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Developing a Health-Oriented Assessment Framework for Office Interior Renovation: Addressing Gaps in Green Building Certification Systems

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Abstract

The increasing frequency of interior renovation and fit-out in office buildings raises concerns about indoor environmental quality, occupant health, and sustainability performance, yet existing certification systems remain largely design-stage or whole-building oriented and provide limited guidance for recurring renovation cycles. This study develops a health-oriented assessment framework for office interior renovation as a structured decision-support tool for practitioners and policymakers. We adopted an integrated approach combining a targeted literature review, expert consultation, the Fuzzy Delphi Method (FDM) for indicator screening, and the Analytic Hierarchy Process (AHP) for hierarchical weighting, based on an expert panel of 20 professionals spanning green building certification, architecture/interior design, MEP engineering, property/facility management, and energy/environmental consulting. Through consensus screening and weighting, four assessment dimensions and eighteen key indicators were identified and prioritized. Environmental quality was ranked highest (39.2%), followed by safety management (23.0%), functional usability (21.1%), and resource efficiency and circularity (16.7%). At the indicator level, indoor air quality management, Heating, Ventilation and Air Conditioning (HVAC) energy efficiency, space-friendly layout, preliminary assessment and planning, and thermal comfort emerged as the top priorities. Overall, the framework bridges the gap between certification-oriented evaluation and the operational realities of office renovation, enabling more consistent integration of health and sustainability considerations across renovation decision-making.

Keywords: green building certification; office interior renovation; health-oriented assessment; post-occupancy renovation; Fuzzy Delphi Method (FDM); Analytic Hierarchy Process (AHP)

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1. Introduction

Office buildings represent one of the most renovation-intensive building types in contemporary urban environments [1–4]. Unlike residential or industrial buildings, commercial office spaces frequently undergo interior renovation and fit-out to accommodate organizational restructuring, technological upgrades, changes in tenant requirements, and evolving workplace strategies [5–8]. Service-life-based asset management studies indicate that interior building components generally require renewal within relatively short time horizons, often within a single decade, due to functional deterioration and changing

operational requirements [9]. In many metropolitan areas, office interiors are renovated on a five- to ten-year cycle [10,11], and in some cases even more frequently. This pattern leads to substantial material consumption, energy use, and repeated disturbance of indoor environments. As a result, interior renovation has become a critical yet underexamined phase in the building lifecycle, particularly in high-density urban contexts where office buildings dominate commercial real estate markets [7,12–15].

The increasing frequency of interior renovation has raised growing concerns regarding occupant health and indoor environmental quality (IEQ). Renovation and fit-out activities are closely associated with short- and long-term health risks, including exposure to volatile organic compounds, particulate matter, noise, thermal discomfort, and inadequate ventilation [16–20]. Beyond physical factors, poorly planned interior renovation may also affect psychological well-being, work efficiency, and perceived comfort of occupants [21–28]. Given that office workers spend a significant proportion of their daily lives indoors, the health implications of interior renovation extend beyond individual buildings and contribute to broader public health and workplace sustainability challenges.

Despite the expanding recognition of healthy buildings and IEQ, existing green building certification systems remain largely design-oriented and whole-building focused. Most certification frameworks prioritize energy efficiency, environmental performance, and sustainability outcomes during the planning and construction phases [29]. However, they offer limited guidance for health-oriented decision-making during interior renovation [30,31]. Certification frameworks such as LEED and BREEAM have substantially advanced energy efficiency and environmental performance at the design stage. Nevertheless, growing evidence suggests that they provide limited operational guidance for health-oriented decision-making in interior renovation. This limitation is particularly evident in existing office buildings where user experience and IEQ play a critical role [32,33].

In recent years, operation-oriented certification schemes such as LEED for Operations and Maintenance (LEED O + M) and BREEAM In-Use have sought to extend sustainability assessment beyond the design and construction stages. These systems emphasize building performance during operation and represent important advances in recognizing the dynamic nature of building use and management. However, their assessment frameworks are primarily structured around whole-building operational performance, periodic audits, and management practices. They do not directly address the decision-making processes associated with recurring interior renovation and fit-out activities.

As a result, while LEED O+M and BREEAM In-Use provide valuable benchmarks for operational sustainability, they offer limited guidance on how health-related factors should be systematically evaluated, prioritized, and traded off during renovation cycles. This is especially relevant in contexts involving frequent spatial reconfiguration, material replacement, and system upgrades. Consequently, the specific health implications of interior renovation—such as short-term exposure risks, construction-phase disturbances, and renovation-induced changes to IEQ—remain insufficiently addressed within these operation-focused certification frameworks.

As a result, certified buildings may achieve high sustainability ratings at the design stage but fail to maintain comparable health performance during subsequent renovation cycles [34–37]. Previous studies on sustainable office renovation primarily operationalize green building rating systems as decision-support tools. These tools typically focus on energy performance, environmental outcomes, and cost criteria. In contrast, health-related considerations are often embedded as secondary assessment categories rather than treated as guiding principles for interior renovation decisions [38]. Similarly, prior research on building renovation has mainly applied certification frameworks to evaluate energy efficiency and environmental performance. Such studies have explicitly acknowledged the

need for further investigation into indoor comfort, hazardous materials, and other health-related outcomes during renovation processes [39]. Together, these findings indicate a strong design-phase bias in existing certification-oriented research. This bias has created a structural gap between certification objectives and the operational realities of office building renovation. In practice, health considerations are often addressed in a fragmented or ad hoc manner.

These limitations highlight the need for a structured, health-oriented assessment framework specifically tailored to interior renovation of office buildings. Such a framework should support systematic evaluation of health-related factors and facilitate informed decision-making among stakeholders. It should also bridge the gap between sustainability-oriented certification systems and the dynamic nature of interior renovation practices. Addressing this gap provides the primary motivation for the present study.

While prior studies have documented the environmental, functional, and health implications of interior renovation in office buildings, the existing literature remains fragmented across disciplinary boundaries. Research on healthy buildings and IEQ has largely examined individual exposure factors or post-occupancy outcomes. In contrast, studies on office renovation practices tend to emphasize energy efficiency, material reuse, or cost performance. At the same time, green building certification research has predominantly focused on design-stage compliance and whole-building evaluation. Viewed together, these strands reveal a critical gap: the absence of an integrated, health-oriented assessment framework specifically tailored to the interior renovation phase of office buildings.

This study integrates insights from three strands of literature: healthy buildings and IEQ, office interior renovation practices, and green building certification systems. The purpose is to identify critical gaps in health-oriented renovation assessment.

Despite growing evidence highlighting the impacts of interior renovation on occupant health, comfort, and work performance, existing assessment frameworks and certification systems remain largely design- and construction-oriented. As a result, they offer limited guidance for health-oriented decision-making during interior renovation [29–33]. In contrast, interior renovation—despite its high frequency and substantial impact on indoor environments—has received comparatively limited scholarly attention from a health-oriented perspective. Current studies addressing interior renovation often focus on energy efficiency, material reuse, or cost control. Meanwhile, health-related factors are either implicitly embedded within broader sustainability criteria or treated as secondary considerations [31,40–45]. Consequently, a systematic assessment framework explicitly designed to evaluate health performance during interior renovation is still lacking.

Furthermore, health considerations in interior renovation decision-making are frequently fragmented and inconsistently applied. In practice, decisions regarding layout modification, material selection, mechanical systems, and construction sequencing are often driven by functional requirements, budget constraints, or aesthetic preferences. These decisions are rarely guided by an integrated evaluation of health impacts. Although individual health-related elements—such as ventilation rates, low-emission materials, or thermal comfort—are commonly addressed in isolation, there is limited guidance on how these factors should be collectively assessed, prioritized, and balanced during renovation planning. This absence of structured decision-support tools constrains the ability of practitioners to make informed, health-oriented renovation choices.

A further gap lies in the disconnection between existing green building certification systems and the operational realities of interior renovation. Most certification schemes emphasize design-stage compliance and whole-building benchmarks. They offer limited mechanisms for evaluating health performance during renovation cycles that occur throughout a building's operational lifespan. Consequently, buildings that achieve high certification

ratings at the design or initial construction stage may experience significant variations in health performance as interior spaces are repeatedly modified. This misalignment highlights the need for an assessment approach that bridges certification-based sustainability objectives with the dynamic and iterative nature of interior renovation practices.

Taken together, these gaps underscore the necessity of developing a health-oriented assessment framework specifically tailored to interior renovation of office buildings. Addressing these shortcomings can enhance the integration of health considerations into renovation decision-making. It can also support more consistent health performance across the building lifecycle.

While previous studies have contributed valuable insights into healthy buildings, IEQ, and sustainable renovation, several unresolved issues remain. Most existing research adopts either single-factor evaluations or whole-building perspectives, with limited attention to the recurring and process-oriented nature of interior renovation in office buildings. Methodologically, many studies rely on energy simulation, post-occupancy surveys, or static certification metrics, which are insufficient for supporting real-time decision-making during renovation planning. Moreover, health-related factors are often treated as secondary or implicit components within broader sustainability frameworks, rather than as explicit decision criteria. These limitations highlight the absence of a structured, health-oriented, and renovation-specific assessment framework capable of integrating expert knowledge into systematic decision support.

Addressing these interrelated gaps requires clearer conceptualization of health performance in interior renovation. It also requires practical decision-support mechanisms that can be operationalized in real-world renovation contexts. In particular, there is a need for an assessment framework that systematically identifies relevant health-related factors and prioritizes them in a transparent manner. Such a framework should also align expert knowledge with the constraints faced by practitioners during renovation planning and implementation. These considerations directly inform the objectives and methodological approach of the present study.

In response to the identified research gaps, this study aims to develop a structured, health-oriented assessment framework specifically designed for interior renovation of office buildings. Unlike existing approaches that primarily address health performance at the design or whole-building level, the proposed framework focuses on the renovation and fit-out phase. This phase involves frequent spatial modification, material replacement, and system upgrades. These changes have direct and recurring impacts on IEQ and occupant health.

The first objective of this study is to establish a comprehensive assessment framework that systematically captures key health-related dimensions and indicators relevant to office interior renovation. Drawing on an extensive review of international literature and professional standards, the framework reflects the multifaceted nature of health performance. It encompasses environmental quality, functional usability, safety management, and resource efficiency and circularity. By structuring these dimensions within a coherent hierarchical model, the framework provides a clear basis for evaluating health performance during renovation planning and implementation.

The second objective is to integrate expert-based decision-making methods to support transparent and consistent prioritization of health-related factors. An integrated Fuzzy Delphi–Analytic Hierarchy Process (AHP) approach is employed to screen indicators through expert consensus. It is also used to determine their relative importance through hierarchical weighting. This methodological integration enables the incorporation of multidisciplinary professional knowledge into the assessment process. At the same time, it reduces subjectivity and enhances the robustness of decision outcomes.

Beyond its methodological contributions, this study offers practical and policy-relevant implications. From a practical perspective, the proposed framework functions as a decision-support tool for architects, interior designers, engineers, property managers, and facility operators involved in office renovation projects. It facilitates informed decision-making by clarifying the relative importance of health-related considerations. It also supports balanced trade-offs among competing renovation objectives.

From a policy perspective, the proposed framework provides a conceptual and analytical foundation for improving existing certification systems. It also supports the development of renovation-oriented health assessment mechanisms that better align sustainability goals with the operational realities of office buildings. Together, these contributions advance the integration of health considerations into interior renovation practices. They further support more consistent health performance across the building lifecycle.

Unlike prior studies that primarily approach green building certification from cost–incentive or construction-phase perspective [46], this study shifts the analytical focus toward health-oriented decision-making in the context of office interior renovation.

In response to these challenges, this study develops a structured, health-oriented assessment framework for office interior renovation by integrating literature-based insights with expert-driven multi-criteria decision-making (MCDM) methods.

The remainder of this paper is organized as follows. Section 2 describes the research framework and methodology, including the rationale for adopting the integrated Fuzzy Delphi–AHP approach. Section 3 presents the indicator screening and weighting results and details the identified assessment dimensions and key health-related indicators. Section 4 discusses the empirical findings and their implications for renovation decision-making and building performance evaluation. Finally, Section 5 concludes the paper by summarizing the main contributions, outlining policy and practical implications, and suggesting directions for future research.

2. Materials and Methods

This section describes the research design and methodological approach adopted to develop the proposed health-oriented assessment framework for office interior renovation. It outlines the overall research framework, the procedures for indicator identification and screening, and the analytical methods used to derive indicator priorities. In particular, this section explains the rationale for integrating the Fuzzy Delphi Method (FDM) with the AHP and details how expert knowledge is systematically incorporated into the assessment process.

2.1. Research Framework and Process

This study adopts a structured, multi-stage research framework to develop a health-oriented assessment framework for interior renovation of office buildings. The overall research design is grounded in the integration of literature-based knowledge and expert-based judgment, aiming to ensure both theoretical robustness and practical relevance. Given the complexity of health-related performance during interior renovation, where standardized quantitative data are often limited, the framework emphasizes a transparent and systematic decision-making process.

The research process consists of four sequential stages. First, an extensive literature review was conducted to establish the conceptual foundation of healthy buildings, IEQ, interior renovation characteristics, and existing green building certification systems. This stage served to identify a preliminary pool of health-related indicators relevant to office interior renovation and to clarify the limitations of existing assessment approaches. The

literature review also informed the initial categorization of indicators into major assessment dimensions.

Second, expert input was incorporated to contextualize and refine the preliminary indicator pool. Professionals with experience in green building certification, architecture, interior design, mechanical and electrical engineering, property management, and energy consulting were consulted to ensure that the selected indicators reflected real-world renovation practices and health concerns. This expert engagement provided critical insights into the feasibility, relevance, and practical implications of different assessment criteria.

The initial categorization of indicators into major assessment dimensions was conducted through a two-step process. First, indicators extracted from the literature were grouped based on their conceptual focus and thematic similarity, following established frameworks in healthy building and IEQ research. Specifically, indicators were coded according to whether they primarily addressed (i) physical environmental conditions, (ii) functional and spatial usability, (iii) safety and risk management, or (iv) resource efficiency and circularity. Second, this preliminary classification was reviewed and refined through expert consultation to ensure conceptual coherence and practical relevance. Experts were asked to evaluate the logical consistency of the grouping and to suggest adjustments where conceptual overlap or ambiguity existed. This process resulted in the four major assessment dimensions adopted in the final framework.

Given the need for both consensus-based indicator screening and structured prioritization, the methodological choice underlying this multi-stage framework warrants further explanation. The selection of the Integrated Fuzzy Delphi–AHP approach is grounded in its methodological strengths and its demonstrated suitability for complex multi-criteria decision environments, particularly in the context of health-oriented renovation assessment. The FDM extends the traditional Delphi technique by incorporating fuzzy set theory to capture expert uncertainty and ambiguity in judgments. This feature helps reduce potential bias and inconsistency inherent in crisp consensus methods [47–49].

By representing expert opinions using fuzzy linguistic variables, FDM facilitates robust aggregation of expert knowledge. This is especially valuable when criteria definitions are nuanced or when divergent perspectives arise across disciplines. Once the indicator set is established through consensus screening, the AHP (AHP) is employed to derive relative weights for the selected criteria and sub-criteria. AHP's hierarchical structuring and pairwise comparison mechanism have been widely applied in building performance evaluation and sustainability assessment. This is due to their ability to elicit consistent priority scales from expert judgments and to accommodate both qualitative and quantitative criteria [50–53].

Unlike non-hierarchical ranking methods such as the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), the Multi-Criteria Optimization and Compromise Solution (VIKOR), or the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE), AHP explicitly models hierarchical relationships among dimensions and sub-dimensions. This characteristic aligns with the multi-layer nature of the proposed assessment framework. A number of comparative studies in the MCDM literature highlight the complementary strengths of Fuzzy Delphi and AHP when integrated. For example, FDM's consensus-building process effectively narrows the indicator set before weighting. This helps mitigate the dimensionality and inconsistency issues that can emerge when applying AHP alone to a large set of criteria [49,54,55].

Other alternatives, such as Decision-Making Trial and Evaluation Laboratory (DEMATEL) or the Best–Worst Method (BWM), offer insights into interrelationships among criteria or reduce the number of pairwise comparisons. However, they do not simultaneously provide both consensus validation and structured hierarchical weighting as effectively as the

Fuzzy Delphi–AHP combination in the context of constructing a consolidated assessment framework. Therefore, the integrated Fuzzy Delphi–AHP approach is particularly well suited to this study's objectives of identifying and prioritizing health-related indicators for office interior renovation in a transparent, systematic, and expert-driven manner.

Third, the FDM was applied to screen and consolidate the assessment indicators through expert consensus. By translating qualitative expert judgments into quantitative fuzzy values, this stage reduced ambiguity and filtered out indicators with low consensus levels. The outcome of this process was a finalized set of assessment dimensions and indicators that represent the most relevant health-related factors in office interior renovation.

Finally, the AHP was employed to determine the relative importance of the identified dimensions and indicators. A hierarchical structure was constructed, and pairwise comparisons were conducted to derive weighting values while ensuring consistency of expert judgments. This weighting analysis established a prioritized assessment framework capable of supporting health-oriented decision-making during interior renovation planning and implementation.

Together, these stages form an integrated research framework that links theoretical understanding, expert knowledge, and systematic analysis. The resulting workflow—from literature review to expert input, indicator screening, and weighting analysis—provides a transparent and reproducible process for developing assessment frameworks in contexts where health performance and renovation dynamics intersect.

Figure 1 summarizes the overall research framework and illustrates the sequential methodological process adopted in this study. The overall research process consists of two sequential stages: indicator screening using the FDM, followed by indicator weighting using the AHP.

2.2. Indicator Identification and Expert Consultation

The identification of assessment indicators was initiated through a comprehensive review of academic literature, professional guidelines, and international building certification systems related to healthy buildings, IEQ, interior renovation, and sustainability. This review aimed to capture a broad range of health-related factors relevant to office interior renovation, encompassing environmental, functional, managerial, and resource-oriented considerations. Indicators commonly referenced in studies on indoor air quality, thermal comfort, lighting, acoustics, material health, safety management, and renovation processes were systematically extracted and synthesized to form an initial indicator pool.

To ensure conceptual clarity and analytical coherence, the preliminary indicators were organized into major assessment dimensions reflecting key aspects of health performance during interior renovation. This structuring process considered both theoretical relevance and practical applicability, allowing the framework to accommodate the multifaceted nature of renovation-related health impacts. At this stage, the indicator pool was intentionally inclusive, serving as a foundation for subsequent refinement through expert input and consensus-based screening.

Expert consultation was then conducted to contextualize and validate the preliminary indicator pool. Experts were selected based on their professional experience and direct involvement in office building design, renovation, certification, or operation. The expert panel consisted of professionals from five major backgrounds: green building certification, architecture/interior design, mechanical and electrical engineering, property management, and energy/environmental consulting (Table 1). This multidisciplinary composition was intended to capture diverse perspectives on health-related decision-making across different stages of interior renovation projects.

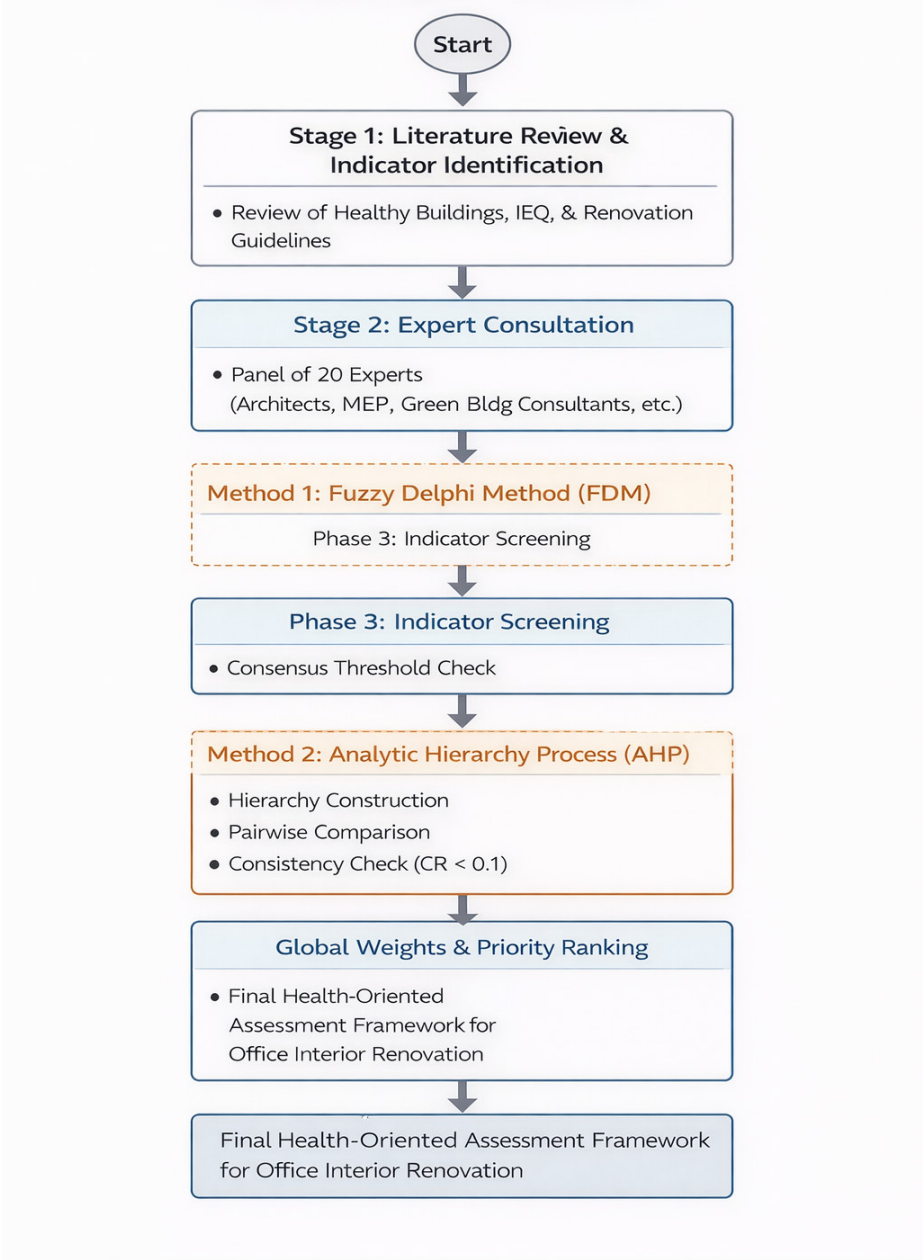


Figure 1. Overall research framework and sequential methodological process.

Table 1. Expert panel composition.

Number	Professional Background	Title	Experience (Years)
1	Green building consultant	Company head	25
2	Society of IEQ	Chairman	30
3	Association of Interior Design	Chairman	35
4	Interior Design	Company head	25
5	Interior Design	Company head	20
6	Green building consultant	Director	35
7	Interior Design	Director	35
8	Green building consultant	Senior Manager	25
9	Green building consultant	CEO	15
10	Green building consultant	Company head	15

The expert panel was purposively selected to ensure a diverse and practice-oriented representation of stakeholders involved in office interior renovation. A total of 20 experts participated in the study, including professionals from green building associations, architectural and mechanical engineering firms, interior design practices, facility management organizations, and energy consultancy companies. Selection criteria included: (1) a minimum of five years of professional experience in building design, renovation, facility management, or sustainability-related fields; (2) direct involvement in office building renovation or green building projects; and (3) familiarity with health, indoor environmental quality, or sustainability assessment issues. The participating experts had an average professional experience of approximately 12 years, with individual experience ranging from 6 to over 25 years. This multi-disciplinary composition was intended to reduce single-profession bias and enhance the credibility and robustness of the expert-based decision-making process.

Although five of the participants were green building consultants, potential professional bias was mitigated through several design features of the study. First, the expert panel was deliberately composed of members from multiple disciplines, ensuring that no single professional group dominated the evaluation process. Second, the FDM emphasizes consensus across experts and filters out indicators that do not achieve sufficient agreement, thereby reducing the influence of individual preferences. Third, the subsequent AHP weighting process was conducted using aggregated judgments rather than individual scores, further minimizing the impact of any single expert's subjective orientation. As a result, the final indicator set and weights reflect collective expert reasoning rather than the interests of specific stakeholder groups.

Selection criteria for expert participation emphasized practical experience with office buildings and familiarity with sustainability or health-oriented building practices. Experts were required to have direct involvement in renovation or fit-out projects, participation in green or health-related certification processes, or professional responsibilities related to indoor environmental management. By incorporating expertise from both design-oriented and operation-oriented roles, the consultation process ensured that the assessment indicators reflected real-world renovation constraints and performance priorities.

The expert consultation phase provided critical input for evaluating the relevance, feasibility, and clarity of the preliminary indicators. Feedback obtained during this stage informed subsequent indicator screening using the FDM, enabling the framework to balance theoretical completeness with practical significance. Through this combined literature-based and expert-informed approach, the study established a robust foundation for developing a health-oriented assessment framework tailored to office interior renovation.

2.3. Hierarchical Structuring and Weight Calculation

The hierarchical structure of the assessment framework was constructed based on the finalized indicator set obtained from the Fuzzy Delphi screening. The framework consists of three levels:

(1) Level 1 represents the overall goal of health-oriented interior renovation assessment;
(2) Level 2 includes four major dimensions (Environmental Quality, Safety Management, Functional Usability, and Resource Efficiency & Circularity);
(3) Level 3 consists of 18 specific health-oriented indicators under the corresponding dimensions.

For weight calculation, the AHP was applied using pairwise comparison matrices. Experts evaluated the relative importance of elements at each level using a 1–9 Saaty scale. Individual matrices were aggregated using the geometric mean method to obtain group judgment matrices. Eigenvector normalization was then applied to derive local and global

weights. Consistency ratios (CR) were calculated for all matrices, and all CR values were below the acceptable threshold of 0.1, indicating satisfactory consistency.

A qualitative sensitivity analysis was conducted to examine the robustness of the weighting results. Minor perturbations (±10%) in expert pairwise judgments did not alter the top-ranked dimensions or the top five indicators. This indicates that the overall ranking structure is stable and not sensitive to small variations in expert opinions.

Reliability of the Fuzzy Delphi screening was validated through expert consensus stability. Indicators retained in the final set all exceeded the consensus threshold and showed low dispersion among fuzzy scores, indicating strong agreement across expert groups. No indicator showed conflicting evaluations between professional categories.

2.4. Fuzzy Delphi Method for Indicator Screening

This section details the first stage of the analysis, in which Fuzzy Delphi was employed to refine and validate the initial indicator pool. To ensure the relevance and consensus of health-oriented indicators for office interior renovation, this study employed the FDM to refine the initial indicator pool derived from the literature review. Compared with the traditional Delphi method, FDM integrates fuzzy set theory to better capture expert uncertainty and ambiguity in subjective judgments, thereby improving the robustness of consensus measurement in complex decision-making contexts such as building renovation assessment.

An initial set of indicators was first compiled based on a comprehensive review of studies related to healthy buildings, IEQ, green renovation, and office interior design. These indicators were then evaluated by a panel (Table 2) of domain experts using linguistic variables representing perceived importance. Each linguistic assessment was transformed into a triangular fuzzy number, consisting of a lower bound, a most plausible value, and an upper bound, to reflect the range of expert opinions.

Table 2. Expert panel composition for AHP weighting analysis.

Professional Category	Areas of Expertise	Number of Experts	Key Qualifications/Experience
Green Building and Certification Experts	Smart and green building systems, IEQ, certification assessment	4	Senior roles in green building associations; experience in GD, IEQ, and healthy building assessment
Architects and Building Designers	Architectural design, interior renovation, LEED-accredited practice	4	Licensed architects and mechanical engineers; LEED AP and WELL AP credentials
Interior Renovation Professionals	Interior design, construction coordination, renovation project management	4	Senior managers and design leads in interior renovation firms
Property and Facility Management Professionals	Office building operation, asset management, facility management	5	Extensive experience in office property and facility management
Energy and Sustainability Consultants	Energy efficiency, carbon reduction, green retrofit consulting	3	Engineers and consultants specializing in energy-saving and carbon mitigation strategies
Total		20	

While a substantial proportion of the panel consisted of professionals involved in design and certification, this composition reflects the actual decision-making structure of office renovation processes. In practice, design and certification actors play a central role in defining health-related strategies. To mitigate potential bias arising from this professional concentration, the study also incorporated facility and property management experts. This ensured that operational and post-occupancy considerations were adequately

represented. Moreover, the consensus-based screening mechanism of the FDM, together with the aggregation procedures applied in the AHP process, reduces the influence of any single professional group. This approach enhances the robustness of the final indicator set.

The health-oriented indicators adopted in this study were systematically derived from a comprehensive review of the literature on healthy buildings, IEQ, office renovation practices, and green building assessment frameworks. Particular attention was paid to studies addressing health risks and comfort impacts associated with interior renovation and fit-out activities. Based on this review, a preliminary pool of indicators was identified and categorized into major assessment dimensions. Table 2 summarizes the derivation of these indicators and their corresponding literature sources, providing a transparent linkage between prior research and the proposed assessment framework.

All indicators included in the final framework were derived from and validated by existing literature on healthy buildings, IEQ, and office renovation. Expert input was used primarily to contextualize and refine these indicators, rather than to introduce arbitrary new constructs. For each indicator, aggregated fuzzy values were calculated and subsequently defuzzified using the center-of-gravity approach to obtain a single representative consensus score. Following established practices in Fuzzy Delphi applications, a consensus threshold value was adopted to determine indicator retention. A total of 20 experts participated in both the FDM and the AHP surveys. All questionnaires were valid and fully completed, resulting in a 100% response rate for both rounds. The expert composition and professional backgrounds are summarized in Table 2. The same panel was retained across both stages to ensure consistency in indicator screening and weighting.

Although the number of experts involved in this study may appear limited from a conventional statistical perspective, it is consistent with established practices in expert-based MCDM research. Prior studies applying the FDM and AHP in building and sustainability assessment commonly employ expert panels ranging from 10 to 30 participants, and in many cases fewer than 20 [56–60]. Methodological literature further suggests that beyond a certain threshold, additional expert responses contribute diminishing marginal gains in consensus quality and ranking stability. In this study, the expert panel consisted of 20 professionals with diverse disciplinary backgrounds, and full response was achieved in both the FDM and AHP rounds, with no invalid questionnaires. Consistency ratios for all AHP matrices satisfied standard thresholds, and strong consensus was observed in FDM screening, indicating that the sample size was sufficient to produce stable and reliable priority structures.

Indicators with defuzzified scores exceeding the threshold were considered to have achieved sufficient expert agreement and were retained for subsequent analysis (Table 3). Indicators below the threshold were excluded or merged due to insufficient consensus or conceptual overlap. During the Fuzzy Delphi screening process, two initially identified indicators—"C*: Support for psychological well-being" and "D*: Electrical and fire safety management"—were excluded based on expert consensus.

Through this screening process, the initial indicator set was refined to a final group of 18 health-oriented indicators (Table 4), organized under four major assessment dimensions. This step ensured that only indicators with clear relevance and shared expert recognition were incorporated into the weighting analysis, thereby enhancing the validity and applicability of the proposed assessment framework.

Table 3. Initial and final indicator screening results (Fuzzy Delphi).

Dimension	Code	Initial Indicator (Derived from Literature)	Consensus Result (1~9)	Retained for AHP	Key Literature Source
Environmental Quality	A1	Energy efficiency of Heating, Ventilation and Air Conditioning (HVAC) systems	6.24	Yes	[61–66]
	A2	Lighting system performance	5.94	Yes	[67–72]
	A3	Water efficiency performance	5.14	Yes	[62,67,68,73,74]
	A4	Use of green and low-emission materials	5.92	Yes	[75–80]
IEQ	B1	Indoor air quality management	6.40	Yes	[76,81–86]
	B2	Acoustic environment control	5.41	Yes	[67,87–93]
	B3	Visual comfort and lighting quality	5.72	Yes	[67,68,70,91,94–97]
	B4	Thermal comfort and adaptability	5.24	Yes	[98–103]
	B5	Electromagnetic environment control	5.13	Yes	[104–107]
Functional Usability	C1	Spatial layout and configuration	5.81	Yes	[67,70,91,108–111]
	C2	Human-centered design elements	4.88	Yes	[112–115]
	C3	Circulation and movement planning	5.45	Yes	[116–119]
	C4	Natural lighting and interior greening	4.99	Yes	[13,67,68,94,115,120]
	C *	Support for psychological well-being	4.80	No (Excluded)	[24,33,121–124]
Safety Management	D1	Preliminary assessment and renovation planning	6.50	Yes	[16,17,125–127]
	D *	Electrical and fire safety management	4.59	No (Excluded)	[128–133]
	D2	Information and communication system monitoring	6.02	Yes	[134–137]
	D3	Maintenance, cleaning, and pest control	5.21	Yes	[108,138–141]
	D4	Green construction management	5.99	Yes	[32,68,76,84,142,143]
	D5	Operation monitoring and adjustment	6.69	Yes	[82,137,144–146]

* These two indicators were subsequently excluded after evaluation using the "FDM".

Table 4. AHP weighting results and ranking of health-oriented interior renovation indicators.

Rank	Code	Indicator	Global Weight
1	B1	Indoor air quality management	0.2061
2	A1	Energy efficiency of HVAC systems	0.0882
3	C1	Spatial layout and configuration	0.0856
4	D1	Preliminary assessment and renovation planning	0.0839
5	B4	Thermal comfort and adaptability	0.0609
6	B3	Visual comfort and lighting quality	0.0521
7	C2	Human-centered design elements	0.0488
8	C3	Circulation and movement planning	0.0473

Table 4. *Cont.*

Rank	Code	Indicator	Global Weight
9	B2	Acoustic environment control	0.0470
10	D5	Operation monitoring and adjustment	0.0433
11	A2	Lighting system performance	0.0407
12	D4	Green construction management	0.0397
13	D3	Maintenance, cleaning, and pest control	0.0366
14	C4	Natural lighting and interior greening	0.0297
15	B5	Electromagnetic environment control	0.0263
16	D2	Information and communication system monitoring	0.0259
17	A4	Use of green and low-emission materials	0.0192
18	A3	Water efficiency performance	0.0185

2.5. Analytic Hierarchy Process (AHP) for Weighting Analysis

Based on the finalized indicators derived from the Fuzzy Delphi process, the Analytic Hierarchy Process was then applied to determine the relative weights and priority structure. Following indicator screening, the AHP was applied to determine the relative importance of the retained indicators and assessment dimensions. AHP is a widely used MCDM technique that enables the systematic decomposition of complex problems into a hierarchical structure and quantifies subjective judgments through pairwise comparisons.

In this study, the AHP hierarchy consisted of three levels:

(1) the overall goal of health-oriented interior renovation assessment;
(2) four major assessment dimensions;
(3) the 18 finalized indicators obtained from the Fuzzy Delphi process.

Experts participating in the AHP phase were asked to conduct pairwise comparisons using a standardized nine-point scale, reflecting the relative importance of one element over another with respect to the evaluation goal. Separate comparison matrices were constructed for both the dimension level and the indicator level within each dimension.

To ensure the reliability of expert judgments, consistency checks were performed for all pairwise comparison matrices. The Consistency Ratio (CR) was calculated, and only matrices with CR values below the commonly accepted threshold of 0.10 were deemed valid. In cases where inconsistency exceeded this threshold, experts were invited to review and revise their judgments to improve logical coherence.

Local weights for indicators within each dimension were first derived from the normalized eigenvectors of the comparison matrices. These local weights were then aggregated with the corresponding dimension weights to obtain global weights, representing the overall relative importance of each indicator within the assessment framework. The resulting global weights formed the basis for indicator ranking and subsequent interpretation of health priorities in office interior renovation.

By integrating Fuzzy Delphi screening with AHP weighting, this two-stage methodological approach ensured both consensus validity and structural consistency, providing a transparent and reproducible foundation for the proposed health-oriented assessment framework. Following the Fuzzy Delphi consensus screening and the refinement of the AHP hierarchical structure, two initially identified indicators were excluded or merged due to conceptual overlap and insufficient suitability for pairwise comparison, resulting in a final set of 18 indicators.

3. Results

3.1. Identification of Assessment Dimensions and Indicators

Based on the indicator screening results derived from the FDM, a finalized assessment framework for health-oriented interior renovation of office buildings was established (Table 4). The framework consists of four major assessment dimensions and eighteen associated indicators, reflecting expert consensus on the most relevant health-related factors influencing interior renovation performance. These dimensions and indicators form the analytical foundation for subsequent weighting and prioritization.

The four identified assessment dimensions are environmental quality, safety management, functional usability, and resource efficiency and circularity. Together, these dimensions capture the multidimensional nature of health performance during office interior renovation, encompassing both direct indoor environmental conditions and broader managerial and sustainability considerations.

The environmental quality dimension includes indicators related to indoor air quality management, thermal comfort, lighting conditions, acoustic performance, and ventilation effectiveness. These indicators address core aspects of IEQ that directly affect occupant physical comfort and health, particularly in office settings characterized by prolonged occupancy and high density.

The safety management dimension focuses on indicators associated with renovation process control, operational safety, and risk prevention. These indicators reflect the importance of systematic planning, monitoring, and management practices in minimizing health and safety risks during renovation activities and subsequent building operation.

The functional usability dimension comprises indicators related to spatial layout, adaptability, accessibility, and support for daily work activities. This dimension recognizes that interior renovation decisions influence not only environmental conditions but also the usability and psychological comfort of office spaces, which in turn affect occupant well-being and productivity.

The resource efficiency and circularity dimension addresses indicators associated with material selection, waste reduction, energy-efficient systems, and life-cycle considerations. These indicators emphasize the integration of sustainability principles into interior renovation, acknowledging the long-term environmental and health implications of resource-intensive renovation practices.

Each indicator within the framework is clearly defined and positioned within a hierarchical structure, linking detailed assessment criteria to broader health-oriented objectives. This structured organization enables consistent evaluation and comparison of health performance across different interior renovation scenarios. The resulting framework provides a comprehensive yet operational set of dimensions and indicators that support subsequent weighting analysis and decision-making.

3.2. Weighting Results of Major Dimensions

Following the application of the AHP, weighting values were derived for the four major assessment dimensions identified in the proposed framework. The results indicate clear differences in the relative importance assigned by experts to various aspects of health-oriented interior renovation in office buildings (Table 5).

Among the four dimensions, environmental quality received the highest weighting, accounting for 39.2% of the overall importance. This result suggests that factors directly related to indoor environmental conditions—such as air quality, thermal comfort, lighting, and acoustics—are regarded as the most critical determinants of health performance during interior renovation. The prominence of this dimension reflects the direct and immediate impact of environmental conditions on occupant health and comfort in office settings.

Table 5. Summary of AHP dimension weights and indicator ranking.

Dimension (Weight)	Code	Indicator	Global Weight	Overall Rank
Resource Efficiency & Circularity (16.67%)	A1	Energy efficiency of HVAC systems	0.0882	2
	A2	Lighting system performance	0.0407	11
	A3	Water efficiency performance	0.0185	18
	A4	Use of green and low-emission materials	0.0192	17
Environmental Quality (39.24%)	B1	Indoor air quality management	0.2061	1
	B2	Acoustic environment control	0.0470	9
	B3	Visual comfort and lighting quality	0.0521	6
	B4	Thermal comfort and adaptability	0.0609	5
	B5	Electromagnetic environment control	0.0263	15
Functional Usability (21.14%)	C1	Spatial layout and configuration	0.0856	3
	C2	Human-centered design elements	0.0488	7
	C3	Circulation and movement planning	0.0473	8
	C4	Natural lighting and interior greening	0.0297	14
Safety Management (22.95%)	D1	Preliminary assessment and renovation planning	0.0839	4
	D2	Information and communication system monitoring	0.0259	16
	D3	Maintenance, cleaning, and pest control	0.0366	13
	D4	Green construction management	0.0397	12
	D5	Operation monitoring and adjustment	0.0433	10

The second most important dimension is safety management, with a weighting of 23.0%. This dimension captures expert concerns regarding the control of renovation processes, operational safety, and risk prevention. The relatively high weighting assigned to safety management highlights the significance of systematic planning, monitoring, and management practices in mitigating health and safety risks associated with renovation activities.

Functional usability ranks third, with a weighting of 21.1%. This dimension emphasizes the role of spatial layout, adaptability, and usability in supporting daily work activities and occupant well-being. Although its weighting is lower than that of environmental quality and safety management, functional usability remains a substantial component of the overall assessment, underscoring the importance of aligning renovation outcomes with user needs and work patterns.

The resource efficiency and circularity dimension received the lowest weighting at 16.7%. While sustainability-oriented considerations such as material efficiency, waste reduction, and life-cycle thinking are recognized as important, experts assigned relatively less priority to these factors when evaluating health performance during interior renovation. This result indicates that, within the context of health-oriented assessment, immediate indoor conditions and operational safety are perceived as more influential than longer-term resource-related considerations.

Overall, the weighting results reveal a structured prioritization pattern among the assessment dimensions, with greater emphasis placed on factors that directly affect occupant health and safety. These relative weights provide a quantitative basis for subsequent indicator-level analysis and form a key component of the proposed decision-support framework for office interior renovation.

3.3. Ranking of Health-Oriented Interior Renovation Indicators

At the indicator level, the AHP produced a clear ranking of health-oriented factors influencing interior renovation performance in office buildings. The results reveal that indicators directly associated with indoor environmental conditions, system performance, and early-stage renovation decision-making occupy the highest priority positions, reflecting expert consensus on their critical role in shaping health outcomes.

Among the eighteen indicators (Figure 2), indoor air quality management emerged as the most influential factor affecting health performance during interior renovation. This indicator encompasses control of ventilation effectiveness, pollutant sources, and air exchange strategies, highlighting the central importance of air quality in office environments characterized by prolonged occupancy and high exposure duration. Its top-ranked position underscores expert recognition of indoor air quality as a foundational determinant of occupant health.

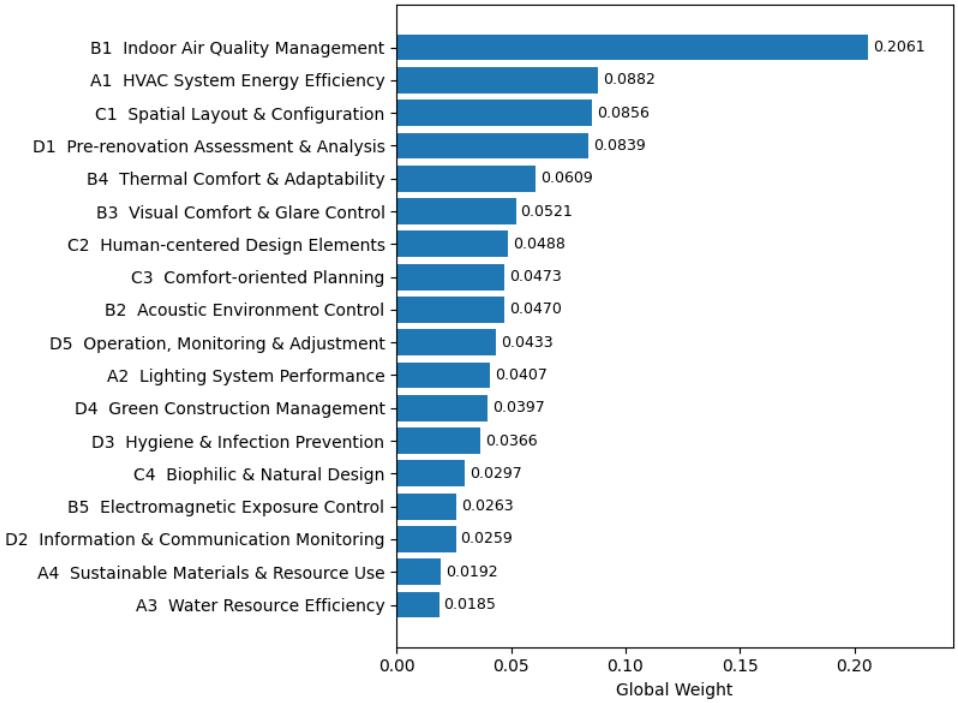


Figure 2. Overall expert weighting of health-oriented interior renovation indicators.

Closely following are indicators related to the energy efficiency and performance of HVAC systems and thermal comfort. These indicators reflect the interdependence between mechanical system design, energy use, and occupant well-being. Efficient and properly configured HVAC systems not only reduce energy consumption but also play a key role in maintaining stable thermal conditions and adequate ventilation, thereby supporting both health and sustainability objectives during interior renovation.

Indicators associated with space-friendly layout and functional planning also ranked highly. This result emphasizes the importance of spatial configuration, adaptability, and usability in shaping occupant comfort and psychological well-being. Office interior renovation decisions that support flexible layouts and user-oriented design contribute to improved work efficiency and perceived comfort, extending health considerations beyond purely environmental parameters.

In addition, preliminary assessment and renovation planning was identified as a high-priority indicator, highlighting the significance of early-stage decision-making processes. This finding suggests that health performance during interior renovation is strongly influ-

enced by systematic planning, including assessment of existing conditions, identification of potential health risks, and coordination among stakeholders. Effective planning serves as a prerequisite for implementing health-oriented strategies throughout the renovation process.

Overall, the ranking results indicate that experts prioritize indicators with immediate and tangible impacts on occupant health, particularly those related to IEQ, system performance, spatial usability, and process management. These findings provide a structured basis for understanding which aspects of interior renovation warrant the greatest attention when seeking to enhance health performance in office buildings. The ranked indicators form a critical input for the proposed assessment framework and inform subsequent discussion on practical and policy implications.

3.4. Robustness and Stability of the AHP Results

To enhance confidence in the stability of the proposed framework, the robustness of the AHP results was examined from a methodological perspective. First, the expert panel was composed of heterogeneous professional groups, which reduces the likelihood of single-domain bias. Second, the Fuzzy Delphi process was applied prior to weighting to filter out low-consensus indicators and mitigate the influence of extreme judgments. Third, all pairwise comparison matrices satisfied the AHP consistency requirement ($CR < 0.1$), indicating acceptable internal logical coherence of expert evaluations.

In addition, the final ranking shows that the top indicators—such as indoor air quality management, HVAC system efficiency, space-friendly layout, preliminary assessment and planning, and thermal comfort—remain consistently dominant across expert groups and are conceptually aligned with established health and IEQ literature. This convergence suggests that minor perturbations in individual judgments are unlikely to substantially alter the overall priority structure of the framework.

While a full quantitative sensitivity analysis (e.g., Monte Carlo simulation) is beyond the scope of this framework-oriented study, future research may further examine the stability of the weighting results under alternative expert compositions or scenario-based testing.

4. Discussion

4.1. Implications for Interior Renovation Practice

The proposed health-oriented assessment framework offers practical implications for decision-making in office interior renovation by translating expert knowledge into a structured and operational tool. By integrating indicator screening and weighting results (Figure 2), the framework enables practitioners to systematically evaluate health-related considerations alongside functional and sustainability objectives. Rather than relying on fragmented or experience-based judgments, renovation teams can use the framework to prioritize critical health factors. This approach supports more transparent and consistent decision-making throughout the renovation process.

Table 6 and Figure 3 present the integrated AHP results, showing that Environmental Quality was identified as the most critical assessment dimension (39.24%), followed by Safety Management (22.95%), Functional Usability (21.14%), and Resource Efficiency (16.67%). At the indicator level, indoor air quality management (B1) received the highest global weight, highlighting its central role in health-oriented interior renovation decision-making.

From a design perspective, the framework provides architects and interior designers with a clear hierarchy of health-oriented priorities that can inform early-stage planning and design development. The prominence of indicators related to IEQ, spatial usability, and early assessment highlights the importance of addressing health considerations at the conceptual stage. At this stage, design decisions exert the greatest influence on long-term

building performance. By clarifying the relative importance of different health-related factors, the framework helps designers balance aesthetic, functional, and health objectives in a more systematic manner.

Table 6. Integrated AHP results of assessment dimensions and health-oriented indicators.

Dimension (Level 1)	Weight (%)	Rank	Indicator Code	Health-Oriented Indicator	Global Weight	Overall Rank
Environmental Quality	39.24	1	B1	Indoor Air Quality Management	0.2061	1
			A1	HVAC System Energy Efficiency	0.0882	2
			C1	Spatial Layout and Configuration	0.0856	3
			D1	Pre-renovation Assessment and Analysis	0.0839	4
			B4	Thermal Comfort and Adaptability	0.0609	5
Safety Management	22.95	2	B3	Visual Comfort and Glare Control	0.0521	6
			C2	Human-Centered Design Elements	0.0488	7
			C3	Comfort-Oriented Planning	0.0473	8
			B2	Acoustic Environment Control	0.0470	9
			D5	Operation, Monitoring, and Adjustment	0.0433	10
Functional Usability	21.14	3	A2	Lighting System Performance	0.0407	11
			D4	Green Construction Management	0.0397	12
			D3	Hygiene and Infection Prevention	0.0366	13
			C4	Biophilic and Natural Design	0.0297	14
Resource Efficiency	16.67	4	B5	Electromagnetic Exposure Control	0.0263	15
			D2	Information and Communication Monitoring	0.0259	16
			A4	Sustainable Materials and Resource Use	0.0192	17
			A3	Water Resource Efficiency	0.0185	18

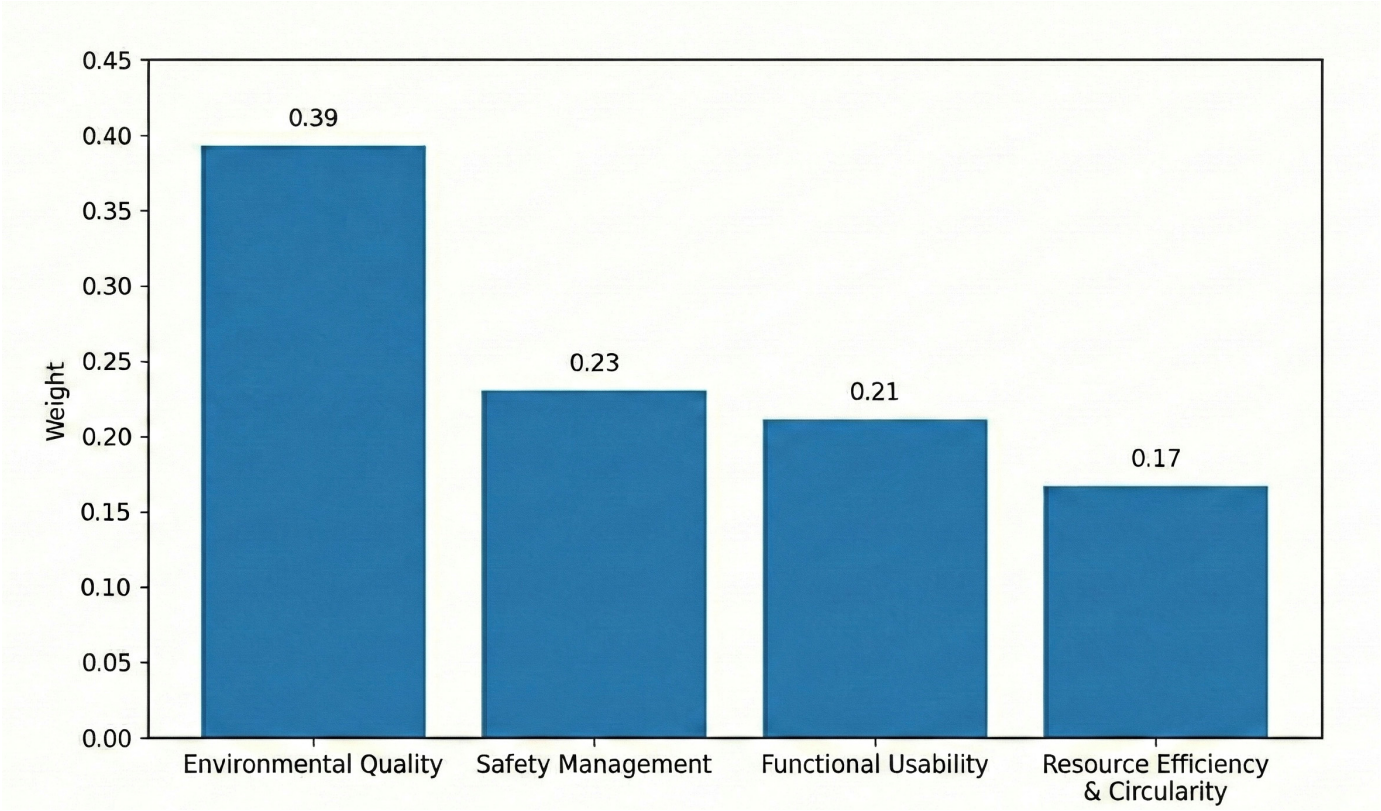


Figure 3. Integrated AHP results across assessment dimensions and key indicators.

For engineers responsible for mechanical, electrical, and building systems, the framework underscores the critical role of system performance in supporting occupant health. This applies both during and after interior renovation. High-ranking indicators related to indoor air quality management, HVAC efficiency, and thermal comfort emphasize the need for careful system selection and configuration. They also highlight the importance of

system integration during renovation projects. The weighting structure can assist engineers in prioritizing system upgrades and allocating resources toward interventions that yield the greatest health benefits.

Facility managers and property operators can also benefit from the framework as a decision-support tool for planning and evaluating renovation strategies. The inclusion of indicators related to safety management and preliminary assessment highlights the importance of process-oriented considerations, such as renovation planning, coordination, and risk control. By applying the framework, facility managers can better anticipate potential health impacts associated with renovation activities. This supports more consistent health performance across successive renovation cycles.

Overall, the framework facilitates cross-disciplinary communication among designers, engineers, and facility managers by providing a shared reference for health-oriented priorities. Its structured and transparent nature supports informed trade-offs among competing renovation objectives and enhances the integration of health considerations into routine interior renovation practice. These practical implications demonstrate the framework's potential to improve health performance in office buildings beyond the initial design phase.

The prominence of indoor air quality management (B1) and the relatively lower rankings of indicators such as green construction management (D4), hygiene and infection prevention (D3), biophilic and natural design (C4), and sustainable materials and resource use (A4) do not indicate methodological inconsistency, but rather reflect the prioritization logic embedded in expert decision-making under real renovation conditions.

Indoor air quality is widely perceived by practitioners as the most immediate and measurable determinant of occupant health during interior renovation, as it directly affects exposure to volatile organic compounds, particulate matter, ventilation adequacy, and short-term health risks. In contrast, indicators such as biophilic design, green construction management, or sustainable material selection are often associated with longer-term benefits, aesthetic enhancement, or sustainability objectives, which, although important, are less directly linked to acute health protection during renovation processes.

This ranking pattern suggests that experts prioritize risk-control and exposure-prevention mechanisms over broader environmental or experiential attributes when evaluating health performance in renovation contexts. Rather than undermining reliability, this ordering reveals the practical logic through which health considerations are operationalized in real-world decision-making, where immediate indoor environmental risks tend to dominate over indirect or long-term sustainability considerations.

4.2. Comparison with Existing Certification Systems

The proposed health-oriented assessment framework does not seek to replace existing green or health-focused certification systems, but rather to complement them by addressing a specific and underexplored stage of the building lifecycle. Widely adopted systems such as LEED, WELL, and other sustainability-oriented certification frameworks have made substantial contributions to improving environmental performance and occupant well-being, particularly at the design and construction stages. Their structured criteria and standardized benchmarks have played an important role in mainstreaming health and sustainability considerations within the building sector.

In terms of conceptual alignment, the proposed framework shares important common foundations with existing certification systems. This is especially evident in its emphasis on IEQ, thermal comfort, ventilation performance, and occupant well-being. Many of the high-ranking indicators identified in this study—such as indoor air quality management, HVAC performance, and thermal comfort—are also reflected in the core criteria of established certification schemes. This overlap suggests that the framework is consistent with

prevailing health-oriented design principles and reinforces priorities already recognized at the certification level.

However, notable divergence emerges in how interior renovation and fit-out are treated. Existing certification systems tend to evaluate health and sustainability performance through a design-phase or whole-building lens, often focusing on compliance at a specific point in time. While some systems provide pathways for interior design or major renovation, they generally lack mechanisms to systematically reassess health performance during the frequent and incremental renovation cycles typical of office buildings. As a result, health-related considerations during routine interior renovation are often addressed indirectly or inconsistently, relying on practitioner discretion rather than structured evaluation.

The added value of the proposed framework lies in its explicit focus on interior renovation as a recurring operational process rather than a one-time certification event. By prioritizing indicators related to early-stage assessment, renovation planning, safety management, and system performance, the framework captures health risks and decision points that are not fully addressed by existing certification schemes. Its weighting structure further distinguishes between factors with immediate impacts on occupant health and those with longer-term sustainability implications, offering a nuanced perspective tailored to renovation contexts.

By bridging the gap between certification-based objectives and the operational realities of office interior renovation, the proposed framework enhances the practical applicability of health-oriented assessment. It can be used alongside existing certification systems to support health-focused decision-making during renovation planning, implementation, and management. In this sense, the framework adds value not by duplicating certification criteria, but by extending health assessment into a phase of the building lifecycle where health performance is highly dynamic yet insufficiently regulated.

4.3. Policy and Management Implications

The findings of this study offer important implications for the evolution of building certification systems and the formulation of sustainability-oriented building policies. As interior renovation becomes an increasingly dominant mode of intervention in office buildings, existing certification frameworks and regulatory instruments face growing pressure to address health performance beyond initial design and construction stages. The proposed health-oriented assessment framework provides a structured reference that can inform future adaptations of certification systems and management practices.

From a certification development perspective, the framework highlights the need to extend assessment logic from static, design-phase evaluation toward more dynamic, lifecycle-oriented approaches. Current certification systems largely rely on one-time compliance checks, which may inadequately capture variations in health performance arising from repeated interior renovation. The identification and prioritization of renovation-specific health indicators suggest that certification schemes could benefit from introducing modular or supplementary assessment components focused on interior renovation and fit-out. Such components could enable periodic reassessment of health performance, support continuous improvement, and enhance the long-term credibility of certification outcomes.

The weighting structure derived in this study also offers insights for refining certification criteria. By distinguishing between indicators with immediate health impacts and those with longer-term sustainability implications, the framework provides a basis for calibrating credit allocation and performance thresholds in future certification revisions. Incorporating expert-informed weighting can help align certification priorities more closely

with practical health risks encountered during renovation processes, thereby strengthening the relevance of certification systems to real-world building operation.

Beyond certification systems, the proposed framework has potential applications in sustainability-oriented building policies and management strategies. Policymakers and public-sector building owners can use the framework as a reference tool to guide health-oriented renovation planning, particularly in office buildings with frequent interior modification. By embedding health-related assessment criteria into renovation guidelines, procurement requirements, or facility management protocols, public agencies can promote more consistent consideration of occupant health alongside energy efficiency and resource conservation objectives.

At the management level, the framework can support governance mechanisms that encourage cross-disciplinary coordination among designers, engineers, facility managers, and regulators. Its structured and transparent nature facilitates communication of health priorities and supports accountability in renovation decision-making. Rather than imposing rigid standards, the framework offers a flexible assessment approach that can be adapted to different regulatory contexts and organizational capacities.

Overall, the policy and management implications of this study underscore the importance of recognizing interior renovation as a critical stage in achieving healthy and sustainable buildings. By informing certification development and sustainability-oriented policies, the proposed framework contributes to bridging the gap between strategic sustainability goals and the operational realities of office building renovation.

4.4. Research Limitations and Future Research

Despite its contributions, this study has several limitations that should be acknowledged. First, the proposed assessment framework is primarily based on expert judgment. Although the integration of the FDM and the AHP provides a structured and transparent mechanism for consolidating expert opinions, the resulting indicator set and weighting structure inevitably reflect the perspectives and professional experiences of the selected experts. While the expert panel was intentionally composed of multidisciplinary professionals with direct involvement in office building renovation and management, the framework may still be influenced by contextual factors. These factors include prevailing practices, professional norms, and regional market conditions.

Second, the framework has not yet been empirically validated through large-scale application in real renovation projects. The current study focuses on framework development, indicator identification, and weighting analysis, rather than on post-renovation performance measurement or longitudinal health outcome evaluation. As a result, the effectiveness of the framework in predicting or improving actual health performance during interior renovation remains to be further examined. Empirical validation using case studies, pilot applications, or post-occupancy evaluations would strengthen the practical robustness of the proposed approach.

Future research can address these limitations in several directions. First, applying the framework to multiple office renovation cases across different contexts would enable comparative analysis and refinement of indicator weights. Such applications could reveal how health priorities vary across building types, organizational cultures, or regulatory environments. Second, future studies may integrate quantitative performance data. These may include indoor air quality measurements, energy consumption records, or occupant satisfaction surveys. Such data would complement expert-based assessments and enhance empirical grounding. Combining the framework with post-occupancy evaluation methods would provide valuable insights into the relationship between renovation decisions and observed health outcomes.

In addition, the framework could be extended to other building types or renovation contexts. These may include educational facilities, healthcare buildings, or mixed-use developments, where interior renovation also plays a significant role in shaping occupant health. Methodologically, future research may explore the integration of additional decision-support techniques, scenario analysis, or digital tools to enhance usability and scalability. By addressing these avenues, subsequent studies can build upon the foundation established in this research. They can also further advance health-oriented assessment approaches for sustainable building renovation.

4.5. Illustrative Application of the Framework

This illustrative application is framed from the perspective of facility managers responsible for planning and evaluating recurring interior renovation in existing office buildings. To illustrate the practical applicability of the proposed framework, a hypothetical office renovation scenario is constructed. The case represents a medium-sized existing office building undergoing interior renovation, with typical constraints in budget, schedule, and occupant health requirements.

Using the derived indicator weights, decision-makers can evaluate alternative renovation strategies by scoring each indicator (e.g., on a 1–5 scale) and calculating composite health performance scores. For example, strategies emphasizing HVAC system upgrades and indoor air quality management receive higher overall scores, reflecting the dominance of environmental quality in the weighting structure. In contrast, renovation plans focusing primarily on aesthetic improvements yield lower health-oriented performance.

This illustrative application demonstrates how the framework can function as a decision-support tool, enabling practitioners to prioritize interventions, compare renovation options, and identify trade-offs between health performance and resource constraints.

The framework can be operationalized through the following steps:

(1) Defining renovation alternatives;
(2) Scoring each alternative against the 18 indicators;
(3) Calculating weighted composite scores;
(4) Supporting trade-off decisions under budget and operational constraints.

4.6. Illustrative Application of the Proposed Framework

Although this study does not focus on evaluating a specific renovation project, the proposed framework is designed to support health-oriented decision-making in practical contexts. In a typical application scenario, the framework can be operationalized through the following steps.

First, decision-makers (e.g., facility managers or design teams) identify renovation objectives and relevant stakeholder concerns. Second, the finalized indicator set is adopted as an assessment checklist to screen key health-related factors associated with the renovation scope. Third, the weighting results derived from the AHP analysis are used to prioritize indicators according to their relative importance. Finally, alternative renovation strategies or design options can be compared by aggregating weighted scores, thereby supporting transparent and systematic decision-making.

This procedural application allows the framework to be flexibly integrated into different renovation contexts without requiring extensive data collection or complex modeling, making it suitable for early-stage planning and strategic evaluation.

5. Conclusions

This study sets out to address the growing need for health-oriented decision support in the interior renovation of office buildings. Existing building certification systems and

assessment approaches are largely design-stage and whole-building focused. As a result, health performance during renovation and fit-out remains highly dynamic yet insufficiently assessed. In response, this research developed a structured framework specifically tailored to the renovation phase. By integrating literature review, expert consultation, the FDM, and the AHP, the study established a systematic approach for identifying and prioritizing health-related factors relevant to office interior renovation.

Existing building assessment tools, such as LEED, WELL, and BREEAM, have made important contributions to integrating sustainability and health considerations into building design and construction. However, these systems are predominantly whole-building and design-phase oriented, and often treat interior renovation as a secondary or fragmented component. In contrast, the proposed framework explicitly focuses on the renovation and fit-out stage of office buildings, where operational decisions, management strategies, and occupant-related factors play a more critical role in shaping health performance.

Unlike certification systems that rely on fixed scoring schemes, the proposed framework adopts a flexible, expert-driven multi-criteria structure, allowing decision-makers to prioritize indicators according to contextual renovation needs. Moreover, while existing tools emphasize compliance and benchmarking, this study contributes a decision-support-oriented framework that bridges health, sustainability, and practical renovation processes. This positioning highlights the complementary role of the proposed framework in addressing a critical gap not fully covered by current certification systems.

The results reveal a clear hierarchy of health-oriented priorities. Four major assessment dimensions—environmental quality, safety management, functional usability, and resource efficiency and circularity—were identified and weighted based on expert consensus. Environmental quality emerged as the most influential dimension. It was followed by safety management and functional usability. Resource efficiency and circularity, although important, received comparatively lower priority in the context of health performance. At the indicator level, indoor air quality management, HVAC system performance, thermal comfort, spatial usability, and early-stage renovation planning were ranked as critical determinants of health outcomes during interior renovation. These findings highlight the central role of indoor environmental conditions, system performance, and process management in shaping health-oriented renovation outcomes.

The study contributes to the existing literature in several important ways. Theoretically, it advances healthy building research by shifting attention from static, design-oriented assessment toward a renovation-focused perspective. This perspective better reflects the operational realities of office buildings. Methodologically, the study demonstrates the value of integrating expert-based decision-making techniques. Such methods help structure complex health considerations in contexts where empirical data are limited.

Practically, the proposed framework provides a transparent and operational decision-support tool for designers, engineers, facility managers, and building owners, enabling more systematic integration of health considerations into renovation planning and implementation. At the policy and management level, the framework offers a reference for enhancing certification systems and sustainability-oriented building policies by extending health assessment into recurring renovation cycles.

In conclusion, interior renovation represents a critical yet underexamined stage in achieving healthy and sustainable office buildings. By proposing a health-oriented assessment framework grounded in expert consensus and structured analysis, this study contributes to bridging the gap between certification-based objectives and everyday renovation practice. The framework provides a foundation for more consistent health performance across the building lifecycle. It also underscores the importance of incorporating health

considerations into renovation decision-making as an integral component of sustainable building management.

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References

1. Pomponi, F.; Farr, E.R.P.; Piroozfar, P.; Gates, J.R. Façade refurbishment of existing office buildings: Do conventional energy-saving interventions always work? *J. Build. Eng.* **2015**, *3*, 135–143. [CrossRef]
2. Kuivjõgi, H.; Uutar, A.; Kuusk, K.; Thalfeldt, M.; Kurnitski, J. Market based renovation solutions in non-residential buildings–Why commercial buildings are not renovated to NZEB. *Energy Build.* **2021**, *248*, 111169. [CrossRef]
3. Wan, S.; Ding, G.; Runeson, G.; Liu, Y. Sustainable Buildings' Energy-Efficient Retrofitting: A Study of Large Office Buildings in Beijing. *Sustainability* **2022**, *14*, 1021. [CrossRef]
4. Ghose, A.; Pizzol, M.; McLaren, S.J.; Vignes, M.; Dowdell, D. Refurbishment of office buildings in New Zealand: Identifying priorities for reducing environmental impacts. *Int. J. Life Cycle Assess.* **2019**, *24*, 1480–1495. [CrossRef]
5. Harris, R. The changing nature of the workplace and the future of office space. *J. Prop. Invest. Financ.* **2015**, *33*, 424–435. [CrossRef]
6. Kaya, S.; Williams, B. Effective churn management for business. *J. Corp. Real Estate* **2005**, *7*, 154–163. [CrossRef]
7. Forsythe, P.; Wilkinson, S. Measuring office fit-out changes to determine recurring embodied energy in building life cycle assessment. *Facilities* **2015**, *33*, 262–274. [CrossRef]
8. Forsythe, P. Quantifying the recurring nature of fitout to assist LCA studies in office buildings. *Int. J. Build. Pathol. Adapt.* **2017**, *35*, 233–246. [CrossRef]
9. Kooymans, R.; Abbott, J. Developing an effective service life asset management and valuation model. *J. Corp. Real Estate* **2006**, *8*, 198–212. [CrossRef]
10. Crosby, N.; Gibson, V.; Murdoch, S. UK Commercial Property Lease Structures: Landlord and Tenant Mismatch. *Urban Stud.* **2003**, *40*, 1487–1516. [CrossRef]
11. Worthington, J. Accommodating change—Emerging real estate strategies. *J. Corp. Real Estate* **2001**, *3*, 81–95. [CrossRef]
12. Sun, P.; Zhang, N.; Zuo, J.; Mao, R.; Gao, X.; Duan, H. Characterizing the generation and flows of building interior decoration and renovation waste: A case study in Shenzhen City. *J. Clean. Prod.* **2020**, *260*, 121077. [CrossRef]
13. Gou, Z. Green building for office interiors: Challenges and opportunities. *Facilities* **2016**, *34*, 614–629. [CrossRef]
14. Nase, I.; Berry, J.; Adair, A. Real estate value and quality design in commercial office properties. *J. Eur. Real Estate Res.* **2013**, *6*, 48–62. [CrossRef]
15. Hasik, V.; Escott, E.; Bates, R.; Carlisle, S.; Faircloth, B.; Bilec, M.M. Comparative whole-building life cycle assessment of renovation and new construction. *Build. Environ.* **2019**, *161*, 106218. [CrossRef]
16. Ismaeel, W.S.E.; Alamoudy, F.O.; Sameh, R. How renovation activities may jeopardise indoor air quality: Accounting for short and long-term symptoms of sick building syndrome in educational buildings. *Archit. Eng. Des. Manag.* **2023**, *19*, 360–377. [CrossRef]
17. Awad, J.; Jung, C. Evaluating the Indoor Air Quality after Renovation at the Greens in Dubai, United Arab Emirates. *Buildings* **2021**, *11*, 353. [CrossRef]
18. Ismaeel, W.S.E.; Mohamed, A.G. Indoor air quality for sustainable building renovation: A decision-support assessment system using structural equation modelling. *Build. Environ.* **2022**, *214*, 108933. [CrossRef]

19. Mucha, W.; Mainka, A.; Brągoszewska, E. Impact of ventilation system retrofitting on indoor air quality in a single-family building. *Build. Environ.* **2024**, *262*, 111830. [CrossRef]
20. Fahad Alomirah, H.; Moda, H.M. Assessment of Indoor Air Quality and Users Perception of a Renovated Office Building in Manchester. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1972. [CrossRef]
21. Obeidat, A.M.; Obeidat, A.M. Interior Design Strategies for Improving Quality of Life: How Can Residential Spaces Reflect a Healthy Lifestyle and Psychological Comfort. *Int. J. Hous. Sci. Its Appl.* **2024**, *45*, 71–86. [CrossRef]
22. Al Horr, Y.; Arif, M.; Katafygiotou, M.; Mazroei, A.; Kaushik, A.; Elsarrag, E. Impact of indoor environmental quality on occupant well-being and comfort: A review of the literature. *Int. J. Sustain. Built Environ.* **2016**, *5*, 1–11. [CrossRef]
23. Agha-Hossein, M.M.; El-Jouzi, S.; Elmualim, A.A.; Ellis, J.; Williams, M. Post-occupancy studies of an office environment: Energy performance and occupants' satisfaction. *Build. Environ.* **2013**, *69*, 121–130. [CrossRef]
24. Tawil, N.; Sztuka, I.M.; Pohlmann, K.; Sudimac, S.; Kühn, S. The Living Space: Psychological Well-Being and Mental Health in Response to Interiors Presented in Virtual Reality. *Int. J. Environ. Res. Public Health* **2021**, *18*, 12510. [CrossRef]
25. Candido, C.; Gocer, O.; Marzban, S.; Gocer, K.; Thomas, L.; Zhang, F.; Gou, Z.; Mackey, M.; Engelen, L.; Tjondronegoro, D. Occupants' satisfaction and perceived productivity in open-plan offices designed to support activity-based working: Findings from different industry sectors. *J. Corp. Real Estate* **2021**, *23*, 106–129. [CrossRef]
26. Hongisto, V.; Haapakangas, A.; Varjo, J.; Helenius, R.; Koskela, H. Refurbishment of an open-plan office–Environmental and job satisfaction. *J. Environ. Psychol.* **2016**, *45*, 176–191. [CrossRef]
27. McArthur, J.J.; Jofeh, C.; Aguilar, A.-M. Improving Occupant Wellness in Commercial Office Buildings through Energy Conservation Retrofits. *Buildings* **2015**, *5*, 1171–1186. [CrossRef]
28. Kwon, M.; Remøy, H.; Van Den Dobbelsteen, A. User-focused office renovation: A review into user satisfaction and the potential for improvement. *Prop. Manag.* **2019**, *37*, 470–489. [CrossRef]
29. Alwisy, A.; BuHamdan, S.; Gül, M. Criteria-based ranking of green building design factors according to leading rating systems. *Energy Build.* **2018**, *178*, 347–359. [CrossRef]
30. Nielsen, A.N.; Jensen, R.L.; Larsen, T.S.; Nissen, S.B. Early stage decision support for sustainable building renovation–A review. *Build. Environ.* **2016**, *103*, 165–181. [CrossRef]
31. Chen, W.; Lai, J. Performance assessment of residential building renovation: A scientometric analysis and qualitative review of literature. *Smart Sustain. Built Environ.* **2024**, *14*, 625–648. [CrossRef]
32. Bibang Bi Obam Assoumou, S.S.; Zhu, L.; Khayeka-Wandabwa, C. Healthy building standards, their integration into green building practices and rating systems for one health. *Discov. Sustain.* **2025**, *6*, 796. [CrossRef]
33. Nicolini, E. Built Environment and Wellbeing—Standards, Multi-Criteria Evaluation Methods, Certifications. *Sustainability* **2022**, *14*, 4754. [CrossRef]
34. Lee, J.-Y.; Wargocki, P.; Chan, Y.-H.; Chen, L.; Tham, K.-W. How does indoor environmental quality in green refurbished office buildings compare with the one in new certified buildings? *Build. Environ.* **2020**, *171*, 106677. [CrossRef]
35. Steinemann, A.; Wargocki, P.; Rismanchi, B. Ten questions concerning green buildings and indoor air quality. *Build. Environ.* **2017**, *112*, 351–358. [CrossRef]
36. Raouf, A.M.; Al-Ghamdi, S.G. Framework to evaluate quality performance of green building delivery: Construction and operational stage. *Int. J. Constr. Manag.* **2023**, *23*, 253–267. [CrossRef]
37. Thomas, L.E. Evaluating design strategies, performance and occupant satisfaction: A low carbon office refurbishment. *Build. Res. Inf.* **2010**, *38*, 610–624. [CrossRef]
38. Šuman, N.; Marinič, M.; Kuhta, M. A Methodological Framework for Sustainable Office Building Renovation Using Green Building Rating Systems and Cost-Benefit Analysis. *Sustainability* **2020**, *12*, 6156. [CrossRef]
39. Ramírez-Villegas, R.; Eriksson, O.; Olofsson, T. Assessment of renovation measures for a dwelling area–Impacts on energy efficiency and building certification. *Build. Environ.* **2016**, *97*, 26–33. [CrossRef]
40. Rashdan, W.; Ashour, A.F. Exploring Sustainability in Interior Design: A Comprehensive Systematic Review. *Buildings* **2024**, *14*, 2303. [CrossRef]
41. Sun, C.-Y.; Chen, Y.-G.; Wang, R.-J.; Lo, S.-C.; Yau, J.-T.; Wu, Y.-W. Construction Cost of Green Building Certified Residence: A Case Study in Taiwan. *Sustainability* **2019**, *11*, 2195. [CrossRef]
42. Ashour, M.; Mahdiyar, A.; Haron, S.H. A Comprehensive Review of Deterrents to the Practice of Sustainable Interior Architecture and Design. *Sustainability* **2021**, *13*, 10403. [CrossRef]
43. Maghsoudi Nia, E.; Qian, Q.K.; Visscher, H.J. Analysis of Occupant Behaviours in Energy Efficiency Retrofitting Projects. *Land* **2022**, *11*, 1944. [CrossRef]
44. Sáez-de-Guinoa, A.; Zambrana-Vasquez, D.; Fernández, V.; Bartolomé, C. Circular Economy in the European Construction Sector: A Review of Strategies for Implementation in Building Renovation. *Energies* **2022**, *15*, 4747. [CrossRef]
45. Liao, H.; Ren, R.; Li, L. Existing Building Renovation: A Review of Barriers to Economic and Environmental Benefits. *Int. J. Environ. Res. Public Health* **2023**, *20*, 4058. [CrossRef] [PubMed]

46. Chen, Y.-A.; Su, F.-I.; Sun, C.-Y. Cost and Incentive Analysis of Green Building Label Upgrades in Taiwan's Residential Sector: A Case Study of Silver to Gold EEWH Certification. *Buildings* **2025**, *15*, 2956. [CrossRef]
47. Chang, P.-T.; Huang, L.-C.; Lin, H.-J. The fuzzy Delphi method via fuzzy statistics and membership function fitting and an application to the human resources. *Fuzzy Sets Syst.* **2000**, *112*, 511–520. [CrossRef]
48. Ishikawa, A.; Amagasa, M.; Shiga, T.; Tomizawa, G.; Tatsuta, R.; Mieno, H. The max-min Delphi method and fuzzy Delphi method via fuzzy integration. *Fuzzy Sets Syst.* **1993**, *55*, 241–253. [CrossRef]
49. Lin, C. Application of fuzzy Delphi method (FDM) and fuzzy analytic hierarchy process (FAHP) to criteria weights for fashion design scheme evaluation. *Int. J. Cloth. Sci. Technol.* **2013**, *25*, 171–183. [CrossRef]
50. Khalil, N.; Kamaruzzaman, S.N.; Baharum, M.R. Ranking the indicators of building performance and the users' risk via Analytical Hierarchy Process (AHP): Case of Malaysia. *Ecol. Indic.* **2016**, *71*, 567–576. [CrossRef]
51. Ameen, R.F.M.; Mourshed, M. Urban sustainability assessment framework development: The ranking and weighting of sustainability indicators using analytic hierarchy process. *Sustain. Cities Soc.* **2019**, *44*, 356–366. [CrossRef]
52. Nilashi, M.; Zakaria, R.; Ibrahim, O.; Majid, M.Z.A.; Mohamad Zin, R.; Chugtai, M.W.; Zainal Abidin, N.I.; Sahamir, S.R.; Aminu Yakubu, D. A knowledge-based expert system for assessing the performance level of green buildings. *Knowl. Based Syst.* **2015**, *86*, 194–209. [CrossRef]
53. AbdelAzim, A.I.; Ibrahim, A.M.; Aboul-Zahab, E.M. Development of an energy efficiency rating system for existing buildings using Analytic Hierarchy Process–The case of Egypt. *Renew. Sustain. Energy Rev.* **2017**, *71*, 414–425. [CrossRef]
54. Khorramshahgol, R.; Moustakis, V.S. Delphic hierarchy process (DHP): A methodology for priority setting derived from the Delphi method and analytical hierarchy process. *Eur. J. Oper. Res.* **1988**, *37*, 347–354. [CrossRef]
55. Han, D.; Kalantari, M.; Rajabifard, A. Identifying and prioritizing sustainability indicators for China's assessing demolition waste management using modified Delphi–analytic hierarchy process method. *Waste Manag. Res.* **2023**, *41*, 1649–1660. [CrossRef]
56. Chen, C.-W.; Wang, J.-H.; Wang, J.C.; Shen, Z.-H. Developing indicators for sustainable campuses in Taiwan using fuzzy Delphi method and analytic hierarchy process. *J. Clean. Prod.* **2018**, *193*, 661–671. [CrossRef]
57. Shao, W.-C.; Chen, J.-W.; Dong, Y.-W.; Lu, C.-L.; Chiou, Y.-T. Developing Indicators for Healthy Building in Taiwan Using Fuzzy Delphi Method and Analytic Hierarchy Process. *Buildings* **2023**, *13*, 1860. [CrossRef]
58. Hsueh, S.-L.; Sun, Y.; Gao, M.; Hu, X.; Meen, T.-H. Delphi and Analytical Hierarchy Process Fuzzy Model for Auxiliary Decision-making for Cross-field Learning in Landscape Design. *Sens. Mater.* **2022**, *34*, 1707–1719. [CrossRef]
59. Xing, Q.; Tan, H.P.; Gan, S.W. Constructing a student development model for undergraduate vocational universities in China using the Fuzzy Delphi Method and Analytic Hierarchy Process. *PLoS ONE* **2024**, *19*, e0301017. [CrossRef]
60. Vidal, L.-A.; Marle, F.; Bocquet, J.-C. Using a Delphi process and the Analytic Hierarchy Process (AHP) to evaluate the complexity of projects. *Expert Syst. Appl.* **2011**, *38*, 5388–5405. [CrossRef]
61. Simpeh, E.K.; Pillay, J.-P.G.; Ndihokubwayo, R.; Nalumu, D.J. Improving energy efficiency of HVAC systems in buildings: A review of best practices. *Int. J. Build. Pathol. Adapt.* **2022**, *40*, 165–182. [CrossRef]
62. Demir, Z.; Köse, A. Evaluation of WELL Certificate in terms of Energy Efficiency and Sustainability in Educational Buildings. *Int. J. New Find. Eng. Sci. Technol.* **2025**, 54–65. Available online: https://dergipark.org.tr/en/pub/ijonfest/article/1736647#article_cite (accessed on 26 January 2026). [CrossRef]
63. Persily, A.K.; Emmerich, S.J. Indoor air quality in sustainable, energy efficient buildings. *Hvac R Res.* **2012**, *18*, 4–20. [CrossRef]
64. Pérez-Lombard, L.; Ortiz, J.; Coronel, J.F.; Maestre, I.R. A review of HVAC systems requirements in building energy regulations. *Energy Build.* **2011**, *43*, 255–268. [CrossRef]
65. Alves, O.; Monteiro, E.; Brito, P.; Romano, P. Measurement and classification of energy efficiency in HVAC systems. *Energy Build.* **2016**, *130*, 408–419. [CrossRef]
66. Asim, N.; Badiei, M.; Mohammad, M.; Razali, H.; Rajabi, A.; Chin Haw, L.; Jameelah Ghazali, M. Sustainability of Heating, Ventilation and Air-Conditioning (HVAC) Systems in Buildings—An Overview. *Int. J. Environ. Res. Public Health* **2022**, *19*, 1016. [CrossRef]
67. Xuan, X. Effectiveness of indoor environment quality in LEED-certified healthcare settings. *Indoor Built Environ.* **2016**, *25*, 786–798. [CrossRef]
68. Lee, J.Y.; Wargocki, P.; Chan, Y.H.; Chen, L.; Tham, K.W. Indoor environmental quality, occupant satisfaction, and acute building-related health symptoms in Green Mark-certified compared with non-certified office buildings. *Indoor Air* **2019**, *29*, 112–129. [CrossRef]
69. Parise, G.; Martirano, L.; Di Ponio, S. Energy performance of interior lighting systems. *IEEE Trans. Ind. Appl.* **2013**, *49*, 2793–2801. [CrossRef]
70. Xuan, X. Study of indoor environmental quality and occupant overall comfort and productivity in LEED-and non-LEED–certified healthcare settings. *Indoor Built Environ.* **2018**, *27*, 544–560. [CrossRef]
71. Nimlyat, P.S. Indoor environmental quality performance and occupants' satisfaction [IEQPOS] as assessment criteria for green healthcare building rating. *Build. Environ.* **2018**, *144*, 598–610. [CrossRef]

72. Veitch, J.A.; Newsham, G.R. Lighting quality and energy-efficiency effects on task performance, mood, health, satisfaction, and comfort. *J. Illum. Eng. Soc.* **1998**, *27*, 107–129. [CrossRef]
73. Silva-Afonso, A.; Rodrigues, C. Water efficiency of products and buildings: The implementation of certification and labelling measures in Portugal. In Proceedings of the 34th International Symposium on CIB W062 Water Supply and Drainage for Buildings, Hong Kong, China, 8–10 September 2008; pp. 230–240. Available online: https://www.irbnet.de/daten/iconda/CIB11776.pdf (accessed on 26 January 2026).
74. Wiengarten, F.; Humphreys, P.; Onofrei, G.; Fynes, B. The adoption of multiple certification standards: Perceived performance implications of quality, environmental and health & safety certifications. *Prod. Plan. Control* **2017**, *28*, 131–141.
75. Eldeeb, A.; Elantary, A. Examining Sustainable Materials: Enhancing Indoor Air Quality for Office Interiors. *Emir. J. Eng. Res.* **2025**, *30*, 2.
76. Wei, W.; Ramalho, O.; Mandin, C. Indoor air quality requirements in green building certifications. *Build. Environ.* **2015**, *92*, 10–19. [CrossRef]
77. Chen, C.C.; Kuo, W.C.; Chiang, C.M.; Liu, K.S.; Nieh, C.K. A study on the impact of different application ratios of ultra-low emission green building materials on human health in indoor environments. *Appl. Mech. Mater.* **2013**, *271*, 126–130.
78. Liu, W.; Zhang, Y.; Yao, Y.; Li, J. Indoor decorating and refurbishing materials and furniture volatile organic compounds emission labeling systems: A review. *Chin. Sci. Bull.* **2012**, *57*, 2533–2543. [CrossRef]
79. Jung, C.; Abdelaziz Mahmoud, N.S.; Al Qassimi, N.; Elsamanoudy, G. Preliminary study on the emission dynamics of TVOC and formaldehyde in homes with eco-friendly materials: Beyond green building. *Buildings* **2023**, *13*, 2847. [CrossRef]
80. Ahmadi, S. From Efficiency to Sustainability: A Review of Low-Emission Glass. *Adv. Stand. Appl. Sci.* **2025**, *3*, 4–14.
81. Wei, G.; Yu, X.; Fang, L.; Wang, Q.; Tanaka, T.; Amano, K.; Yang, X. A review and comparison of the indoor air quality requirements in selected building standards and certifications. *Build. Environ.* **2022**, *226*, 109709. [CrossRef]
82. Zhang, H.; Srinivasan, R. A systematic review of air quality sensors, guidelines, and measurement studies for indoor air quality management. *Sustainability* **2020**, *12*, 9045. [CrossRef]
83. Tse, M.; Chau, C.K.; Lee, W.L. Assessing the benefit and cost for a voluntary indoor air quality certification scheme in Hong Kong. *Sci. Total Environ.* **2004**, *320*, 89–107. [CrossRef] [PubMed]
84. Tsai, W.-T. Overview of green building material (GBM) policies and guidelines with relevance to indoor air quality management in Taiwan. *Environments* **2017**, *5*, 4. [CrossRef]
85. Saffell, J.; Nehr, S. Improving indoor air quality through standardization. *Standards* **2023**, *3*, 240–267. [CrossRef]
86. Licina, D.; Langer, S. Indoor air quality investigation before and after relocation to WELL-certified office buildings. *Build. Environ.* **2021**, *204*, 108182. [CrossRef]
87. Torresin, S.; Aletta, F.; Babich, F.; Bourdeau, E.; Harvie-Clark, J.; Kang, J.; Lavia, L.; Radicchi, A.; Albatici, R. Acoustics for supportive and healthy buildings: Emerging themes on indoor soundscape research. *Sustainability* **2020**, *12*, 6054. [CrossRef]
88. Marques, G.; Pitarma, R. A real-time noise monitoring system based on internet of things for enhanced acoustic comfort and occupational health. *IEEE Access* **2020**, *8*, 139741–139755. [CrossRef]
89. Evans, J.B.; Himmel, C.N. Acoustical and noise control criteria and guidelines for building design and operations. In Proceedings of the 9th International Conference for Enhanced Building Operations, Austin, TX, USA, 17–19 November 2009. Available online: https://oaktrust.library.tamu.edu/server/api/core/bitstreams/62965881-4f31-4c93-8274-47858a9c244f/content (accessed on 26 January 2026).
90. Yaman, M.; Ulukavak Harputlugil, G.; Kurtay, C. A holistic approach to different regulations for acoustic improvements in industrial facilities. *Noise Vib. Worldw.* **2024**, *55*, 499–511. [CrossRef]
91. Lee, Y.S.; Kim, S.-K. Indoor environmental quality in LEED-certified buildings in the U.S. *J. Asian Archit. Build. Eng.* **2008**, *7*, 293–300. [CrossRef]
92. Torresin, S.; Albatici, R.; Aletta, F.; Babich, F.; Oberman, T.; Kang, J. Acoustic design criteria in naturally ventilated residential buildings: New research perspectives by applying the indoor soundscape approach. *Appl. Sci.* **2019**, *9*, 5401. [CrossRef]
93. Kurukose Cal, H.; Aletta, F.; Kang, J. Integration of soundscape assessment and design principles into international standards and guidelines for learning environment acoustics. *Build. Acoust.* **2025**, *32*, 463–479. [CrossRef]
94. Hwang, T.; Kim, J.T. Effects of indoor lighting on occupants' visual comfort and eye health in a green building. *Indoor Built Environ.* **2011**, *20*, 75–90. [CrossRef]
95. Kwong, Q.J. Light level, visual comfort and lighting energy savings potential in a green-certified high-rise building. *J. Build. Eng.* **2020**, *29*, 101198. [CrossRef]
96. Lee, Y.S. Comparisons of Indoor Air Quality and Thermal Comfort Quality between Certification Levels of LEED-Certified Buildings in USA. *Indoor Built Environ.* **2011**, *20*, 564–576. [CrossRef]
97. Altomonte, S.; Schiavon, S.; Kent, M.G.; Brager, G. Indoor environmental quality and occupant satisfaction in green-certified buildings. *Build. Res. Inf.* **2019**, *47*, 255–274. [CrossRef]

98. Jain, H. Critical insights into thermal comfort optimization and heat resilience in indoor spaces. *City Built Environ.* **2024**, *2*, 14. [CrossRef]
99. Yang, L.; Wang, F.; Zhao, S.; Gao, S.; Yan, H.; Sun, Z.; Lian, Z.; Duanmu, L.; Zhang, Y.; Zhou, X.; et al. Comparative analysis of indoor thermal environment characteristics and occupants' adaptability: Insights from ASHRAE RP-884 and the Chinese thermal comfort database. *Energy Build.* **2024**, *309*, 114033. [CrossRef]
100. Carlucci, S.; Bai, L.; de Dear, R.; Yang, L. Review of adaptive thermal comfort models in built environmental regulatory documents. *Build. Environ.* **2018**, *137*, 73–89. [CrossRef]
101. Amaripadath, D.; Mirzaei, P.A.; Attia, S. Multi-criteria thermal resilience certification scheme for indoor built environments during heat waves. *Energy Built Environ.* **2025**, *6*, 1052–1063. [CrossRef]
102. Ning, H.; Wang, Z.; Ji, Y. Thermal history and adaptation: Does a long-term indoor thermal exposure impact human thermal adaptability? *Appl. Energy* **2016**, *183*, 22–30. [CrossRef]
103. Albatayneh, A.; Jaradat, M.; AlKhatib, M.B.; Abdallah, R.; Juaidi, A.; Manzano-Agugliaro, F. The Significance of the Adaptive Thermal Comfort Practice over the Structure Retrofits to Sustain Indoor Thermal Comfort. *Energies* **2021**, *14*, 2946. [CrossRef]
104. Chiaramello, E.; Bonato, M.; Fiocchi, S.; Tognola, G.; Parazzini, M.; Ravazzani, P.; Wiart, J. Radio Frequency Electromagnetic Fields Exposure Assessment in Indoor Environments: A Review. *Int. J. Environ. Res. Public Health* **2019**, *16*, 955. [CrossRef] [PubMed]
105. Ramirez-Vazquez, R.; Escobar, I.; Thielens, A.; Arribas, E. Measurements and Analysis of Personal Exposure to Radiofrequency Electromagnetic Fields at Outdoor and Indoor School Buildings: A Case Study at a Spanish School. *IEEE Access* **2020**, *8*, 195692–195702. [CrossRef]
106. Bashir, M.T.; Alrowais, R.; Lal, R.; Bashir, M.; Sikandar, M.A.; Zahid, N.; Khan, M.M.H.; Saad, S.; Abbas, M.I.; Khan, M.W.; et al. Synergizing Health and Technology in Green Buildings: A Critical Review of Indoor Air Quality Monitoring and Solutions. *Indoor Air* **2025**, *2025*, 1281155. [CrossRef]
107. The International Commission on Non-Ionizing Radiation Protection. ICNIRP statement on EMF-emitting new technologies. *Health Phys.* **2008**, *94*, 376–392. [CrossRef]
108. Loftness, V.; Hakkinen, B.; Adan, O.; Nevalainen, A. Elements that contribute to healthy building design. *Env. Health Perspect* **2007**, *115*, 965–970. [CrossRef]
109. Salonen, H.; Lahtinen, M.; Lappalainen, S.; Nevala, N.; Knibbs, L.D.; Morawska, L.; Reijula, K. Design approaches for promoting beneficial indoor environments in healthcare facilities: A review. *Intell. Build. Int.* **2013**, *5*, 26–50. [CrossRef]
110. Spengler, J.D.; Chen, Q. Indoor air quality factors in designing a healthy building. *Annu. Rev. Environ. Resour.* **2000**, *25*, 567–600. [CrossRef]
111. Salonen, H.; Lahtinen, M.; Lappalainen, S.; Nevala, N.; Knibbs, L.D.; Morawska, L.; Reijula, K. Physical characteristics of the indoor environment that affect health and wellbeing in healthcare facilities: A review. *Intell. Build. Int.* **2013**, *5*, 3–25. [CrossRef]
112. Aristizabal, S.; Porter, P.; Clements, N.; Campanella, C.; Zhang, R.; Hovde, K.; Lam, C. Conducting Human-Centered Building Science at the Well Living Lab. *Technol. Archit. Des.* **2019**, *3*, 161–173. [CrossRef]
113. Ferhati, K.; Gottschald, M. Enhancing Fiscal Outcomes through Human-Centered Design: The Economic Benefits of Salutogenic Architecture in Public Health Care Facilities. *J. Salut. Archit.* **2023**, *2*, 1–18. [CrossRef]
114. Samaras, G.M.; Horst, R.L. A systems engineering perspective on the human-centered design of health information systems. *J. Biomed. Inform.* **2005**, *38*, 61–74. [CrossRef]
115. Rek-Lipczyńska, A. Salutogenic Factors and Sustainable Development Criteria in Architectural and Interior Design: Analysis of Polish and EU Standards and Recommendations. *Sustainability* **2025**, *17*, 9661. [CrossRef]
116. Jiang, S.; Verderber, S. On the Planning and Design of Hospital Circulation Zones:A Review of the Evidence-Based Literature. *HERD Health Environ. Res. Des. J.* **2017**, *10*, 124–146. [CrossRef]
117. Shin, J.; Lee, J.-K. Indoor Walkability Index: BIM-enabled approach to Quantifying building circulation. *Autom. Constr.* **2019**, *106*, 102845. [CrossRef]
118. Geldermans, B.; Tenpierik, M.; Luscuere, P. Human Health and Well-Being in Relation to Circular and Flexible Infill Design: Assessment Criteria on the Operational Level. *Sustainability* **2019**, *11*, 1984. [CrossRef]
119. Langiano, E.; Ferrara, M.; Falese, L.; Lanni, L.; Diotaiuti, P.; Di Libero, T.; De Vito, E. Assessment of Indoor Air Quality in School Facilities: An Educational Experience of Pathways for Transversal Skills and Orientation (PCTO). *Sustainability* **2024**, *16*, 6612. [CrossRef]
120. Fonseca, F.; Paschoalino, M.; Silva, L. Health and Well-Being Benefits of Outdoor and Indoor Vertical Greening Systems: A Review. *Sustainability* **2023**, *15*, 4107. [CrossRef]
121. Potrč Obrecht, T.; Kunič, R.; Jordan, S.; Dovjak, M. Comparison of Health and Well-Being Aspects in Building Certification Schemes. *Sustainability* **2019**, *11*, 2616. [CrossRef]
122. Rohde, L.; Larsen, T.S.; Jensen, R.L.; Larsen, O.K. Framing holistic indoor environment: Definitions of comfort, health and well-being. *Indoor Built Environ.* **2020**, *29*, 1118–1136. [CrossRef]

123. Han, H.; Hyun, S.S. Green indoor and outdoor environment as nature-based solution and its role in increasing customer/employee mental health, well-being, and loyalty. *Bus. Strategy Environ.* **2019**, *28*, 629–641. [CrossRef]
124. Kent, M.G.; Parkinson, T.; Schiavon, S. Indoor environmental quality in WELL-certified and LEED-certified buildings. *Sci. Rep.* **2024**, *14*, 15120. [CrossRef]
125. Yu, C.W.F.; Kim, J.T. Building Environmental Assessment Schemes for Rating of IAQ in Sustainable Buildings. *Indoor Built Environ.* **2011**, *20*, 5–15. [CrossRef]
126. Tleuken, A.; Tokazhanov, G.; Guney, M.; Turkyilmaz, A.; Karaca, F. Readiness Assessment of Green Building Certification Systems for Residential Buildings during Pandemics. *Sustainability* **2021**, *13*, 460. [CrossRef]
127. Sesana, M.M.; Salvalai, G. A review on Building Renovation Passport: Potentialities and barriers on current initiatives. *Energy Build.* **2018**, *173*, 195–205. [CrossRef]
128. Hassanain, M.A.; Aljuhani, M.; Hamida, M.B.; Salaheldin, M.H. A Framework for Fire Safety Management in School Facilities. *Int. J. Built Environ. Sustain.* **2022**, *9*, 1–9. [CrossRef]
129. Ivanov, M.L.; Chow, W.-K. Fire safety in modern indoor and built environment. *Indoor Built Environ.* **2023**, *32*, 3–8. [CrossRef]
130. Agus Salim, N.A.; Salleh, N.M.; Jaafar, M.; Sulieman, M.Z.; Ulang, N.M.; Ebekozien, A. Fire safety management in public health-care buildings: Issues and possible solutions. *J. Facil. Manag.* **2021**, *21*, 69–83. [CrossRef]
131. Roberts, D. Risk Management and Electrical Safety: Implementation of an Occupational Health and Safety Management System. *IEEE Ind. Appl. Mag.* **2015**, *21*, 67–74. [CrossRef]
132. Muhamad Salleh, N.; Agus Salim, N.A.; Jaafar, M.; Sulieman, M.Z.; Ebekozien, A. Fire safety management of public buildings: A systematic review of hospital buildings in Asia. *Prop. Manag.* **2020**, *38*, 497–511. [CrossRef]
133. Park, S.; Lee, S.; Jang, H.; Yoon, G.; Choi, M.-i.; Kang, B.; Cho, K.; Lee, T.; Park, S. Smart Fire Safety Management System (SFSMS) Connected with Energy Management for Sustainable Service in Smart Building Infrastructures. *Buildings* **2023**, *13*, 3018. [CrossRef]
134. Zhao, L.; Yang, Y.; Wu, Z. Review of Communication Technology in Indoor Air Quality Monitoring System and Challenges. *Electronics* **2022**, *11*, 2926. [CrossRef]
135. Firdhous, M.F.M.; Sudantha, B.H.; Karunaratne, P.M. IoT enabled proactive indoor air quality monitoring system for sustainable health management. In Proceedings of the 2017 2nd International Conference on Computing and Communications Technologies (ICCCT), Chennai, India, 23–24 February 2017; pp. 216–221.
136. Marques, G.; Pitarma, R. An Indoor Monitoring System for Ambient Assisted Living Based on Internet of Things Architecture. *Int. J. Environ. Res. Public Health* **2016**, *13*, 1152. [CrossRef] [PubMed]
137. Sun, S.; Zheng, X.; Villalba-Díez, J.; Ordieres-Meré, J. Indoor Air-Quality Data-Monitoring System: Long-Term Monitoring Benefits. *Sensors* **2019**, *19*, 4157. [CrossRef] [PubMed]
138. Srivani Maddala, V.K. Green pest management practices for sustainable buildings: Critical review. *Sci. Prog.* **2019**, *102*, 141–152. [CrossRef]
139. Stephens, M.; Hazard, K.; Moser, D.; Cox, D.; Rose, R.; Alkon, A. An Integrated Pest Management Intervention Improves Knowledge, Pest Control, and Practices in Family Child Care Homes. *Int. J. Environ. Res. Public Health* **2017**, *14*, 1299. [CrossRef]
140. Zainol, N.N.; Ramli, N.A.; Mohammad, I.S.; Sukereman, A.S.; Sulaiman, M.A. Assessing measurement model of green cleaning components for green buildings. *J. Facil. Manag.* **2023**, *21*, 556–572. [CrossRef]
141. Allen, J.G.; MacNaughton, P.; Laurent, J.G.C.; Flanigan, S.S.; Eitland, E.S.; Spengler, J.D. Green Buildings and Health. *Curr. Environ. Health Rep.* **2015**, *2*, 250–258. [CrossRef]
142. Mallawaarachchi, H.; De Silva, L.; Rameezdeen, R. Indoor environmental quality and occupants' productivity: Suggestions to enhance national green certification criteria. *Built Environ. Proj. Asset Manag.* **2016**, *6*, 462–477. [CrossRef]
143. Buyukcinar, R.A.; Komurlu, R.; Arditi, D. Green-Certified Healthcare Facilities from a Global Perspective: Advanced and Developing Countries. *Sustainability* **2025**, *17*, 9974. [CrossRef]
144. Parkinson, T.; Parkinson, A.; de Dear, R. Continuous IEQ monitoring system: Performance specifications and thermal comfort classification. *Build. Environ.* **2019**, *149*, 241–252. [CrossRef]
145. Amin Beigh, F.; Rasool Shah, S.; Ahmad, K. A Perspective on Indoor Air Quality Monitoring, Guidelines, and the Use of Various Sensors. *Environ. Forensics* **2025**, *26*, 350–367. [CrossRef]
146. Pitarma, R.; Marques, G.; Ferreira, B.R. Monitoring Indoor Air Quality for Enhanced Occupational Health. *J. Med. Syst.* **2016**, *41*, 23. [CrossRef]

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