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AMBIENTE CONSTRUÍDO E USUÁRIO: PERSPECTIVAS LATINO-AMERICANAS

Interrelations between Indoor Environmental Quality and Occupants: A Critical Review

Interrelaciones entre la Calidad del Ambiente Interno y los Ocupantes: Una Revisión Crítica

Inter-relações entre Qualidade do Ambiente Interno e Ocupantes: Uma Revisão Crítica

Conforto Ergonômico e Qualidade Ambiental / *Conforto Ergonómico y Calidad Ambiental /*

Ergonomic Comfort and Environmental Quality

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Resumo

Este artigo revisa as inter-relações entre a Qualidade do Ambiente Interno (QAI) e o bem-estar dos ocupantes, enfocando aspectos como conforto térmico, acústico, visual e qualidade do ar. Através da análise de 28 artigos revisados por pares na base de dados Scopus, a pesquisa identifica como essas variáveis influenciam a saúde e a satisfação dos usuários. Os resultados mostram que ambientes internos inadequados podem levar a problemas como a Síndrome do Edifício Doente e reduzir a produtividade. O estudo ressalta a importância de abordagens integradas que considerem medições objetivas e percepções subjetivas dos ocupantes, especialmente em habitações sociais, onde as condições frequentemente são substandard. A pesquisa contribui para o entendimento das dinâmicas entre QAI e bem-estar, sugerindo direções para futuras investigações e práticas de design que promovam ambientes mais saudáveis.

Palavras-chave: Qualidade do Ambiente Interno. Conforto. Saúde.

Resumen

Este artículo revisa las interrelaciones entre la Calidad del Ambiente Interno (QAI) y el bienestar de los ocupantes, enfocándose en aspectos como el confort térmico, acústico, visual y la calidad del aire. A través del análisis de 28 artículos revisados por pares en la base de datos Scopus, la investigación identifica cómo estas variables influyen en la salud y la satisfacción de los usuarios. Los resultados muestran que ambientes internos inadecuados pueden llevar a problemas como el Síndrome del Edificio Enfermo y reducir la productividad. El estudio resalta la importancia de enfoques integrados que consideren mediciones objetivas y percepciones subjetivas de los ocupantes, especialmente en viviendas sociales, donde las condiciones suelen ser deficientes. La investigación contribuye a la comprensión de las dinámicas entre QAI y bienestar, sugiriendo direcciones para futuras investigaciones y prácticas de diseño que promuevan ambientes más saludables.

Palabras clave: Calidad del Ambiente Interno. Confort. Salud.

Abstract

This article critically reviews the interrelations between Indoor Environmental Quality (IEQ) and occupant well-being, focusing on aspects such as thermal, acoustic, visual comfort, and air quality. Through the analysis of 28 peer-reviewed articles from the Scopus database, the research identifies how these variables influence users' health and satisfaction. The results indicate that inadequate indoor environments can lead to issues such as Sick Building Syndrome and reduce productivity. The study emphasizes the importance of integrated approaches that consider both objective measurements and subjective perceptions of occupants, especially in social housing where conditions are often substandard. This research contributes to understanding the dynamics between IEQ and well-being, suggesting directions for future investigations and design practices that promote healthier environments.

Keywords: Indoor Environmental Quality. Comfort. Health.

Introduction

Internal Environmental Quality (IEQ) significantly affects the health, comfort, and productivity of occupants. With urbanization leading individuals to spend up to 90% of their time indoors (Coulby et al., 2020), IEQ has become a key concern for researchers and building managers. This focus has driven research on the relationship between indoor conditions and human well-being, highlighting the importance of understanding IEQ variables such as thermal comfort, air quality, and acoustic and visual comfort.

Wong et al. (2018) show that poor air quality, thermal discomfort, inadequate lighting, and noise pollution impact occupant satisfaction and are linked to health issues like Sick Building Syndrome (SBS), which includes headaches and respiratory irritations. Indoor air quality is especially critical, as pollutants like CO_2 and VOCs can harm health and reduce productivity. For instance, a 1°C increase above 25°C can decrease work efficiency by up to 2% (Seppanen et al., 2004), making effective IEQ management essential for comfort and organizational performance.

Additionally, poor indoor air quality can lead to annual costs exceeding $100 billion due to absenteeism and related illnesses (Fisk and Rosenfeld, 2011), significantly affecting quality of life and efficiency. Implementing IEQ improvement strategies, such as proper ventilation and temperature control, can provide substantial benefits, reducing illness and enhancing occupant satisfaction and productivity.

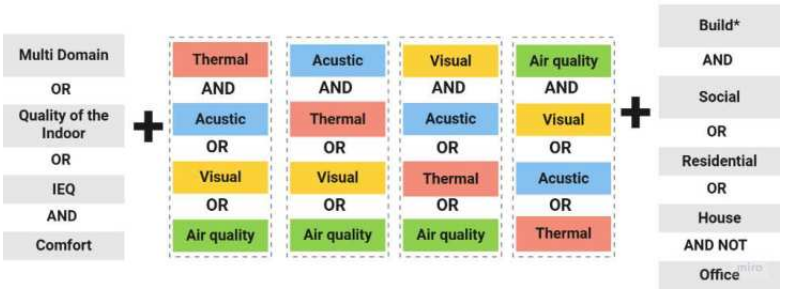
Acoustic and visual comfort, often overlooked, are also vital to occupant experience. Acoustic satisfaction typically ranks lowest in IEQ surveys (Jensen and Arens, 2005), while natural and quality artificial lighting greatly influence psychological and physical well-being. This study aims to explore how existing reviews address the interplay between factors influencing IEQ, occupant behavior, and housing conditions, focusing on their impact on health, satisfaction, and well-being.

Methodology

Articles published in peer-reviewed journals in English up to October 2024 were considered, using the Scopus database for the search. The decision to restrict the research to articles published in English, along with the use of the Scopus platform, is based on the fact that most relevant

publications in the field of Indoor Environmental Quality (IEQ) are conducted in English, which ensures access to a broader and more diverse body of knowledge, reflecting the latest innovations and discoveries. Furthermore, Scopus is recognized for its rigor in including peer-reviewed articles, ensuring that the selected studies meet high standards of quality and credibility. This combination not only facilitates the comparison and integration of data but also promotes a more cohesive and consistent analysis of the results, which is essential for understanding the complex interactions between IEQ and occupant well-being. Keywords and Boolean criteria focused on "Indoor Environmental Quality" (IEQ), "Multi-Domain," and "Comfort," covering thermal, acoustic, visual types, and indoor air quality (Figure 01). This yielded 80 scientific documents, which were screened by citation order, limiting the selection to English-language review articles.

Figure 1: Flowchart of the construction of the search string



The screening involved reading titles, abstracts, and keywords, selecting only those addressing IEQ assessment in thermal, acoustic, and visual comfort, as well as indoor air quality. Review articles unrelated to the topic and duplicates were excluded, resulting in 28 review articles.

Figure 2: Dimensions considered in the screening of review articles



The articles were categorized into research dimensions, including occupants, simulation, regulations, technologies, energy efficiency, and consumption, with seven articles in the occupant dimension and four in others (Figure 02). This state-of-the-art review focuses on the occupant dimension to deepen the understanding of the relationship between IEQ, environmental comfort, and air quality.

The journal Building and Environment leads with three publications on the topic (Zhao and Li, 2023; Diaz Lozano Patino and Siegel, 2018; Wong, Mui, and Tsang, 2018). Other notable journals include the Journal of Engineering, Design and Technology (Mewomo et al., 2023), the International Journal of Environmental Research and Public Health (Coulby et al., 2020), Energies (Šujanová et al., 2019), and Facilities (Asadi, Mahyuddin, and Shafigh, 2017).

The first two review articles explore factors influencing IEQ and occupant satisfaction: "What are the critical factors affecting indoor environmental quality (IEQ) and how do their interactions influence occupant health, productivity, and satisfaction?" (Zhao and Li, 2023; Mewomo et al., 2023). Coulby et al. (2020) and Wong, Mui, and Tsang (2018) focus on IEQ monitoring and occupant well-being, addressing the question: "How do monitoring technologies and acceptance models contribute to the assessment of IEQ and occupant well-being?" To investigate sustainable strategies and IEQ, Šujanová et al. (2019) and Asadi, Mahyuddin, and Shafigh (2017) ask: "In what ways do sustainable architectural strategies and occupant behavior impact IEQ and user health?" Finally, Diaz Lozano Patino and Siegel (2018) examine the relationship between IEQ and social housing, questioning: "Is there evidence that IEQ in social housing is worse than in non-social housing, and how does this correlate with health outcomes?"

This article aims to understand how existing reviews address the interrelationship between factors influencing IEQ, occupant behavior, and housing conditions, focusing on their impact on health.

Thermal Comfort

The definition of thermal comfort refers to the mental condition that expresses satisfaction with the thermal environment (ASHRAE, 2021; Kapoor et al., 2021). It can be understood as the subjective mental state concerning the thermohygrometric conditions of the air as well as the air movement in the environment (speed and direction), typically assessed subjectively, depending on the thermal acclimatization of the residents. This acclimatization can also be affected by factors such as the time of year, geographical location, climate, gender, age, and race (Quang et al., 2014).

Asadi et al. (2017) state that temperature complaints are the most common among occupants of commercial buildings, while Diaz and Siegel (2018) highlight that thermal comfort is the most important parameter perceived by residents of social housing. Moreover, thermal comfort has a direct influence on occupant productivity (Alhorr et al., 2016; Li et al., 2011). It is noteworthy that when analyzing thermal comfort in relation to occupant exposure in housing, particularly in social housing, there are few studies, and no study directly compares IEQ in social housing (Diaz and Siegel, 2018), thus revealing a research gap.

The assessment of thermal comfort in indoor environments is governed by a series of parameters that, when measured correctly, can provide a more accurate understanding of the conditions affecting occupant satisfaction. According to Asadi et al. (2014), Mewomo et al. (2023), Diaz and Siegel (2018), and Zhang, Mui, and Wong (2023), the environmental parameters influencing occupant perception include air temperature (°C), air velocity (m/s), mean radiant temperature (°C), and relative humidity (%), while metabolic rate (Met) and clothing (clo) are two personal parameters of the occupants. Environmental parameters can be directly measured using sensors, while personal parameters can be quantified, albeit indirectly, as they depend on observation or the application of questionnaires, making this assessment subjective (Asadi, Mahyuddin, and Shafigh, 2017). In addition to these variables, Nicol and Humphreys identified three contextual variables that influence thermal comfort perception: climate, the nature of the building, and the time during which changes occur that occupants must adapt to.

According to Sujanová et al. (2019), standards and regulations such as ASHRAE Standard 55 (2021), ISO 17772, and EN ISO 7730 (2005) establish methods for measuring and evaluating thermal environments, as well as providing calculation tools that allow for predicting overall occupant satisfaction with indoor thermal conditions. The methods commonly used to quantify occupant satisfaction regarding these environments are the predicted mean vote (PMV) and the predicted percentage of dissatisfied (PPD) (Sujanová et al., 2019; Asadi, Mahyuddin, and Shafigh, 2017; Zhang, Mui, and Wong, 2023). The PMV consists of a thermal principle based on heat transfer in a steady state occurring between the occupant's body and the environment. The PPD refers to the predicted percentage of dissatisfied individuals at each PMV (Fanger, 1970). However, the PMV and PPD indices have limitations in air-conditioned environments.

Furthermore, the measured parameters not only influence comfort perception but also have direct implications for occupant health. Studies indicate that environments that do not meet thermal comfort standards can lead to an increase in complaints related to Sick Building Syndrome (SBS), as well as respiratory problems and other health conditions (Diaz and Siegel, 2018). This is corroborated by Mewomo et al. (2023), who state that thermal comfort is directly related to occupant productivity, indicating that thermally comfortable environments promote not only well-being but also work efficiency. Therefore, the integration of rigorous standards and effective assessment methods is essential to ensure healthy and comfortable indoor environments.

Occupant health is profoundly influenced by the quality of the thermal environment. The review by Mewomo et al. (2023) highlights that exposure to inadequate thermal conditions, such as overheating or undercooling, can result in a range of health issues, including respiratory diseases and increased fatigue. Residents of social housing, as discussed by Diaz and Siegel (2018), often face lower IEQ conditions, with a higher likelihood of exposure to indoor pollutants and thermal discomfort. This not only compromises physical health but also impacts psychological well-being, as dissatisfaction with the built environment can lead to elevated stress levels and emotional discomfort.

Moreover, Šujanová et al. (2019) note that the relationship between indoor temperature and performance is critical in indoor environments, where inadequate temperatures can result in decreased productivity and increased errors. Rising indoor temperatures have been associated with a higher incidence of health complaints, such as headaches and eye irritation, highlighting the need for stricter control of internal environmental conditions. Therefore, the interrelationship between thermal comfort, health, and occupant productivity reinforces the importance of careful planning and the implementation of effective solutions to improve IEQ.

Finally, thermal comfort is a crucial element of indoor environmental quality, with direct impacts on the health and productivity of occupants. The literature emphasizes the complexity of the factors influencing this perception, and although standards exist for its assessment, there remains a significant research gap, particularly in social housing or informal dwellings. Integrated approaches that consider the interactions between thermal comfort and other aspects of the

indoor environment are essential for developing effective solutions that promote healthy and comfortable environments.

Acoustic Comfort

Acoustic comfort, defined as contentment with the sound environment (Mewomo et al., 2023; Mujan et al., 2019), involves complex sound perception influenced by intensity, context, and individual factors like age and emotional state (Šujanová et al., 2019). The human hearing range is 20 Hz to 20 kHz, with sensitivity decreasing with age; sound pressure levels can range from 10^{-5} Pa to 100 Pa, where 0 dB is the threshold of hearing and 130 dB is the threshold of pain.

The quality of the sound environment depends on both the sound's physical properties and those of the surrounding space (Wang et al., 2021). Loud sounds (e.g., 130 dB) can cause deafness, while prolonged exposure to levels above 85 dB can lead to hearing loss. Lower sound levels can also negatively impact health, making good acoustic comfort essential to avoid discomfort (AlHorr et al., 2016).

Noise is a significant contributor to discomfort in naturally ventilated buildings, highlighting the need for effective noise control. Mewomo et al. (2023) note that factors like sound insulation, absorption, and reverberation time influence the acoustic environment, with unwanted sounds originating from various sources (Dascalaki et al., 2009; Salonen et al., 2013; AlHorr et al., 2016). A noisy environment can lead to stress and health issues, decreasing productivity and job satisfaction (Lee et al., 2015; Mark and Wang, 2015; Kim and De Dear, 2012).

Objective measures like sound pressure level (SPL) are essential for assessing acoustic conditions (Zhang, Mui, and Wong, 2023). Other indicators include reverberation time and speech intelligibility metrics. However, these may not reflect occupants' subjective perceptions, which vary based on auditory sensitivity and personal experiences (Coulby et al., 2020).

In conclusion, analyzing acoustic comfort reveals its complexity and significance for occupant well-being. Sound perception is shaped by both objective factors (sound intensity and frequency) and subjective experiences. Although objective metrics exist, they often fail to capture individual perceptions, underscoring the need for integrated approaches that consider both technical

measurements and occupant feedback. Understanding the interplay between physical space characteristics and human responses to sound remains a challenge for building designers.

Visual Comfort

Visual comfort is a subjective condition of visual well-being influenced by the luminous environment (Šujanová et al., 2019; Frontczak and Wargocki, 2011). It encompasses light intensity, illumination uniformity, light color, and glare. Mewomo et al. (2023) highlight that visual comfort is affected by physical properties like luminance distribution and natural light availability, underscoring the importance of daylight for occupants' psychological well-being. While assessments of visual quality often rely on objective indicators like illuminance (Zhang, Mui, and Wong, 2023), subjective indicators such as glare perception are also important.

The definition of visual comfort includes a psychological dimension, yet many physical properties are used for its objective evaluation (Mannan and Al-Ghamdi, 2021). Visual parameters include luminance distribution, illuminance, glare, and natural light (Mewomo et al., 2023). Literature categorizes visual comfort into aspects like lighting distribution, illumination level, and climatic factors affecting the visual experience (Mewomo et al., 2023).

Daylight is essential for human metabolism and mental activities (Van Duijnhoven et al., 2019). As the ideal indoor lighting source, natural light enhances visual comfort without impairing vision, contributing to psychological health (Mewomo et al., 2023). Increasing natural light in building design reduces environmental impact and improves user well-being. Šujanová et al. (2019) show that inadequate lighting can disrupt biological rhythms and affect occupant performance and health.

A well-designed lighting system should ensure safety and visual comfort while facilitating color perception. Monitoring parameters like illuminance and glare is crucial, with an emphasis on daylight for psychological well-being (Šujanová et al., 2019). The type of artificial lighting impacts energy consumption and resident comfort (Kang et al., 2017), as poorly planned lighting can cause discomfort (Galasiu and Veitch, 2006). Activities performed in spaces also influence satisfaction with indoor lighting (Jennings et al., 2000; Yamakawa et al., 2000).

Visual comfort involves a complex interaction between physical and psychological factors, promoting healthy and productive environments. Integrating natural light and carefully considering artificial lighting are essential for achieving adequate visual comfort, positively impacting user health and well-being. Therefore, assessing visual comfort should be part of indoor environmental quality (IEQ) metrics, considering both quantitative and qualitative aspects that affect user experience.

Indoor Air Quality

Indoor air quality (IAQ) is directly related to discomfort caused by odors and sensory irritations, being considered satisfactory in the absence of harmful contaminants (Mannan and Al-Ghamdi, 2021). According to ASHRAE 62.1 (2022), the ventilation rate must be adequate to ensure comfort for at least 80% of the occupants. Mewomo et al. (2023) identify several factors that influence IAQ, such as ventilation, temperature, humidity, building characteristics, and pollutants like dust, chemicals, and human activities. Poor air quality can significantly impact health and productivity, resulting in symptoms such as fatigue, headaches, and respiratory problems (Alhorr et al., 2016; Mujan et al., 2019).

The most common pollutants in indoor environments include CO_2, particulate matter up to 2.5 µm (PM2.5), formaldehyde (HCHO), nitrogen dioxide (NO_2), and mold. CO_2 is often monitored due to its impact on health and productivity. The World Health Organization (WHO) recommends that indoor CO_2 levels do not exceed 1,000 ppm to ensure the comfort and health of occupants. Although concentrations below 10,000 ppm generally do not cause adverse effects, levels above 1,000 ppm can impair cognitive function and user comfort (Coulby et al., 2020).

PM2.5, which refers to fine particles with a diameter of less than 2.5 micrometers, is the most frequently reported pollutant after CO_2 (Diaz and Siegel, 2018). These particles can originate from various sources, such as dust and vehicle emissions, and have the ability to penetrate deeply into the lungs, causing significant health problems. Logue et al. (2018) highlight that PM2.5 has the greatest chronic health impact among common residential pollutants. Furthermore, studies reveal that PM2.5 concentrations can be alarmingly high in social housing areas, underscoring the need for effective policies to reduce this pollutant.

Formaldehyde (HCHO) is recognized as one of the most common indoor pollutants, widely used in industry and present in cleaning products. Investigations indicate that HCHO concentrations in social housing vary but tend to be lower than those found in residences in some Canadian cities (Colton et al., 2018). The presence of smokers and the age of buildings can influence these concentrations, emphasizing the importance of monitoring and controlling HCHO to ensure occupant health.

NO_2, a gas primarily generated by the combustion of fossil fuels, is frequently found in social housing and is associated with health problems. Studies show that air exchange rates in low-income housing are directly related to NO_2 concentrations, especially during the heating season (Zota et al., 2018). Interventions in housing design, such as additional ventilation, can help reduce these levels.

Finally, mold is a significant contaminant, especially in social housing, often associated with moisture problems. Although the literature recognizes the negative health effects of mold, the relationship between fungal growth and health outcomes still needs to be better understood (Brugge et al., 2018). Studies show that the presence of mold and moisture should be monitored, as fungal spores can trigger allergic reactions and exacerbate respiratory issues. Proper management of air quality, including the reduction of pollutants such as CO_2, PM2.5, HCHO, NO_2, and mold, is essential to promote healthy and comfortable indoor environments, reflecting the importance of considering these factors in the analysis of indoor environmental quality.

Discussions

Thermal comfort is a key factor in occupant satisfaction, with literature indicating that its perception is subjective and varies based on acclimatization, geographical location, and personal characteristics. Inadequate thermal conditions can lead to health complaints and reduced productivity, particularly in social housing, where environments are often substandard. The lack of studies comparing indoor environment quality in social housing reveals a significant research gap, highlighting the need for more integrated approaches.

Acoustic comfort is equally vital for occupant well-being. Noise discomfort can cause stress and health issues, underscoring the importance of effective sound control in buildings. Sound

perception is complex and varies among individuals, necessitating assessments that consider both objective measurements and subjective experiences. Creating satisfactory acoustic environments remains a challenge, requiring a deep understanding of the interplay between physical space characteristics and human responses.

Visual comfort is also crucial, with the review emphasizing the importance of natural light and adequate lighting for psychological well-being. The relationship between physical factors, such as light distribution and glare, and occupants' subjective experiences is essential for promoting visually comfortable environments. Solutions that maximize natural light enhance environmental quality and contribute to user health and productivity.

Finally, indoor air quality (IAQ) is critical for occupant health and satisfaction. Pollutants like CO_2, PM2.5, formaldehyde, and mold are linked to health issues, including respiratory diseases and mental fatigue. The review highlights the interrelationship between housing conditions, occupant behavior, and air quality, stressing the need for interventions that ensure healthy indoor environments. Table 01 summarizes these discussions.

Table 1: Key Aspects of Indoor Environmental Quality (IEQ): Definitions, Influences, and Relevance

Aspect	Definition	Influence on IEQ	Relevance in IEQ
Thermal Comfort	Subjective condition of satisfaction with the thermal environment, influenced by factors such as acclimatization, temperature, humidity, and air velocity.	Directly impacts health, productivity, and occupant satisfaction. Inadequate environments can lead to Sick Building Syndrome (SBS).	Essential for promoting well-being and work efficiency. There are gaps in research, especially in social housing, that need to be addressed.
Acoustic Comfort	State of contentment with the sound environment, influenced by sound intensity, context, and physical environment characteristics.	Excessive noise causes discomfort and health issues, such as stress and decreased productivity. Evaluation should consider subjective perception.	Fundamental for the well-being, productivity, and mental health of occupants. Creating satisfactory acoustic environments is an ongoing challenge for designers.
Visual Comfort	Subjective condition of visual well-being, influenced by light intensity, uniformity, color, and glare.	Adequate lighting impacts psychological health, biological rhythms, and performance. Natural light is crucial for visual comfort.	Important for healthy and productive environments. Evaluation should include both objective and subjective measures to capture occupant experience.
Indoor Air Quality (IAQ)	Condition of indoor air, free from contaminants and odors, affecting comfort and health.	Concentrations of CO_2, PM2.5, formaldehyde (HCHO), nitrogen dioxide (NO_2), humidity, and presence of mold.	Poor IAQ causes discomfort, respiratory issues, and reduced productivity; proper management improves user health and satisfaction.

Conclusion

The analysis of factors influencing indoor environmental quality (IEQ) reveals the complexity of interactions between thermal, acoustic, visual comfort, and indoor air quality, all essential for occupant well-being and health. This work highlighted the importance of considering the subjective perception of users, which varies according to personal characteristics and specific contexts, especially in social housing, where research gaps are evident. The integration of regulations and more specific approaches is fundamental to ensuring environments that not only meet quality standards but also promote occupant satisfaction and productivity.

Furthermore, the review emphasizes the need for interventions that address not only the physical aspects of the environment but also the subjective experiences of users. Creating healthy indoor environments requires a deep understanding of the interrelationships between different IEQ factors and occupant behavior. Thus, future research should focus on strategies that improve indoor environmental quality, aiming to promote not only physical health but also psychological well-being and overall user satisfaction.

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Agreements

The MORE: Well-being and Low Carbon in Self-Managed Constructions research network, an initiative of HubIC, the University of São Paulo (USP) and the Brazilian Association of Portland Cement (ABCP), for the collaboration in a multidisciplinary network for the development of this research.