Synthesis of critical factors influencing indoor environmental quality and their impacts on building occupants health and productivity

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Abstract

Purpose – The present shift and change in the human lifestyle across the world are undeniable. Currently, individuals spend a substantial amount of time indoors due to the global COVID-19 pandemic that strikes the entire world. This change in human lifestyle has devastating effects on human health and productivity. As a result, the influence of indoor environmental quality (IEQ) on the health and productivity of building users becomes a critical field of research that requires immediate attention. As a result, the purpose of this study is to review the state-of-the-art literature by establishing a connection between the factors that influence health and productivity in any given indoor environment.

Design/methodology/approach – The methodology involves a thorough review of selected published journals from 1983 to 2021, and the result was analysed through content analysis. The search included journal articles, books and conference proceedings on the critical factors influencing IEQ and their impact on building occupants, which was sourced from different databases such as ScienceDirect, Taylor, GoogleScholar and Web of Science.

Findings – The findings from the 90 selected articles revealed four critical factors influencing the quality of the indoor environment and are categorised into; indoor air quality, indoor thermal comfort, visual comfort and acoustic comfort. The findings suggested that when developing a system for controlling the quality of the indoor environment, the indoor air quality, indoor thermal comfort, visual comfort and acoustic comfort should be taken into account.

Originality/value – The indoor environment deeply impacts the health of individuals in their living and work environments. Industry must have a moral responsibility to provide health facilities in which people and workers feel satisfies and give conditions for prosperity. Addressing these essential aspects will not only help the decision-making process of construction professionals but also encourages innovative construction techniques that will enhance the satisfaction, wellness and performance of building occupants.

Keywords Indoor environmental quality, Productivity, Occupant satisfaction, Well-being, Indoor comfort, Occupants health

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1. Introduction

The fact that indoor environmental quality (IEQ) has a direct and indirect effect on human health and productivity is undeniable (Nimlyat and Kandar, 2015). As a result, people continue to attempt to seek interior spaces in which they can be comfortable. The majority of individuals spend a huge amount of time within a building, whether it is a residential, institutional and commercial building. Mujan *et al.* (2019) and AlHorr *et al.* (2016) buttressed the fact that 80% of the life of an individual is spent majorly in a building. It is, therefore, important to identify the factors that influence the comfort of occupants in a building in terms of IEQ and their impacts on health and productivity, especially considering the fact that information on this subject is not widespread. Generally, the majority of environmental features have a significant influence on the quality, comfort, satisfaction and even productivity of individuals (Heinzerling *et al.*, 2013; Katafygiotou and Serghides, 2015; Asadi *et al.*, 2017). However, the present global shift from a manufacturing to a knowledge-based economy has fine-tuned researchers' interest in the level of individuals' satisfaction with their environment (Haynes *et al.*, 2017; Kim and De Dear, 2013). In view of this, IEQ in buildings has been considered a significant aspect that must be put into consideration at the initial and final stage of the building process (Larsen *et al.*, 2020).

IEQ is a complex subject, and there are different aspects of IEQ that have been considered in the literature:

- Thermal comfort, which is referred to as that condition of mind that expresses satisfaction with the thermal environment (Kapoor *et al.*, 2021). When thermally comfortable, a building user will wish to feel neither warmer nor cooler if asked about the thermal state and preference (Frontczak *et al.*, 2012).
- Visual comfort, which is the subjective condition of visual well-being induced by the visual environment (Frontczak and Wargocki, 2011). Although the definition of visual comfort implies that there is a psychological dimension of comfort, a number of physical properties of the visual environment are defined and used to evaluate its quality in an objective way (Mannan and Al-Ghamdi, 2021). Visual conditions are characterised by such parameters as luminance distribution, illuminance and its uniformity, glare, colour of light and the amount of daylight;
- Acoustic comfort, which is the state of contentment with the acoustic environment (Mujan *et al.*, 2019). Providing good acoustic comfort is preventing the occurrence of discomfort (annoyance). The quality of the sound environment is linked to numerous physical parameters, which include both the physical properties of sound itself and the physical properties of a room (Wang *et al.*, 2021). Sound is characterised by the sound pressure level in a short and long-term period and by sound frequency. The acoustic environment can be influenced by physical room properties such as sound insulation, absorption and reverberation time.
- Indoor air quality (IAQ), which is mainly linked with a lack of discomfort due to odour and sensory irritation that may be caused by visitors to indoor spaces. When there are no contaminants or harmful odour in an indoor space, the condition of indoor air quality is said to be satisfactory (Mannan and Al-Ghamdi, 2021).

The majority of research affirmed that effective IEQ in a building can help to increase occupants' productivity, satisfaction and improved health and well-being (AlHorr *et al.*, 2016; AlHorr *et al.*, 2016). The comfort of an individual will be greatly achieved, and more natural ventilation will be used, thereby reducing the electrical energy consumed for indoor comfort if an effective IEQ is maintained, which is the major goal of any society that cares about sustainability (Katafygiotou and Serghides, 2015). People's comfort, productivity and pleasure in their physical environs can be hampered if not properly taken care of (Mujan *et al.*, 2019). Several research on occupants' comfort in buildings has been undertaken, with an emphasis on the influence of IEQ and its impacts on the satisfaction, comfort and performance of building occupants (Seppanen *et al.*, 2006; El Asmar *et al.*, 2014; Rohdin *et al.*, 2014; Broderick *et al.*, 2017). Korsavi *et al.* (2020) examined the impact of the individual aspects of IEQ on students' overall comfort in primary schools in the UK. Lipczynska *et al.* (2018) discovered that individual office personnel reported an improvement in daily productivity with an increase in thermal comfort. Mulville *et al.* (2016) observed a negative relationship between frequent occurrences of noise, indoor air quality on individual's health and discomfort within a multi-user office setting, as well as the influence of IEQ on productivity. In addition, De Been and Beijer (2014) discovered that employees in open-spaced offices were less comfortable with their physical working environment than those in shared room workplaces. In Californian elementary schools, Mendell and Heath (2013) found a link between ventilation and illness-related absenteeism. This means that IEQ is an important factor that should be considered for comfort (Asadi *et al.*, 2017), health and well-being of building occupants (Lai *et al.*, 2009; Heinzerling *et al.*, 2013) to be achieved in the environment.

Also, several health challenges have been attributed to IEQ; the major one is termed sick building syndrome (SBS) symptoms which include; cold symptoms, headaches, dizziness, nausea, cognitive disturbances, respiratory illnesses, eye problems, cough, depression and skin problems (Yee, 2014; Wong *et al.*, 2009; Kamaruzzaman *et al.*, 2017; Zhang *et al.*, 2017; Hou *et al.*, 2021). Some of these symptoms, according to AlHorr *et al.* (2016), are caused by the closing of natural openings, the use of new building materials that have not been thoroughly tested and licensed and the kind of furniture and interior equipment such as printing machines and computers, distressing temperature and humidity, chemical and biological pollutants and physical condition, are all key factors of SBS, according to Abu Eleinen *et al.* (2018). Therefore, during the design phase, the assessment and quantification of IEQ should be addressed (Chen *et al.*, 2016; Yang and Mak, 2020). In view of this, this study addressed the crucial components influencing IEQ in buildings and their effects on the overall well-being of building occupants.

2. Research methodology

This study examined the state-of-the-art of published literature on the influence of IEQ on productivity and health. The major goal of this research is to better understand and identify the critical factors influencing IEQ in the environment. To achieve the aim and focus of this study, the methodology adopted in this research is a systematic literature review. A systematic literature review is a method for evaluating, analysing and synthesising all relevant research in a specific research topic to identify knowledge gaps and recommend opportunities for additional exploration (Kitchenham, 2004). The study was carried out as a systematic literature review. The primary data was obtained using a qualitative research approach. A desktop study was carried out using keywords such as "Indoor environmental quality", "occupant well-being", "Indoor air quality", "thermal comfort", "visual comfort" and "acoustic comfort", in the first round to collect articles from several search databases such as Web of Science, Google Scholar, Science Direct and Scopus. The literature dataset contains English-language journals and peer-reviewed publications and conferences from 1983 to 2021. The initial number of articles found from the database was 123 articles, after which irrelevant articles to the current research were eliminated, resulting in the selection of 96 articles for further investigation. These articles were further considered for eligibility based on inclusion, exclusion and quality criteria based on the language used, the discarding of incomplete articles and the focus of the research. The articles were then limited to 90 articles, which served as the final number of articles eligible for the research (Figure 1).

Following the recovery of the papers, they were critically evaluated and assessed. The following factors were categorized into; indoor air quality, indoor thermal comfort, indoor lighting quality and acoustic comfort. These results of the factors affecting IEQ were itemized, and their impacts were addressed. The review process follows the flow chart shown in Figure 2. The data was analysed using content analysis.

3. Result of findings

3.1 Framework showing factors influencing indoor environmental quality

For the result, a conceptual framework for factors influencing IEQ is developed, and a comprehensive argument regarding the different elements of the framework is presented. The four main elements of the framework are thermal comfort, acoustic comfort, visual comfort and indoor air quality. Each element includes a number of sub-elements which is discussed in details.

3.1.1 Indoor air quality. This section presents a categorisation of publications with considerations regarding indoor air quality. The literature review revealed that there are various elements attributed to IAQ, such as ventilation, temperature, humidity, excess moisture, building characteristics, dust and other airborne particles, chemicals and other toxic substances, human activities such as smoking and personal hygiene and outdoor pollution. IAQ is another significant aspect impacting human comfort, productivity and quality of life in buildings (Mujan *et al.*, 2019). Bad indoor air quality has a significant influence on human life, reducing productivity and causing health imbalance symptoms such as weariness, headaches, sluggishness and mental exhaustion (Alhorr *et al.*, 2016; Kosonen and Tan, 2004). Research conducted on commercial and residential buildings has revealed that air quality is a major source of discontent among workers and residents and

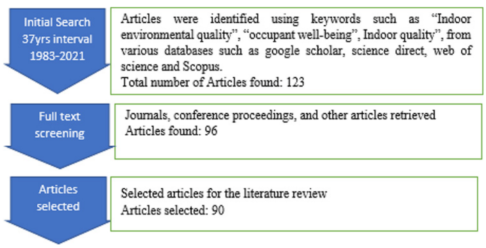


Figure 1.
Flow diagram of the searching process and paper retrieval

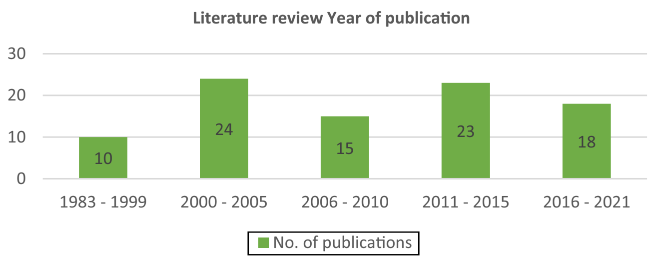
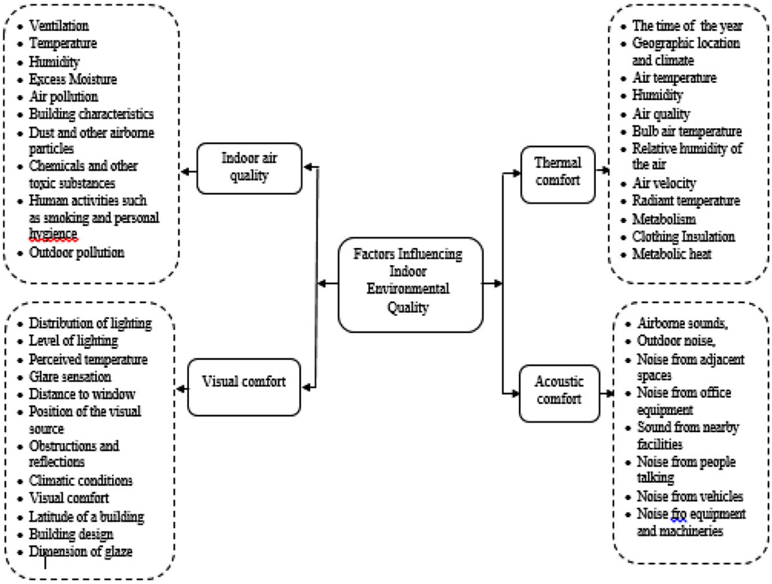


Figure 2.
Reviewed literature year of publication frequency

that it is linked to health complications in individuals (Mujan *et al.*, 2019). SBS and even asthma can develop as a result of the symptoms, which can range from moderate to severe (Mujan *et al.*, 2019). SBS is directly related to the building, and the most common symptoms are inflammation of the eyes (itching and burning), irritation of the nose and sinus difficulties and less frequently, irritation of the respiratory system, headache, lethargy and mental fatigue (Tham *et al.*, 2015; Kalender *et al.*, 2019; Licina and Yildirim, 2021). The field of indoor air quality is a direct endeavour by researchers to address, measure and solve these health complications. Varjo *et al.* (2015) identified intensity as a key element that is impacted by the frequency of ventilation within the building, as well as the sources of gaseous emissions from the building and the living load (occupants, furniture and equipment). Nonetheless, Kang *et al.* (2017) believed that boosting the level of IAQ in a building by increasing ventilation within the building is an efficient way to do so. Sundell *et al.* (2011) conducted a comprehensive evaluation of the impact of ventilation rates on human health. Their research found that increasing the ventilation rate in a workplace to nearly 25 L/s per person is effective in reducing harmful health symptoms. Furthermore, research conducted by Park and Yoon, (2011) and Kang *et al.*, (2017) found that increasing the rate of airflow in a building reduces the percentage of individuals who are dissatisfied with the air quality in the building, which increases dwellers' efficiency. Ventilation, if properly designed, can help reduce the consumption of energy and provide considerable energy savings from cooling (Borgeson and Brager, 2011). Therefore, individuals in any building who feel air freshness circulation will have a significant positive satisfaction association with IAQ. Knasko (1993) found that smell irritation has a detrimental impact on the mood, task performance and health of occupants. Furthermore, Al-Omari and Okasheh (2017) concluded that improving the work environment of employees will increase job performance. The IAQ metrics used to assess indoor air quality are; oxygen, carbon monoxide, air temperature, relative humidity, particle pollution levels, carbon dioxide, ozone, nitrogen dioxide, sulphur dioxide, volatile organic compounds, ammonia and air velocity within the building (Mujan *et al.*, 2019). To allow fresh air into an environment, the rate at which outdoor air is supplied should be proportional to the pollutants within the building (AlHorr *et al.*, 2016). The amount of pollutants inside the building will vary depending on the load and number of occupants. Alhorr *et al.* (2016) also mentioned that the two most common approaches in building design for controlling IAQ in a building are the use of airflow frequency, which reduces air impurity and reduces or completely eliminates pollution sources inside and outside the building. Increasing outside air supply rates in residential and workplace areas improves air quality and reduces air pollution intensity (Park and Yoon, 2011). Therefore, the building needs to have a mechanism to accurately assess the indoor pollutants and vary the rate of introducing outdoor air accordingly.

3.1.2 Thermal comfort. Twelve prevalent variables have been identified in the literature as listed in the framework (Figure 3), which includes the time of the year, geographic location and climate, air temperature, humidity, air quality, bulb air temperature, relative humidity of the air, air velocity, radiant temperature, metabolism, clothing insulation and metabolic heat. Thermal comfort is related to the degree of air circulation within the building, which has a direct influence on occupants' productivity (Alhorr *et al.*, 2016; Li *et al.*, 2011) and satisfaction with the building environment (Humphreys, 2005). Also, thermal comfort refers to the subjective state of mind satisfaction with the thermal environment and is assessed by subjective evaluation (Djongyang *et al.*, 2010). Furthermore, thermal comfort is dependent on resident thermal acclimation, which is affected by; the time of the year, geographic location and climate, gender, age and race (Quang *et al.*, 2014). Mujan *et al.* (2019) mentioned that individuals can produce in full capacity only if they feel thermally



Note: There will be an increase in an individual's productivity level if thermal comfort is adequate

Figure 3.
Framework showing factors influencing indoor environmental quality

comfortable because thermal comfort has a significant impact on productivity. Thermal comfort is primarily influenced by four environmental factors (bulb air temperature, relative humidity of the air, air velocity and mean radiant temperature (environmental) and two personal factors (human metabolism and clothing level) (Katafygiotou and Serghides, 2015; Mujan *et al.*, 2019). Alhorr *et al.* (2016) mentioned that the factors should be considered at the design stage of a construction process. Prek (2005) mentioned that the temperature of the body is maintained through the exchange of heat between the human body and its environment through the means of evaporation, convection and radiation. The degree of occupants' satisfaction with indoor temperature in 26 multi-user offices in Europe was revealed in a survey report by Humphreys (2005). Furthermore, Mak and Lui (2012) conducted a survey in Hong Kong, and the result showed that the degree of interior temperature has a significant positive link with job productivity and occupants' satisfaction. Hygge and Knez (2001) and Lan *et al.* (2011) discovered that when the room temperature rises from the permitted range (21–25°C) to higher ranges (above 26°C), workers' performance tends to decline. Furthermore, Maula *et al.* (2016) mentioned that improper temperature has a detrimental influence on occupants' focus, mood and desire for work. The predicted mean vote (PMV) model, which is based on an international standard (ISO 7730, 2005), BS EN ISO 7730, (2005) and ASHRAE (2013), provides a benchmark and well-organized method for assessing the internal thermal comfort in a building. It is used by designers as a building standard and is generally acceptable. Furthermore, psychological and physical factors should be considered when assessing thermal comfort (Alhorr *et al.*, 2016; Lin and Deng, 2008). The term "thermal comfort" encompasses a wide range of dynamic parameters that may or may not be related, such as dressing level, person activity, personal position, window position and mood, amongst others (Mujan *et al.*, 2019). Achieving perfect thermal comfort is a difficult task that necessitates knowledge of people's reactions to dynamic changes in the environment. This is influenced by elements such as age, sex, metabolism and so on; thermal comfort has both an individual and a geographical aspect (Ngoc *et al.*, 2014). If thermal comfort is sufficient, an individual's production level will rise. Jazizadeh *et al.* (2014) and Praseeda *et al.* (2014) suggested that building design for thermal comfort should be addressed in the design stage, as changing a building after it has been built is expensive and ineffective.

3.1.3 Visual comfort. Visual comfort is a must-have feature and is classified in literature as distribution of lighting, level of lighting, perceived temperature, glass sensation, distance to window, position of the visual source, obstruction and reflections, climatic conditions, visual comfort, latitude of a building, building design and dimension of glare. Daylight is required for people's metabolisms to function properly and for them to have the strength to engage in physical and mental activity during the day (Van Duijnhoven *et al.*, 2019). Because the majority of individuals spend most of their time indoors, it is vital to design the interior to take full use of everyday natural light (Peters and Halleran, 2020). Those ramifications must not be overlooked. Natural lighting (daylight), which is the major source of interior lighting, is regarded as the optimal source of light because it provides the finest illumination for human vision while also providing comfort without impairing human vision. Van Bommel and Van den Beld (2004) and Nagy *et al.* (1995) mentioned that natural illumination through doors, windows and any other opening in the structure is more important to the inhabitants' comfort than its basic necessity for vision and light. It also has an influence on occupant' psychological requirements. Proper measures to increase the share of daylight in the lighting scheme of the building provide opportunities for reducing the impact of a building on the greenhouse effects and creating conditions for a more pleasant work and life of people. Also, daylighting and lighting design in a building should be designed strategically to achieve comfortable lighting levels for the human eye. However, the type of artificial lighting used in the building has an impact on the total electrical energy consumption and the comfort of the residents (Kang *et al.*, 2017). Artificial illumination, on the other hand, has an effect on occupants, whether it is over-designed or under-designed. When interior illumination is not appropriately planned, occupants are likely to be unpleasant (Galasiu and Veitch, 2006). The nature of the activities performed in the workplaces has an impact on the inhabitants' pleasure with interior illumination (Jennings *et al.*, 2000; Yamakawa *et al.*, 2000). Human behaviour towards visual comfort is influenced by contextual factors such as solar altitude, sunlight, window direction, outside temperature, season and time of day. Reviewing historic and vernacular architecture to generate simple yet effective lighting design solutions is also recommended in the literature. It would improve residents' comfort, happiness and performance while also lowering the use of energy.

3.1.4 Acoustic comfort. Occupants' discomfort in an environment can be caused by noise (AlHorr *et al.*, 2016). Therefore, the need for noise control in buildings should never be overlooked. A noisy and unpleasant environment can increase occupants' worries and cause respiratory problems and stress development, which could affect occupants' immune system. Unwanted sound in a building can come from a variety of sources, including mechanical sources as well as internal partitions and walls (Dascalaki *et al.*, 2009; Salonen *et al.*, 2013; AlHorr *et al.*, 2016). Although some other research studies to pinpointed two key causes of IEQ-related issues to; noise disruption (Lee *et al.*, 2015; Kim and De Dear, 2012) and a lack of communication privacy (Landstorm *et al.*, 1995; Hygge and Knez, 2001; Kim and De Dear, 2012). The capacity of building acoustics lies in its ability to protect its occupants from noise pollution; therefore, providing an acoustical environment that meets the primary function of the building design is very important (Giannakourou and Balla, 2006).

In commercial buildings, Landstrom *et al.* (1995) found a clear link between occupant productivity and acoustic comfort. Although Sundstrom *et al.* (1994) claimed that the increase in multi-user offices has resulted in difficulties such as acoustic discomfort and a loss of privacy in the building, these were regarded as significant issues influencing staff productivity and motivation to work efficiently. Nonetheless, Andersen *et al.* (2009) and Anderson (2008) recognised acoustic discomfort as an essential element in IEQ and opined that acoustic comfort is not given significant attention during building design by construction experts. Numerous studies have also concluded that poor acoustic conditions could harm building occupants, results in decreased productivity, job dissatisfaction and health-related issues (Lee *et al.*, 2015; Mark and Wang, 2015; Kim and De Dear, 2012; Mak and Lui, 2012; Smith-Jackson and Klein, 2009). Several field studies and laboratory trials have shown that increased speech privacy reduces the detrimental impact of unwanted speech noise while also increasing occupants' productivity (Haka, *et al.*, 2009; Venetjoki *et al.*, 2006; Hongisto, 2005). Occupants of a building could suffer from a variety of detrimental effects if acoustic comfort is not given due importance (Frontczak *et al.*, 2012). These negative effects can have an influence on the inhabitant's productivity and health-related issues. Literature attributed acoustic discomfort to noise from humans, locomotion, telephone rings and uncontrolled discussion (Veitch *et al.*, 2002; Kim and De Dear, 2012). As a result, numerous elements, such as the types of noise and demographic aspects of the occupants, could contribute to unpleasant negative effects induced by noise (Kaarlela-Tuomaala *et al.*, 2009; Venetjoki *et al.*, 2006; Mak and Lui, 2012; Ou, 2015). As a result, acoustic issues need to be considered early in the design process. It is necessary to examine what will happen in the external and internal areas of a building to manage acoustic challenges during the design stage (Bluyssen *et al.*, 2011a; Bluyssen *et al.*, 2011b).

3.2 Relationship of the proposed framework

This study reviewed a broad range of literature available on factors influencing IEQ and how it influences the health and productivity of occupants. The literature review has highlighted four factors (Figure 3) that affect IEQ and occupants' productivity. IAQ, thermal comfort, acoustic comfort and visual comfort were found to be highly significant in affecting occupants' productivity. Numerous case studies and academic studies highlighted a significant relationship between these elements and occupant productivity. The review showed a clear relationship between visual comfort, thermal comfort and acoustic qualities of an indoor environment as well as a link between these IES components. This analysis can be used as a starting point to create models that examine the scope and effects of different interactions between these IEQ components. The literature analysis also highlighted how difficult it is to comprehend, evaluate and increase occupant productivity in an indoor setting. The physical characteristics of the indoor environment have a direct impact on occupant comfort. Satisfaction is a reaction to the physical state brought on by the interaction of the environment's physical features. Different industry standards from various nations suggested various acceptable ranges for the physical characteristics of interior space. However, a range of occupants' acceptance and responsiveness to these recommended levels have been found in various studies. According to the study, there is a comfort zone for each element but no point assessment for comfort. Occupant comfort is highly subjective and depends on various independent personal variables such as individual metabolism, clothing preference, activity patterns and conditions of different zones of a building. The analysis also emphasises how crucial cultural and contextual elements are when creating an indoor workspace for individuals. It comprises different aspects of the social and physical climate of the environment.

This review can be taken as starting point to develop models to look at magnitude and impacts of various interactions between these IEQ factors.

4. Theoretical and practical implications

According to the review, natural ventilation or increased ventilation rates may have a negative impact on occupants' acoustic comfort because they may allow more ambient noise from the outside to enter the building (Arif *et al.*, 2016). Research findings have also shown a connection between the building's envelope and residents' thermal and visual comfort. Building plans are created to strike a balance between acoustics, natural ventilation and daylighting. As long as the acoustic design is taken into consideration, an open room with adequate illumination may be a productive workspace (Frontczak *et al.*, 2012). The choice of materials needs special consideration because it has a significant impact on a building's functionality (Šenitková and Kraus, 2016). Thermal performance, indoor air quality, visual comfort and acoustical comfort are all impacted by the materials used in construction. Construction experts can choose components that do not emit unpleasant odours. The choice of material can maximise sound absorption potential (Arif *et al.*, 2016). Furthermore, an effective sound concealing system can completely eradicate any remaining acoustic issues after occupancy (Arif *et al.*, 2016). Another significant concern is the use of tougher materials for the walls and floors to aid in cleaning. The ability of a substance to absorb sound decreases as it becomes tougher. Therefore, using tougher materials could make the interior area noisier. The health and well-being of the residents will eventually be impacted by all of these problems. The overall satisfaction of building occupants is affected by a number of measures, including giving control to the occupants and increasing their awareness through training. Buildings in urbanised locations might have more natural ventilation at night because there is less noise and pollution because fewer people are out and about at that time.

IEQ must also be taken into account during the building's lifespan. Throughout the building's history, decisions made throughout the design, construction and maintenance phases have an effect. Particles of dirt are captured by the design of exterior entrances with permanent entryways, preventing them from entering the interior space. A balance between energy efficiency and the ideal amount of fresh air can be achieved through joint collaboration among building industry professionals. As interior circumstances or even neighbourhood conditions might vary often, source control should be used during building operations to ensure adequate IEQ. The interaction of people with their natural surroundings and views of the outside world may also be beneficial to building design. Using natural light while also using shading tools to lessen direct glare in the range of view is advantageous. Light wall colour choices may also enhance visual comfort. Additionally, it might help to attain visual comfort if residents could manage illumination with dimming controls. There is a significant level of attention on monitoring and management to ensure that buildings are providing what they are planned for, and it is quite vital to balance a building's sustainability efforts with the well-being of its residents (Azhar *et al.*, 2011). It is crucial to take building occupants into consideration while designing (Iwaro and Mwasha, 2013). The needs, comfort and well-being of occupants must increasingly be incorporated into the design of buildings (Hua *et al.*, 2014).

5. Conclusion

The potential health concerns and factors affecting IEQ have been explored, and it has been demonstrated that inadequate IEQ has an impact on occupants' well-being, comfort, convenience and well-being. The study also revealed the significance of the impact of the physical and behavioural environment on occupants' comfort and productivity. The article brings to light the four important crucial factors influencing inhabitant well-being, environmental satisfaction, comfort, work productivity in offices and occupant health: These factors are; indoor air quality, thermal comfort and indoor lighting capacity. A large number of empirical studies and research papers showed a strong link between these characteristics and users' productivity. This review can be used to construct experiments to investigate the size and consequences of various combinations between these IEQ components. The report also emphasises the difficulty of comprehending, quantifying and attaining occupants' productivity in buildings. Occupant comfort directly relates to the physical factors of the indoor environment. This state-of-the-art research gives a comprehensive analysis of occupants' productivity and the indoor environment. It brings together literature from vast knowledge areas. In the future, construction professionals need to understand these IEQ factors and their impact on occupant productivity to design better buildings. These IEQ parameters need to be studied to ensure that these guidelines provide the optimum conditions for an indoor environment during a whole building life span.

6. Recommendations

Occupants' comfort is incredibly subjective and is influenced by a variety of independent personal factors such as individual metabolism, clothing preferences, activity patterns and the localised conditions of different areas within an environment. To improve IEQ, advanced technology can be used to generate new research programs to examine the impact on occupant productivity and IEQ aspects in greater detail. The technology can be used to compare occupants' performance in various buildings and also enable architects, engineers and designers to establish perfect designs. These four factors undoubtedly have an influence on human health, convenience and performance of building occupants. IEQ can be improved by attentive design and operation of building systems. IEQ can also be influenced by how equipment is designed, manufactured and operated. It is, therefore, necessary to decide and use materials that can provide excellent indoor conditions by eliminating all negative influences on occupants' health and providing high-performance, sustainable and healthy buildings. The findings of this research have significant implications for the establishment of green and healthy building policies. The existing policies are primarily concerned with some physical design elements as well as objective measures of building environmental effects. The societal aim of these building designs, however, will not be accomplished if residents' IEQ remains unsatisfactory. Policymakers can decide which factors are most relevant for assessing overall IEQ satisfaction and improving building designs that meet those requirements. This will aid in a better understanding of IEQ and have significant implications for building design and management for long-term sustainability. To design better buildings in the future, construction professionals will need to grasp these IEQ elements and their impact on occupants' productivity. The long-term goal is to investigate how current global sustainability standards and rating systems interact with occupants' comfort and productivity in buildings. Future research can also be directed towards investigating the relationship and degree of impact of the variables on IEQ factors.

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