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Exploring Gaps and Trends in the Algorithmic Design of Building Facade Shading Systems for Daylight Control: A PRISMA-Based Systematic Review

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ABSTRACT
Increasing living standards highlights the important role of daylighting in enhancing thermal, and visual comfort. Shadings, as well-known building facade elements, encourage efficient energy usage, can offer multiple health benefits to users, and help create more efficient working spaces by solving potential issues of glare and heat through daylight control.

To solve multi-objective design challenges of shadings, the Genetic Algorithm (GA) emerges as a contemporary solution. To have a better understanding of GA in shading design, this study developed a systematic review of the literature examining shading design via GA in the Scopus index, based on the systematic review process, PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Once the selection criteria and the performance criteria were established, 23 publications of literature were included in the review. The performance criteria for shading design reviewed in the publications include functional aspects related to visual and thermal comfort, user interaction, aesthetics, energy efficiency and environmental performance.

The gaps in research and emerging trends suggested that there was a growing interest in using algorithmic design methods, especially GAs, to meet the multifaceted challenges of shading design. This paper aims to contribute valuable insights into the development of innovative shading solutions that effectively balance user comfort and energy demands, ultimately advancing the field of sustainable architectural design. This study highlights the critical need for further exploration in the algorithmic design of shading systems and offers more effective solutions to contemporary challenges of sustainable space design.
Keywords: algorithmic design, building facade design, daylight control, shading design.

1. INTRODUCTION

Due to numerous socioeconomic advancements, people's expectations of indoor environments have increased (Duan et al. 2024). As living standards improve, individuals increasingly seek more comfortable spaces that enhance their quality of life. Daylighting is vital for assuring that thermal and visual comfort levels are maintained by ensuring there is enough natural light without too much glare which will contribute positively to energy efficiency (Rezakhani & Kim, 2024). Exposure to natural light brings multiple psychological and physiological health benefits (Wen et al., 2023; Knoop et al., 2020) and can considerably improve users' work performance (Wen et al., 2023). However, it is important to recognize that excessive sunlight can lead to visual discomfort due to glare, as well as thermal issues caused by increased heat (Beck et al. 1999, Wen et al., 2023). To achieve indoor comfort levels, it is crucial to focus on building facade design, as it is the primary element of the building that controls natural light as it separates indoor spaces from the outdoors (Nazari et al., 2023; Rizi et al. 2021).

In advanced societies, individuals now spend an overwhelming 90% of their time indoors (Knoop et al., 2020). The increase in indoor activity correlates with a significant rise in energy consumption (Duan et al. 2024), with buildings alone accounting for approximately 40% of global energy use (Alajmi et al., 2019; Elmaky & Araji, 2024; Tsangrassoulis et al., 2006), implementing passive design techniques has the potential to reduce energy consumption by 80-90%, depending on climatic conditions (Nazari et al., 2023). Since lighting accounts for 15% of total building energy consumption, daylighting emerges as an effective passive strategy (P’erez-Lombard et al., 2008; Wen et al., 2023). Shadings on building facades (such as overhangs, fins, awnings, Venetian blinds, louvers, solar screens, and roller shades), as a passive solar strategy, play a role in optimizing energy efficiency by regulating indoor lighting and preventing overheating, shading contributes to maintaining comfortable indoor environments while minimizing energy demand (Choi et al., 2017; Moscoso et al., 2021). Some studies indicate that the lack of shadings can enhance overheating (Moscoso et al., 2021 and Nazari et al., 2023) and glare during the summer months (Chi et al., 2020 and Nazari et al., 2023). In addition to this, using shades can potentially result in building energy savings of up to 20% (Nazari et al., 2023).

Considering the demands of indoor comfort and energy demand, it is critical to concentrate on the shading design strategies. Effective shading design techniques will alleviate the unwanted summer solar that needs to be mitigated while allowing the solar heat gain in the winter season, which reduces energy consumption and increases comfort for the occupants (Ishac and Nadim, 2021; Zhao and Du, 2020).

The shading system design is a multi-faceted complex design problem and one that requires modern methods for a solution. Simply changing a single design variable may improve one performance objective while deteriorating other performance metrics (Wen et al., 2023). Thus, the use of algorithmic design principles has increased to tackle this complex problem.

The Genetic Algorithm (GA), commonly used as a generative algorithm in shading design, also called the Evolutionary Algorithm, is inspired by Natural evolution as described by Darwin’s theory (Darwin, 1964), where stronger individuals survive over generations. These coding techniques are commonly used in situations where the problem to solve is not easily breakable into a chain of logical decisions and allows randomness to play a key role in the generation of the expected result. Alajmi et. al. (2019) explains GA as it starts with a group of alternative possible solutions for a given problem. It uses three key processes: selection, crossover, and mutation (Goldberg, D.E., 1989). The role of natural selection is absolved by a "testing function" that measures the performance of the different alternatives against some Key Performance Indicators (KPI) and selects the most performative alternatives for the next generation of possible solutions while those with below-average fitness are eliminated. The crossover process randomly mixes the "genetic materials" of the selected alternatives into a new generation of individuals. Finally, the mutation process introduces small changes to the new chromosomes (Alajmi et al. 2019) before the new iteration of the overall algorithm.

There are some other review studies published in the field. For example, Machairas et al. (2014) conducted a comprehensive review of algorithms applied to design buildings. Costa-Carrapiço et al. also published a systematic review (2020) that examined genetic algorithm-based multi-objective optimization methods (MOOM) for building retrofitting with the objective of energy performance improvements. In a somewhat overlapping area, Alexakis et al. (2024) published a review of studies examining GA-based MOOM applied to building retrofitting that covered the scope of 175 studies. They concluded that the most preferred algorithm, judging by the studies examined, was the NSGA-II method based on efficiency and quality of solution.

In 2023, Liu et al. published a review paper that was developed to provide a systematic review to serve as a reference for choosing and tuning machine learning algorithms (MLAs) for daylight prediction applications. Al-Masrani et al. (2018) also published a review in 2018 of solar shading systems applied to office buildings in the tropics by establishing three different categories: passive, active and hybrid. The review of solar shading systems emphasized adaptive, low-energy shading responses for tropical climates, which also need to consider the increased humidity present in tropical climates, as well as the non-uniformity of sky luminance.

Nazari et al. (2024) published a comprehensive review focusing on challenges with accuracy and validation in architectural research related to digital daylighting simulations. The study stressed that the uncertainties associated with input data quality, computational algorithms, and validation are very important to the reliability of results.

Madan et al. (2024) conducted a systematic review examining the restorative effects of daylight in indoor environments. A review of 33 studies revealed that a total of about 42% of the examined relationships were positively associated with the presence of natural daylight on restorative outcomes, especially affective and clinical outcomes. Their review concluded that direct sunlight was an important factor to restorativity, as well as acknowledging that a not insignificant factor was within the variability of the current literature on links with orientation and availability of daylight and noting the constraints of methods studied.

Özlük et al. (2025) undertook a systematic literature review of artificial intelligence algorithms, simulation tools and software for optimizing the performance of adaptive building facades. The result of their review was that GAs were the most applied AI optimization method and the software tools of emerging importance were Grasshopper, EnergyPlus and Rhino.

The study aims to systematically review the literature focusing on shading design with GA to identify the current research gaps and trends. The PRISMA method was chosen due to its widespread use and established credibility in conducting systematic analyses. While many studies focus on holistic building design or optimization methods for energy efficiency, this study specifically targets shading design using GA for more than one performative criterion. Functional performance, which includes visual comfort, thermal comfort, and user interaction, was analyzed in addition to energy efficiency and aesthetics. A systematic literature analysis begins with formulating a clear and well-defined research question. This study focuses on the research question: “What are the current trends and scientific gaps in the algorithmic design of building facade shading systems for daylight control using GAs?”

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This research is a part of a Ph.D. study work at Gebze Technical University, Türkiye with the co-supervision program with The University of Sassari, Italy which aims to develop a new approach to algorithmic design of shadings for daylight control in the Mediterranean climate.

2. METHODOLOGY

2.1 PRISMA Analysis

The literature review method was adopted to systematically address the research question and achieve the specified objectives. To ensure that the literature review was conducted within a structured framework, the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) method was chosen (Moher et al., 2010). PRISMA flow diagram 2020, used in this study is gathered from the Prisma Statement website (https://www.prisma-statement.org/prisma-2020-flow-diagram).

PRISMA is a guideline specifically developed for systematic reviews and meta-analyses, guiding researchers in ensuring methodological transparency and accuracy (Moher et al., 2010). Within the PRISMA framework, academic studies that meet the predefined criteria are assessed through a series of structured phases. These phases include topic selection, literature search, application of inclusion and exclusion criteria, data extraction, and the analysis process.

The PRISMA method was applied through the following steps (Figure 2.1):

- Defining the Research Question: The key focus areas of the study were identified to establish a systematic framework.
- Selecting Data Sources: A literature review was conducted using the Scopus database which is well known and reliable among academics.
- Determining Inclusion and Exclusion Criteria: Articles that did not align with the study's scope were excluded based on established criteria.
- Data Extraction and Analysis: The selected studies were examined in detail, and relevant data contributing to the research content were analyzed.

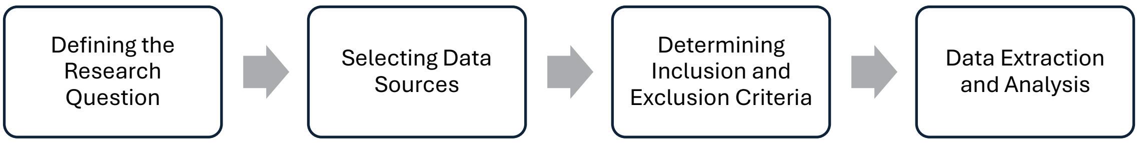

Figure 2.1 PRISMA Method steps.

Firstly, the research question was set. The main research question was “What are the current trends and scientific gaps in the algorithmic design of building facade shading systems for daylight control using GA?”. It was decided that the study would focus on shading design with GA.

Then the database was set to Scopus which is well known and reliable among academics. During the Scopus search, the query for the study was set to: (TITLE-ABS-KEY ("algorithm" OR "algorithmic design" OR "parametric design") AND ("pattern" OR "pattern design") AND ("daylight optimization" OR "daylight control" OR "daylighting") AND ("building envelope" OR "building skin" OR "facade"))

The query utilized popular keywords from the field to enhance the number of relevant publications. However, keywords such as “genetic algorithm” and “shading” or “sun shade” proved to be ineffective during the search process. Although some papers discussed GAs and shading design, the Scopus search did not retrieve them with those specific keywords. Therefore, less specific and related keywords from the field were employed in the query and then, irrelevant ones were eliminated during the manual title and after the manual abstract elimination process. In the end, only 23 publications were left and all were related to the research question. Additionally, keywords related to pattern design were included in the search to encompass not only optimization but also aesthetic aspects.

With the query, we reached a total of 293 publications (Figure 2.2). The language was limited to English only which led to the elimination of 2 documents. Next, we specified the document types to include only academic research articles, reviews, and conference papers, resulting in the exclusion of 9 documents due to document type. We also set the subject areas to Engineering, Energy, Social Sciences, Computer Science, Environmental Science, Materials Science, Arts and Humanities, and Multidisciplinary fields. As a result, 10 documents were excluded as they fell outside of these relevant subject areas. In total, 21 documents were excluded based on these selection criteria.

The research examines publishing from 2003 to 2024, conducted between October 13 and 25, 2024. Records were only available after 2003, with no publications existing before that year. Between 2003 and 2005, only two records were available.

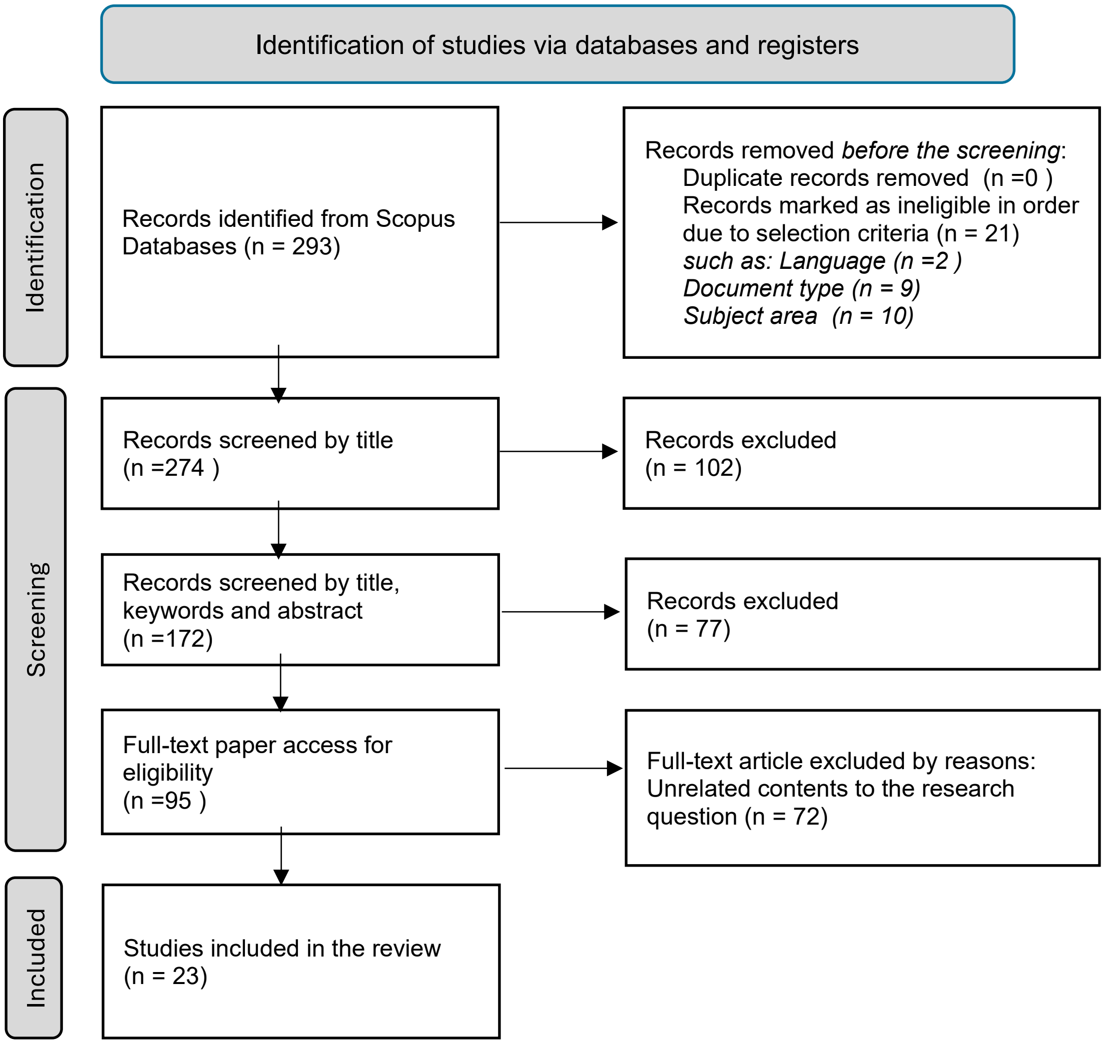

Figure 2.2 PRISMA flow diagram 2020.

Initially, screening was conducted using MS Excel. Out of 274 records screened by title, 102 were excluded due to irrelevance. Subsequently, 172 records were screened based on title, keywords, and abstracts, resulting in the elimination of 77 records, while access to one record was not possible. Afterward, 95 documents were manually screened, leading to the exclusion of 62 documents that did not focus on GA and shading design. Ultimately, 23 documents were included for review in the study.

2.2 Review Method

After eliminating irrelevant documents, a total of 23 relevant documents were identified for review. To ensure a systematic approach, we decided to classify them based on performance criteria for building facade shading. We focused on three key areas: functional performance, energy and environmental performance, and aesthetics - excluding durability.

Functional performance was set to indoor comfort needs such as; visual comfort and thermal comfort and also user interaction. Visual comfort is needed for physicological eye health, biological rhythm, and efficient working (Knoop et al., 2020). Thermal comfort is needed for physicological health and comfort also which is well understood in this field. User interaction, and adaptability of the shading to different conditions with user control, also is considered a need for psychological health as being able to control and interact with the building element can positively affect users' satisfaction with the building (Tabadkani, 2018). Being able to make changes during different times can be helpful if the shade is static and planned working hours shift during the day. Different hours provide different daylight but also the user could be able to see outside which could be psychologically beneficial (Knoop et al., 2020).

Energy efficiency and environmental impact mainly focused on energy-saving solutions and aesthetics are also considered as performance criteria. As aesthetics is subjective, authors did not criticize the aesthetics of the works, instead, they focused on whether the topic “aesthetics” was discussed in the paper or not.

3. RESULTS

The 23 reviewed documents were classified (Table 3.1) by study type such as; optimization, simulation analysis, comparative studies, new approaches, and combinations thereof (comparison and optimization, new approach with simulation analysis, and simulation analysis combined with optimization. Optimization refers to the studies that shading performance optimization was studied; simulation analysis relates to the studies that daylight performance was analyzed with simulations; comparison refers to the studies where two or more types of shading systems or approaches were compared, and new approach refers to a development of a new design approach or model for daylight control with shadings.

Out of 23 documents, 19 studies were conducted on visual comfort, 8 on thermal comfort, 3 on user interaction, 17 on energy efficiency and environmental performance, and 4 on aesthetics (Table 3.1).

Visual comfort is a key performance aspect studied in this field. Rezakhani et al. (2024) focused on enhancing visual comfort by optimizing façade patterns to minimize disturbances such as glare and unwanted reflections. They implemented irregular and broader patterns around windows, resulting in improved occupant satisfaction. Rizi et al. (2021) examined an adaptive façade system that dynamically responds to occupant positions, optimizing shading surfaces to enhance visual comfort and achieving a significant 76% improvement. Baghoolizadeh et al. (2023) studied the optimization of Venetian blinds in office buildings and found that efficient control of these blinds could significantly improve thermal and visual comfort for the users. Alajmi et al. (2019) reviewed window shading devices in a hot Kuwaiti climate and discovered that efficient design could provide maximum daylight availability and minimum glare, which in turn could offer improved overall visual comfort. Stevanović et al. (2018) evaluated curvilinear external shading design solutions and ultimately found that these types of shadings not only contributed to visual comfort but also reduced the overall cooling loads while allowing for energy efficiency and good environmental performance.

Table 3.1 Classification of the reviewed studies by study type, year and the performance criteria

Study type	Authors	Year	Functional Performance			Energy Efficiency and Environmental Performance	Aesthetics
			Visual Comfort	Thermal Comfort	User Interaction		
Optimization	Rezakhani, M., & Kim, S. A.	2024	●				●
	Baghoolizadeh, M., Rostamzadeh-Renani, M., Rostamzadeh-Renani, R., & Toghraie, D.	2023	●	●		●	
	Rizi, R. A., & Eltaweel, A.	2021	●	●	●	●	
	Alajmi, A., Abaalkhail, F., & Alanzi, A.	2019	●	●		●	
	Stevanović, S., & Stevanović, D.	2018				●	
	Negendahl, K., & Nielsen, T. R.	2015	●	●		●	
	Tsangrassoulis, A., Geros, V., & Bourdakis, V.	2006				●	
Simulation Analysis	Wanas, A., Aly, S., Farghal, A., & El-Dabaa, R.	2015	●				
Comparison	Vojdani, B., Rahbar, M., Fazeli, M., Hakimazari, M., & Samuelson, H. W.	2024	●			●	
	Nazari, S., Keshavarz Mirza Mohammadi, P., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Doan, D. T., & Almhafdy, A.	2023	●	●		●	
	Lee, K. S., Han, K. J., & Lee, J. W.	2016	●			●	
New Approach	Duan, Y., Zhang, T., Yang, Y., Li, P., Mo, W., Jiao, Z., & Gao, W.	2024	●	●		●	
	Elmalky, A. M., & Araji, M. T.	2024				●	●
	Tabadkani, A., Banihashemi, S., & Hosseini, M. R.	2018	●			●	
	Choi, S. J., Lee, D. S., & Jo, J. H.	2017	●	●		●	
	Caldas, L., & Santos, L.	2016	●		●		
	Von Buelow, P.	2016					●
Comparison and Optimization	Wen, S., Hu, X., Hua, G., Xue, P., & Lai, D.	2023	●			●	
New Approach and Simulation Analysis	Xiao J., Liu Y., Deng Q.	2022	●				
Simulation Analysis and Optimization	Sorooshnia, E., Rashidi, M., Rahnamayiezekavat, P., Rezaei, F., & Samali, B.	2023	●				
	Tabadkani, A., Dehnavi, A. N., Mostafavi, F., & Naeini, H. G.	2023	●		●	●	
	Taveres-Cachat, E., & Goia, F.	2020	●	●		●	
	Fathy, F., Sabry, H., & Faggal, A. A.	2017	●			●	●

Thermal comfort is also closely correlated with daylight control. Effective daylighting can lessen the amount of air conditioning needed. Rizi et al. (2021) optimized thermal comfort by not only considering visual comfort but also physical façade geometry. In addition to minimizing the heat gain throughout the year, the optimization improved overall thermal comfort. Alajmi et al. (2019) evaluated window shading devices for thermal comfort in hot climates, as well as optimizing daylighting and providing adequate daylighting while achieving significant energy savings. Baghoolizadeh et al. (2023) demonstrated that optimized control strategies for Venetian blinds could significantly improve thermal comfort, which emphasizes the connection between thermal comfort and visual comfort. Stevanović et al. (2018) looked at curvilinear external shading solutions and showed that they would be effective at reducing cooling loads. They also showed a balance between the heating and lighting requirements contributing to thermal comfort in office environments.
User interaction, allowing the user to adapt to the system to variable conditions over a day or a year, has been shown to positively impact user satisfaction (Knoop et al., 2020 and Duan et al., 2024). Rizi et al. (2021) incorporated user interaction into their adaptive façade system through occupant position detection, thus allowing for a direct approach to

improving visual comfort based on the users' location. Baghoolizadeh et al. (2023) recognized the importance of user behavior related to controlling their Venetian blinds and concluded that the performance of their solutions contributed to improved performance in visual comfort and thermal comfort, with appropriate adjustments. Alajmi et al. (2019) discussed the necessity of understanding the user interaction with window shading devices, which impacted the effectiveness of their solutions under specific climatic conditions. Stevanović et al. (2018) examined shading systems, focusing on design efficiency, implying that user input could be beneficial in adaptive solutions in future designs by increasing overall functionality.

Energy efficiency and environmental performance metrics are amongst the most studied aspects of sustainable design. Baghoolizadeh et al. (2023) discovered that the optimization of the control of Venetian blinds can lead to substantial reductions in total building energy consumption, whereby total building energy savings of approximately 40-50% were achievable resulting in the likelihood of improved occupant comfort and support for energy conservation. Alajmi et al. (2019) noted that their window shading strategies resulted in 24-27% energy savings thus indicating that climatic context-dependent forms are crucial to support energy efficiency. Stevanović et al. (2018) determined that curvilinear external shading designs produced highly effective cooling load reductions, balancing heating and lighting demands which also highlights their contribution to energy performance. Rezakhani et al. (2024) provided examples of optimized façade designs supporting visual comfort which also contributed to energy efficiency, while Rizi et al. (2021) detailed the adaptive façades and their energy efficiency improvements through responses to occupant needs and constraints in conjunction with the environment.

Aesthetic considerations were studied in only a few studies. Rezakhani et al. (2024) examined façade patterns that successfully combined visual appeal with functional performance, ensuring that designs fulfilled both technical requirements and aesthetic standards. Alajmi et al. (2019) highlighted the aesthetic aspects of window shading devices, demonstrating how well-designed solutions can enhance energy efficiency while improving the visual quality of buildings. Rizi et al. (2021) aimed to create an adaptive façade that is not only functional but also visually engaging, emphasizing the significance of aesthetics in user experience. Stevanović et al. (2018) explored curvilinear external shading designs that maintained aesthetic appeal while achieving energy efficiency, illustrating the harmonious balance between functionality and design. As a whole, these studies highlight the essential interplay between aesthetics and performance in architectural design.

After reviewing the publications, it has been determined that studies conducted between 2003 and 2024 focused on the following areas: 37% on visual comfort, 16% on thermal comfort, 6% on user interaction, 33% on energy efficiency and environmental performance, and 8% on aesthetics (Figure 3.2).

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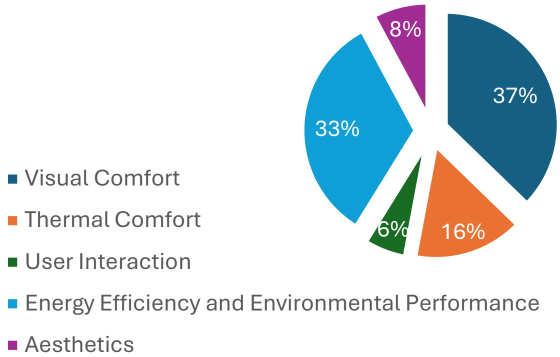

Figure 3.2 The percentages of the reviewed studies that researched performance criteria.

The majority of studies on visual comfort have been conducted in recent years, but there have always been some studies on the topic (Figure 3.3). Energy efficiency and environmental performance have also gained popularity both in the past and recently. While thermal comfort has consistently been a concern, it has maintained a steady level of interest over time. In contrast, research related to aesthetics in this field remains scarce.

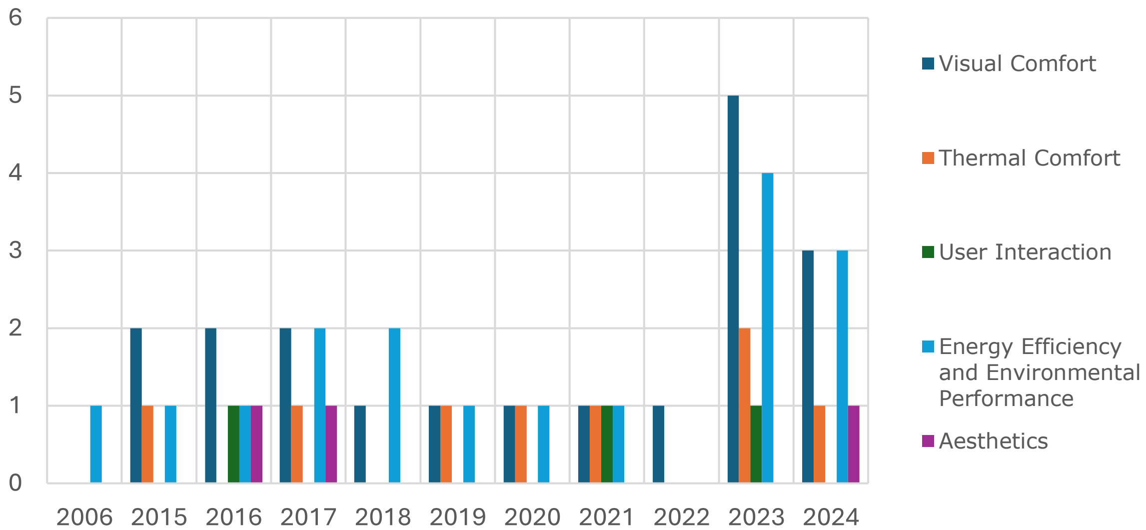

Figure 3.3 The performance criteria researched over the years.

According to the graphic in Figure 3.3, only one study in 2006 focused on energy efficiency and environmental performance. By 2015 and 2016, visual comfort became the most studied performance criterion. In 2017, there was a slight peak in publications related to energy efficiency and environmental performance. The years 2019, 2020, and 2021 which were impacted by the pandemic, saw a decrease in publications in this field. However, in 2023, there was a significant increase in research on visual comfort, with five papers published. There was also a rise in studies related to thermal comfort and energy efficiency. In 2024, visual performance and energy efficiency were the predominant themes in published studies.

Optimization studies are not a recent development in this field (Figure 3.4); in fact, we have a reference to such studies as far back as 2006. Since 2016, researchers have increasingly focused on developing new approaches. While comparisons and simulation analyses have been common practices, 2023 saw a notable peak in optimization studies, along with a rise in comparison and simulation analysis work. In 2024, new approaches were emphasized again.

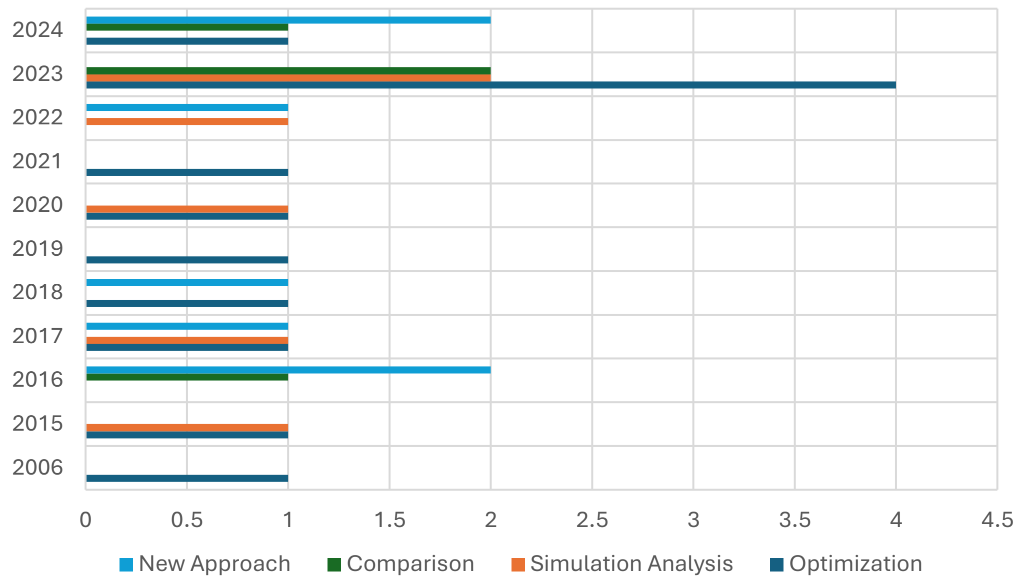

Figure 3.4 Study types researched over the years.

Table 3.5 The reviewed studies by study type, the country the study was conducted in, the year of publication, and the tools used.

Study type	Country	Authors	Year	Tools
Optimization	South Korea	Rezakhani, M., & Kim, S. A.	2024	Rhinoceros, Grasshopper, Galapagos, Karamba
	Iran	Baghoolizadeh, M., Rostamzadeh-Renani, M., Rostamzadeh-Renani, R., & Toghraie, D.	2023	EnergyPlus, JEPLUS, JEPLUS+EA, Morris Sensitivity Analysis
	Iran	Rizi, R. A., & Eltaweel, A.	2021	Rhinoceros,Grasshopper, Octopus, Ladybug, Honeybee
	Kuwait	Alajmi, A., Abaalkhail, F., & Alanzi, A.	2019	EnergyPlus, JEPLUS+EA
	Serbia	Stevanović, S., & Stevanović, D.	2018	Rhinoceros, Grasshopper, Octopus, Ladybug
	Denmark	Negendahl, K., & Nielsen, T. R.	2015	Rhinoceros, Grasshopper, Honeybee, Termite, HQSS
	Greece	Tsangrassoulis, A., Geros, V., & Bourdakis, V.	2006	Radiance, Summer-Building, TRNSYS, DOE-2, ESP-r
Simulation Analysis	Egypt	Wanas, A., Aly, S., Farghal, A., & El-Dabaa, R.	2015	Rhinoceros, Grasshopper, DIVA, Radiance
Comparison	USA, Iran	Vojdani, B., Rahbar, M., Fazeli, M., Hakimazari, M., & Samuelson, H. W.	2024	Rhinoceros, Grasshopper, MATLAB
	Iran, New Zealand	Nazari, S., Keshavarz Mirza Mohammadi, P., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Doan, D. T., & Almhafdy, A.	2023	Rhinoceros, Grasshopper, Ladybug
	South Korea	Lee, K. S., Han, K. J., & Lee, J. W.	2016	Rhinoceros, Grasshopper, DIVA
New Approach	China	Duan, Y., Zhang, T., Yang, Y., Li, P., Mo, W., Jiao, Z., & Gao, W.	2024	Rhinoceros, Grasshopper, Octopus
	Canada	Elmalky, A. M., & Araji, M. T.	2024	Rhinoceros, Grasshopper, MATLAB
	Iran	Tabadkani, A., Banihashemi, S., & Hosseini, M. R.	2018	Phyton
	South Korea	Choi, S. J., Lee, D. S., & Jo, J. H.	2017	Shading calculation tool (polygon method)
	Portugal	Caldas, L., & Santos, L.	2016	Rhinoceros, Grasshopper, Radiance
	USA	Von Buelow, P.	2016	Rhinoceros, Grasshopper, Digital Project (by CATIA), Autodesk Inventor, Generative Components (Bentley Systems)
Comparison and Optimization	China	Wen, S., Hu, X., Hua, G., Xue, P., & Lai, D.	2023	Rhinoceros, Grasshopper, Wallacei X (NSGA II Algorithm)
New Approach and Simulation Analysis	China	Xiao J., Liu Y., Deng Q.	2022	Rhinoceros, Grasshopper, DIVA, Radiance
Simulation Analysis and Optimization	Australia	Sorooshnia, E., Rashidi, M., Rahnamayiezekavat, P., Rezaei, F., & Samali, B.	2023	Rhinoceros, Grasshopper, Wallacei
	Australia	Tabadkani, A., Dehnavi, A. N., Mostafavi, F., & Naeini, H. G.	2023	Phyton
	Norway	Taveres-Cachat, E., & Goia, F.	2020	Rhinoceros, Grasshopper, EnergyPlus
	Egypt	Fathy, F., Sabry, H., & Faggal, A. A.	2017	Rhinoceros, Grasshopper, DIVA, Radiance, Daysim, Galapagos

The majority of the studies (Table 3.5) employed Rhinoceros and Grasshopper, as these tools facilitate parametric and algorithmic design approaches for designers. For optimization studies, some researchers did not use Rhinoceros and its plugins. Choi et al. (2017) used a shading calculation tool for the polygon method to develop a new approach. Alajmi et al. (2019), Baghoolizadeh et al. (2023) used EnergyPlus, and Tsangrassoulis et al. (2006) used Radiance for optimization. Tabadkani et al. (2018, 2023) conducted two studies using Phyton. One study, published in 2018, took place in Iran, where the authors developed a new approach, while the other was conducted in Australia in 2023 for simulation analysis and optimization.

4. CONCLUSION

The increasing demand for enhanced indoor environments highlights the importance of daylight control, which contributes to thermal comfort and visual comfort, ultimately benefiting people's well-being and work efficiency (Knoop et al., 2020, Duan et al., 2024). Additionally, managing natural light helps save energy by reducing the need for air conditioning and artificial lighting. To achieve sustainability goals, passive design strategies play a crucial role, and one effective passive strategy for daylight management is the use of shades (Choi et al., 2017; Moscoso et al., 2021). These shades can be designed in various shapes and made from different materials, depending on the climate, and they help prevent overheating. To reach high-performance levels in design, digital and algorithmic solutions have emerged. GA is a generative method based on Darwin's theory of evolution (Darwin, 1964). It generates different design options with the principle of survival of the fittest.

This study systematically examines current trends and research gaps in building facade shading systems using GA. The 293 publications were reached from Scopus databases published between 2003 and 2024. With the PRISMA method, many were eliminated due to selection criteria like language, subject area, keywords, title, and abstract. Finally, 23 publications were left. After reviewing these publications, classifications according to study type, year, tools, and performance criteria were made.

After reviewing 23 studies, it is clear that Rhinoceros and Grasshopper are commonly used tools in this field, while only a few studies utilized Python and EnergyPlus. Grasshopper is often preferred for implementing GAs due to its user-friendly visual programming interface, which allows users to create complex algorithms through a simple drag-and-drop method. This accessibility makes it easier for designers and architects, who may not have extensive programming backgrounds, to experiment with and understand algorithmic processes. In contrast, while Python offers greater flexibility and powerful capabilities for coding, it may require a steeper learning curve, making Grasshopper a more appealing option for those looking to quickly prototype and iterate on design solutions.

In recent years, developing new approaches and systems has become a prominent trend. Comparison studies are also gaining popularity. Simulation analyses and optimization studies have consistently been popular. Many modeling programs with plugins now offer built-in simulation analyses that are becoming increasingly user-friendly. Furthermore, artificial intelligence (AI) technologies have emerged from these tools, well known in the field to be a game changer.

To analyze systematically, performance criteria for shadings are set. Functional performance (visual performance, thermal performance, user interaction), energy efficiency and environmental performance, aesthetics are considered desired performance demands in shading.

The literature review identifies a notable gap in research on aesthetics, particularly within daylight control studies that tend to focus on quantitative metrics rather than qualitative insights. Designers need to engage with both dimensions, which necessitates a more thorough investigation into the aesthetic performance of shading systems. For instance, while Buelow (2016) explored aesthetics in pattern design, his analysis didn't extend to

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shading solutions. Similarly, Rezakhani (2024) and Elmalky (2024) missed the opportunity to systematically consider aesthetic factors. It is important to evaluate aesthetic and functional performance criteria together.

The relationship between aesthetic considerations and functional performance deserves more investigation. Studies, like the ones carried out by Rezakhani et al. (2024), suggest a connection between aesthetics and usability, yet do not consider how visual appeal affects occupant satisfaction and comfort. Future studies could critically analyze the psychological effects of design aesthetics of shadings on user experience methodologically with qualitative methods like interviews or focus groups.

Another pressing issue is the lack of user feedback. Gathering this data can be labor-intensive due to the intricacies involved in shading design and building interactions. There is a need to find more efficient ways to collect user feedback early in the design process.
While existing research has provided valuable insights into visual and thermal comfort, user interactions, energy efficiency, and aesthetics, several key areas still need attention. One major focus should be on how occupants perceive and respond to optimized façade shading designs. Although Rezakhani et al. (2024) discussed visual comfort, it’s clear that more detailed studies are required to explore the impact of façade patterns on psychological and physiological factors. Future research should include field experiments and surveys designed to gather occupant feedback in various lighting and shading conditions.

Additionally, understanding user behavior in design optimization has not been adequately addressed. Baghoolizadeh et al. (2023) and Rizi et al. (2021) recognized its importance but didn’t delve deeply into how occupancy patterns and individual preferences influence shading and façade performance. Future studies could leverage IoT sensors and applications to capture user interactions over time and evaluate their effects on comfort.
Furthermore, a holistic approach to assessing comfort is crucial. While Alajmi et al (2019) examined energy and daylight metrics, they overlooked thermal, acoustic, and air quality dimensions. Future studies need to be considered to develop comprehensive frameworks integrating more comfort parameters, ideally in cooperation with professionals from environmental psychology and building science.

The practical feasibility of the advanced façade systems and shading devices also needs to be taken into consideration. While Rizi et al (2021) & Stevanović et al (2018) addressed performance success in façades and shading devices, they did not consider the practical implementation. Future research should consider lifecycle costs, maintenance, and installation procedures for adaptive façades and shading solutions to facilitate their adoption in new constructions and renovations.

In discussions around GA for shading design, there’s a notable absence of focus on their educational potential and how easily they can be learned. This represents a clear area for further investigation.

As new methodologies related to energy efficiency and environmental performance are emerging, their transferability across different climates has not been studied comprehensively. Perhaps the reliance on simulation tools such as Honeybee and Ladybug, since they allow fast simulations, also leads to the researcher's realization of shortcomings in design performance.

Energy efficiency has been an important aspect to consider, however, there has been little research on how shading design performance is affected by a combination of local climate, cultural context, and type of building. There is much future work to be done to develop adaptable design reasoning and reflection that responds to these factors, including research that uses fieldwork to understand variations in climate and their implications for design processes.

This systematic literature review has provided some insight into the current trends and gaps in research regarding daylight control through shading design techniques with GAs. It aims to contribute to daylight control solutions for shading by exploring the effects on user satisfaction and sustainability. As part of ongoing research towards a PhD, these findings are intended to inform future research as well as practical implications. It is hoped that this research will be a useful reference for researchers and practitioners, promoting further exploration in the field.

References

Alajmi, A., Abaalkhail, F., & Alanzi, A. (2019, September). Climate-Based Daylighting Metrics Assessment to Select among Optimum Energy Efficient Windows' Shading Devices Solutions: case study of an office in a hot climate. In *Building Simulation 2019* (Vol. 16, pp. 1114-1120). IBPSA.

Alexakis, K., Benekis, V., Kokkinakos, P. Askounis D. (2024), Genetic algorithm-based multi-objective optimisation for energy-efficient building retrofitting: A systematic review,

Al-Masrani, S. M., Al-Obaidi, K. M., Zalin, N. A., & Isma, M. A. (2018). Design optimisation of solar shading systems for tropical office buildings: Challenges and future trends. Solar Energy, 170, 849-872.

Baghoolizadeh, M., Rostamzadeh-Renani, M., Rostamzadeh-Renani, R., & Toghraie, D. (2023). Multi-objective optimization of Venetian blinds in office buildings to reduce electricity consumption and improve visual and thermal comfort by NSGA-II. *Energy and Buildings*, *278*, 112639.

Beck, W. Korner, O. Gross, J. Fricke (1999), Making better use of natural light with a light-redirecting double-glazing system, Sol. Energy 66 (3), 215–221.

Caldas, L., & Santos, L. (2016). Painting with light: An interactive evolutionary system for daylighting design. *Building and Environment*, *109*, 154-174.

Chi, F. A., Wang, R., Li, G., Xu, L., Wang, Y., & Peng, C. (2020). Integration of sun-tracking shading panels into window system towards maximum energy saving and non-glare daylighting. Applied Energy, 260, 114304.

Choi, S.-J., Lee, D. S., Koo, S. H., & Jo, J. H. (2017). Algorithmic design of external movable shading devices for energy conservation, illuminance satisfaction, and glare protection. *Energy and Buildings, 150*, 328–338. https://doi.org/10.1016/j.enbuild.2017.07.037

Costa-Carrapiço, I., Raslan, R., & González, J. N. (2020). A systematic review of genetic algorithm-based multi-objective optimisation for building retrofitting strategies towards energy efficiency. Energy and Buildings, 210, 109690.

Darwin, C. (1964). On the origin of species: A facsimile of the first edition. Harvard University Press.

Duan, Y., Zhang, T., Yang, Y., Li, P., Mo, W., Jiao, Z., & Gao, W. (2024). A multi-objective approach to optimizing the geometry and envelope of rural dwellings for energy demand, thermal comfort, and daylight in cold regions of China: A case study of Shandong province. *Energy Conversion and Management*, 322, 119128.

Elmalky, A. M., & Araji, M. T. (2024). Optimization models for photosynthetic bioenergy generation in building façades. *Renewable Energy*, *228*, 120607.

Fathy, F., Sabry, H., & Faggal, A. A. (2017). External Versus Internal Solar Screen: Simulation Analysis for Optimal Daylighting and Energy Savings in an Office Space. *Proceedings of the PLEA, Edinburgh, UK*, *16*.

Goldberg, N. E. (1989). Genetic Algorithms in Search, Optimization, and Machine Learning. Addison-Wesley, Reading, MA.

Ishac, M., & Nadim, W. (2021). Standardization of optimization methodology of daylighting and shading strategy: a case study of an architectural design studio–

the German University in Cairo, Egypt. Journal of Building Performance Simulation, 14(1), 52-77.
Knoop, M., Stefani, O., Bueno, B., Matusiak, B., Hobday, R., Wirz-Justice, A., ... & Norton, B. (2020). Daylight: What makes the difference?. Lighting Research & Technology, 52(3), 423-442.
Lee, K. S., Han, K. J., & Lee, J. W. (2016). Feasibility study on parametric optimization of daylighting in building shading design. *Sustainability*, *8*(12), 1220.
Liu, Q., Chen, Y., Liu, Y., Lei, Y., Wang, Y., & Hu, P. (2023). A review and guide on selecting and optimizing machine learning algorithms for daylight prediction. Building and Environment, 244, 110822.
Machairas, V., Tsangrassoulis, A., & Axarli, K. (2014). Algorithms for optimization of building design: A review. Renewable and sustainable energy reviews, 31, 101-112.
Madan, Ö. K., Chamilothori, K., van Duijnhoven, J., Aarts, M. P., & de Kort, Y. A. (2024). Restorative effects of daylight in indoor environments–A systematic literature review. Journal of Environmental Psychology, 97, 102323.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. International journal of surgery, 8(5), 336-341.
Moscoso, C., Chamilothori, K., Wienold, J., Andersen, M., & Matusiak, B. (2021). Window size effects on subjective impressions of daylit spaces: indoor studies at high latitudes using virtual reality. Leukos, 17(3), 242-264.
Nazari, S., Keshavarz Mirza Mohammadi, P., Ghaffarianhoseini, A., Ghaffarianhoseini, A., Doan, D. T., & Almhafdy, A. (2023). Comparison of shading design between the northern and southern hemispheres: using the NSGA-II algorithm to reduce building energy consumption and improve occupants' comfort. *Smart and Sustainable Built Environment*.
Negendahl, K., & Nielsen, T. R. (2015). Building energy optimization in the early design stages: A simplified method. *Energy and Buildings, 105*, 88-99.
Özlük, R., Aydın, F., & Yıldız, Y. (2025). Artificial intelligence algorithms, simulation tools and software for optimization of adaptive facades: A systematic literature review. Journal of Building Engineering, 112566.
Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and buildings*, *40*(3), 394-398.
Rezakhani, M., & Kim, S. A. (2024). Genetic Algorithm-Driven optimization of pattern for parametric facade design based on support position data to increase visual quality. *Buildings*, *14*(4), 1086.
Rizi, R. A., & Eltaweel, A. (2021). A user detective adaptive facade towards improving visual and thermal comfort. *Journal of Building Engineering, 33*, 101554. https://doi.org/10.1016/j.jobe.2020.101554
Sorooshnia, E., Rashidi, M., Rahnamayiezekavat, P., Rezaei, F., & Samali, B. (2023). Optimum external shading system for counterbalancing glare probability and daylight illuminance in Sydney's residential buildings. *Engineering, Construction and Architectural Management*, *30*(1), 296-320.
Stevanović, S., & Stevanović, D. (2018). Optimisation of curvilinear external shading of windows in cellular offices. *Plos one*, *13*(9), e0203575.
Tabadkani, A., Nikkhah Dehnavi, A., Mostafavi, F., & Ghorbani Naeini, H. (2023). Personalization framework for modular adaptive façades in shared office spaces: A simulation-based methodology. *Journal of Building Engineering, 69*, 106118. https://doi.org/10.1016/j.jobe.2023.106118
Tabadkani, S. M., Mostafavi, S., & Darvishi, A. (2018). Parametric analysis of daylighting and visual comfort using shading systems. *Building and Environment, 132,* 101-112.
Taveres-Cachat, E., & Goia, F. (2020). Co-simulation and validation of the performance of a highly flexible parametric model of an external shading system. *Building and Environment*, *182*, 107111.

Tsangrassoulis, A., Geros, V., & Bourdakis, V. (2006). Energy conscious automated design of building façades using genetic algorithms. *session 20: generative design systems-eCAADe*, *24*.

Vojdani, B., Rahbar, M., Fazeli, M., Hakimazari, M., & Samuelson, H. W. (2024). Comparative study of optimization methods for building energy consumption and daylighting performance. *Energy & Buildings, 323*, 114753. https://doi.org/10.1016/j.enbuild.2024.114753

Von Buelow, P. (2016). Genetically enhanced parametric design in the exploration of architectural solutions. *Structures and Architecture - Proceedings of the 3rd International Conference on Structures and Architecture, ICSA 2016 Pages 675 – 683.*

Wanas, A., Aly, S., Farghal, A., & El-Dabaa, R. (2015). Use of kinetic facades to enhance daylight performance in office buildings with emphasis on egypt climate. *J. Eng. Appl. Sci*, *62*(1), 339-361.

Wen, S., Hu, X., Hua, G., Xue, P., & Lai, D. (2023). Comparing the performance of four shading strategies based on a multi-objective genetic algorithm: A case study in a university library. *Journal of Building Engineering*, 63, 105532. https://doi.org/10.1016/j.jobe.2022.105532

Xiao, J., Liu, Y., & Deng, Q. (2022). High-density building form generation considering daylight performance with a daylight performance optimization method integrating genetic algorithm and cellular automata. *Journal Title*, 524, 524-534.

Zhao, L., & Du, H. (2020). A review on multi-objective optimization algorithms for energy-efficient building designs. *Energy and Buildings*, 222, 110017. https://doi.org/10.1016/j.enbuild.2020.110017