A Review of Indoor Environmental Quality (IEQ) Parameters and Their Impact on Occupant Satisfaction in Educational Buildings

ADEFEMI A. LAWAL[1], OLADIPO A. DARE-ABEL[2], Oluwatoyin O. AJAYI[3]
[1,2,3] *Department of Architecture, College of Environmental Science and Management*
Caleb University, Imota, Ikorodu, Lagos, Nigeria

Abstract- - Indoor Environmental Quality (IEQ) is increasingly recognized as a critical determinant of health, satisfaction, and performance in educational buildings. This literature review synthesizes findings from 26 studies conducted across diverse geographic and educational contexts, focusing on four core IEQ parameters: thermal comfort, indoor air quality (IAQ), lighting, and acoustic conditions. The analysis reveals that while each IEQ component individually influences occupant satisfaction, their cumulative and interactive effects are more indicative of overall comfort and well-being. Key themes emerging from the review include the importance of adaptive thermal and ventilation strategies, the value of natural lighting paired with glare control, and the significant role of acoustic quality in cognitive performance, especially among younger learners. Methodologically, the reviewed studies employ a mix of qualitative and quantitative approaches, including field measurements, post-occupancy evaluations, and statistical modeling (e.g., SEM). While technological and design innovations such as green certifications and smart retrofits show promise, the review highlights that such interventions do not always translate into higher occupant satisfaction if not aligned with user needs. The findings underscore the importance of context-specific and user-centric strategies in IEQ planning, especially in educational settings where prolonged exposure, high occupancy, and varying age groups amplify the stakes of environmental quality. This paper concludes by recommending a holistic, evidence-based approach to IEQ management, integrating subjective occupant feedback with objective monitoring, particularly in resource-constrained and climatically diverse regions.

Indexed Terms- - Acoustics, Indoor air quality, Lighting, Occupant satisfaction, Thermal comfort

I. INTRODUCTION

Indoor Environmental Quality (IEQ) plays a crucial role in determining the health, comfort, and productivity of building occupants, particularly in educational settings where students and staff spend a significant portion of their time (Thomas, Clark Burton, Mueller, & Page, 2010). IEQ encompasses several key parameters, including thermal comfort, indoor air quality (IAQ), acoustic performance, and visual comfort (lighting), all of which collectively influence occupant satisfaction and overall well-being (Wang & Zamri, 2013). In educational buildings, poor IEQ has been linked to reduced cognitive performance, increased absenteeism, and lower academic achievement (Radwan & Issa, 2017). As such, understanding the interplay between these IEQ factors and occupant satisfaction is essential for designing and maintaining healthier, more productive learning environments (Almeida, De Freitas & Delgado, 2015). The growing emphasis on sustainable and human-centric building designs has further amplified the need for comprehensive IEQ assessments in schools and universities (Bae, Martin & Asojo, 2021). While previous studies have examined IEQ in office and residential buildings, educational facilities present unique challenges due to high occupant density, varying activity levels, and prolonged exposure periods (Pittana, 2022). Additionally, children and young adults may be more sensitive to environmental conditions than adults, making IEQ optimization even more critical in these settings (Pistore, Pittana, Cappelletti, Romagnoni & Gasparella, 2020).

Despite advancements in building standards and green certification systems (e.g., LEED, WELL, and BREEAM), inconsistencies remain in how IEQ parameters are measured, prioritized, and perceived by occupants. Some studies highlight thermal comfort as the most influential factor (Sirror, Labib, Abowardah, Metwally & Mitchell, 2024), while others emphasize the significance of indoor air quality due to its direct impact on respiratory health (Sadick & Issa, 2018). Furthermore, the subjective nature of occupant satisfaction introduces variability, as individual preferences and adaptive behaviors can mediate responses to environmental conditions (Lee, Mui, Wong, Chan, Lee & Cheung, 2012). This literature review aims to synthesize existing research on IEQ parameters in educational buildings and evaluate their relative impact on occupant satisfaction. In analyzing peer-reviewed studies, industry reports, and benchmarking tools, this paper seeks to:

i. identify the key IEQ factors affecting students and staff in educational environments; and
ii. examine the relationship between objective IEQ measurements and subjective occupant feedback.

The findings of this review will provide valuable insights for architects, facility managers, and policymakers seeking to enhance IEQ in educational buildings while fostering optimal learning and working conditions. Additionally, this study contributes to the broader discourse on sustainable building design by emphasizing the importance of occupant-centric approaches in IEQ management.

II. LITERATURE REVIEW

Indoor Environmental Quality (IEQ) has garnered significant attention over the past two decades, particularly in the context of educational buildings, where the physical learning environment directly affects students' cognitive function, academic performance, health, and overall satisfaction.

A. Thermal Comfort

Thermal comfort is one of the most extensively studied aspects of IEQ. It is typically defined as the condition of mind that expresses satisfaction with the thermal environment (ASHRAE Standard 55, 2017). Several studies (e.g, El Asmar, Chokor & Srour, 2014; Zhang, 2019) have found a strong correlation between thermal comfort and students' productivity and satisfaction. Research suggests that educational buildings often fail to maintain optimal thermal conditions due to poorly designed HVAC systems, outdated infrastructure, or climatic extremes (Arif, Katafygiotou, Mazroei, Kaushik & Elsarrag, 2016). Occupants exposed to thermal discomfort, whether from high temperatures, poor insulation, or inconsistent airflow, tend to report lower levels of satisfaction and concentration (Zhang, 2019). Notably, adaptive comfort models (Roumi, Zhang, Stewart & Santamouris, 2023) have highlighted that expectations and thermal adaptability vary among students depending on geography, cultural background, and clothing habits. These models suggest that occupant satisfaction can be improved not only through mechanical control but also by allowing users to adapt or control their environment.

B. Indoor Air Quality (IAQ)

Indoor air quality is crucial in maintaining a healthy and comfortable indoor environment. Key IAQ indicators include CO_2 levels, ventilation rates, humidity, and the presence of pollutants such as volatile organic compounds (VOCs) and particulate matter (PM). Studies (e.g., Thomas, Clark, Mueller & Page, 2010; Nasir, Musa, Che-Ani, Utaberta, Abdullah & Tawil, 2011) have established that poor IAQ contributes to symptoms like headaches, drowsiness, respiratory issues, and diminished cognitive performance, all of which negatively influence satisfaction and learning outcomes. In educational settings, where classrooms may be densely occupied and ventilation systems are often inadequate, IAQ tends to decline rapidly, especially in naturally ventilated buildings (Radwan & Issa, 2017). Evidence also shows that occupants' perception of air freshness significantly influences their overall satisfaction, often more than measured pollutant concentrations themselves (Bae, Martin & Asojo, 2021).

C. Lighting Quality

Lighting, both natural and artificial, has a profound influence on visual comfort, circadian rhythm, mood, and academic performance. Studies (e.g., Afifi, Kamel & Ezzeldin, 2025) have shown that well-designed lighting systems that provide adequate illumination, glare control, and access to daylight significantly enhance occupant satisfaction and alertness. Daylighting, in particular, has been associated with improved test scores and reduced absenteeism in schools (Pistore, Pittana, Cappelletti, Romagnoni & Gasparella, 2020). However, uncontrolled daylight can lead to glare and overheating, which in turn reduces comfort (Pittana, 2022). The balance between daylight access and artificial lighting remains a critical area in the design of educational spaces (Radwan & Issa, 2017). Moreover, subjective satisfaction with lighting often depends on the level of individual control and visual task requirements (Pistore, Pittana, Cappelletti, Romagnoni & Gasparella, 2020).

D. Acoustic Quality

Acoustic quality, although sometimes overlooked, is vital in learning environments where speech intelligibility and concentration are paramount. Poor acoustics, resulting from high reverberation times, background noise, and inadequate insulation, can impede verbal communication between teachers and students, especially for young children or non-native speakers (Nasir, Musa, Che-Ani, Utaberta, Abdullah & Tawil, 2011). Research by Wang & Zamri (2013) and El Asmar, Chokor & Srour (2014) indicates that noise disruptions in classrooms are strongly associated with student dissatisfaction, stress, and cognitive fatigue. In open-plan or multi-use educational spaces, acoustic design becomes even more critical. The literature also highlights the importance of involving end-users in acoustic evaluations to better align design strategies with actual user needs (Pittana, 2022).

E. Integrated Effects and Trade-offs

While individual IEQ parameters have been widely studied, recent research has begun to explore the interactive and cumulative effects of multiple parameters. For instance, a comfortable temperature may be insufficient if air quality is poor, or effective lighting may be undermined by acoustic distractions. Studies by Sirror, Labib, Abowardah, Metwally & Mitchell (2024) emphasize the need for a holistic approach to IEQ, recognizing that occupant satisfaction is shaped by the dynamic interplay of environmental factors, user expectations, and spatial use patterns. Moreover, the role of individual differences, such as age, gender, health status, and cultural background, has emerged as an important area of inquiry (Bae, Martin & Asojo, 2021). Students' perceived satisfaction often varies significantly, even under identical physical conditions, underscoring the importance of subjective and qualitative assessments alongside objective measurements (Zhang, 2019).

F. Research Gaps and Future Directions

Despite the growing body of evidence on IEQ in educational settings, several gaps remain. Firstly, most studies have focused on higher education institutions, with fewer investigations into primary and secondary school environments. Secondly, there is a lack of longitudinal studies that track satisfaction and performance over time in relation to IEQ changes. Thirdly, many studies are geographically biased toward developed countries with temperate climates, limiting the generalizability of findings to tropical or resource-constrained contexts. Furthermore, emerging technologies such as smart building systems, occupant-centered controls, and post-occupancy evaluation tools offer new opportunities for enhancing IEQ and measuring its effects more accurately. Future research should aim to integrate real-time monitoring with subjective feedback mechanisms to provide more adaptive and personalized indoor environments.

III. METHODOLOGY

This study adopts a systematic literature review approach to identify, analyze, and synthesize existing research on Indoor Environmental Quality (IEQ) parameters and their impact on occupant satisfaction in educational buildings. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which provides structured guidelines for conducting literature reviews. A combination of qualitative synthesis and quantitative mapping was employed to ensure both depth and breadth in the analysis of existing studies. A comprehensive literature search was conducted using Google Scholar. The search covered publications from 2000 to 2024 (1 literature per year) to capture contemporary findings and evolving trends. To ensure relevance and quality, specific inclusion and exclusion criteria as shown in Table 1, were applied.

Table 1: Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Peer-reviewed journal articles, conference papers, technical reports, and high-quality institutional publications.	Studies not focused on educational buildings (e.g., offices, hospitals).
Studies conducted in educational environments (primary, secondary, and tertiary).	Publications lacking empirical evidence (e.g., editorials, opinion pieces).
Research that explicitly investigates at least one IEQ parameter in relation to occupant perception or satisfaction.	Articles not written in English.
Studies using empirical, experimental, or mixed methods.	Duplicates or inaccessible full texts.

A standardized data extraction template was developed to capture essential details from each study, including: Author(s) and year of publication, Country or region of study, Type of educational building, IEQ parameters examined, Methodology used (quantitative, qualitative, mixed methods), Measurement tools and metrics (e.g., surveys, sensors, standards), and Key findings related to occupant satisfaction.

S/N	Author(s) and year of publication	Country of study	Type of educational building	IEQ parameters examined	Method used	Measurement tools and metrics	Key findings related to occupant satisfaction.
1	Efficiency (2000)	United States	K–12 School building	Indoor Air Quality and thermal comfort	Quantitative modeling study	Simulation via DOE-2.1E model; metrics: ventilation rates (cfm/person), CO_2 thresholds, energy cost, thermal comfort parameters (ASHRAE standards)	Increasing ventilation (to improve IAQ/satisfaction) increases energy use; variable air volume (VAV) systems help balance energy and IAQ, enabling better satisfaction at lower energy cost.
2	Eley (2001)	United States	K–12 school buildings	Thermal comfort, indoor air quality and acoustics	Mixed methods	Design guidelines referencing standards (e.g., ASHRAE), software tools (DOE-2, EnergyPlus, Energy-10), daylighting,	High-performance school design improves occupant comfort and satisfaction, thermally

						acoustics criteria, ventilation rates, material selection metrics	comfortable, well-lit, low-noise, good IAQ; leads to increased teacher retention, student performance, health, and reduced liability.
3	Hodgson, Hotchi, Lee, Sullivan & Apte (2002)	United States	K–12 classrooms	Thermal comfort, indoor air quality and acoustics	Mixed-methods	On-site environmental sensors (temperature, humidity, CO_2, VOC monitoring), energy use logging, documentation of HVAC operations; referenced DOE-2/EnergyPlus simulation comparisons	Improved ventilation and low-emitting materials enhanced IAQ and thermal comfort, leading to better occupant satisfaction and energy efficiency
4	Miller (2003)	United States	Elementary schools	Thermal comfort, indoor air quality lighting and acoustics	Mixed methods	On-site sensors for microclimate and air pollutants; continuous light and sound measurements; EPA IEQ survey questionnaires	General improvement in occupant comfort reported post-HVAC retrofit, though results were inconclusive and varied by school. Environmental metrics improved, but satisfaction responses were mixed.
5	Apte, Faulkner, Hodgson & Sullivan (2004)	United States	Elementary/K–12 classrooms	Thermal comfort and acoustic	Quantitative field-based study	Continuous sensors: CO_2, temperature, RH, VOCs, acoustic noise levels, HVAC power consumption; seasonal pollutant sampling; LonWorks® network for remote data collection; follow-up statistical analysis	Improved HVAC system (IHPAC) achieved enhanced ventilation, lower noise, maintained thermal comfort, and likely improved IEQ, suggesting

							positive impacts on occupant satisfaction and energy efficiency.
6	Mysen (2005)	Norway	Primary (elementary) schools	Indoor air quality, thermal comfort and air quality	Mixed methods	CO_2 sensors for demand-controlled ventilation; bag filters for pollutant loading; temperature sensors; occupant surveys on perceived air quality and SBS; energy and climate logging; control strategies including temperature-compensated CO_2 setpoints	Demand-controlled ventilation (DCV) significantly improved IAQ while reducing energy use (~38–51% savings). In cold-climate facade supply school, pupils reported higher satisfaction and fewer SBS symptoms in winter than summer. Temperature-compensated CO_2 controls recommended to boost thermal comfort and perceived air quality with minimal energy penalty
7	NRC (2006)	United States	K–12 schools	Ventilation, Lighting quality and Acoustics	Systematic literature review	report synthesizes external studies; focuses on IEQ characteristics with references to standards (e.g., ASHRAE, ANSI S12.60)	Increased ventilation above ASHRAE minimums likely improves comfort and productivity. Reduced noise levels correlate with improved student achievement, strongest evidence
8	Hreha	United	K–12 schools	Indoor air	Quantitati	In-class CO_2 sensors	Elevated CO_2

	(2007)	States		quality	ve	(ventilation proxy); collection of student standardized test scores; multivariate regression analysis controlling for socio-demographics	(poor ventilation) was significantly associated with lower math test scores (P<0.10). Suggests that improving classroom air quality could enhance academic performance.
9	De Bruin (2008)	South Africa	Public primary/secondary schools	Thermal comfort and lighting	Mixed methods	Temperature sensors, roof/wall U-value simulations, indoor air temp profiling (e.g., comparisons of insulation materials).	Concluded that passive energy interventions (roof/wall insulation, shading, ventilation design) led to improved thermal comfort, and deduced occupant comfort improvements.
10	Ali, Almomani & Hindeih (2009)	Jordan	Public school buildings	Indoor air quality, thermal comfort and acoustics	Mixed methods	Semiconductor multi-channel data loggers (temp, RH, CO_2, noise), Gas meters, airflow meters, Building physical inspection (openings, orientation, mass), Questionnaires & interviews, Review of student medical records	Significant IEQ variation across school designs and locations. Passive design (site selection, planning, natural ventilation) improves IEQ. Improved environmental quality led to enhanced occupant comfort and satisfaction
11	Thomas, Clark, Mueller & Page (2010)	United States	High school	Indoor air quality and visual contrast sensitivity	Mixed methods	F.A.C.T. handheld chart for VCS testing, Questionnaire for symptoms, IEQ monitors (CO_2, temperature, RH), Air/mold sampling	Employees at mold-damaged school reported significantly higher rates of respiratory, systemic, and neurobehavioral

						(culturable, spore traps, MSQPCR)	symptoms and lower VCS scores compared to control. Elevated CO_2 and mold levels confirmed environmental hazard. While not direct satisfaction, these issues reflect poor occupant well-being and environmental discomfort.
12	Nasir, Musa, Che-Ani, Utaberta, Abdullah & Tawil (2011)	Malaysia	University architecture studio	Thermal comfort, indoor air quality, lighting levels, acoustics and ergonomic layout	Mixed methods	Multi-channel data loggers (temperature, CO_2, light, sound levels); structured questionnaires on perceived comfort and satisfaction	Among IEQ parameters, thermal comfort and CO_2 levels were primary contributors to perceived comfort. Lighting and acoustics followed, while ergonomic layout drove satisfaction in studio settings.
13	Lee, Mui, Wong, Chan, Lee & Cheung (2012)	Hong Kong	University teaching rooms	Thermal comfort, Indoor air quality, Acoustic environment and Visual environment	Mixed methods	Environmental sensors for air temp, RH, air speed, MRT, CO_2, sound level, light, Observations on occupant activity & clothing insulation, Surveys on perceived IEQ and learning performance metrics	IEQ satisfaction votes strongly associated with measured parameters. Acoustic (aural) environment identified as the most significant single factor affecting learning performance. Thermal comfort, air quality, and

							visual comfort also important, but less critical than acoustic. Learning performance loss correlates with number of IEQ complaints; empirical expressions were proposed to quantify such losses.
14	Wang & Zamri (2013)	Australia	University green building	Thermal quality, indoor air quality (IAQ), acoustic quality and room/space layout	Mixed methods	Structured online questionnaire (non-probability sampling); correlation and multiple regression analyses; no physical sensors mentioned	High overall satisfaction with IEQ, except for IAQ and room layout. Thermal, acoustic, and spatial layout availability were the strongest predictors of perceived study/work performance. Demonstrated significant positive correlations between IEQ satisfaction and occupant performance.
15	El Asmar, Chokor & Srour (2014)	United States and Lebanon	Higher education facilities	Thermal comfort, indoor air quality, lighting level and acoustic quality	Quantitative	Self-administered survey completed by 320 occupants (Likert-scale ratings across IEQ dimensions)	Average IEQ satisfaction differed by ~17% between campuses; specific strengths/weaknesses in layout, maintenance, lighting, cleanliness, and air quality influenced

							overall satisfaction
16	Almeida, De Freitas & Delgado (2015)	Portugal	Existing school buildings undergoing rehabilitation	Thermal performance and IAQ implications	Mixed methods	Simulation models, enclosure performance data (U-values, thermal transmittance), design analysis	Optimized enclosure improved thermal comfort and energy efficiency; implied occupant comfort benefits but subjective satisfaction not directly measured.
17	Arif, Katafygiotou, Mazroei, Kaushik & Elsarrag (2016)	Global literature	Built environment	Thermal comfort, IAQ, visual (lighting) and acoustic comfort	Systematic literature review	Survey of literature; no direct primary data collection	IEQ factors directly influence well-being and comfort; interactions among parameters complicate design; holistic strategies recommended.
18	Radwan & Issa (2017)	Canada	K–12 school buildings	Thermal comfort, indoor air quality, lighting quality, and acoustics	Mixed methods	Sensors for temperature, relative humidity, CO_2, lighting, and noise; field observation forms; teacher surveys on IEQ satisfaction and well-being	New schools (both green and non-green) showed better thermal comfort and IAQ versus the older school. Teachers in new schools reported higher satisfaction with overall IEQ, lighting, and IAQ compared to the middle-aged school. While green school classrooms had significantly better relative humidity control, overall satisfaction was

							comparable across new schools
19	Sadick & Issa (2018)	Canada	K–12 schools: new, renovated, and non-renovated buildings	Thermal comfort, lighting, air quality and acoustic	Quantitative–survey	Adapted IEQ satisfaction survey; developed psychological, social, and physical well-being surveys; Likert scales	Teachers in new and renovated schools showed significantly higher IEQ satisfaction than those in non-renovated schools. Ventilation/ thermal comfort had strongest impact on physical well-being.
20	Zhang (2019)	China	University libraries	Lighting, thermal comfort, air quality and acoustics	Quantitative post-occupancy evaluation	556 validated face-to-face questionnaires; latent variables for ID, IEQ, satisfaction, and performance; SEM used to assess mediator effects	Occupant satisfaction fully mediates the relationship between interior design/IEQ and performance. Interior design and IEQ directly and positively influence satisfaction, which in turn strongly enhances performance. Reinforces that improving satisfaction should be the primary strategy when aiming to boost occupant performance.
21	Pistore, Pittana, Cappelletti, Romagnoni &	Italy	Educational building (school)	Thermal comfort, air quality, lighting and	Quantitative survey-based case study	Structured occupant questionnaires; environmental perception scales	Subjective responses used to evaluate IEQ; analysis provided insights into occupant comfort

	Gasparella (2020)			acoustics			levels and highlighted parameter categories requiring improvement.
22	Bae, Martin & Asojo (2021)	USA	Higher education classrooms	Thermal comfort, IAQ, lighting and acoustics	Quantitative post-occupancy evaluation	Self-administered student surveys over 9 years (n=3,140); Likert scales; Mann–Whitney U tests; logistic regression	Highest satisfaction: cleaning, IAQ, electric lighting; lowest: outlet access, daylighting. Gender differences found; electric lighting was the strongest predictor of overall classroom satisfaction
23	Pittana (2022)	Italy	School buildings	Thermal comfort, indoor air quality, acoustic comfort, visual comfort	Mixed methods	Environmental sensors (temperature, humidity, CO_2, sound, light); validated multi-domain comfort questionnaire; energy model calibrated via optimization-based approach	Demonstrated strong correlations between perceived comfort and measured environmental conditions, both within individual IEQ domains and across domains.
24	Roumi, Zhang, Stewart & Santamouris (2023)	Australia	Educational building	Thermal comfort, IAQ, lighting and acoustics	Quantitative	Developed a weighting model balancing occupant satisfaction against energy use; identified that thermal comfort and air quality receive higher weightings from users, suggesting priority areas for sustainable designs	Using Kano model, IEQ factors classified as: basic, performance, bonus. (i) Basic: acoustic environment, lighting, privacy, cleanliness (ii) Performance: thermal quality, IAQ, furnishings, space, personal

							control (iii) Bonus: window view
25	Sirror, Labib, Abowardah, Metwally & Mitchell (2024)	Saudi Arabia (Riyadh)	Higher education building	Thermal comfort, IAQ, lighting and acoustics	Mixed methods	Survey results used to benchmark occupant satisfaction in a hot-dry climate; findings support sustainable workplace IEQ interventions	Likely findings indicate that sustainability-focused IEQ upgrades in arid climates improve occupant comfort and reduce complaints. Offers preliminary benchmark on EE vs IEQ in a region with severe thermal challenges.
26	Afifi, Kamel & Ezzeldin (2025)	Egypt (Nasr City, Cairo)	Elementary school classrooms	Thermal comfort, IAQ, acoustical comfort	Quantitative	Generally positive feedback on ventilation and lighting; proximity to windows improved focus; issues identified with seasonal temperature shifts, street/playground noise, and occasional air freshness concerns	Most students were satisfied with ventilation and daylight; those near windows experienced higher focus. Complaints arose during temperature extremes (heat), traffic/playground noise, and occasional stuffiness. Demonstrates that natural ventilation can be satisfactory, but requires noise and thermal strategies in dense, hot urban contexts

CONCLUSION AND RECOMMENDATIONS

This review has systematically examined the interplay between Indoor Environmental Quality (IEQ) parameters and occupant satisfaction within educational buildings, drawing from a diverse range of international studies. The findings affirm that thermal comfort, indoor air quality (IAQ), lighting (both natural and artificial), and acoustic conditions are pivotal determinants of perceived comfort and performance among building occupants, students, teachers, and administrative staff alike. Across different educational contexts, from K–12 schools to higher education institutions, evidence consistently shows that well-regulated environmental conditions positively influence occupants' cognitive function, satisfaction, health, and academic performance. However, this review also highlights several recurring challenges. Some retrofitted or green-certified buildings failed to yield proportionate increases in satisfaction levels, pointing to the disconnect that can occur when IEQ interventions are applied without thorough occupant-centered evaluations. Moreover, cultural, climatic, and operational differences across regions (such as Cairo, Riyadh, or Manitoba) influence how occupants perceive comfort, suggesting that IEQ strategies must be contextually grounded. Based on the cumulative evidence, the following recommendations are made:

i. Holistic Design and Retrofit Planning: IEQ strategies should be integrated at the design phase or during retrofitting, ensuring that thermal comfort, acoustics, lighting, and air quality are balanced simultaneously rather than prioritized in isolation. Post-occupancy evaluations should be incorporated into these processes to inform decision-making and close the gap between technical performance and user experience.
ii. Occupant-Centered Assessments: Educational institutions should adopt validated, multi-domain survey tools (e.g., CBE IEQ surveys or those adapted from Pittana, 2022) to regularly assess student and staff satisfaction. These instruments should complement physical measurements to capture the nuanced interplay between perception and environmental performance.
iii. Localized Standards and Adaptive Comfort Models: IEQ benchmarks should be adapted to reflect regional climate conditions and cultural comfort norms. For example, naturally ventilated classrooms in hot arid regions like Cairo (Afifi et al., 2025) may require different thresholds than air-conditioned university offices in the UAE (Kim et al., 2022).
iv. Evidence-Based Investment in IEQ: Policy-makers and school administrators should prioritize interventions with proven links to satisfaction and performance, such as improved ventilation (Hreha, 2007; NRC, 2006), acoustic design (Roumi et al., 2023), and daylight integration (Zhang, 2019). Limited resources should be directed toward areas that offer the greatest educational and well-being returns.

v. Further Longitudinal and Causal Research: Although correlations between IEQ and occupant satisfaction are well-documented, longitudinal and experimental studies remain limited. Future research should aim to establish causal relationships, particularly in underrepresented regions such as sub-Saharan Africa and Latin America, where climatic and infrastructural conditions differ markedly from those in Western contexts.

In conclusion, creating truly comfortable, healthy, and productive educational environments requires a dynamic, evidence-informed approach to indoor environmental quality—one that aligns technical standards with human-centered outcomes. By synthesizing lessons from global case studies, this review provides a foundation for more responsive and resilient educational facility design.

REFERENCES

[1] Afifi, S., Kamel, T., & Ezzeldin, S. (2025). Indoor environmental quality assessment of naturally-ventilated school classrooms within a dense arid urban setting of Cairo, Egypt. *Scientific Reports*, *15*(1), 1-20.

[2] Ali, H. H., Almomani, H. M., & Hindeih, M. (2009). Evaluating indoor environmental quality of public school buildings in Jordan. *Indoor and Built Environment*, *18*(1), 66-76.

[3] Almeida, R. M., De Freitas, V. P., & Delgado, J. M. (2015). *School buildings rehabilitation: indoor environmental quality and enclosure*

optimization (pp. 35-83). Basel, Switzerland: Springer International Publishing.
[4] Apte, M. G., Faulkner, D., Hodgson, A. T., & Sullivan, D. P. (2004). Classroom HVAC: Improving Ventilation and Saving Energy.
[5] Arif, M., Katafygiotou, M., Mazroei, A., Kaushik, A., & Elsarrag, E. (2016). Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *International Journal of Sustainable Built Environment*, *5*(1), 1-11.
[6] Bae, S., Martin, C. S., & Asojo, A. O. (2021). Higher education students' indoor environmental quality satisfaction benchmark. *Building Research & Information*, *49*(6), 679-694.
[7] De Bruin, L. (2008). *Effectiveness of Passive Energy Interventions in Improving Physical Learning Environments in South African Schools*. University of Johannesburg (South Africa).
[8] Efficiency, E. (2000). Energy Cost and IAQ Performance of Ventilation Systems and Controls. Energy.
[9] El Asmar, M., Chokor, A., & Srour, I. (2014). Are building occupants satisfied with indoor environmental quality of higher education facilities?. *Energy procedia*, *50*, 751-760.
[10] Eley, C. (2001). High Performance Schools Best Practices Manual. Volume I: Planning [and] Volume II: Design [and] Volume III: Criteria.
[11] Hodgson, A. T., Hotchi, T., Lee, S. M., Sullivan, D. P., & Apte, M. G. (2002). Final Methodology for a Field Study of Indoor Environmental Quality and Energy Efficiency in.
[12] Hreha, D. M. (2007). The influence of indoor air quality (IAQ) on student test performance.
[13] Lee, M. C., Mui, K. W., Wong, L. T., Chan, W. Y., Lee, E. W. M., & Cheung, C. T. (2012). Student learning performance and indoor environmental quality (IEQ) in air-conditioned university teaching rooms. *Building and Environment*, *49*, 238-244.
[14] Miller, A. (2003). Qualitative measurements of occupant comfort in five US schools.
[15] Mysen, M. (2005). Ventilation systems and their impact on indoor climate and energy use in schools: studies of air filters and ventilation control.
[16] Nasir, A. R. M., Musa, A. R., Che-Ani, A. I., Utaberta, N., Abdullah, N. A. G., & Tawil, N. M. (2011). Identification of indoor environmental quality (IEQ) parameter in creating conducive learning environment for architecture studio. *Procedia Engineering*, *20*, 354-362.
[17] National Research Council, Division on Engineering, Physical Sciences, Board on Infrastructure, the Constructed Environment, Committee to Review, ... & Productivity Benefits of Green Schools. (2006). *Review and assessment of the health and productivity benefits of green schools: An interim report*. National Academies Press.
[18] Pistore, L., Pittana, I., Cappelletti, F., Romagnoni, P., & Gasparella, A. (2020). Analysis of subjective responses for the evaluation of the indoor environmental quality of an educational building. *Science and Technology for the Built Environment*, *26*(2), 195-209.
[19] Pittana, I. (2022). The Indoor Environmental Quality (IEQ) and comfort in educational buildings.
[20] Radwan, A., & Issa, M. H. (2017). An evaluation of indoor environmental quality and occupant well-being in Manitoba school buildings. *Journal of Green Building*, *12*(1), 123-141.
[21] Roumi, S., Zhang, F., Stewart, R. A., & Santamouris, M. (2023). Weighting of indoor environment quality parameters for occupant satisfaction and energy efficiency. *Building and Environment*, *228*, 109898.
[22] Sadick, A. M., & Issa, M. H. (2018). Differences in teachers' satisfaction with indoor environmental quality and their well-being in new, renovated and non-renovated schools. *Indoor and Built Environment*, *27*(9), 1272-1286.
[23] Sirror, H., Labib, W., Abowardah, E., Metwally, W., & Mitchell, C. (2024). Sustainability in the Workplace: Evaluating Indoor Environmental

Quality of a Higher Education Building in Riyadh. *Buildings*, *14*(7), 2115.

[24] Thomas, G., Clark Burton, N., Mueller, C. A., & Page, E. H. (2010). Comparison of Mold Exposures, Work-related Symptoms, and Visual Contrast Sensitivity between Employees at a Severely Water-damaged School and Employees at a School without Significant Water Damage [Alcee Fortier Senior High School; New Orleans, Louisiana].

[25] Wang, C. C., & Zamri, M. A. (2013). Effect of IEQ on occupant satisfaction and study/work performance in a green educational building: a case study. In *ICCREM 2013: Construction and Operation in the Context of Sustainability* (pp. 234-246).

[26] Zhang, Z. (2019). The effect of library indoor environments on occupant satisfaction and performance in Chinese universities using SEMs. *Building and Environment*, *150*, 322-329.