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Daylighting Optimization and Visual Comfort in Building Facade Design: A Bibliometric Analysis

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Abstract

Daylighting optimization and visual comfort are increasingly recognized as critical aspects of sustainable building design, particularly in relation to facade performance. This article is written with the aim of mapping the knowledge structure, research trends, and inter-topic relationships in this field. Metadata from the Scopus database covering the period 2021–2026 were analyzed, with 2,077 documents processed using VOSviewer software to visualize networks of keywords, authors, and countries. The results reveal a significant upward trend in publications, peaking in 2025, with research shifting toward the complexity of facade design in educational facilities. Geographically, China dominates global output, while Indonesia has recently emerged as a rapidly growing contributor. Keyword mapping identified five major clusters: visual comfort, architectural design, energy efficiency, daylighting, and multi-objective optimization. The novelty of this article lies in its systematic mapping of the research landscape, offering a typological synthesis that highlights emerging clusters and regional contributions. The implications are both theoretical and practical, providing researchers with insights into research gaps and guiding future studies to integrate energy efficiency, user comfort, and architectural innovation in sustainable building design.

INTRODUCTION

Buildings play a crucial role in shaping the quality of the visual environment within spaces, particularly through natural lighting (daylighting) strategies, as optimal daylighting design significantly influences the visual quality of spaces and the well-being of their occupants in IEA 2026. A recent report from the International Energy Agency (2023) indicates that the building sector accounts for more than one-third of global final energy consumption, with lighting as one of the main components of the electricity load. The high reliance

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on artificial lighting is largely driven by suboptimal natural lighting design; therefore, efforts to improve access to and control of daylight in building design must be prioritized to reduce energy consumption and enhance occupants' visual comfort. The penetration of natural light depends on the interaction between facade elements and the distribution of light into the interior, and underscores the importance of selecting design elements to control incoming light in order to support the visual comfort of occupants (Al-Rqaibat et al., 2025). Therefore, facade design is one of the key factors determining lighting performance and visual comfort within a building.

Lighting plays a fundamental role in architectural spaces; its significant impact is evident in its direct influence on spatial appearance, the surrounding atmosphere, and functionality (Liu et al., 2025). Based on its source, lighting is divided into two types: artificial lighting and natural lighting. Artificial light is generated by human-made sources, such as lamps. Artificial light also requires energy to produce light, so its use often raises energy-related issues. This contrasts with natural light, which comes directly from the sun. Consequently, excessive energy consumption in artificial lighting systems can be reduced by utilizing passive (natural) energy specifically, by making use of natural light during the day (Oesterle et al., 2026).

In addition to helping address the issue of excessive energy use, exposure to natural light such as sunlight entering through large windows has also been shown to enhance visual comfort in a room and improve cognitive and emotional well-being (Payedar-Ardakani et al., 2024). Although natural light offers numerous benefits compared to artificial light, the amount of natural light entering a room must be regulated to avoid both excess and deficiency (Plörer et al., 2021). Daylight utilization can be optimized through efforts to optimize façade shading design (Yun et al., 2014).

A review study indicates that although the topics of daylighting and visual comfort are attracting increasing attention, the broad range of research approaches and focuses suggests that the field has not yet been fully integrated (Ünlütürk, 2024). Research on daylighting reveals diverse research objectives, encompassing energy performance, visual comfort, and façade control for multi-objective balancing, which highlights the variation and fragmentation of approaches in studies of natural lighting performance in buildings (Alsukkar et al., 2026). To date, there has been no comprehensive mapping that specifically analyze the knowledge structure, research trends, and inter-topic relationships in studies on the optimization of natural lighting based on visual comfort in buildings.

Although the topics of daylighting and visual comfort are attracting increasing attention, previous research approaches have remained varied and fragmented, with separate focuses on energy performance, visual comfort, and facade control; consequently, there is no comprehensive mapping that thoroughly analyzes the knowledge structure and interrelationships among these topics. To address this gap, this study employs bibliometric analysis to identify emerging trends through the evaluation of keywords, citation flows, and text frequency, which are then visualized as an interactive network (Van Eck & Waltman, 2010). Through this method, the novelty of this study lies in providing a comprehensive mapping that integrates previously fragmented objectives such as artificial energy use, façade shading design, and occupants' cognitive and visual comfort into a single, cohesive analytical framework. Theoretically, this study is expected to provide a structured literature foundation to guide future academics and researchers in exploring areas of study that can still be developed, particularly regarding multi-objective balancing in building performance. Meanwhile, from a practical standpoint, this study is designed to provide architects and designers with more targeted insights into optimizing the use of façade shading, so that they can design buildings capable of precisely controlling natural light to prevent glare, enhance occupants' cognitive function, reduce reliance on artificial lighting, and support the creation of sustainable buildings.

METHODS

This study employs a quantitative approach using bibliometric analysis to quantitatively measure publication performance and examine patterns and trends in scientific literature (Soedarmono & Yusgiantoro, 2023; Widodo, 2025), including investigating citations and mapping the scope of research fields (Effendy et al., 2021). Data collection was sourced from the internationally renowned Scopus database, with the search focused on a combination of the keywords "daylighting," "visual comfort," and "facade design." The collected scientific article metadata was exported into CSV format and then processed in an initial stage using Microsoft Excel. Subsequently, the main analysis phase was conducted using VOSviewer software to evaluate and visualize bibliometric networks (Akem et al., 2025; Baroud et al., 2025; Engkizar et al., 2024, 2025, 2026; Muhlasin et al., 2026; Surya et al., 2024). Technically, the data analysis was conducted using a clustering technique based on the VOS (Visualization of Similarities) algorithm to map the relationships between articles and research trends based on the number of clusters and the density of items, thereby producing an interactive network map that comprehensively synthesizes the literature review framework (Budianto & Dewi, 2023).

The data was sourced from Scopus, an internationally indexed scientific literature database. Scientific articles retrieved from the Scopus database were in CSV format and processed using Microsoft Excel. The data processed in Microsoft Excel was then analyzed using VOSviewer software. The steps in the VOSviewer analysis included mapping the results of bibliometric network visualization and trends in scientific publications using the VOSviewer (Visualization of Similarities) algorithm based on the number of clusters and items, and mapping research topics based on a literature review (Rohimah et al., 2023). Data was extracted from the Scopus database using keywords specified by the authors, namely: daylighting, visual comfort, and facade design.

Figure 1 below illustrates the research process, which begins with identifying search keywords in Scopus, followed by a data search. After obtaining the results, the data is filtered based on criteria such as year, field of study, document type, publication stage, keywords, source type, and language. The processed metadata is then downloaded in CSV format. Next, the CSV data was processed using VOSViewer to generate the desired visualizations, and the process concluded with the download of those visualizations. Figure 2 then presents the steps taken in the process of defining the boundaries of bibliometric data from Scopus, in accordance with the details outlined in Table 1 and the workflow described in Figure 2.

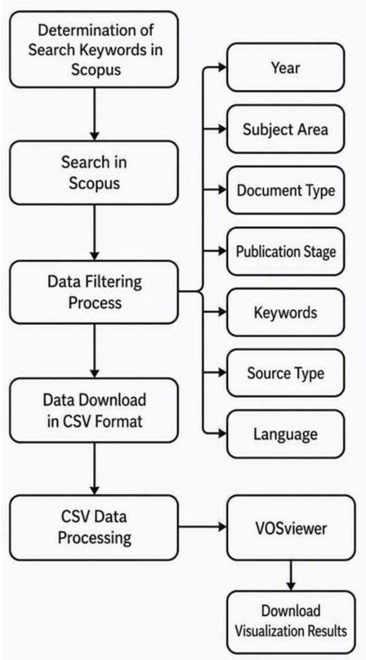

Fig 1. The Keyword Selection Process

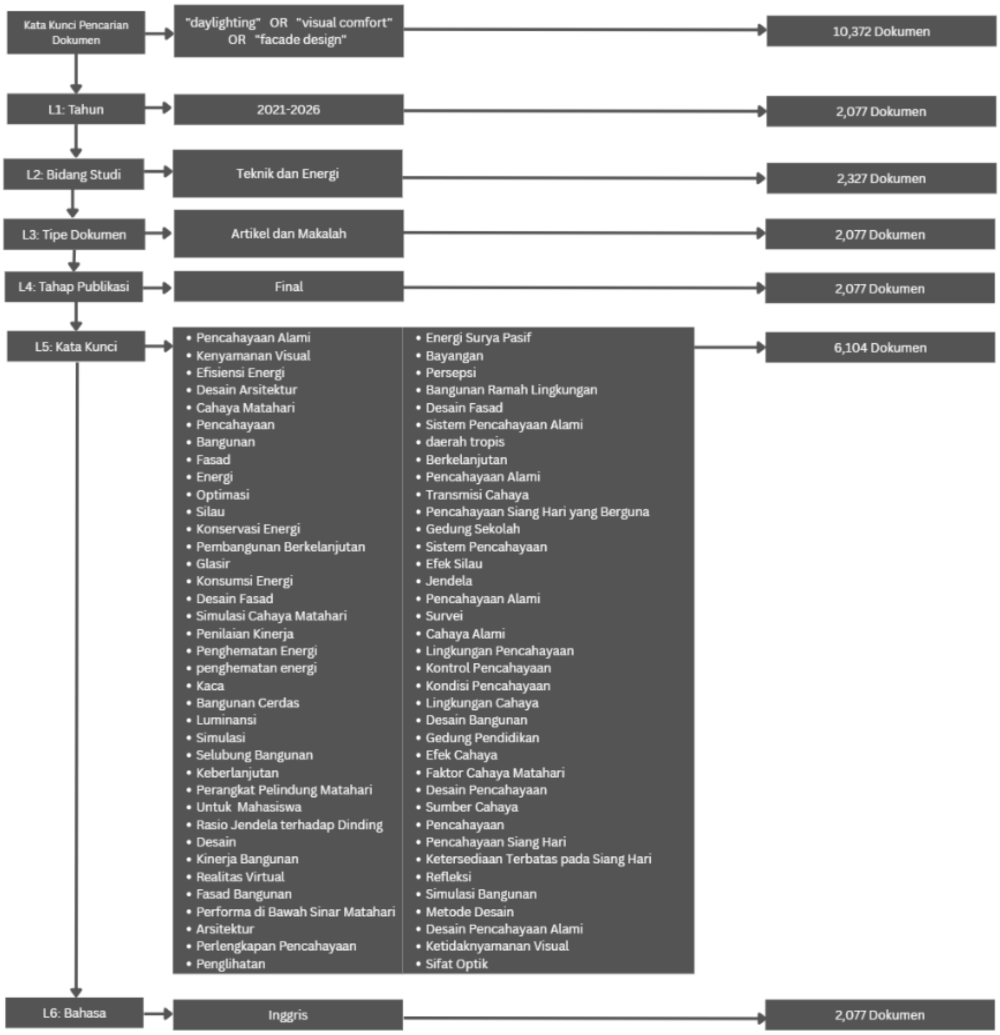

Fig 2. The Process of Defining Numerical Data Boundaries

RESULT AND DISCUSSION

Based on an analysis of the publication years of documents that reached the final stage, the data shows that the total number of publications from 2021 to 2026 is 2.077. Analysis on Scopus itself can generate indicator graphs and diagrams based on data from published documents. These graphs can show the number of publications per year, which can help researchers understand the progress of the research they have conducted (Bunyamin et al., 2025). In 2025, the number of publications remains low because the data collected for this study only extends through the first quarter (Figure 3). However, overall, the publication trend has shown a fairly significant increase each year, except in 2023, which saw a decline compared to 2022. By 2025, researchers began to consider visual comfort, the use of natural light (daylighting), and façade design in the context of educational facilities. Consequently, there was an increase in the number of journal articles published in 2025 due to the rise in more complex research. Table 1 shows that the field of engineering is the discipline with the most published documents, followed by energy science, social sciences, computer science, and mathematics. Table 2 indicates that "Building and Environment" is the journal most frequently cited in relation to this research.

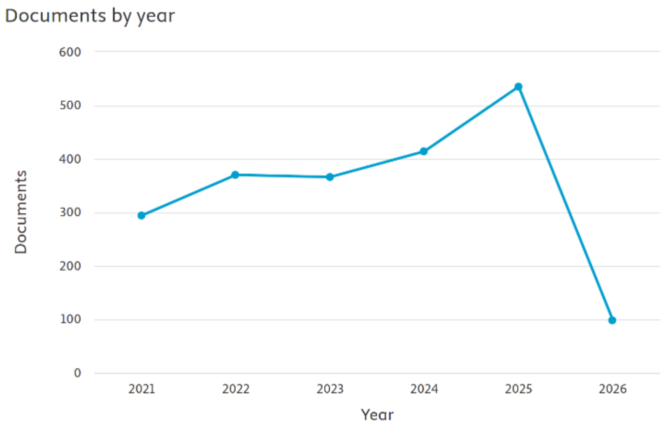

Fig 3. Analysis by Year

Table 1. Documents by Field and Subject

Subject	Percentage
Engineering	39.1%
Energy	13.1%
Environmental Science	10.2%
Social Sciences	9.2%
Computer Science	8.3%
Mathematics	5.3%
Materials Science	5.0%
Physics and Astronomy	2.8%
Chemical Engineering	1.5%
Arts and Humanities	1.1%
Others	3.9%

Table 2. Most Frequently Published Journals/Proceedings

Journal/Proceedings	Number of Documents
Building and Environment	186
Buildings	157
Energy and Buildings	145
Journal of Building Engineering	141
Sustainability Switzerland	82
Light and Engineering	68
Solar Energy	64
Journal of Daylighting	53
Building Simulation Conference Proceedings	43
Energies	38

Government Involvement in Research

The data show that countries with different climatic backgrounds demonstrate a strong correlation between the research analyzed in Scopus and various projects in those countries. China leads as the country most focused on daylight utilization through facade design optimization, with 614 publications. It is followed by the United States with 217 publications, and so on. A meta-analysis using VOSViewer reveals a network among countries involved in research with the keywords: visual comfort, daylighting, educational buildings, and facade design. A minimum threshold of 25 documents per country identified 28 countries, all of which met the minimum threshold (Figure 4). The visual results from VOSViewer (Figure 5) show data that is not significantly different from the graph in Figure 4. In Figure 5, China dominates regional publication output in Asia, while the United States acts as a global intermediary, connecting each cluster containing various geographic groups. The density of the network also indicates an integrated global research community.

The overlay visualization in Figure 6 also shows a fairly significant temporal shift in global research. China has maintained its high productivity from 2021 through 2024–2025. Another point worth noting is the emergence of a new wave of research influence in several countries, such as Indonesia, Jordan, and Saudi Arabia. These countries are identified by light yellow-green nodes, representing the newest and fastest-growing contributors in this field. In contrast to the United States and several European countries, which served as early pioneers in research during the 2021–2022 period even though their trend nodes are not as bright as those of China and some Asian countries they have emerged as key reference points for several regions in Asia and the Middle East. This demonstrates that the research landscape is increasingly shaped by Asian and Middle Eastern perspectives, including Indonesia, which has emerged as a key strategic partner in the contemporary global research landscape.

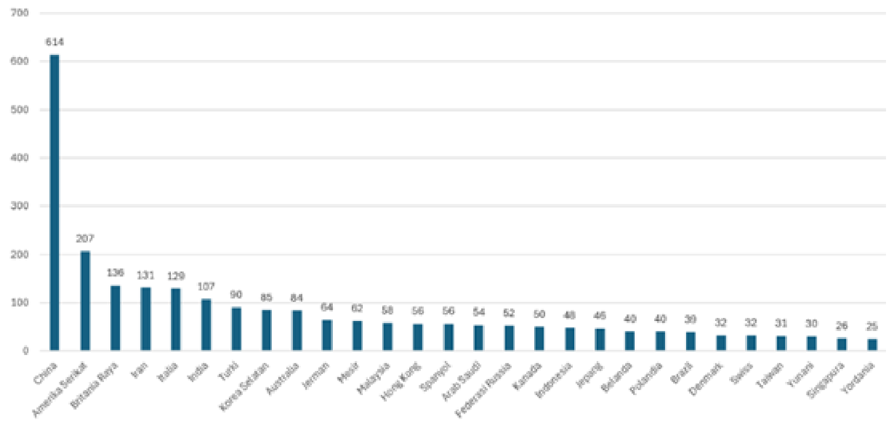

Fig 4. Analysis by Country

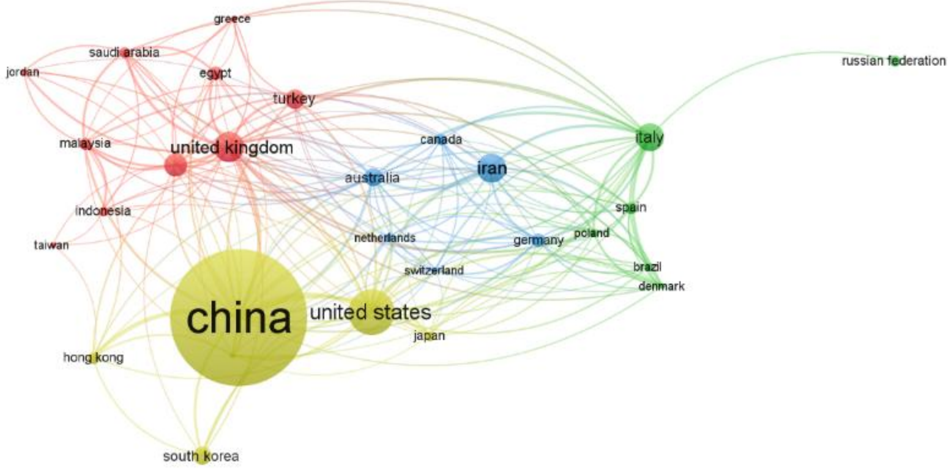

Fig 5. State Involvement in the VOSviewer Analysis

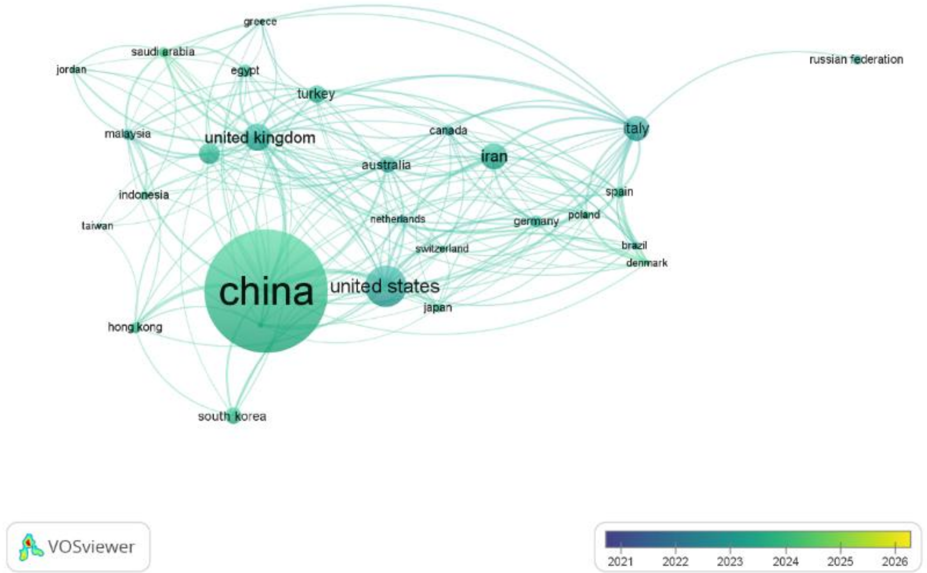

Fig 6. State Involvement in VOSviewer Analysis During the 2021–2026 Period

Keyword Analysis

In this study, the author's keywords were used to identify relationships between keywords and to illustrate cluster formation (Van Eck & Waltman, 2010). The analysis in this study required a minimum of 15 occurrences of a keyword in the analyzed metadata, resulting in 272 thresholds across 5 clusters with different colors in the visualization using VOSViewer (Figure 7).

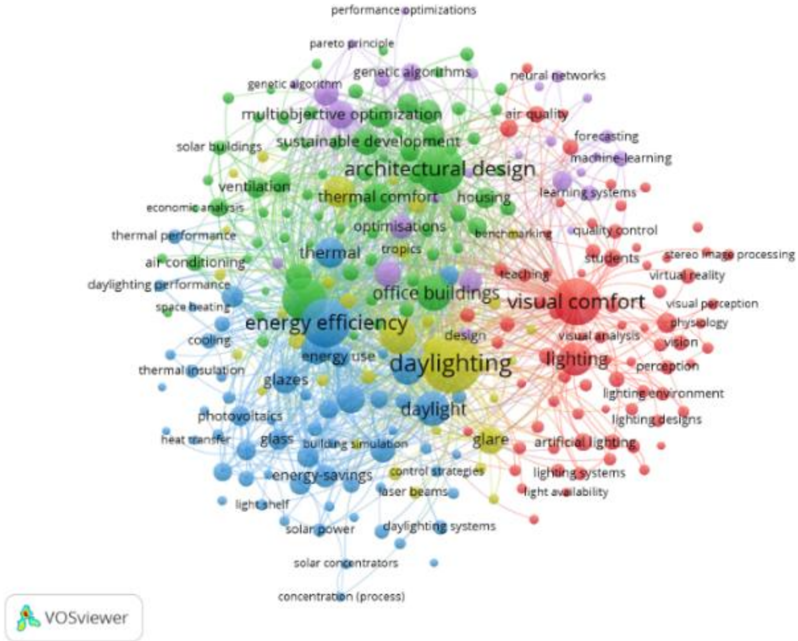

Fig 7. VOSViewer Keyword Analysis

These five clusters are also interconnected. The red cluster contains the most keywords in this field of research and is categorized as "visual comfort." This indicates that this term is discussed most frequently and has the broadest relevance to the issues under study. Next, the green cluster is the second cluster with the most keywords, categorized as architectural design. This cluster covers the interactions among the various factors that influence building design to make it more efficient and comfortable. The third cluster the blue cluster is categorized as energy efficiency because the keywords in this cluster focus on the impact of natural lighting on energy consumption in a building. This is followed by the fourth cluster the yellow cluster categorized as "natural lighting," which details factors related to natural lighting. Finally, the purple cluster, categorized as "multi-objective optimization," describes the use of software for lighting optimization and simulation to achieve visual comfort. The details are presented in Table 3.

Table 3. Cluster Indicators

No.	Indicator Color	Data Classification	Content
1.	Red	Visual Comfort	Present day, Acoustic comfort, Adaptive control systems, Air quality, Algorithms, Articles, Artificial lighting, Augmented reality, Automation, Behavioral research, Built environment, Color, Comparative studies, Computer simulation, Conditions, Control systems, Color temperature, Daylighting, Deep learning, Efficiency, Electric lighting, Environmental quality, Field studies, Humans, lighting, Image enhancement, Indoor air, Indoor air pollution, Indoor air quality, Indoor

			environment, Indoor environmental quality, Indoor lighting, Lamps, Light availability, Lighting effects, Light-emitting diodes, Lighting environment, Light quality, Light sources, Illumination, Lighting conditions, Lighting control, Lighting design, Lighting, Lighting quality, Lighting systems, Natural lighting, Non-visual, Numerical models, Occupant satisfaction, Office spaces, Parameter estimation, Perception, Physiological models, Physiology, Quality control, Regression analysis, Rendering (computer graphics), Stereo image processing, Students, Supervision, Teaching, Urban areas, Urban planning, Virtual reality, Vision, Visual analysis, Visual comfort, Visual discomfort, Visual effects, Visual environment, Visual perception, Visual performance, Visualization, Well-being.
2.	Green	Architectural Design	Architectural design, Air conditioning, Apartments / apartment buildings, Architectural planning, Architecture, Building design, Building energy, Building envelope, Building Information Modeling (BIM), Carbon, Carbon dioxide, Carbon emissions, Case studies, Climate Change, Climate Models, Cold Regions, Colder Climates, Comfort Performance, Commercial Buildings, Computational Fluid Dynamics (CFD), Computer Software, Construction Industry, Cooling Systems, Cost-Benefit Analysis, Cost-Effectiveness, Costs, Decision Making, Design Optimization, Eco-design, Economic Analysis, Economic and Social Impacts, Educational Buildings, Energy demand, Energy conservation / energy efficiency, Energy management, Energy simulation, Energy utilization, Energy consumption, Environmental impact, Environmental management, Facade design, Floors, Geometry, Global warming, Green buildings, Historic building preservation, Homes, Housing, Smart buildings, Investment, Life cycle, Natural ventilation, Occupants, Residential buildings, Optimal systems, Lodging facilities, Building retrofits / upgrades to existing buildings, Roofs, Saudi Arabia, School buildings, Sensitivity analysis, Solar-powered buildings, Structural design, Sustainability, Sustainable buildings, Sustainable development, High-rise buildings, Thermal comfort, Urban growth, Ventilation, Walls (structural partitions), Zero-energy

			buildings.
3.	Blue	Energy Efficiency	Alternative energy, Buildings, Building energy efficiency, Building energy conservation, Building-integrated photovoltaics, China, Concentration (process), Control strategies, Cooling, Natural light, Natural lighting performance, Natural lighting systems, Design methods, Detection methods, Double-skin facades, Power generation, Electrochromic devices, Electrochromism, Energy, Energy savings, Energy conservation, Energy efficiency, Energy performance, Energy use, Experimental studies, Glass, Glass coatings, Heat transfer, Heating, Light shelf, Light transmission, Optical properties, Optics, Passive solar, Performance assessment, Performance evaluation, Photovoltaic systems, Photovoltaics, Properties, Reflection, Semi-transparent photovoltaics, Shading, Simulation, Smart windows, Solar concentrators, Solar energy, Solar heat gain, Solar heating, Light shelf.
4.	Yellow	Natural Lighting	Performance comparison, Building facade, Building simulation, Concrete, Natural lighting autonomy, Natural light availability, Natural lighting factor, Probability of natural light glare, Natural lighting performance, Natural lighting, Natural lighting design, Design parameters, Glare causing discomfort, Facade, Opening system, Glare, Glare effects, Inside buildings, Kinetic facades, Laser beams, Mortar, Natural light, Parametric design, Performance, Assessment, Shading systems, Structural analysis, Structural dynamics, Tropical regions, Useful daylight, Window-to-wall ratio, Windows, Workflow.
5.	Purple	Multi-objective optimization	Artificial intelligence, Building energy consumption, Building performance, Building performance simulation, Daylight simulation, Design, Design process, Early design stage, Forecasting, Genetic algorithm, Learning algorithm, Learning system, Machine learning, Mean squared error, Multi-objective optimization, Neural network, Optimization, Parametric model, Pareto principle, Performance optimization, Simulation platform.

Table 4. Cluster Indicators

Author's Name	Title	Citations	Keywords
(Abraham et al., 2023)	Highly transparent silanized cellulose aerogels for boosting energy efficiency of glazing in buildings	200	Biopolymers, Cellulose, Energy efficiency, Glaze, Heat transfer, Building envelope, Building interiors, Cellulose aerogel, Energy, High thermal performance, High transparency
(Martín-Chivelet et al., 2022)	Building-Integrated Photovoltaic (BIPV) products and systems: A review of energy-related behavior	190	Active facades, BIP forecasting, BIPV modules, BIPV systems, building-integrated photovoltaics, colored PV Temperature of laminated glass PV modules, semi-transparent PV, solar heat gain coefficient, thermal transmission
(Rabani et al., 2021)	Achieving zero-energy building performance with thermal and visual comfort enhancement through optimization of fenestration, envelope, shading device, and energy supply system	138	Building renovation, Optimization process, Shading control methods, Window opening control methods, Zero-energy buildings
(C. Wu et al., 2024).	Multi-objective optimization of residential building energy consumption, daylighting, and thermal comfort based on BO-XGBoost-NSGA-II	137	Multi-objective building optimization, Natural lighting performance in residential buildings, Thermal comfort performance, XGBoost
(Condino et al., 2021)	Perceptual limits of optical see-through visors for augmented reality guidance of manual tasks	133	Augmented Reality, Focus cues, Head-mounted displays, Optical see-through, Convergence-accommodation conflict
(Wang et al., 2021)	Multi-objective optimization (MOO) for high-rise residential buildings' layout centered on daylight, visual, and outdoor thermal metrics in China	129	Artificial neural network (ANN), Daylight factor (DF), Multi-objective optimization (MOO)
(K. Liu et al., 2023)	A multi-objective optimization framework for designing urban block forms considering daylight, energy consumption, and photovoltaic energy potential	122	Computational urban design, Energy consumption, Multi-objective optimization, Solar photovoltaic power generation, Sun hours, Urban block form

(Usman & Abdullah, 2023)	An Assessment of Building Energy Consumption Characteristics Using Analytical Energy and Carbon Footprint Assessment Model	122	Assessment model, buildings; carbon footprint, energy use, greenhouse gases
(Houser et al., 2021)	Human-centric lighting: Myth, magic or metaphor?	113	Core materials; Lighting design; Lighting equipment; Lighting products; Lighting professionals; Medical professionals; Neurobehavioral; Visual response
(Skandalos & Karamanis, 2021)	An optimization approach to photovoltaic building integration towards low energy buildings in different climate zones	107	Building-integrated photovoltaics, Energy savings, Indoor comfort, Energy-efficient buildings, PV flexibility
(H. Wu & Zhang, 2022)	Multi-objective optimization of energy, visual, and thermal performance for building envelopes in China's hot summer and cold winter climate zone	103	Building envelope, Energy consumption, Multi-objective optimization, Thermal comfort, Visual comfort
(Xu et al., 2021)	A two-stage multi-objective optimization method for envelope and energy generation systems of primary and secondary school teaching buildings in China	101	Building design optimization; Meta-model, Multi-objective, School buildings
(Baghoolizadeh et al., 2023)	Multi-objective optimization of Venetian blinds in office buildings to reduce electricity consumption and improve visual and thermal comfort by NSGA-II	99	Electricity consumption; Multi-objective optimization; Sensitivity analysis; Thermal comfort; Venetian blinds; Visual comfort
(Alkhatib et al., 2021)	Deployment and control of adaptive building facades for energy generation, thermal insulation, ventilation and daylighting: A review	95	Adaptive buildings; Adaptive facades; Adaptive facade control; Energy utilization; nZEB
(Geng et al., 2022)	Combined effects of visual-acoustic-thermal comfort in campus open spaces: A pilot study in China's cold region	93	Acoustic comfort; Campus open spaces; Cold regions of China; Combined effects; Outdoor thermal comfort; Visual comfort

Documents and Authorship

This study is based on the results of a document analysis conducted on Scopus. According to the Scopus analysis, out of a total of 2,077 documents, 15 were found to be highly influential and relevant to the author's research topic (Table 4). These include: visual comfort, the use of natural light, daylighting, and facade design in the context of educational facilities. Furthermore, the Scopus analysis also identified the top 10 authors in this research field (Table 5). The authors listed in this table are ranked by the frequency of their contributions to this field based on the number of documents published in Scopus.

Table 5. Top Ten Authors by Research Area

Author's Name	Number of Documents
Ji, J.	18
Mahdavinejad, M.	14
Mangkuto, RA	14
Wu, Y.	13
Wang, C.	12
Hong, X.	12
Ghosh, A.	11
Xue, P.	11
Atthaillah	11
Wang, T.	11

CONCLUSION

Global research on visual comfort, the use of natural light, daylighting, and facade design is experiencing significant growth, peaking around 2025, with China as the leading contributor, along with several other Asian and Eastern countries. Nevertheless, the United States and several European countries, such as Italy and the United Kingdom, are also playing a significant role in the development of this research.

This study focuses on optimizing visual comfort through façade design in the context of high-rise educational buildings. Although research on educational facilities remains scarce, studies addressing this issue in buildings with more than two stories are becoming increasingly common. The results of the analysis indicate that visual comfort not only impacts human activities within the building but also has the potential to save electricity by utilizing natural sunlight. Furthermore, visual comfort is closely linked to architectural design elements such as the use of windows or shading façades in a building. The amount of sunlight entering a building can be controlled and simulated in advance using computer software. However, studies that explicitly address the use of shading façades in educational facilities specifically focusing on visual comfort remain relatively rare. Therefore, this study highlights the research gap and the potential for further investigation in this area within the context of educational facilities, where sunlight plays a significant role in students' visual comfort. Overall, this study presents concrete data on the potential for further research in the field of natural lighting in educational facilities and aims to serve as a valuable information source for future researchers.

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DECLARATIONS

Author contribution

Muhammad Ismail Hasan: data curation, writing-original draft preparation and editing, conceptualization, **Nayla Husniyyatizzahro & Ardilla Musthika Putri**: methodology, **Ratih Widiastuti & Chely Novia Bramiana**: validation, visualization, **Previari Umi Pramesti**: supervision, software.

AI Statement

The data and the grammatical structure in this article have been validated and verified by English language experts and no AI-generated sentences are included in this article.

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Conflict of interest

The authors declare that this research was conducted without any conflict of interest in the research.

Ethical clearance

The research company has agreed to carry out the research and is willing if the results of this research are published.

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