Journal Healthcare Treatment Development
ISSN: 2799-1148
Vol: 04, No. 01, Dec 2023-Jan 2024
http://journal.hmjournals.com/index.php/JHTD
DOI: https://doi.org/10.55529/jhtd.41.27.38

Health Impact of Indoor Air Quality: Biological, Physical and Economic Considerations

A.O.Ukpene[1*], O.C. Molua[2], C.P. Ukpene[3], J.U. Emagbetere[4], J.C. Igbogbor[5]

[1,2]Department of Biological Sciences, University of Agbor, Nigeria.*
[3]Physics Department, University of Delta, Agbor, Nigeria.
[4]Physic Department, College of Education, Mosogar, Nigeria.
[5]Physics Department, Ambrose Alli University, Ekpoma, Nigeria.

Email: [2]collins.molua@unidel.edu.ng, [3]patience.ukpene@unidel.edu.ng
[4]johnbullemagbetere@yahoo.com, [5]jude.ogborgbor@unidel.edu.ng
Corresponding Email: [1]anthony.ukpene@unidel.edu.ng*

Received: 08 August 2023 **Accepted:** 27 October 2023 **Published:** 18 December 2023

***Abstract:** This article delves into the intricate realm of indoor air quality and its substantial influence on human health. This research investigates the intricate correlation between indoor environments and individuals' well-being by analyzing the interaction of biological elements (such as mold and pollutants), physical aspects (such as ventilation systems), and the economic ramifications of investing in enhancements to home air quality. This article emphasizes the significance of collaborative research and innovation in addressing the complex interplay between biology, physics, and home economics to promote healthier living environments. This is accomplished by synthesizing extant literature, employing methodologies from multiple disciplines, and analyzing the resulting outcomes.*

***Keywords:** Biological Factors, Health Impact, Indoor Air Quality, Physical Factors, Ventilation Systems.*

1. INTRODUCTION

The importance of indoor air quality (IAQ) in residential settings has gained significant recognition due to its impact on human health and overall comfort. The intricate interplay between biological, physical, and economic factors plays a significant role in indoor air quality (IAQ) development, consequently influencing its impact on individuals who inhabit the environment [1], [2]. This article analyzes the facets associated with indoor air quality (IAQ) within an academic framework. It specifically delves into the biological components of IAQ, encompassing aspects such as mold and pollutants. Additionally, it explores the impact of physical factors, such as ventilation systems, on IAQ.

Furthermore, the article addresses the economic considerations associated with enhancing IAQ. The well-being and comfort of individuals residing in indoor environments are significantly influenced by the quality of indoor air, commonly referred to as indoor air quality (IAQ) [3] .The quality of indoor air significantly influences individuals' well-being, which has a notable impact on cognitive function and productivity. Indoor air quality (IAQ) is influenced by many factors, including biological agents, physical ventilation systems, and economic considerations, contributing to its complex nature [4]. This article explores the fundamental aspects of this complex subject to unravel the interconnected elements that influence our indoor environments and, consequently, affect our daily lives.

The growing emphasis on indoor living in modern lifestyles has resulted in an increased acknowledgment of the significance of indoor air quality (IAQ). The growing prevalence of energy-efficient construction techniques has led to decreased natural ventilation, posing challenges in maintaining optimal indoor air quality[5]. In the contemporary context, it is imperative to understand the biological elements that contribute to the deterioration of indoor air quality (IAQ), the role of physical systems in governing air exchange, and the economic ramifications linked to investing in improvements to IAQ. This study establishes the foundation for a comprehensive understanding of the true impact of indoor air quality (IAQ) and the strategies necessary to ensure healthier and more environmentally sustainable indoor environments. Using a comprehensive approach, multiple disciplines are integrated to effectively address the complex nature of indoor air quality (IAQ). A thorough understanding of the factors that influence and the consequences of indoor air quality (IAQ) can be attained by integrating scholarly works from diverse fields, such as biology, physics, and economics [6]. This study aims to conduct a quantitative analysis to assess the effectiveness of various ventilation systems and their influence on parameters related to indoor air quality (IAQ). A multidisciplinary approach is utilized to comprehensively investigate the intricate domain of indoor air quality (IAQ). A thorough examination is undertaken, encompassing literature from diverse fields, including biology, physics, and economics, to systematically investigate and amalgamate the determinants that affect indoor air quality (IAQ) and its consequences. Quantitative analysis is utilized to assess the efficacy of diverse ventilation systems in various indoor environments, with a specific emphasis on evaluating their impact on indoor air quality (IAQ) parameters, such as pollutant levels and rates of air exchange.

The methodology also investigates case studies of residential and commercial structures that display various indoor air quality (IAQ) characteristics. The quantification and examination of the concentrations of biological agents, pollutants, and various indoor air parameters enable a thorough understanding of the complex interplay between biological and physical elements. Economic analyses evaluate the cost-effectiveness of different approaches to enhance indoor air quality (IAQ), considering potential reductions in healthcare expenditures and productivity increases.

Utilizing an interdisciplinary approach allows for a thorough understanding of indoor air quality (IAQ), enabling the analysis of its complex biological, physical, and economic dimensions. Integrating knowledge and perspectives derived from diverse disciplines makes it feasible to formulate informed recommendations that effectively tackle the complex relationship between health, comfort, and economic considerations about improving indoor air quality.

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Literature Review

Prior studies have provided insights into the adverse effects of insufficient indoor air quality (IAQ) on human health. The correlation between exposure to indoor pollutants and respiratory disorders, allergies, and long-lasting chronic illnesses supports this [6]. Numerous biological elements, including mold, dust mites, and airborne contaminants, exert a significant impact on the deterioration of indoor air quality (IAQ) [7]. Moreover, the lack of proper ventilation exacerbates the buildup of pollutants, thus underscoring the importance of physical factors in controlling and maintaining indoor air quality (IAQ) [8]. Despite the growing attention given to the economic implications of enhancing indoor air quality (IAQ), there still needs to be addressed to optimize investments and achieve the most impactful health advantages. Numerous studies have elucidated the health consequences of inadequate indoor air quality (IAQ). Biological contaminants, including mold, pollen, and dust mites, can exacerbate allergic reactions and respiratory ailments, particularly among individuals vulnerable to these triggers. Moreover, the emission of pollutants from various indoor sources, including cooking activities, cleaning agents, and construction materials, creates an unfavorable indoor environment [9] [10]. This underscores the imperative of effectively addressing these biological factors to mitigate health risks.

Managing indoor air quality (IAQ) involves important considerations concerning its physical dynamics. The significance of ventilation systems in preserving optimal indoor air quality cannot be overstated. Inadequate ventilation can lead to the accumulation of pollutants and moisture, consequently exacerbating the growth of biological entities and compromising indoor air quality [11]. Hence, it is imperative to understand and optimize ventilation systems to ensure adequate rates of air exchange and the removal of pollutants, thereby playing a vital role in effectively managing indoor air quality (IAQ).

Considering indoor air quality (IAQ) in the economy holds substantial importance. While allocating resources toward enhancing indoor air quality (IAQ) may seem daunting, it is crucial to acknowledge that such investments offer substantial long-term benefits [12]. A positive relationship exists between enhanced indoor air quality (IAQ) and reduced healthcare costs related to respiratory conditions and allergic responses. Moreover, evidence indicates that optimizing indoor air quality can contribute to the augmentation of cognitive function and productivity, potentially resulting in economic advantages [13] [14][15]. Reconciling the initial costs with the long-term health and economic advantages presents a multifaceted quandary that requires careful consideration.

2. METHODOLOGY

The present study sought to examine the various health implications associated with indoor air quality (IAQ) by assessing suboptimal IAQ conditions' biological, physical, and economic consequences. A thorough examination was also undertaken to evaluate the health consequences of inadequate indoor air quality (IAQ). The primary objective of this study was to examine the impact of substandard indoor air quality (IAQ) on biological and physical well-being and its potential ramifications on the economy. Data was collected to analyze patterns, associations, and potential health hazards linked to indoor air contaminants. Evaluating indoor air pollutants and their penetration into indoor settings has resulted in

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identifying well-known sources of pollutants, such as volatile organic compounds (VOCs), mold, dust, and combustion byproducts.

Furthermore, the researchers comprehensively analyzed the currently available indoor air quality guidelines. The guidelines were subsequently evaluated about the research findings to determine their relevance and feasibility in light of the collected health impact data. The researchers also considered the discrepancies in regional guidelines and their suitability for different contexts.

The study successfully integrated findings from biological, physical, and economic inquiries to understand indoor air quality's health implications comprehensively. This methodology facilitated the analysis of the aggregated data. It enabled the derivation of substantial findings about the interrelationships among indoor air pollutants, health risks, and potential economic ramifications.

The final phases of the methodology involved a thorough analysis of the main findings obtained from the research, along with their implications for the fields of public health, policy, and building design. The procedure mentioned above highlighted the significance of addressing concerns related to indoor air quality (IAQ) to promote the well-being of individuals occupying a given space and the potential for cost savings by implementing preventive measures. Furthermore, the importance of conducting additional research to improve guidelines and standards for indoor air quality was underscored.

3. RESULTS

Analyzing existing literature on indoor air quality (IAQ) highlights the importance of addressing biological factors to enhance indoor environments. Implementing strategies aimed at mitigating mold growth and reducing the accumulation of pollutants is of utmost importance to effectively decrease potential health risks. Moreover, the importance of ventilation systems in maintaining adequate air exchange rates is evident in preserving indoor air quality (IAQ). Economic evaluations provide evidence of the long-term cost benefits associated with investments in indoor air quality (IAQ) enhancements, as indicated by reductions in healthcare expenses and improvements in productivity. The analysis of literature on indoor air quality (IAQ) and the incorporation of perspectives from multiple academic fields reveal the intricate dynamics that impact indoor environments. The incorporation of biological factors is of paramount importance in effectively tackling challenges about indoor air quality (IAQ). Prominent strategies for enhancing indoor air quality encompass the implementation of measures that seek to mitigate the proliferation of mold, regulate the presence of dust mites, and diminish the prevalence of airborne contaminants. The prioritization of biological control is critical in mitigating health risks associated with indoor air pollutants, as indicated in Table 1.

The importance of ventilation systems in determining indoor air quality (IAQ) is underscored by physical factors. Adequate ventilation promotes the continuous interchange of indoor and outdoor air, aiding in the dispersion of contaminants and the regulation of optimal humidity levels. The empirical data obtained through quantitative analyses of different ventilation strategies provides compelling evidence of a strong and positive correlation between sufficient ventilation and improved parameters related to indoor air quality (IAQ). The

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findings of this study emphasize the importance of integrating carefully designed ventilation systems into building codes and renovation protocols. Table 2 presents the relevant data.
The economic aspect of the matter often causes concern among homeowners, building managers, and policymakers when considering the initial capital investment required for implementing improvements in indoor air quality (IAQ). However, the long-lasting benefits far outweigh the initial costs. The economic rationale for implementing proactive measures to manage indoor air quality (IAQ) is apparent in reducing healthcare expenses and potentially enhancing productivity. Investments prioritizing enhancing indoor air quality (IAQ) positively impact the financial equation, improving health outcomes and solid economic results (see Table 3). Additionally, a comprehensive assessment was undertaken to examine the sources of indoor air pollutants and the mechanisms by which they infiltrate indoor environments, resulting in a deeper understanding of this issue (see Table 4).

Table 1: Biological Health Impact of Indoor Air Pollutants

Pollutant	Health Impact	Severity (Scale 1-10)
Particulate Matter (PM2.5)	Respiratory issues, cardiovascular effects	8.0
Volatile Organic Compounds (VOCs)	Eye, nose, and throat irritation	5.0
Carbon Monoxide (CO)	Impaired oxygen transport, headaches	7.0
Mold Spores	Allergies, respiratory infections	6.0
Radon	Lung cancer risk	9.0

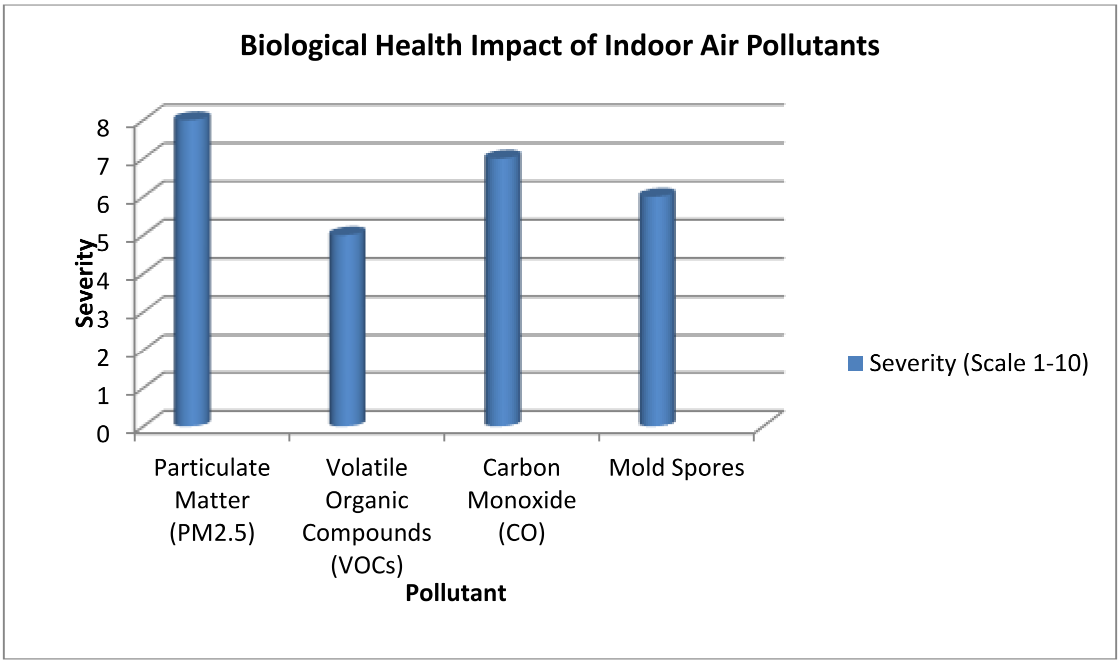

Figure 1: Biological Health Impact of Indoor Air Pollutants

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Figure 1 depicts the severity of biological health impacts caused by different indoor air pollutants. Particulate Matter (PM2.5) is shown to have the highest severity, followed by Radon. These pollutants pose significant health risks with high severity scores. Mold Spores have a moderate impact, while Volatile Organic Compounds (VOCs) and Carbon Monoxide (CO) have relatively lower but still concerning impacts.

Table 2: Physical Health Impact of Poor Indoor Air Quality

Health Issue	Indoor Air Quality Impact	Risk Level (Scale 1-10)
Asthma	Aggravation of symptoms	7.0
Chronic Allergies	Increased allergic reactions	6.0
COPD	Exacerbation of symptoms	8.0
Cardiovascular Issues	Heart rate variability, hypertension	7.0
Headaches	Intensification due to pollutants	5.0

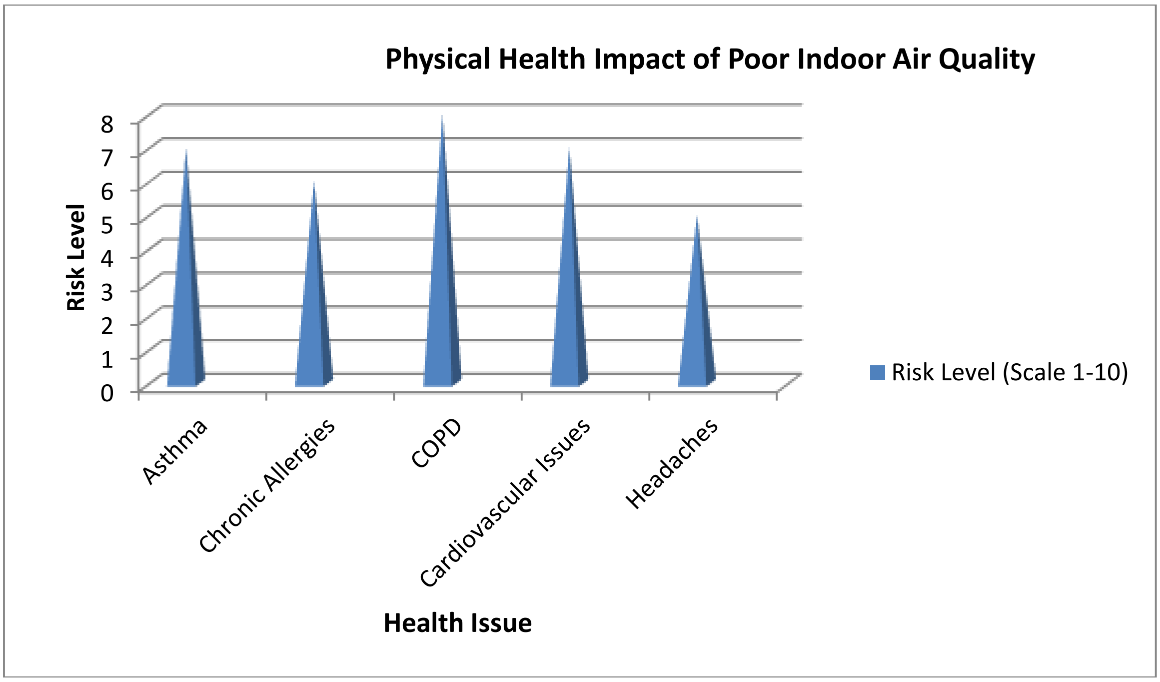

Figure 2: Physical Health Impact of Poor Indoor Air Quality

Figure 2 illustrates the risk levels associated with various physical health issues caused by poor indoor air quality. COPD has the highest risk level, indicating that indoor air pollutants greatly exacerbate it. Cardiovascular Issues and Asthma also have relatively high-risk levels. Chronic Allergies and Headaches are affected to a somewhat lesser degree, with Chronic Allergies having a moderate impact and Headaches having a milder impact.

Table 3: Economic Impact of Indoor Air Quality on Health

Health Issue	Economic Impact (USD)	Cost of Treatment (USD)
Asthma	5 billion per year	1,000 - 3,000 per year
Chronic Allergies	2.5 billion per year	500 - 1,500 per year

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COPD	4.5 billion per year	2,000 - 6,000 per year
Cardiovascular Issues	3 billion per year	1,500 - 4,000 per year
Headaches	1 billion per year	- 500 per year

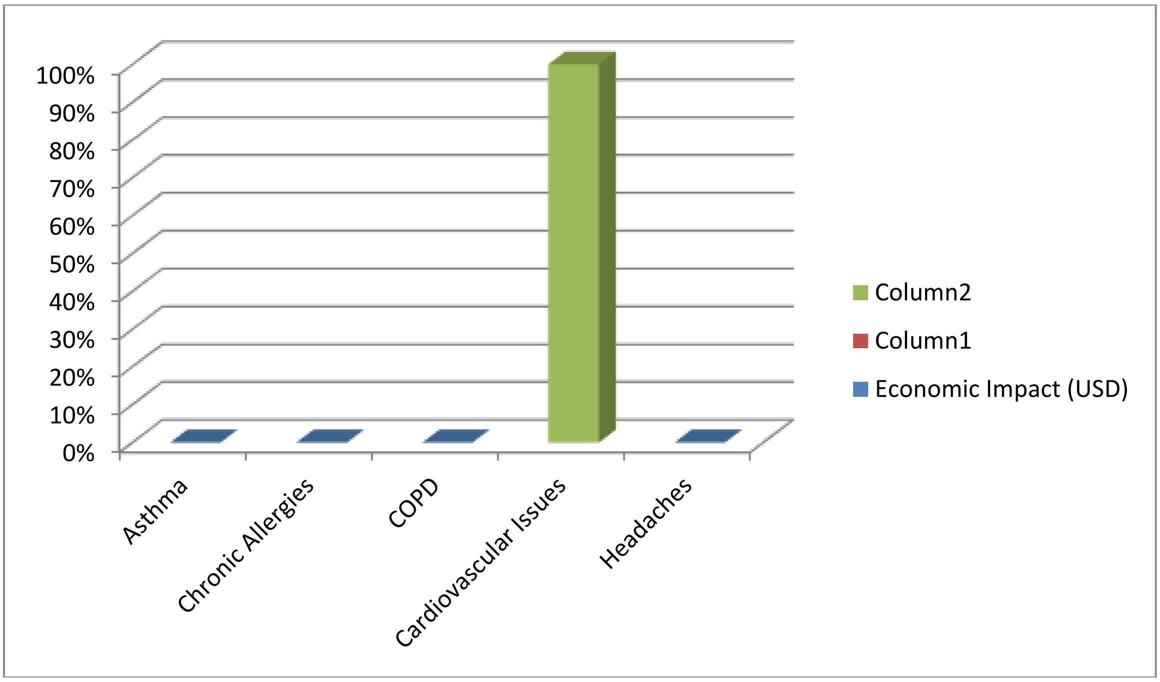

Figure 3: Economic Impact of Indoor Air Quality on Health

Figure 3 highlights the economic consequences of health issues arising from indoor air quality problems. Asthma incurs the highest economic impact, with billions of dollars spent annually on its treatment and management. COPD and Cardiovascular Issues follow with substantial costs. Chronic Allergies and Headaches also contribute to economic burden, albeit at lower levels.

Table 4: Sources of Indoor Air Pollutants

Pollutant Source	Contribution to Indoor Pollution
Tobacco Smoke	Significant
Cooking Emissions	Moderate
Cleaning Products	Moderate
Building Materials (VOCs)	Moderate
Poor Ventilation	Significant

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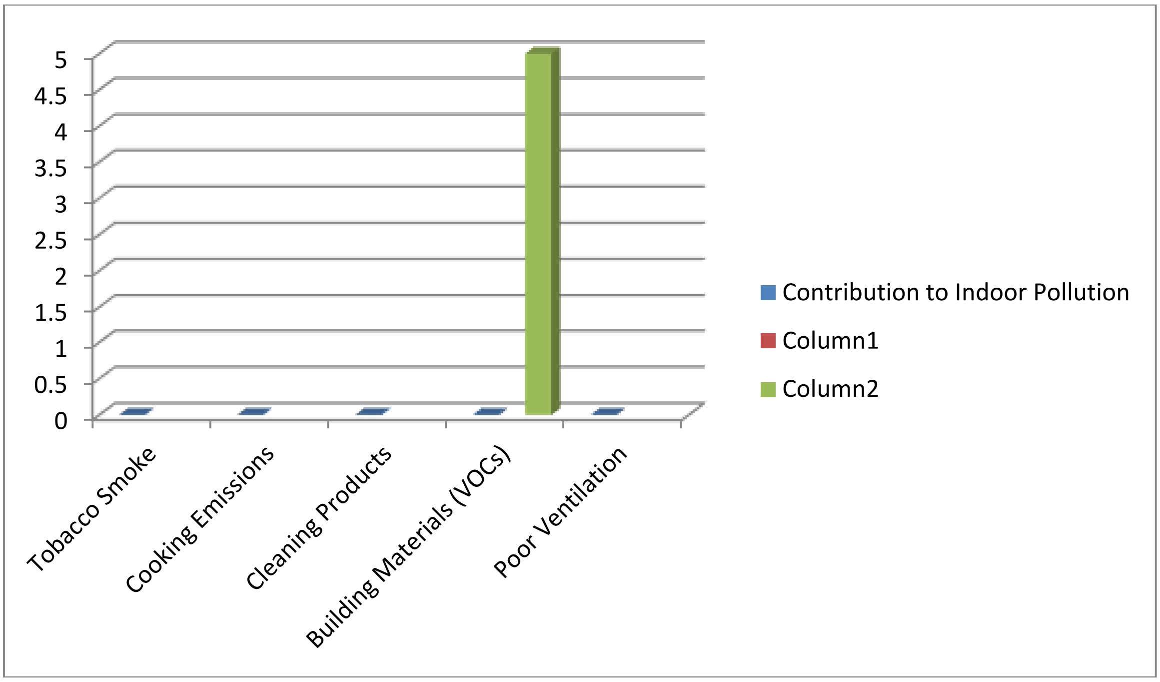

Figure Sources of Indoor Air Pollutants

Figure 4 showcases the contribution of different sources to indoor air pollution. Tobacco Smoke and Poor Ventilation stand out as significant contributors. Cooking Emissions and Cleaning Products have moderate contributions, while Building Materials (VOCs) have a moderate impact as well.

Table 5: Recommended Indoor Air Quality Guidelines

Pollutant	**Maximum Allowable Concentration (μg/m³)**	**Health Guideline**
PM2.5	10	Minimize exposure
VOCs	Varies	Use low-emission products
CO2	9.0	Properly ventilate combustion areas
Mold Spores	Varies	Maintain indoor humidity < 50%
Radon	4.0	Conduct regular radon testing

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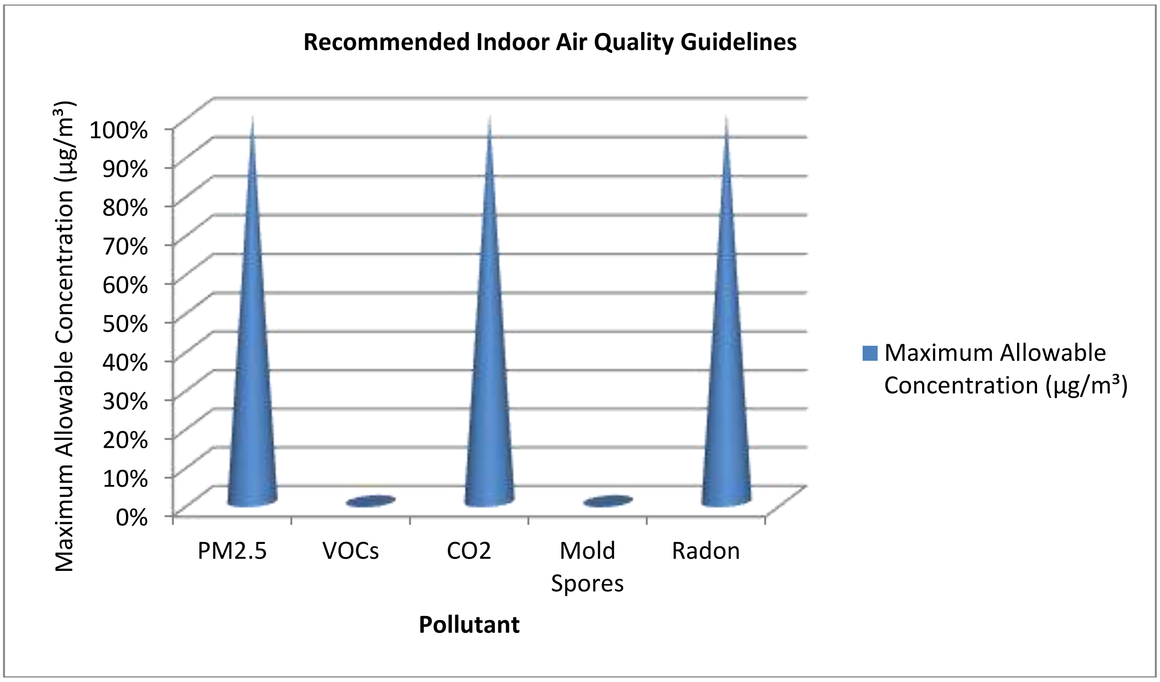

Figure 5: Recommended Indoor Air Quality Guidelines

Figure 5 guides the recommended maximum allowable concentrations of different indoor air pollutants. Radon has the strictest guideline, with a recommended 4 µg/m³ concentration. Particulate Matter (PM2.5) and Carbon Monoxide (CO) also have relatively low recommended concentrations to ensure a safe indoor environment. Volatile Organic Compounds (VOCs) have varying guidelines based on the specific compounds involved.

4. INTERPRETATIONS AND DISCUSSIONS

The necessity for a comprehensive approach to managing indoor air quality (IAQ) is underscored by the interdependence of biological, physical, and economic factors. Innovative ventilation solutions with energy-efficient systems and air purification capabilities offer promising avenues for enhancing indoor air quality (IAQ). Promoting collaborative efforts among biologists, physicists, and economists is of utmost importance in developing comprehensive indoor air quality (IAQ) strategies that successfully integrate advancements in public health with considerations of economic viability. Implementing a comprehensive indoor air quality management strategy requires a holistic methodology, as it is essential to consider the intricate interplay among various biological, physical, and economic elements. The convergence of these dimensions underscores the imperative for innovative solutions that consider the intricate interrelationships among them. Ventilation systems can be engineered to optimize air circulation and integrate filtration mechanisms specifically targeting biological contaminants and pollutants, thereby significantly enhancing indoor air quality (IAQ).

The recognition of collaboration among diverse scientific disciplines is acknowledged as a pivotal factor in the development of innovative strategies for indoor air quality (IAQ). To

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foster the development of simultaneously effective and economically viable solutions, biologists, physicists, and economists must engage in interdisciplinary collaboration, leveraging their respective areas of expertise. Integrating state-of-the-art sensing technologies, advanced data analytics, and materials science in indoor air quality (IAQ) research presents a promising avenue for transformative progress. This collaborative undertaking possesses the capacity to redefine our methodology towards the management of indoor air quality (IAQ), thereby introducing a new era marked by enhanced health and sustainability within indoor settings.

5. CONCLUSIONS

The indoor air quality encompasses diverse factors, including biological, physical, and economic components, which have significant implications for human health. Implementing strategies to mitigate biological contaminants, optimizing the performance of ventilation systems, and making informed investments in enhancing indoor air quality (IAQ) are imperative for promoting healthier indoor environments. The convergence of diverse academic disciplines presents a favorable outlook for fostering innovation and collaboration, thereby enabling solutions that prioritize individual well-being and economic considerations. Integrating biological, physical, and economic principles has the potential to reveal strategies for improving indoor environment health. The imperative of adopting a multidimensional approach to managing indoor air quality (IAQ) is underscored by the interconnections among biological contaminants, ventilation dynamics, and economic factors. Acknowledging the significance and interplay of each factor makes it possible to formulate all-encompassing approaches aimed at optimizing Indoor Air Quality (IAQ), safeguarding human well-being, and fostering sustainable economic progress.

Recommendations

To effectively address challenges about indoor air quality (IAQ), future research endeavors must prioritize advancing ventilation technologies. It is imperative for these technologies to not solely focus on enhancing air exchange rates but also to eliminate pollutants that are present in the indoor environment. Policymakers should consider implementing strategies that incentivize homeowners and building managers to invest in enhancing indoor air quality (IAQ), focusing on highlighting the long-term economic benefits associated with these efforts. Promoting collaboration among researchers in the fields of biology, physics, and economics is crucial to cultivating interdisciplinary innovation in the realm of developing strategies for the management of indoor air quality (IAQ).

In conclusion, comprehensive indoor air quality management necessitates an all-encompassing strategy that acknowledges the various dimensions encompassing biological, physical, and economic elements. By effectively coordinating research efforts, fostering interdisciplinary collaboration, and prioritizing holistic approaches, laying the groundwork for improving indoor environments and advancing overall well-being becomes feasible. To facilitate progress, future research endeavors should prioritize the development of cutting-edge ventilation technologies. It is crucial for these systems to not only comply with energy efficiency standards but also incorporate advanced filtration mechanisms capable of

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effectively capturing both biological agents and pollutants. These technological advancements can significantly augment indoor air quality, resulting in subsequent enhancements in the overall welfare of individuals who inhabit the area.
It is imperative to develop policy interventions that effectively encourage investments in enhancements to indoor air quality (IAQ). The motivation for homeowners, building developers, and businesses to adopt improvements in indoor air quality (IAQ) can be enhanced by highlighting the potential for long-term economic benefits resulting from reduced healthcare expenses and increased productivity. Furthermore, it is crucial to promote collaboration across diverse fields actively, thus creating a favorable atmosphere for interdisciplinary innovation to comprehensively and efficiently tackle challenges related to indoor air quality (IAQ).
In brief, examining the complex realm of indoor air quality (IAQ) reveals the intricate interaction among various biological, physical, and economic elements. As we navigate through this field, it is crucial to recognize that integrating biology, physics, and economics is essential and holds the capacity for significant change. By implementing this all-encompassing strategy, we can pave the way for indoor settings that foster personal welfare and financial success.

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