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Review

Green Buildings: Human-Centered and Energy Efficiency Optimization Strategies

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Abstract: The rapid growth of the global population and urbanization has led to environmental degradation, resulting in a worldwide energy crisis. In response, the quality of architecture has evolved to prioritize energy efficiency, impacting indoor human health in the process. Green buildings have emerged as a solution to this problem, aiming to improve indoor environmental quality (IEQ) and human well-being while minimizing negative environmental impacts. This comprehensive review focuses on the role of green buildings in enhancing indoor human health and energy efficiency. It examines the published research on the effects of green buildings on IEQ and occupant health, highlighting sustainable architectural practices that promote good health. The study concludes that green buildings provide healthier environments for their occupants by creating healthy indoor environments, and minimizing negative environmental impacts. The study also explores the link between sustainable architecture and health promotion, with a focus on IEQ. It presents evidence-based and biophilic design strategies that can impact treatments and health promotion in the built environment. Overall, this review emphasizes the critical role that green buildings can play in addressing the global energy crisis while promoting the health and well-being of building occupants.

Keywords: energy optimization; human health; IEQ factors; green building; healthy building

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1. Introduction

Innovation is key to a sustainable future, and that is why energy optimization strategies in green buildings and indoor human health are crucial to achieving it. Green buildings are designed to be more energy-efficient, thereby reducing energy consumption and improving indoor air quality. This, in turn, can have a positive impact on human health. Energy optimization strategies not only reduce energy costs but also improve occupant comfort while reducing environmental impacts. This paper delves into the various energy optimization strategies available for green buildings and their potential benefits for indoor human health. However, implementing these strategies in existing buildings comes with its own set of challenges, which this paper addresses. It also emphasizes the importance of monitoring energy performance to ensure that these strategies achieve their intended outcomes.

It is no secret that we spend a significant portion of our time indoors—estimates range from 80 to 90%. As such, it is crucial to ensure that the indoor environments we inhabit are optimized for energy efficiency and indoor air quality. By exploring innovative energy optimization strategies and addressing the challenges associated with implementing them, we can create healthier and more sustainable living spaces for ourselves and future generations [1].

Indoor environments can significantly impact our health due to the higher concentration of pollutants found indoors compared to outdoors. These pollutants can include chemicals from cleaning products, pesticides, volatile organic compounds (VOCs) from building materials and furnishings, and particulate matter from sources such as tobacco smoke and mold. Additionally, indoor environments can impact our health through poor air quality, inadequate lighting, and poor thermal comfort [2]. Indoor environmental quality, which encompasses the design, analysis, and operation of energy-efficient, healthy, and comfortable buildings, is a significant area of study. The goal of indoor environments is to minimize adverse effects on human health, comfort, and efficiency, and to promote enjoyment and well-being for occupants [3–5] Green building movements have emerged as a response to the recognition that buildings can have both positive and negative effects on inhabitants and the natural environment, to minimize negative impacts while maximizing positive benefits. Green building design and construction can improve indoor environmental quality by incorporating natural ventilation, high-efficiency HVAC systems, and renewable energy sources. Additionally, green building design can promote better health and well-being by incorporating natural light, access to nature, and promoting physical activity [6].

The World Health Organization (WHO) has recognized access to sustainable environments as a human right. According to WHO, sustainable environments are essential for the physical and mental well-being of individuals and for the protection of public health. While the energy savings associated with green buildings are well-known, the impact of green buildings on indoor environmental quality and human health has yet to be thoroughly studied. This research aims to investigate the role of green buildings in providing better and healthier environments, focusing on indoor environmental quality and its effects on human health and well-being [4–6]. There is abundant evidence indicating that better indoor environments lead to more satisfaction, productivity, well-being, sleep quality, comfort, performance, and health in occupants. The study first examines building-related factors influencing human health and the foundational features that impact indoor environmental quality. It then investigates the specific features of green buildings that contribute to enhanced indoor environmental quality and the role of green buildings in promoting better and healthier environments for occupants [7–11].

Recent research has shown that the impact of green buildings on indoor environmental quality and human health has yet to be thoroughly studied. This paper aims to investigate the role of green buildings in providing better and healthier environments, focusing on indoor environmental quality and its effects on human health and well-being. There is abundant evidence indicating that better indoor environments lead to more satisfaction, productivity, well-being, sleep quality, comfort, performance, and health in occupants [12–16]. Therefore, this paper provides a comprehensive review of the various energy optimization strategies available for green buildings and their potential benefits for indoor human health.

The paper also addresses the challenges associated with implementing these strategies in existing buildings and emphasizes the importance of monitoring energy performance to ensure that these strategies achieve their intended outcomes. Furthermore, this paper incorporates the latest research to emphasize the significance of the topic in recent years, highlighting the timeliness and importance of the research.

2. Literature Review

This manuscript discusses the importance of green buildings in improving indoor environmental quality (IEQ) and human health. It reviews various energy optimization strategies proposed for green buildings, including natural ventilation systems, daylighting techniques, and passive design strategies, and how they impact thermal comfort, visual comfort, acoustics, productivity, stress levels, moods, and concentration levels of occupants. The review also highlights various building-related factors that can influence the occupants' health, including environmental threats, architectural design, operation, maintenance,

and social and behavioral factors. The manuscript also explains the physical and non-physical factors that affect IEQ and the foundational features that affect IEQ, including IAQ, thermal comfort, lighting, ventilation, and acoustic conditions. The manuscript concludes that green buildings with optimized IEQ can significantly improve human health outcomes [17–21].

Green buildings have been gaining traction in recent years as a way to reduce energy consumption and improve indoor environmental quality (IEQ) and human health. The literature has explored various energy optimization strategies proposed for green buildings, including natural ventilation systems, daylighting techniques, and passive design strategies, and how they impact thermal comfort, visual comfort, acoustics, productivity, stress levels, moods, and concentration levels of occupants [22–25]. Additionally, it has highlighted various building-related factors that can influence the occupants' health, including environmental threats, architectural design, operation, maintenance, and social and behavioral factors [26,27].

Passive design strategies have also been suggested to optimize energy efficiency in green buildings. Passive design strategies involve building materials and construction methods that minimize energy consumption while maximizing occupant comfort. Studies have shown that these strategies can reduce energy consumption by up to 50%, providing improved thermal comfort for occupants and reducing the risk of airborne diseases. Additionally, passive design strategies can provide improved acoustics within a building, leading to better concentration levels among occupants and improved mental health outcomes.

Green buildings also utilize renewable energy sources (RES)-technologies to generate electricity and heat, contributing to energy autonomy and safety [28]. The use of RES can significantly reduce the carbon footprint of a building and reduce its reliance on non-renewable energy sources. Additionally, green roofs and walls, which are becoming increasingly popular in green building design, can provide numerous benefits, including improved thermal insulation, reduced urban heat island effect, reduced stormwater runoff, and improved air quality [29]. The use of sustainable and environmentally friendly building materials in green buildings, such as recycled content materials, low VOC paints and adhesives, and sustainably harvested wood, can also significantly reduce the environmental impact of a building and improve the indoor air quality of the building [30].

2.1. Building-Related Factors Influencing Occupants' Health

Building-related illnesses consist of symptoms that are associated with sick building syndrome [6]. These symptoms include headaches, eye problems, sore throats, nasal and chest congestion, and neurological symptoms such as difficulty concentrating, dizziness, and dry skin [7]. These symptoms may not keep people away from their daily work, but they cause people to complain and lose productivity and dissatisfaction with their work environment [8].

More than 40 years of research on the indoor environmental qualities of spaces have revealed many insights into how buildings relate to human health and affect the occupants' well-being and productivity. Some of the most important factors are listed below.

- Environmental threats (physical, biological, radiological, chemical, Pandemic) [9–11].
- Architectural design (acoustics, lighting, ventilation, material selection, biophilic design, physical activity promotion, air quality promoting) [11,31,32].
- Operation and maintenance (cleaning, regular maintenance) [33].
- Social and behavioral factors (safety, location, wellness programs, mental well-being (stress, depression, and anxiety), human interaction) [10,34,35].

2.2. Foundational Features Affecting Indoor Environmental Quality

The factors affecting indoor environmental quality and occupants' well-being can be divided into physical and non-physical [4]. Physical factors include indoor air quality, thermal comfort, lighting, ventilation, and acoustic conditions (see Figure 1). Corresponding

measurable parameters can calculate these factors. Non-physical factors are the indoor qualities that are difficult to evaluate by instruments. These factors include safety and security, cleanliness, views, and space layout [36].

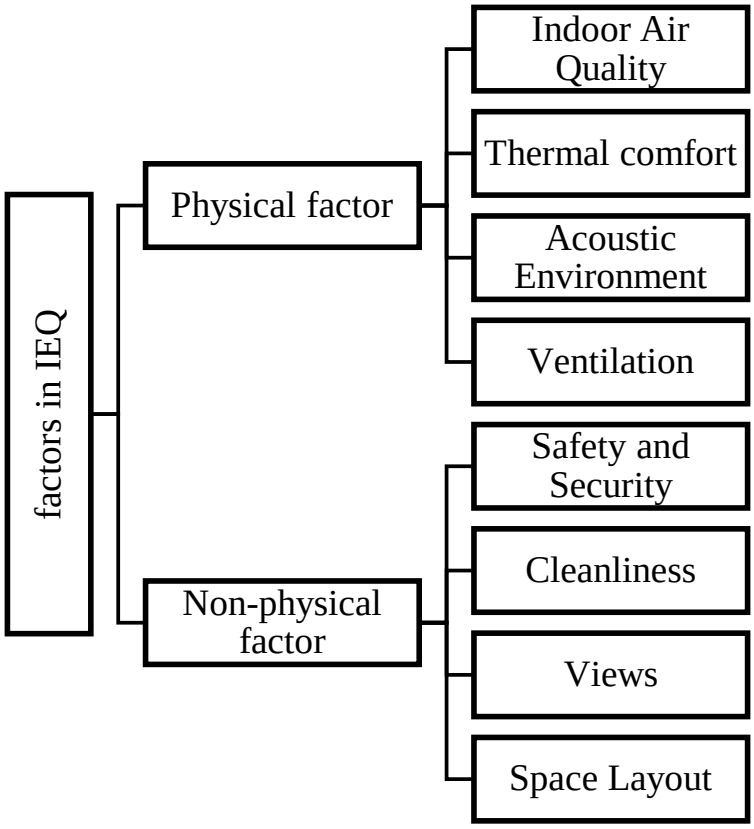

Figure 1. Physical and non-physical factors in IEQ studies [37].

2.3. Physical Factors

Indoor Air Quality (IAQ): refers to the air quality within indoor spaces and its impact on human health, well-being, and productivity. IAQ encompasses all indoor air pollutants, including those from building materials, human activities, and pets, as well as outdoor pollutants that can penetrate the building, and the building systems and conditions. Poor IAQ can result in both acute and chronic effects, such as asthma, headaches, irritation, and even cancer, depending on the type, concentration, and duration of exposure to pollutants [5]. IAQ is a multidisciplinary phenomenon that is closely linked to other factors within the building that can impact the health and well-being of occupants. These factors include thermal comfort, lighting, acoustic environment, and ventilation.

Thermal comfort: refers to satisfaction with the thermal environment, and is influenced by factors such as air temperature, speed, humidity, and personal metabolic activity. Poor thermal comfort can result in symptoms such as headaches, breathing problems, depression, and decreased productivity [38–40].

Lighting: Access to daylight is crucial for indoor space quality, impacting visual and non-visual health and well-being. The non-visual effects of light relate to circadian rhythms, which can affect metabolic disorders and cardiovascular disease. Adequate access to daylight also enhances visual comfort, energy efficiency, sleep quality, mood, and reduces stress and depression [41].

Acoustic Environment: When designing buildings that promote the health and well-being of occupants, one critical aspect to consider is the acoustic environment. Research has shown that exposure to low-frequency noise can lead to adverse health outcomes such as cardiovascular disease and sleep disturbances. Therefore, building designers

should minimize noise penetration and provide adequate sound insulation to create a more comfortable and healthier acoustic environment. One effective design strategy is to use double-paned windows, which can significantly reduce noise penetration and improve the acoustic environment inside a building. Additionally, incorporating sound-absorbing materials into walls, floors, and ceilings can help reduce the noise level entering a space. For example, installing acoustic ceiling tiles or carpets with high sound-absorption ratings can help reduce noise levels and create a more comfortable acoustic environment.

Another important consideration in building design and acoustics is the orientation of windows. Research has shown that buildings with street-oriented windows are at a higher risk of noise penetration, which can lead to adverse health outcomes such as cardiovascular disease and hypertension. Therefore, it is essential to carefully consider the orientation of windows and their placement in relation to noise sources when designing buildings. In some cases, white noise machines can be used to help block out unwanted noise sources and improve people's attention in the workplace. These machines work by emitting low-level background noise that can help mask other sounds and create a more comfortable acoustic environment. While this approach can be effective, it is essential to ensure that the noise level is appropriate and does not create additional health risks or distractions for occupants.

Finally, it is worth noting that the current research on the transformation of green buildings is constantly evolving. Many researchers are exploring new design strategies and building materials that can improve the acoustic environment while also reducing energy consumption and promoting sustainability. For example, some studies have shown that incorporating natural materials such as wood and plants into building design can help absorb sound and create a more comfortable acoustic environment. As the field of green building design continues to grow and evolve, it is essential to stay up to date on the latest research and design strategies to create buildings that promote the health and well-being of occupants.

Ventilation: Ventilation plays a crucial role in creating better indoor air quality by regulating air temperature, concentrations of pollutants, and humidity [42]. People who live or work in places with poor ventilation often experience headaches, tiredness, dizziness, and itchy skin [43]. Research shows that the use of enhanced ventilation in office buildings with green criteria, in addition to economic advantages, also has a positive effect on improving employees' health and well-being, efficiency, and decision-making [44].

Ventilation is the process of exchanging indoor (polluted) air with outdoor air, which should preferably be clean. The purpose is to create optimal conditions for the occupants of indoor environments, considering their health, comfort, and cognitive and physical performance, by providing air for breathing while removing and diluting contaminants. Ventilation is, in some cases, also used to control the indoor thermal environment (temperature and moisture) by providing heating or cooling and by adjusting the humidity (by adding or removing water) [45] In addition, in recent years, with the spread of COVID-19 in the world and the importance of implementing health principles and paying attention to the characteristics of the COVID-19 virus in the design of the artificial environment, ventilation in the indoor environment of buildings has also become particularly important and research on this issue has increased. This research mostly revolves around reducing the presence of viruses in indoor air and increasing indoor air quality [46,47].

2.4. Non-Physical Factors

Safety and Security: Safety and security are critical elements in building design and construction, impacting occupants' physical and psychological well-being. Threats to one's sense of security can trigger the release of stress hormones, which may have chronic effects on the body, such as suppressed immunity [48]. Emergency preparedness is crucial for a healthy building, involving design elements such as sturdy walls, secure entrances, and emergency plans for occupants. Building security systems, such as surveillance cameras,

alarms, access control, fire suppression systems, emergency lighting, and marked exits, further enhance building safety [49].

It is also important to note that safety and security should be considered in the design and construction of a building and its operation and maintenance. This includes regular fire drills, emergency response training, and maintenance of building systems such as smoke detectors, fire suppression systems, and emergency lighting. Overall, safety and security are essential components of a healthy building and should be considered throughout the design, construction, operation, and maintenance. This includes elements such as emergency preparedness, building security systems, and regular maintenance and training to ensure the safety of occupants in case of an emergency [50].

Cleanliness: Butte and Heinzow (2002) say that dust can be thought of as a place where harmful things such as bacteria, allergens viruses, and outdoor pollutants that enter the building can hide [51]. There are variable amounts of allergens that can be found in buildings. These allergens can contribute to an allergic reaction when inhaled or in contact with the eyes. Pesticides that kill microbial contamination are often linked to various human health effects. Symptoms range from mild (e.g., headache, dizziness) to moderate (e.g., blurred vision, muscle incoordination) and extreme (unconsciousness, inability to breathe, and death) [52]. Reducing pesticide exposure inside the house is best achieved by ensuring enough ventilation, eliminating pests without chemicals, and using integrated pest management.

View: Visual comfort is an essential criterion of the well-being of the people in buildings. The therapeutic impacts of natural views have been established in the literature [53]. Several visual comforts criteria, such as the view type and quality of the view, severely influence physical and psychological health. Visual comfort plays an essential role in the efficiency of occupants [54].

Space layout: The way in which a space is designed and laid out can have a profound impact on the individuals who occupy it. As Winston Churchill famously stated, "We shape our buildings. After that, they shape us." This insightful quote underscores the significant role that our environment plays in shaping not only our physical surroundings but also our emotional and mental well-being. In today's fast-paced and rapidly changing world, creating spaces that promote relaxation, productivity, and overall well-being is more important than ever. By taking a deliberate approach to space layout and design, individuals and organizations can positively impact their health, mood, and productivity. Research has shown that certain design elements, such as natural light, ergonomic furniture, and biophilic design, can improve mood and reduce stress levels. Furthermore, well-designed spaces can foster creativity, collaboration, and innovation in the workplace, ultimately leading to increased success and overall satisfaction [55].

3. Green Building

The green building movement, which emerged in the 1990s, is a response to issues related to the energy crisis and a global vision to minimize the use of energy, water, and materials, improve the productivity of buildings, and mitigate impacts on humans and the environment. Green building aims to reduce the negative impacts of built environments and create healthy spaces for people to live, study, and work [56]. Green buildings can directly impact the health of occupants through the optimization of indoor spaces and improved indoor efficiency. This includes factors such as ventilation, materials, and lighting, which have been shown to improve indoor air quality and overall indoor environmental quality (IEQ) in green buildings. Additionally, green buildings can have an indirect impact on population health by reducing energy usage and air pollutants, thus reducing the negative impact of buildings on the environment [57,58]. Moreover, green buildings can also have a positive impact on economic and productivity issues. Studies have shown that green buildings can achieve a higher level of indoor environmental quality compared to standard buildings, which leads to improved health, productivity, and satisfaction among

occupants. They are designed to minimize the environmental impact through energy and water conservation measures and limiting the local impact on the building site [59–61].

It is important to note that while green building certification is becoming more common, the focus on indoor environmental quality (IEQ) and the health of occupants is still not well understood by the public. Therefore, it is important for authorities to pay particular attention to IEQ when assessing green building certification and for occupants to understand the health benefits associated with green buildings [62].

3.1. Green Building's Features Related to Human Health (The Health Aspects of Green Buildings)

Green sustainable design is a strategy that aims to create healthier and more efficient buildings for occupants. The health issues arising from poor indoor quality in conventional buildings have contributed to the emergence of sustainable design and green building strategies such as the Leadership in Energy and Environmental Design (LEED) rating system and that of the U.S. Green Building Council (USGBC) [42].

LEED certification, for example, aims to decrease the environmental footprint of buildings and protect the comfort and well-being of occupants. In addition to energy efficiency and environmental performance, the LEED rating systems also include a section focusing on indoor environmental quality (IEQ). This section includes guidelines for improving ventilation and filtration, controlling chemicals and pollutants in indoor spaces, improving lighting and thermal conditions, using low-emitting materials, and monitoring indoor air quality, as well as providing access to natural daylight for building occupants. Most of the green building certifications that are directly related to the health of individual occupants fall under the indoor environmental quality category. Research has established that indoor environmental quality problems in buildings can directly impact occupants' health, productivity, and comfort. Implementing green building strategies, such as those outlined in the LEED rating system, can greatly improve indoor environmental quality and ultimately enhance the overall health and well-being of building occupants [42–44].

3.2. Green Buildings and SDGs (Sustainable Development Goals)

Green buildings and SDGs (sustainable development goals) are closely related, and integrating green building principles and practices into building design, construction, and operation can help achieve several SDGs. The SDGs provide a comprehensive framework for global sustainability. Green buildings can contribute to several of these goals by improving indoor environmental quality, reducing energy and water consumption, and promoting responsible consumption and production. Research has shown that green buildings can align with several SDGs, including SDG 3 (Good Health and Well-being), SDG 7 (Affordable and Clean Energy), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production). In particular, SDG 12 (Responsible Consumption and Production) is the goal that benefits the most from green buildings, as they promote the use of sustainable materials, reduce waste, and improve energy and water efficiency.

Similarly, research conducted in Nigeria has identified that investing in green building can achieve SDGs such as SDG 3 (Good Health and Well-being), SDG 6 (Clean Water and Sanitation), SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action). Green buildings can also help achieve other SDGs such as SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation and Infrastructure) and SDG 11 (Sustainable Cities and Communities) by creating jobs in the construction and building-related industries, promoting innovation and sustainable infrastructure, and creating livable and inclusive communities. In general, it can be said that green buildings can play a significant role in achieving sustainable development goals by improving indoor environmental quality, reducing energy and water consumption, promoting responsible consumption and production, and contributing to economic growth and livable communities (Table 1). Additionally, this subject is going to be more and more significant due to the impacts of climate change on both buildings and our daily life [63,64].

Table 1. General description of the related SDGs to green buildings [65].

SDGs	Brief Description of the Goals	Aim of the Goals
SDG 3	Good Health and Well-being	Ensure healthy lives and promote well-being for all at all ages.
SDG 6	Clean Water and Sanitation	Ensure availability and sustainable management of water and sanitation for all.
SDG 7	Affordable and Clean Energy	Ensure access to affordable, reliable, sustainable and modern energy for all.
SDG 11	Sustainable Cities and Communities	Make cities and human settlements inclusive, safe, resilient, and sustainable.
SDG 12	Responsible Consumption and Production	Ensure sustainable consumption and production patterns.
SDG 13	Climate Action	Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy.

3.3. Strategies Used in Green Building to Enhance IEQ Factors

In this section, IEQ factors, already known as influential factors for the health of occupants in green buildings, are investigated. Indoor air quality, thermal comfort, lighting, visual comfort, and acoustic comfort are the four key factors defining the indoor environmental quality of the space [45].

Indoor Air Quality: Improved indoor air quality (IAQ) is one of the key components of the design of green buildings. IAQ has been regarded as a standard component of green building certification programs since they were first developed. IAQ is a component of indoor environmental quality, and in some cases, it is a component of health and well-being [46]. The use of energy-saving techniques, sealing/tightening of structures, and green building strategies can all help green buildings decrease the penetration of external contaminants and produce cleaner, better indoor air quality [47]. Measurement of indoor air quality, ventilation, and control of pollution sources are crucial IAQ management techniques utilized in green buildings [66]. These routes focus on different stages of the house's life cycle. The calculation for indoor air is used to check the levels of indoor pollutants and compare them to the threshold values. Emission source control strives to design and select low-emission materials for painting, furniture, carpets, and flooring while ventilation aims to provide an appropriate air exchange between indoor and outdoor settings to maintain high IAQ [67].

Thermal comfort: Green design and innovative technology can be used to improve thermal comfort. For instance, green buildings will use non-energy-demanding approaches to take advantage of the buildings' natural opportunities, such as wind, to increase natural ventilation and reduce the temperature to an adequate level. The green design also uses passive strategies to simplify natural ventilation [68], better daylighting [69] and combat the impacts of climate change [70] by considering space layout, openings' size, and building orientation from the early design stages. Bluyssen et al. (2016) say that using the building's envelope and the suitable insulation materials in the exterior walls are also important ways to improve the thermal comfort of the interior [40].

Lighting and visual comfort: Green building strategies such as paying attention to the building's shape and orientation have an essential role in the building's lighting. Furthermore, placing and sizing windows accurately and paying attention to space layout will affect the amount of natural lighting that comes into the space and provide occupants with enhanced visual comfort. In addition, factors that provide comfort levels effectively, such as glare, indoor light color, luminance distribution, and uniformity should be considered when designing IEQ improvements in green buildings [50].

Acoustic comfort: Noise, as one of the primary sources of complaints, is an essential element to be considered in standards and schemes for green buildings. However, green building standards have begun incorporating acoustic comfort as an optional criterion [71]. Some physical properties of the built environment can define acoustic settings. These factors are absorption, sound insulation, and reverberation time. Despite studies showing the impact of these indoor acoustics on comfort levels, these considerations are often ignored in the design requirements of green buildings [52].

3.4. IEQ Factors in Green Buildings Compared to Non-Green Buildings

Studies examining IEQ factors in LEED-certified and non-certified buildings and their effects on occupants' well-being and mental performance found that people in green buildings performed better than those in traditional buildings and had fewer sick building symptoms [4]. Several studies have surveyed occupants' health and satisfaction with IEQ factors in green buildings. Some of these studies and their results are summarized in the table below.

4. Methodology

A systematic approach was used to identify relevant studies for this review. A search strategy was developed in consultation with a librarian and included the following databases: PubMed, Web of Science, Scopus, and Google Scholar. The search terms used were "green building" OR "energy optimization" AND "indoor human health". The search was limited to articles published in English between January 2000 and January 2023. The inclusion criteria for this review were studies examining the relationship between green building energy optimization strategies and indoor human health outcomes. Studies that focused solely on energy efficiency or renewable energy sources without considering indoor human health outcomes were excluded from the review. The exact search query used was: ("green building" OR "energy optimization") AND "indoor human health". Additionally, the reference lists of all relevant articles were reviewed for additional studies.

The data extraction process included collecting information about the study design, sample size, study population, study location, energy optimization strategies used, indoor human health outcomes measured, and main findings from each article. Additionally, a quality assessment was conducted using the Newcastle–Ottawa Scale (NOS) for non-randomized studies to assess the risk of bias in each study included in this review. This research used a qualitative method and combined documentary research with literature reviews of articles related to green buildings and healthy environments. The gathered data was analyzed to define the critical role of "green buildings" in providing healthier spaces by enhancing indoor environmental quality (IEQ) factors and affecting the well-being of their occupants. The type of research was descriptive research, and the data collection technique used was document analysis and literature review.

One potential limitation of this methodology is the exclusion of studies focusing solely on energy efficiency or renewable energy sources without considering indoor human health outcomes. These exclusion criteria may limit the scope of the review and potentially omit important information on the relationship between green buildings and indoor human health. Additionally, the search was limited to articles published in English, which may result in omitting relevant studies published in other languages. Lastly, the quality assessment of each study included in the review was conducted using the Newcastle–Ottawa Scale for non-randomized studies, which may fail to fully capture the quality of randomized controlled trials or other study designs. These limitations should be considered when interpreting the results of the review. The framework of the research workflow is presented in Figure 2.

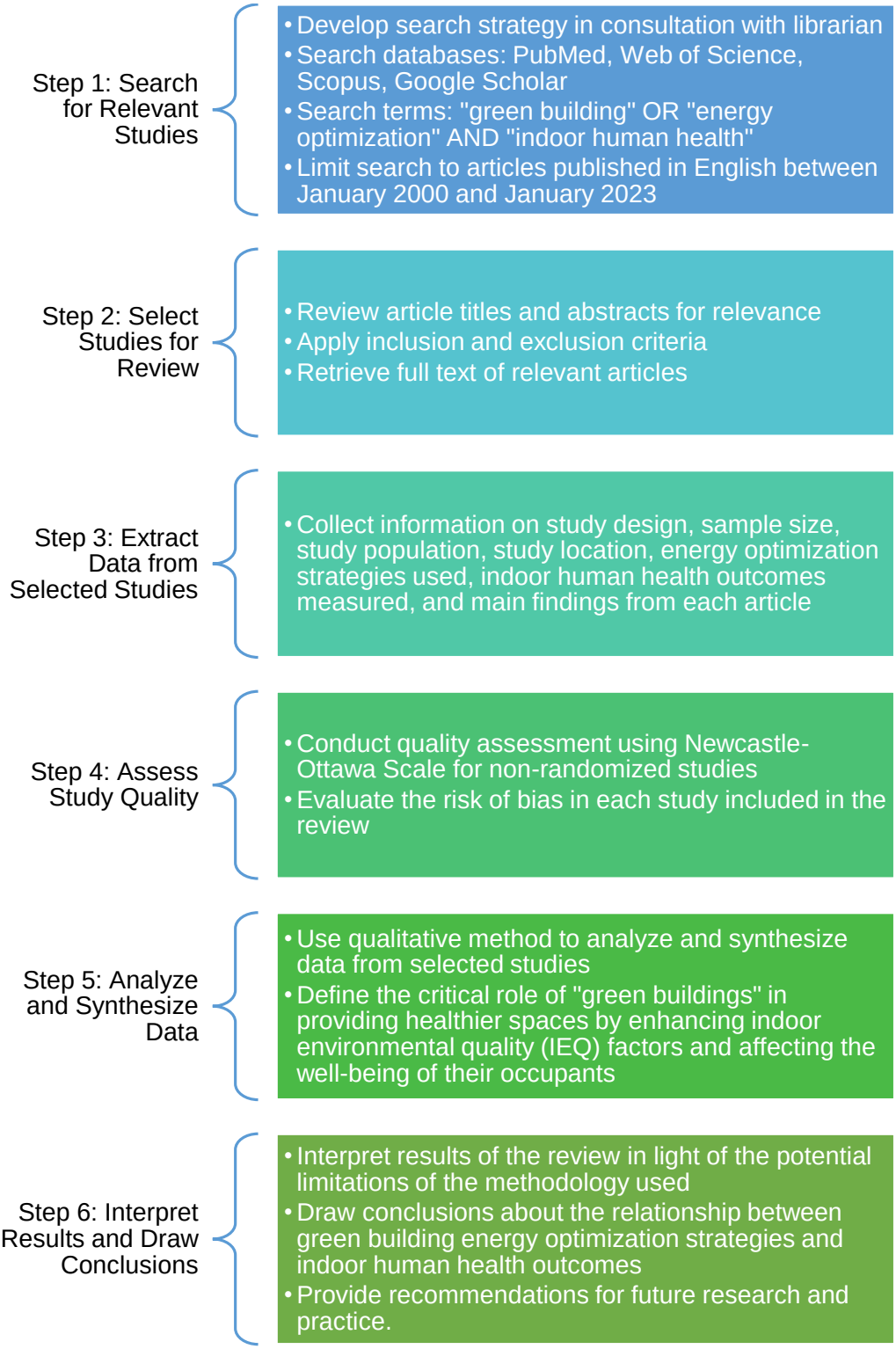

Figure 2. Chart of research methodology.

5. Result

5.1. Building-Related Factors Impacting Human Health

A range of building-related factors can impact indoor environmental quality and, in turn, human health. These include factors such as building location, site selection, ventilation, insulation, and building materials, among others [31]. Building location can

impact occupant health by increasing the risk of exposure to pollutants, such as particulate matter and noise. Site selection is another crucial factor, with proximity to sources of pollutants, such as highways and industrial sites, increasing the risk of exposure [33]. Adequate ventilation is crucial to maintaining indoor air quality, reducing the risk of exposure to pollutants, and promoting occupant health [34]. Insulation plays a role in energy efficiency but can also impact indoor air quality by trapping pollutants inside the building. Similarly, building materials can emit VOCs and other harmful substances that can affect indoor air quality and occupant health [72].

5.2. Foundational Features Impacting Indoor Environmental Quality

The foundation of a building is crucial to maintaining indoor environmental quality. Proper foundation design can prevent moisture buildup, which can lead to mold growth and poor indoor air quality. Additionally, appropriate landscaping and site drainage can prevent moisture from entering the building, reducing the risk of mold growth [35].

5.3. Green Building Features Contributing to Enhanced Indoor Environmental Quality

Green buildings incorporate various features that contribute to enhanced indoor environmental quality, including natural ventilation, high-efficiency HVAC systems, and renewable energy sources [36]. Natural ventilation can improve indoor air quality by increasing air exchange rates and reducing the risk of exposure to pollutants. High-efficiency HVAC systems can reduce energy consumption while maintaining comfortable indoor temperatures and reducing the risk of exposure to pollutants [38]. Renewable energy sources, such as solar panels and wind turbines, can reduce the reliance on fossil fuels and, in turn, improve indoor air quality by reducing the emission of pollutants [39].

5.4. Role of Green Buildings in Promoting Better and Healthier Environments for Occupants

Green buildings play a crucial role in promoting better and healthier environments for occupants by improving indoor environmental quality and reducing negative environmental impacts. Research has shown that green buildings can improve occupant health by reducing the risk of exposure to pollutants and promoting physical activity [40]. Additionally, green buildings can improve occupant well-being by increasing access to natural light, reducing noise levels, and improving thermal comfort [41].

5.5. Energy Optimization Strategies for Green Buildings

A range of energy optimization strategies are available for green buildings, including passive solar design, high-efficiency lighting and appliances, and renewable energy sources. Passive solar design incorporates features such as large windows, south-facing facades, and thermal mass to reduce the need for heating and cooling [42]. High-efficiency lighting and appliances can reduce energy consumption while maintaining comfortable indoor conditions [43]. Renewable energy sources, such as solar panels and wind turbines, can reduce the reliance on fossil fuels and reduce the emission of pollutants [28].

An integrated approach to the findings is important to fully understand the impact of green buildings on human health, the environment, and the economy. Green buildings have the potential to improve indoor environmental quality, reduce negative environmental impacts, and promote occupant health and well-being. To achieve these goals, it is important to consider a range of building-related factors, foundational features, and green building features. Energy optimization strategies can also play a crucial role in reducing energy consumption and improving indoor environmental quality. However, implementing these strategies in existing buildings can be challenging, requiring careful planning and management. Monitoring energy performance is important to ensure that energy optimization strategies achieve their intended outcomes and to identify areas for further improvement. By taking an integrated approach to these findings, we can promote better and healthier environments for occupants while also reducing negative environmental impacts and achieving greater energy efficiency.

6. Discussion

The present study aimed to investigate the impact of energy optimization strategies in green buildings on indoor human health. The findings reveal that green building design, construction, and operation can contribute to reducing energy consumption while improving indoor air quality, which, in turn, can positively impact the health of occupants in such buildings. Moreover, the use of energy optimization strategies does not compromise occupant comfort or safety. Based on the results, several potential strategies can be suggested to optimize energy use in green buildings, including natural ventilation systems, efficient lighting systems, and renewable energy sources. Furthermore, the use of smart technologies such as occupancy sensors and automated control systems can help optimize energy use while ensuring occupant comfort and safety.

It should be noted that the effectiveness of these strategies may vary depending on the specific building design and operational practices employed by each building owner or operator. Therefore, building owners and operators should consider their specific needs when selecting an appropriate strategy for optimizing energy use in their green buildings. Further research is necessary to understand how different strategies may affect indoor air quality and occupant health in different green buildings. The researchers adopted a holistic approach to examining the impact of green buildings on improving buildings' internal environment (IEQ) and public health. They found that by improving both the physical and non-physical factors of indoor environments, green buildings can enhance the physical and mental health of occupants. The most influential factors for indoor environment quality are indoor air quality, temperature comfort, lighting, visual comfort, and sound comfort. Further investigations on indoor air quality reveal that it significantly affects the health of residents. Green buildings can improve indoor air quality by purifying outdoor air and preventing pathogenic pollutants from entering the building environment. Moreover, studies have shown that pollutants in the external environment contribute to increasing pollution and reducing air quality indoors. As shown in Table 2, temperature comfort is one of the factors of indoor air quality that has received more attention in green buildings than in past and ordinary buildings. Research has demonstrated that green buildings can enhance residents' well-being, physical and mental health, and productivity by controlling the environment's temperature and creating temperature satisfaction for residents using green and technological solutions.

Table 2. Current literature on the comparison of IEQ factors between green buildings and conventional buildings.

IEQ Criteria	Results (Compared to Conventional Buildings)	References
Air quality	Increased	[53–56,72,73]
	Decreased	-
Thermal comfort	Increased	[53–55,74]
	Decreased	[75]
Lighting and visual comfort	Increased	[55,56,76,77]
	Decreased	-
Acoustic comfort	Increased	[55,56,71]
	Decreased	[76]

However, it is essential to note that this does not imply that the quality of the IEQ is unimportant. With the help of design, green buildings reduce noise from the external environment to improve physical and mental health, and insulation of the internal climate increases the quality of life by reducing noise from the external environment.

It is important to consider the future uncertainties in indoor environment quality assessments as well as contemporary sustainability challenges in all aspects. In order to address these challenges, using new technologies and analyses seem highly necessary.

According to Figure 3, synthesizing the findings of this study indicates that by improving the physical and non-physical factors of building internal environment quality (IEQ), green buildings can ensure their residents' mental and physical health.

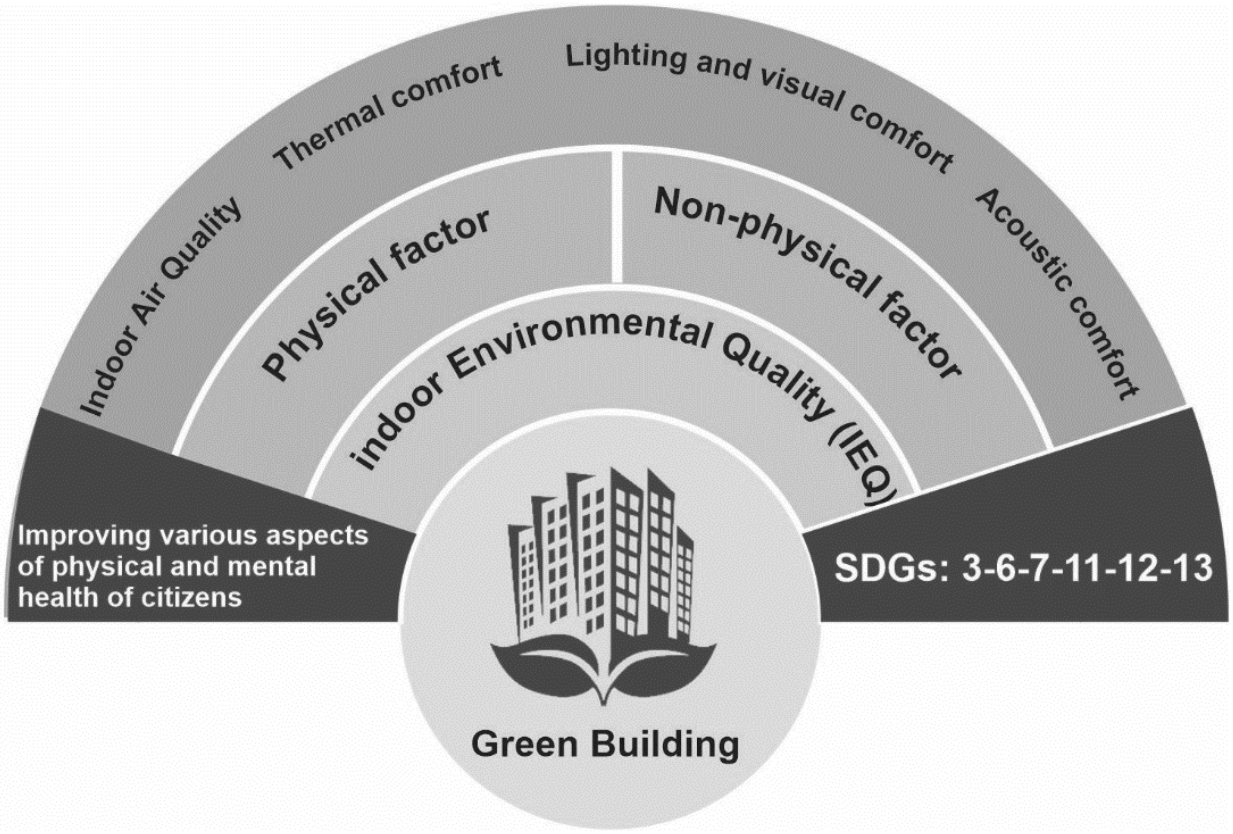

Figure 3. Linkage of green building and IEC and SDGs.

Green buildings can play a vital role in improving the general health of society and the development of any country. This study showed that green buildings could also help communities and nations achieve sustainable development goals (SDGs) three, six, seven, eleven, twelve, and thirteen, and a sustainable lifestyle, which is the main objective. The main goals are the public's health, preserving the environment, and ensuring future generations' lives. By improving physical and non-physical factors, indoor air quality, temperature comfort, lighting, visual comfort, and acoustic comfort, green buildings contribute not only to the general health of citizens. It can, however, be effective in achieving green building objectives.

The use of emerging technology to realize a future free of carbon emissions may constitute an additional, supplementary strategy toward the accomplishment of the objectives of green construction.

7. Conclusions

The main conclusion of the manuscript is that green building design, construction, and operation can contribute to reducing energy consumption while improving indoor air quality, which positively impacts the health of occupants. The study identifies four factors that contribute the most to the development and research of green buildings, including indoor air quality, temperature comfort, lighting, visual comfort, and acoustic comfort. By implementing energy optimization strategies such as using renewable energy resources,

efficient HVAC systems, controlling indoor air quality, and optimizing daylight and artificial lighting, green buildings can positively impact indoor human health. This study emphasizes the importance of sound comfort in green building design. Policymakers, designers, and employers can use the findings and clarifications presented in this research to utilize green and healthy solutions for the development of cities and investment in construction that prioritizes energy efficiency and occupant health.

In this study, the role of green buildings in improving the internal environment quality (IEQ) factors of buildings is emphasized. By identifying overlapping research, it was demonstrated that green buildings play a significant role in promoting the health and well-being of occupants, particularly through the use of nature-friendly solutions. As a green and healthy solution for the development of cities and investment in construction, policymakers, designers, and employers can utilize the findings and clarifications presented in this research.

The study highlights four factors that contribute the most to the development and research of green buildings: indoor air quality, temperature comfort, lighting, visual comfort, and acoustic comfort. To improve the quality of the indoor environment of buildings and various health dimensions, improving indoor air quality is essential. It is important to note that in the countries of the Global South, improving the health and well-being of the public, preserving the environment, and ensuring a sustainable future for generations to come are crucial goals at the core of the 2030 UN Agenda and climate change agenda.

By implementing energy optimization strategies, such as using renewable energy resources, efficient HVAC systems, controlling indoor air quality, and optimizing daylight and artificial lighting, green buildings can positively impact indoor human health. This study also emphasizes the importance of sound comfort in green building design.

The practical implications of these findings are significant. Policymakers and designers can use the information presented in this study to promote the development of green buildings that prioritize energy efficiency and occupant health. To achieve this, digital twins can be used to simulate the performance of buildings in real-time, allowing for optimization of IEQ and energy efficiency. Policymakers can provide incentives for the construction of green buildings and implement regulations requiring building standards that prioritize energy efficiency and occupant health. By reducing energy consumption, improving the health and well-being of occupants, and decreasing the environmental impact of buildings, the strategies and recommendations outlined in this research can help achieve sustainable development goals. Furthermore, this study emphasizes the need for further research and development to fully understand the long-term effects of green building design. Effective energy optimization strategies must be developed to ensure that healthy indoor environments are created to tackle the threat of climate change.

Finally, the results of this study have important implications for policymakers and designers looking to promote green buildings as a healthy and sustainable solution. By utilizing the strategies and recommendations presented in this research, we can achieve sustainable development goals, promote the health of citizens, and reduce our environmental footprint. The importance of promoting the health and well-being of occupants, preserving the environment, and ensuring a sustainable future for generations to come cannot be overstated, particularly in the Global South, where these goals are at the core of the 2030 UN Agenda and climate change agenda. Green buildings represent a significant opportunity to achieve these goals, and the findings presented in this research can play a critical role in promoting their development and adoption.

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