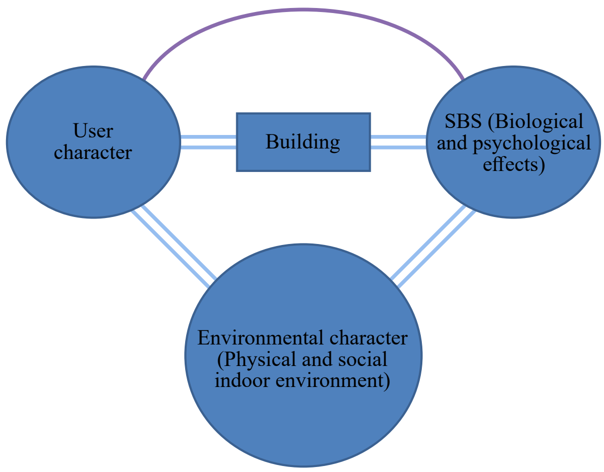

Figure 3. Building interaction with occupants and SBS

Most building designers focus more on building occupants' thermal comfort than air quality [30], which also impacts a building's thermal performance and occupants' health. Though there is a significant relationship between how building occupants perceive IAQ and thermal comfort, a building designed for effective IAQ performance would have invariably addressed design for thermal comfort. Designing buildings for IAQ should specifically be geared towards the reduction of pollutants as well as the removal of such pollutants through appropriate ventilation. Pollutants such as VOCs, when confined within a building space, can increase in concentration due to reprocessing and new releases [61]. Likewise, the level of CO_2 concentration within an indoor space could depend on its design configuration for effective air exchange. As seen in a Monte Carlo simulation carried out in a school classroom, it indicates that air exchange rate, CO_2 exhalation rate, and the number of people within the occupied classroom are the most important parameters influencing the concentration level of CO_2 [80].

The poor nature of IAQ in buildings has been attributed to poor design, management, operation, maintenance, and cleaning [8]. Poor workplace designs have an adverse effect on a building's IAQ, resulting in problems such as physical discomfort or psychological problems. A study by Hildebrandt et al. [41] inferred that the provision of more windows and frequent cleaning had an affirmative influence on building occupants' health. A CFD simulation of different building architectural alternatives has also revealed the feasibility of designing alternative openings at the initial building design stage to reduce CO_2 emissions [34]. This is achieved through proper ventilation.

The basic factors that influence a building's IAQ are its location, climate, and building system or components [33]. The design for natural ventilation in buildings requires consideration of certain factors such as climate, site planning, envelope fenestration, layout and sizing, and floor plan and interior partition configuration [30]. Carefully incorporating these factors in the passive design of buildings for natural ventilation will enable them to meet the requirements for thermal comfort and IAQ as specified by the American National Standards Institute (ANSI)/ASHRAE [81] and ASHRAE [82].

Natural ventilation in buildings is one of the energy-efficient strategies whose adoption would bring about the control or decrease of thermal gains and losses in a building. The passive design of buildings towards achieving proper ventilation should always be adopted, especially in the tropical regions of Nigeria and other parts of the world that are well suited for natural ventilation and cooling. Where this seems not so suitable, a mixed-mode ventilation system could be adopted in the design. The use of mixed-mode ventilation is typical when natural ventilation is substituted with mechanical ventilation or cooling systems, especially for peak cooling or when natural ventilation is unavoidable.

9.1 *The environmental character of a building's indoor space*

Architectural design decisions as well as decisions taken during a building's construction towards meeting the comfort requirements of users can impact the building's interaction with the occupants either negatively or positively. Maintaining a healthy building through its lifecycle could be difficult since sustainability is affected by both time and the building's condition. The "physical" and "social" indoor environments make up a building's environmental character (Figure 3). These are affected by the physical and social environment, as well as the building configuration and its usage [83]. Healthy office buildings can be achieved where their architectural designs meet the users' needs concerning both the physical and social indoor environments of the buildings.

Figure 4 shows the interaction between architecture, IAQ, and SBS. An architectural design could respond either positively or negatively to how buildings interact with their occupants. When the users' needs are not properly defined, it results in a negative interaction. On the other hand, a positive quality is achievable by harnessing a building's environmental features and design decisions, which are in turn reflected in the actual construction. An architectural design that cannot adequately define the needs of occupants in terms of the quality of the indoor air may lead to SBS.

9.1.1 *Physical indoor environment building elements*

The character of a building's physical environment includes its spatial dimension, spatial features, and components of construction. These significantly contribute to SBS when not harnessed appropriately. The architectural design of a space requires an understanding of its functions and the space's anthropometrics. Where there is no harmony in the character of a building's physical environment, the impact on the building's occupants could be adverse as a result of the prevalence of SBS.

9.1.2 *Social indoor environment building elements*

Every building should be able to meet the social needs of its occupants or users. Where these social and environmental needs are not met, it could result in a long-term health effect on the building's users. Some of the elements of the social indoor environment to be considered at the architectural design stage of buildings include the character assessments of the different occupant groups, the building occupant norms assessment, and the occupant socialization processes.

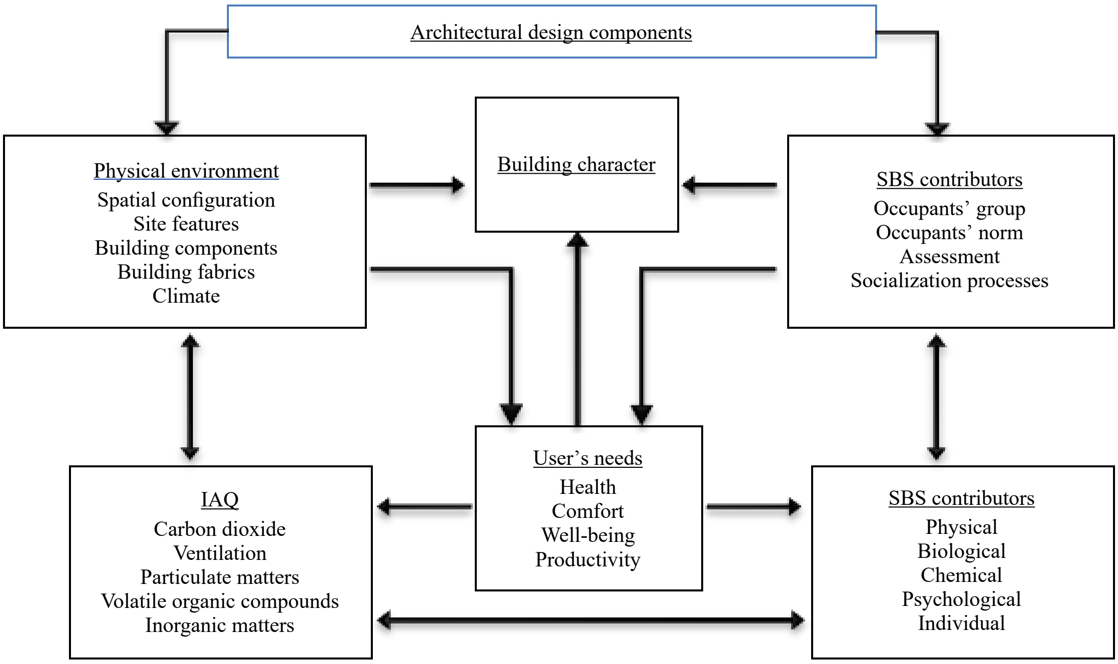

Figure 4. Relationship between architectural design components, IAQ and SBS

9.2 *The passive design of indoor spaces for SBS*

SBS thrives where the architecture of a building does not meet the users' comfort requirements. If buildings are not designed in tune with existing realities of meeting the requirements for users' well-being, they risk having IAQ that could be worse than the outdoor air. A study by Shika et al. [84] has established that where passive and sustainable measures are employed as mitigation or improvement for SBS sources, occupants' performance and health could be enhanced. Therefore, building design must focus more on isolating and mitigating certain allergic problems related to office building indoor environments as well as controlling the indoor contaminant sources using passive design mechanisms or strategies towards improving IAQ. As acknowledged by Yüksel et al. [3], the focus of researchers in achieving a healthy environment should be on passive design initiatives and smart technologies.

The architectural design of office buildings through the adoption of passive design principles entails emphasizing natural cross ventilation, the provision of open spaces, thermal control, and building insulation. Ventilation rate, temperature, moisture, air particles, VOCs, lighting, noise, etc. are elements or variables that have been ascertained to be related to SBS. Achieving a comfortable balance of the above-mentioned environmental elements is possible through passive design principles in building architecture. Buildings with natural ventilation have been found to have a lower prevalence of SBS as compared to airtight buildings running on artificial ventilation [85]. Furthermore, reducing the use of heating, ventilation, and air conditioning (HVAC) systems through the passive design of office buildings provides a more comfortable work environment for users and eliminates the prevalence of SBS. In considering healthy IAQ in buildings, the specification of low-emission materials is paramount. The health benefit of such a passive approach to building's occupants' needs is remarkable.

9.3 *Office building quality design for better IAQ*

Building materials used in construction have been associated with air contamination, whose pollutants are released into the air as construction work is completed. These construction materials-related pollutants (VOCs and microbes) can be dispersed from within the building's indoor space with proper ventilation [61]. Proper management of the IAQ of a building is one sure way or strategy that could bring about a reduction in occupational health hazards. With the recent scorch of the COVID-19 pandemic that is ravaging our communities globally, different solutions have been recommended for controlling of its transmission pathway, especially within buildings' indoor spaces.

Building design and construction that effectively increase thermal resistance, reduce air leakages, and improve air circulation and flow would also provide an indoor environment that improves the well-being of occupants. CO_2 concentration levels in buildings are affected by the building envelope's airtightness as well as the intermittent behavior of the building's occupants [80]. This level of CO_2 concentration in an enclosed indoor space has been discovered at varying altitudes to be constant. Keeping the level of CO_2 concentration low within an indoor space is achievable. A reduction in CO_2 concentration levels through proper ventilation could result in a healthier office environment for the users. Ventilation in buildings, therefore, plays a vital role in determining the quality of indoor air as a control for SBS. Where proper natural ventilation in office buildings is guaranteed through passive and sustainable techniques, having a highly improved IAQ is a sure bet.

The risk of airborne disease transmission, such as COVID-19, is enhanced in buildings with poor ventilation systems [86]. An occupant who is exposed to this kind of environment where infected aerosols contaminate the room air is liable to contract such an infection. Similarly, the chances of virus transmission by air to an exposed, healthy person in close proximity within an indoor space are always high [87]. The removal of virus-like airborne infections from within an indoor space is achieved by having proper ventilation, whereby contaminated indoor air is removed by undiluted fresh air filtration [86]. Through cross-ventilation, natural ventilation can bring about a reduction or removal of indoor air contaminants [88, 89]. The building design for natural ventilation can be achieved through the adoption of different methods and analytical solutions involving either mathematical models or simulation models or both.

The design of a building's indoor environment should be such that requirements for lighting and sound are well appropriated in order to create a healthy building. Poor visual and acoustic design of a building can result in health problems such as irritability, blurred vision, eye fatigue, stress, nausea, dizziness, anxiety, lack of concentration, etc. Building features that are responsible for maintaining visual and acoustic comfort can affect occupants' health [90, 91]. Building ventilation design, layout and configuration, damp reduction, as well as green building initiatives have been identified as strategies that could improve or eliminate the impact of SBS. Therefore, professionals in the built environment have a greater role to play towards achieving cleaner, healthier indoor spaces.

Some of the passive design strategies that can be applied in the design of office buildings for improved IAQ and the reduction of SBS prevalence are: building orientation, building configuration, materials of construction, building façade and openings, and vegetation. All these can be harnessed as a control measure towards achieving a healthy indoor environment in buildings. It has also been noted that passive design techniques substantially improve the quality of a building's indoor spaces; however, they cannot in totality solve all the problems of the occupants' health and comfort.

10. Conclusion

Since man spends most of his life indoors, such an environment must therefore be designed towards achieving a healthy dwelling environment. When an environmental condition does not meet human needs, then it poses a health challenge. For this reason, the interaction of building occupants with the building has to be integrated at the initial design stage of the building. This interaction, which can either have a positive or negative impact, plays a major role in building design configuration, features, and components. The relationship between architectural design, building quality, and SBS needs to be established to provide a comfortable working environment for healthy living and productivity. The main contribution of this study is a presentation of highlights and insights towards office building design for improved indoor environment and building occupants' health and well-being. It also affords fresh insight into building design professionals' views of the primary design requirements for IAQ and SBS in office buildings. Consequently, the wheel of architectural design will be reinvented by adopting passive and innovative technologies to develop buildings that are environmentally friendly and healthy for their users. This review is nonetheless limited as it does not provide details on the progress made so far in the assessment and monitoring of IAQ and SBS impacts on office occupants. There is a gap in knowledge related to IAQ monitoring and assessment standardization that needs to be closed, and more aspects of IAQ need to be analyzed and discussed in more detail. The study also revealed some inconsistencies in the interactions among IAQ, SBS, and building design features, which stands out as an emerging research area and practice. The information available here would provide building professionals, particularly architects, with the potential for incorporating design and the development of guidelines for the control of SBS-related environmental parameters in order to create a healthy and comfortable indoor environment.

11. Areas for future research

This review is carried out in terms of IAQ and SBS impacts on occupants' health and the role architectural design plays in promoting a healthy building environment. The study, therefore, opens up more debates for built environment professionals on the need to promote and achieve a better indoor environment in buildings. A study carried out by Orosa and Olivera [92] has suggested the need to investigate more on the impact of building design components or features on the IEQ, as well as how passive design principles could be implemented. Consequently, we advocate future research as follows:

- Evaluating the impact of various building design elements on the quality of indoor air. This would lead to the development of an effective design framework for better IAQ in office buildings.
- Future studies should be able to make a comparison between different design models for IAQ toward the development of guidelines and standards.
- Examining different approaches for interpreting the interrelationship between building design and occupants' acceptability of IAQ.
- Furthermore, the need to consider IAQ requirements that are related to epidemic prevention in office buildings is also paramount.

Declaration

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

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Author contributions

The authors contributed equally to writing and proofreading this manuscript.

Conflict of interest

The authors declare no conflicts of interest in any form.

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