Trends And Innovations In Sustainable Architecture: A Bibliometric Review Of Energy Savings, Green Building, Ventilation System, And Thermal Comfort Research

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Abstract

This study aims to provide a comprehensive overview of research trends in sustainable architecture, with particular emphasis on the keywords energy savings, green buildings, and thermal comfort. Using a bibliometric approach, this article analyzes the development of relevant literature in the field of sustainable architecture, identifies research patterns, and uncovers the evolving international collaborations. The publication period between 2020-2025 with specific limitations led to the emergence of 56 documents for analysis. Scopus' in-built analysis system and VOSviewer were used to generate graphical and visual analyses of research trends. Scopus' built-in analysis system and VOSviewer were used to generate graphical and visual analyses of research trends. This study highlights the countries involved in research on building materials, façades, and thermal performance, which has attracted contributions from various nations. The results of sustainable architecture research in this study contribute to the development of more sustainable and attractive built environments worldwide.

Keywords : green building, energy efficiency building, thermal performance. optimization, ventilated facade

Introduction

In the face of escalating environmental challenges, the built environment has emerged as a critical focal point for sustainability efforts. As the global population continues to grow and urbanization accelerates, the demand for energy-efficient, environmentally conscious, and comfortable buildings has never been greater (Nations, 2019). Sustainable architecture, a discipline focused on minimizing the environmental impact of the built environment, has evolved in response to these challenges (Wedul, 2011).

Core components of this approach include energy savings, green building practices, and thermal comfort—three interconnected areas that play an essential role in creating buildings just environmentally responsible to improve the quality for the occupants (Zhou & Zheng, 2020). Energy consumption in buildings accounts for a substantial portion of global energy use, making energy-saving strategies a cornerstone of sustainable architectural practices (IEA, 2020).

The integration of renewable energy sources, energy-efficient systems, and the optimization of building performance through passive design have become central themes in contemporary architecture (GhaffarianHoseini et al., 2013). Meanwhile, green buildings, characterized by their use of sustainable materials, resource-efficient systems, and reduced ecological footprints, have garnered increasing attention as essential solutions to mitigate the environmental impacts of construction (Kats, 2010).

Equally important is thermal comfort, a critical factor influencing occupant satisfaction and productivity. Achieving thermal comfort while minimizing energy consumption requires innovative approaches to building design, materials selection, and climate-responsive technologies (Shaw, 1972). The relationship between energy efficiency and thermal comfort represents a key challenge for architects and researchers striving to create spaces that are both sustainable and conducive to human well-being (Bungau et al., 2024).

This bibliometric review seeks to provide an in-depth analysis of trends and innovations within these key areas—energy savings, green building, and thermal comfort—by synthesizing the evolving body of research published between 2020 and 2025. By leveraging bibliometric tools, the study aims to map the growth of these research themes, identify leading technologies and methodologies, and highlight the global networks driving innovation in sustainable architecture. The review contributes to a deeper understanding of the current landscape of sustainable architecture and offers insights into future research directions, emphasizing the need for integrated solutions that address both environmental and human-centric design challenges.

Methodology

In this study, bibliographic analysis is used to map knowledge and graphically visualize the map. Bibliographic analysis also explains the geographic sources and identifies prominent authors and affiliations involved in specific research keywords. The data source used in this study was obtained from Scopus, including the number, summaries, and keywords. The first step involved using four keywords determined by the authors during the collation process and querying the Scopus database using the following keywords: buildings, ventilation, energy, and heat. These keywords are explained in the Introduction chapter. They are crucial keywords in the current research from the sustainability perspective of modern urban architecture. The number of published documents includes publications from 2020 to 2025, covering various subjects, types of sources, and the final two phases of publication that define exclusions limiting documents before the data were exposed to the meta-analysis goals. The limitations (L) include Year (L1), Specialist Area (L2), Publication Phase (L3), and Language (L4) (Table 1). After searching and filtering the document results, the data was exported to a CSV Excel file containing citation layers and abstract keywords. Therefore, the extracted CSV Excel file was processed using VosViewer to create a meta-analysis of 56 publications. VosViewer enables researchers to visually understand the meta-analysis by displaying labels, density, cluster density view, and distribution view.

Result and discussion

A total of publications related to sustainable architecture design, energy savings, green buildings, and thermal comfort were analyzed. Table 1 shows the trend of publications from 2020 to 2025 shows fluctuations, with a significant increase in 2024 reaching its peak at 16 documents, followed by a sharp decline in 2025. The steady growth from 2020 to 2022 suggests rising research interest, while the sudden drop in 2025 may indicate incomplete data collection or shifting research priorities.

Table 1. Data Exclusion

Limitation criteria	Limitation	Information
L1: Year	2020 - 2025	Completed year
L2: subject area	Engineering Environmental science Energy	Correlation to keyword
L3: Publication Stage	Final	Final and officially published
L4: Language	English	The standard language for high impact journal

Regarding Table 2, the majority of research falls within the engineering field (44.1%), followed by environmental science (29.9%) and energy studies (26%). This distribution highlights the interdisciplinary nature of sustainable architecture, emphasizing engineering innovations, environmental impacts, and energy efficiency strategies.

Table 2. Documents by Subject Area

Subject	Percentage
Engineering	44,1 %
Environmental Science	29,9 %
Energy	26 %

In terms of publication sources, Table 3 shows that key journals and proceedings include Sustainability Switzerland, Lecture Notes in Civil Engineering, IOP Conference Series: Earth and Environmental Science, energy, and Buildings, each contributing four documents. Other notable sources include Building and Environmental, Renewable and Sustainable Energy Reviews, and Atmosphere. These journals play a crucial role in disseminating findings on sustainable architectural solutions, reflecting the growing significance of this research domain.

Table 3. Most Published Journals/proceedings.

Journal/Proceeding Name	Total documents
Sustainability Switzerland	4

Lecture Notes In Civil Engineering	4
Iop Conference Series Earth And Environmental Science	4
Energy And Building	4
Building And Environmental	3
Renewable And Sustainable Energy Reviews	2
Atmosphere	2

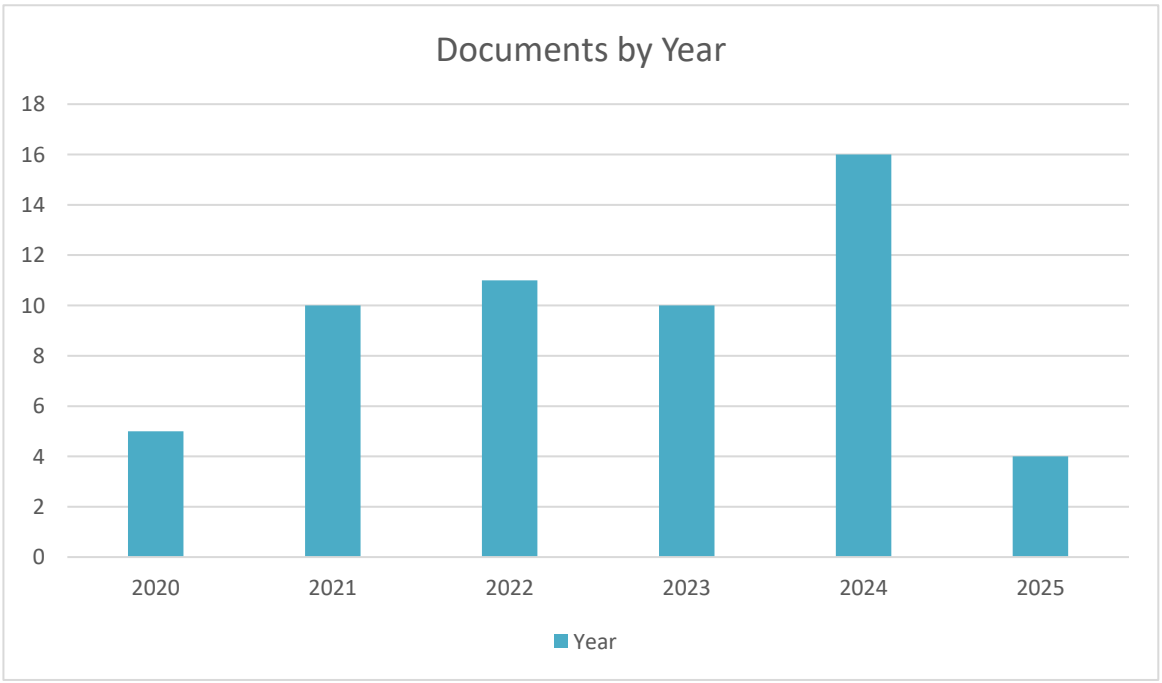

Chart 1. Documents diagram about sustainability architecture by year

Research on building materials, façades, and thermal performance has attracted contributions from various countries. The dataset analysis using VOSViewer highlights key countries engaged in this field. The visualization measures the strength of the links between these countries based on co-authorship and collaborative research networks.

China emerges as the most active country in this domain, contributing to four research documents indexed in Scopus. Italy, United Kingdom, and Australia follow, each contributing one document. The network visualization indicates the extent of collaboration between these nations, shedding light on global research efforts towards improving building performance and sustainability.

This analysis aligns with prior research trends, where European countries and China consistently lead in scientific contributions related to sustainable architecture and energy-efficient buildings. The interconnected research efforts demonstrate a growing international interest in optimizing building

design through innovative materials and technologies. (Harus dari negara tropis, bisa jadi point plus karna belum ada)

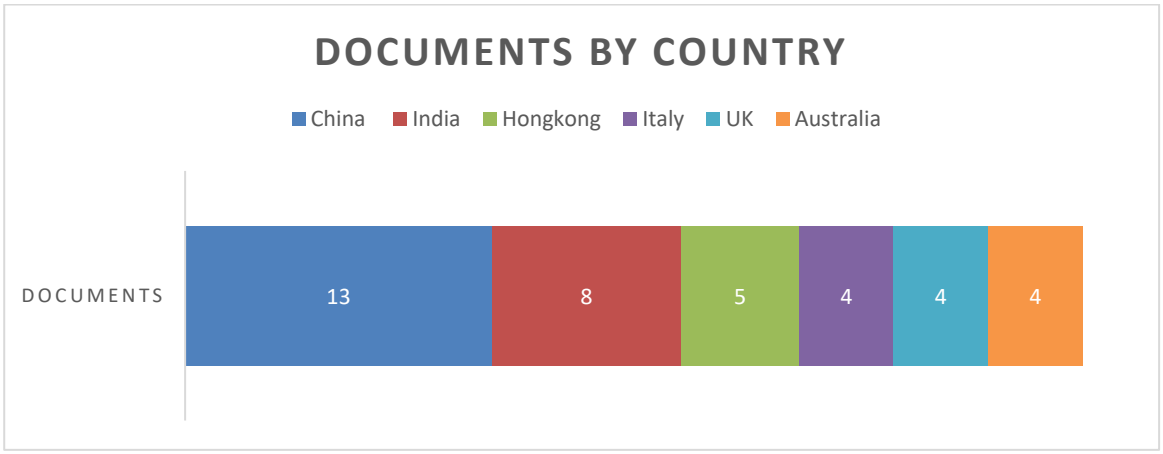

Chart 2. Documents by Country.

The VOSviewer visualization reveals three key clusters related to sustainable architecture design, each representing different but interconnected aspects. The first cluster (red) focuses on thermal comfort and ventilation strategies, including keywords like **architectural design, climate change, energy conservation, natural ventilation, and air quality.** This cluster highlights how ventilation and indoor air quality play a crucial role in maintaining thermal comfort while optimizing energy use. It also emphasizes the relationship between climate change adaptation and architectural solutions for improving natural ventilation and reducing indoor air pollution.

The second cluster (green) centers on energy efficiency and sustainable building practices, featuring terms such as energy efficiency, air conditioning, energy utilization, green building, and sustainable development. This cluster underlines the importance of energy-saving strategies in reducing the environmental impact of buildings while ensuring sustainability. The close connection between energy consumption and green building technologies suggests that energy-efficient solutions contribute to sustainable development by integrating smart materials and design techniques.

The third cluster (blue) highlights energy savings and green building innovations, with keywords like energy, thermal insulation, energy savings, and green buildings. This cluster demonstrates how thermal insulation is a critical factor in reducing energy consumption, as it helps maintain indoor temperatures with minimal reliance on heating and cooling systems. The link between energy savings and green buildings suggests that integrating thermal insulation and sustainable materials can enhance overall building performance.

Overall, these three clusters are deeply interconnected. Thermal comfort and ventilation strategies (Cluster 1) influence energy efficiency (Cluster 2), as proper natural ventilation can reduce reliance on air conditioning. In turn, energy efficiency (Cluster 2) supports energy savings (Cluster 3) by reducing overall power consumption in green buildings. Furthermore, thermal insulation (Cluster 3) contributes to thermal comfort (Cluster 1), showcasing the importance of selecting sustainable materials in architectural design. This bibliometric analysis highlights the need for an integrated approach to sustainable architecture, where energy efficiency, ventilation strategies, and thermal comfort solutions work together to create eco-friendly and high-performance buildings.

Table 4. VOSviewer Cluster Indicators.

No	Colour	Label Name	Contain
1	Red	Air quality	Air quality
			Architectural design
			Building
			Climate change
			Enercy conversation
			Indoor air pollution
			Natural ventilation
			Optimization
			Thermal comfort
			Ventilation
2	Green	Air conditioningl	Air conditioning
			Energy efficiency
			Energy utilization
			Energy consuption
			Environmental impact
			Green building
			Sustainability
			Sustainable building
			Sustainable developer

3	Blue	Energy	Energy Energy savings Green building Thermal insulation

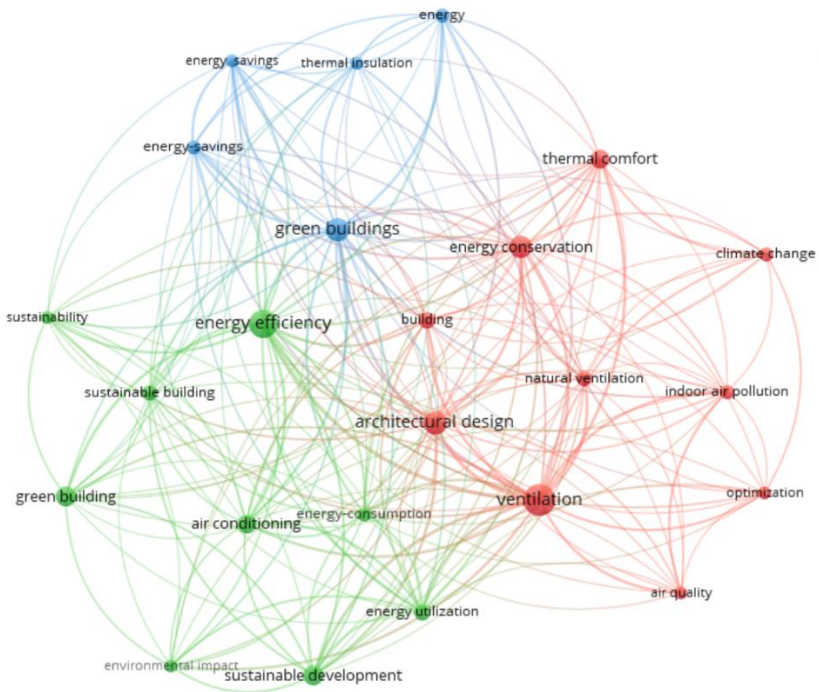

Figure 1. VOSViewer Visual Keyword Analysis.

This study highlights the most cited documents on Scopus, showcasing the key influential works within this field **Table 5**. Among the 56 documents analyzed, this paper identifies the three most significant publications related to architectural design, climate change, energy conservation, natural ventilation, and air quality. Additionally, several prominent authors are recognized to better understand their expertise in this research domain. The Scopus analysis reveals the top 10 authors contributing to this area of study **Figure 4**. These authors are noted for their frequent contributions based on the number of documents they have published on Scopus.

Table 5. Most Cited Documents

Authors	Document Title	Cited by	Author Keywords
(Mustafa et al., 2023)	Smart window technology and its potential for net-zero buildings: A review	70	Building energy consumption Cost-benefit analysis Energy storage and harvesting Life cycle assessment Net-zero buildings Smart window technology
(Alhusban et al., 2022)	How the COVID 19 pandemic would change the future of architectural design	48	Architectural design Home design Pandemic Spaces Special design Urban design
(Pérez et al., 2022)	Seasonal influence of leaf area index (LAI) on the energy performance of a green facade	46	Building Normalized difference vegetation index (NDVI) Passive energy saving Shadow effect Urban green infrastructure Vertical greening systems
(Xiang et al., 2022)	Research on sustainability evaluation of green building engineering based on artificial intelligence and energy consumption	44	Air conditioning Artificial intelligence Energy consumption Green building Heating Long short-term memory (LSTM) Ventilation

(Zhou & Zheng, 2020)	Multi-level uncertainty optimisation on phase change materials integrated renewable systems with hybrid ventilations and active cooling	39	Active cooling Hybrid ventilations Latent storage Multi-level uncertainty based optimisation Supervised learning

Figure 4. Top 10 Authors in The Reasearch Area.

Conclusion

This research offers an in-depth look at prevailing patterns and advancements in eco-friendly architecture, concentrating on energy conservation, environmentally conscious structures, and comfortable thermal conditions. Using a bibliometric method, it was discovered that progress in this area has been substantial, with a significant rise in the adoption of energy-saving technologies, sustainable materials, and passive architectural strategies for green structures. Recent developments underscore the importance of intelligent technologies and climate-adaptive design in enhancing energy efficiency and thermal comfort, while ecologically sound buildings are increasingly recognized as a means to lessen the ecological impact of construction.

Additionally, the assessment indicates that, although the majority of global partnerships are primarily located in nations like China, the participation of other countries in sustainable architecture research is becoming more vital, fueled by an increasing awareness of global climate change issues. The research also stresses the necessity of incorporating sustainability principles more thoroughly within architectural training and practice, with the goal of fostering a more eco-friendly and effective built environment for the future.

Consequently, it is advised to further embed cutting-edge technologies and sustainability concepts into architectural education and to boost international cooperation in this domain. This approach will accelerate the realization of sustainability objectives and enhance the overall quality of the constructed environment worldwide.

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