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APPLICATION OF BRISE-SOLEIL IN ARCHITECTURE: A CASE STUDY OF A NEWLY DESIGNED RESIDENTIAL NEIGHBORHOOD IN BAOŠIĆI CONSIDERING BIOCLIMATIC AND URBAN PLANNING PARAMETERS

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Abstract

Global warming and rising energy demand make brise-soleil systems increasingly important in energy-efficient cooling and reducing carbon emissions in warm climates. This study examines a newly designed residential neighborhood in Baošići, Montenegro, characterized by a Mediterranean climate with hot, dry summers and mild winters. The effectiveness of brise-soleil systems in improving energy efficiency and thermal comfort is widely documented; however, there is little research on the performance of such systems in specific residential applications across a range of climates. This research fills that gap by evaluating the performance of brise-soleil in reducing cooling energy consumption from late March to mid-November. Simulation results show that cooling energy demand is reduced by 9% to 31% during summer months and annual savings of 12%. In addition to energy savings, brise-soleil systems help achieve bioclimatic design by minimizing solar heat gain and improving indoor comfort. They also enhance the architectural design. Adaptive shading technologies will be applied in future research to different climates to maximize energy savings and achieve sustainability.

Keywords: *Energy Efficiency, Bioclimatic Design, Sustainable Architecture, Solar Shading*

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1. INTRODUCTION

Bioclimatic architecture merges centuries-old principles of design inspired by adaptations of natural organisms. The approach optimizes energy efficiency (EE) using local climatic factors and natural resources such as solar gain and wind. For example, the orientation of the building can significantly reduce heating and cooling demands, while natural materials enhance insulation and promote sustainability [1,2]. Concerning the urgent need to cut energy consumption (EC) and resource depletion, this design philosophy minimizes the reliance on artificial energy sources and promotes the use of renewable energy [3]. Accordingly, the study by Koç Sena Göknur and Maçka Kalfa Sibel [4] demonstrates that passive solar techniques, central to bioclimatic design, are key to sustainable architecture through brise-soleil systems.

Architects can reduce their ecological footprint, conserve resources, and improve the well-being of their occupants by embracing bioclimatic principles. Stable indoor environments, low energy demands, and good thermal comfort (TC) are achieved through natural ventilation and high-quality insulation. Solar radiation management is, therefore, a significant concern, especially in residential buildings that receive high solar radiation. Brise-soleils are a good solution to balance natural light and cooling needs. They enable simultaneous solar shading, natural ventilation, and EE. Elzeyadi [2] and Meerbeek et al. [5] demonstrate that dynamic brise-soleils dramatically increase TC and energy performance in regions with high solar exposure.

This paper cites the studies that have given the foundation for how shading systems can contribute to EE and TC. This research contributes to existing findings by focusing on brise-soleil systems in a particular residential neighborhood in Baošići, Montenegro, and filling the gaps in understanding their performance in transitional climates. In contrast to other shading studies, the simulations in this paper are detailed and quantify energy savings in a bioclimatic approach that considers urban planning parameters. It provides a unique focus by utilizing EnergyPlus simulations to bridge theoretical research and the practical application of sustainable architecture, specifically through the detailed design and evaluation of brise-soleil systems.

However, their performance depends on precise design, placement, and orientation, especially during cooler months when solar gains are desirable. To optimise their design, Energyplus simulations are used to investigate the effectiveness of brise-soleils as a design element for coastal climates in a residential neighborhood in Baošići, Herceg Novi, Montenegro.

2. SUN PROTECTION THROUGH HISTORY - LITERATURE REVIEW

Sun protection, a cornerstone of bioclimatic architecture, has been integrated for centuries. Socrates' example of the sun-oriented house is an early example of solar control for TC (Figure 1). Over time, architectural progress has incorporated modern materials and technologies and has perfected these principles for more building performance and sustainability [6].

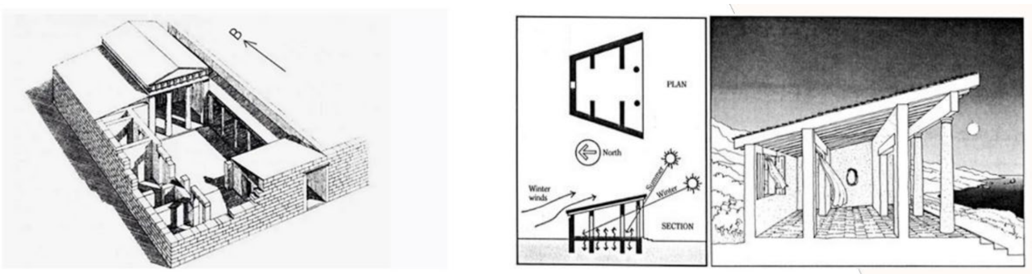

Figure 1. Application of the principle of sun protection in the ancient age - Socrates' house [7,8]

Deep openings and overhangs, as measured by ancient civilizations like the Greeks, Egyptians, and Persians, were used to address solar exposure. In the 20th century, modernist architects such as Le Corbusier and Oscar Niemeyer popularized the brise-soleils as a blend of perfect functionality and aesthetics. However, these systems have become indispensable for EE building designs, which reduce mechanical cooling demands and improve visual appeal [8].

Today's brise-soleils, equipped with advanced materials and intelligent technologies, provide flexible light and temperature control, making them indispensable in sustainable architecture. Different shading devices, from static systems to automated blinds, effectively balance natural light, ventilation, and energy savings.

Recent research highlights the dual impact of brise-soleils on EE and occupant comfort, as Elzeyadi [2] demonstrated in solar radiation control and Meerbeek et al. [5] in occupant satisfaction. Additionally, Lai et al. [1] and Baghoolizadeh et al. [9] demonstrated the flexibility of shading devices for various climates and used such devices with photovoltaic technologies to improve performance.

Self-shading façades have been further explicitly studied for their benefits in reducing cooling loads and improving energy performance [10, 11] and a growing body of literature has further emphasized the effectiveness of shading devices in warm climates. Dynamic shading and glazing technologies have also enhanced energy and visual performance and have placed adaptive shading solutions in a central role for contemporary buildings [12]. In addition, shading devices coupled with radiative cooling strategies are a focus of EE design in hot climates [13]. Our findings support using well-designed shading systems like brise-soleils to enable architecturally responsive climates.

3. CONCEPTUAL ARCHITECTURAL AND URBAN DESIGN SOLUTION

3.1. Climatic Parameters of the Location

Herceg Novi has a Mediterranean climate with mild winters, warm summers, and an annual temperature of 15.8°C, with temperatures regularly over 20°C in summer. The clear skies prevail during summer and get 2,417 hours of sunshine annually. Rainfall averages 1,940 mm annually, mostly in winter, and temperatures seldom fall below 0°C.

The wind conditions vary: In colder months, the jugo brings moist air, while the bora brings cold winter winds. In summer, with a moderate climate, the maestral moderates the climate, but it is ideal for outdoor activities.

3.2. Site Conditions

Baošići has a hot, dry (summer temperature above 32°C, winter temperate above 10°C) Mediterranean climate. It allows bioclimatic architecture by enabling solar energy use without overheating.

Connectivity is guaranteed by the linear laying out of the settlement along the main road. The residential structures blend into modern, tourism-oriented buildings with red tiled roofs and natural stone facades. Mediterranean vegetation and parks add to the scenic and environmental attractiveness of the region.

The site comprises three residential buildings on a gentle slope facing the Bay of Kotor. It is very accessible, close to the E65 highway, and there is a pedestrian path to the bay. A hedge provides sound insulation, and schools and commercial facilities are nearby.

Baošići is an ideal location for permanent residence and tourism-related activities due to its proximity to beaches, cafes, and recreational areas. The site's natural beauty and convenient access to amenities make it highly suitable for future development (Figure 2). Macro- and micro-location analyses highlight the site's strategic positioning in relation to the E65 highway, nearby schools, and recreational areas along the Bay of Kotor.

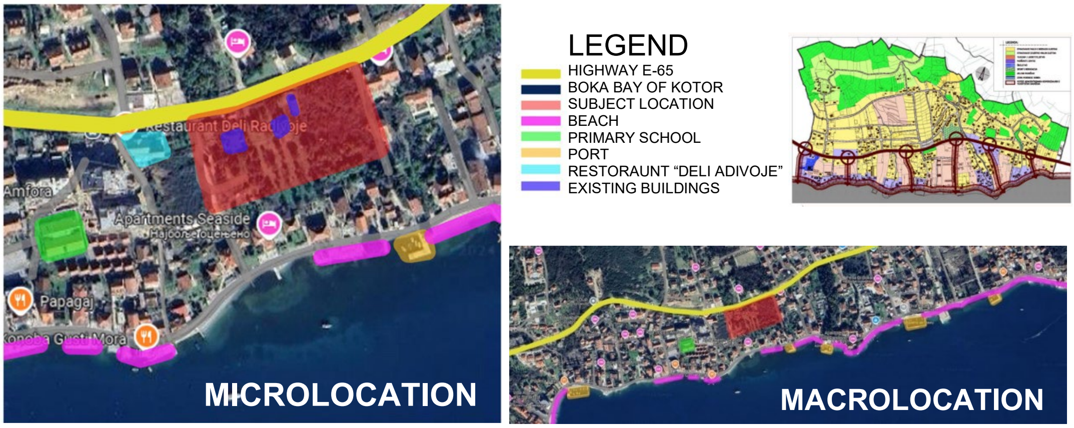

Figure 2. Macro and Micro Location Analysis

3.3. Urban Parameters of the Location

Baošići is urbanized following local regulations, which classify the site for low to medium-density residential use. The layout comprises sixteen detached buildings that conform to the terrain's natural slope and harmoniously fit the landscape.

Type A (6.8 m tall, three levels) and Type B (4.2 m tall, two levels) buildings are categorized as buildings with eight residential units. The design strikes an elegant balance between density and spaciousness in creating a high-quality living environment.

Green buffers between buildings ensure privacy, are natural barriers, and provide acoustic insulation. The E65 highway is mitigated by a green belt, which reduces noise pollution and adds visual appeal to the residential environment.

Density indices meet zoning requirements: Coverage index of 0.4, Construction index of 0.8, and height limit of two stories above ground. Medium-density zones allow up to four-story mixed-use buildings at a construction index 1.2.

Pathways and stairways are included in the ground-level parking, making walking easy. They include courtyards, pools, and outdoor spaces that improve the quality of life while paving materials respect the natural terrain to minimize environmental impact.

3.4. Program Analysis, Architectural and Functional Design Concept

The project is designed as a bioclimatic architectural and urban design for a residential neighborhood in Baošići. Scenic views are encouraged, and the natural slope toward the Bay of Kotor orients buildings.

It favors simplicity, harmony with nature, and better living conditions. Designed to function seamlessly in the environment whilst minimizing visual impact, all sixteen residential buildings are strategically positioned along the slope.

Stability and durability are provided by the robust structural system of reinforced concrete (20x20 cm columns and 20x40 cm beams). Soft white finishes combine with natural stone and wood to create facades that integrate seamlessly with the landscape.

Solar management is achieved through wood-colored aluminum brise-soleils, designed for horizontal adjustments on southern facades to shield against high summer sun angles, and vertical adjustments on eastern and western facades to block lower morning and evening sun, ensuring optimal shading throughout the day and across seasons. These shading devices increase EE, comfort, and privacy while responding to daily and seasonal variations in sunlight. It is arranged with three levels of residential units. (Figure 3).

Figure 3. Master plan of the settlement, Floor plans, and Sections of the objects

The design features a highly sustainable approach, with a flat green roof with ten solar panels to generate renewable energy and improve insulation. The swimming pool is integrated with the outdoor area to provide residents with a comfortable and quality life through accessible recreational spaces. Taken together, the architectural and functional aspects of the complex result in a visually attractive, energy efficient, environmentally responsive living environment that meets the visual and environmental requirements of the modern age. (Figure 4.).

Figure 4. 3D render of the designed objects

Diagrams illustrating summer and winter conditions were analyzed to evaluate the buildings' response to solar movement (Figure 5). These diagrams visualize seasonal variations in solar exposure, emphasizing the importance of adaptive shading solutions in balancing energy efficiency and indoor comfort throughout the year.

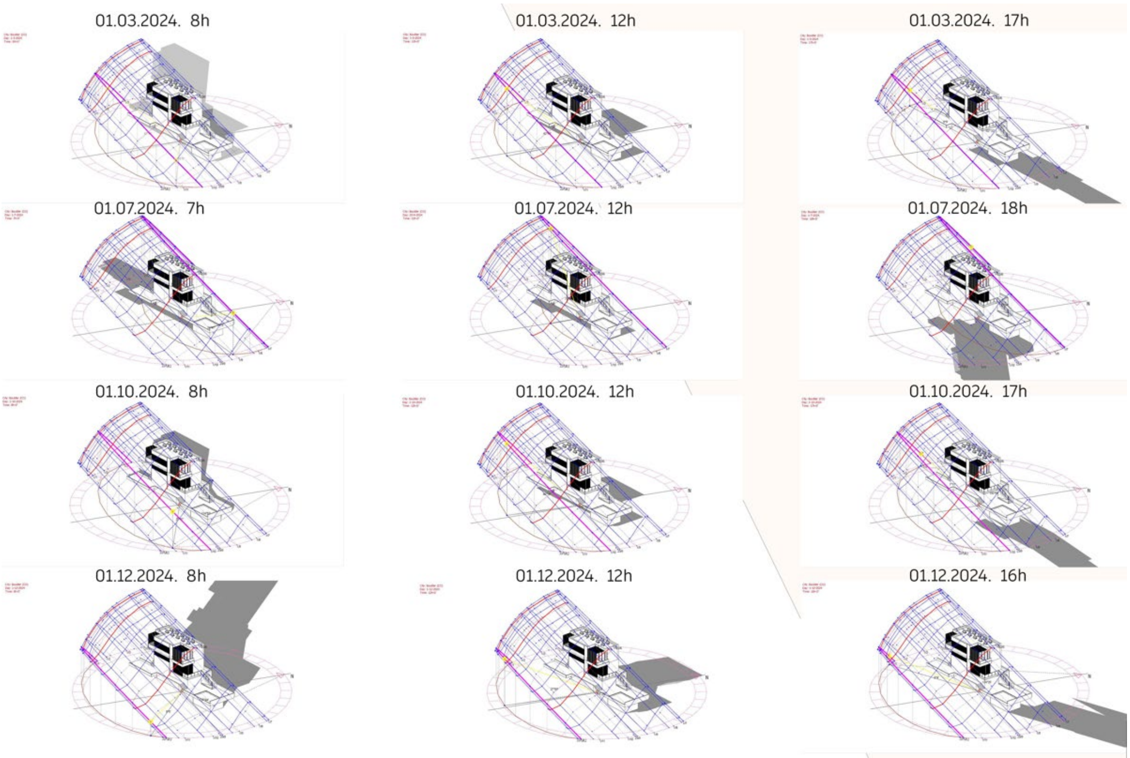

Figure 5. The impact of solar movement

3.6. Seasonal Performance

Brise-soleils reduce heat gain during summer, blocking intense morning and evening sunlight on the eastern and western facades. Solar panels on the roof generate electricity, while the green roof absorbs excess heat, maintaining stable indoor temperatures and reducing cooling loads.

At night, operable windows and vents enable cross ventilation, achieving airflow rates of up to 0.6 air changes per hour, which helps to refresh indoor air and reduce cooling loads by approximately 10% during summer months.

In winter, brise-soleils retract to maximize solar heat gain, while the green roof retains warmth. Solar panels generate electricity even on cold days, and the heat pump adjusts indoor temperatures for comfort.

This dynamic design approach combines passive and active strategies to year-round enhance comfort, EE, and environmental sustainability.

4. METHODOLOGY

Energy simulations can provide valuable insights into a building's energy performance and optimize design and systems under different scenarios. Simulations are imperfect with simplified models and assumptions, but they provide tremendous cost and time savings in the design phase and a base for making informed decisions on EE.

The detailed simulation capabilities of EnergyPlus were selected for their ability to simulate cooling demands and EC under varying conditions, including the presence or absence of brise-soleil systems, to evaluate their impact on cooling EC. Working with the SketchUp package means working with a perfectly matching geometry modeling workflow that enables accurate visualization and input of architectural details. EnergyPlus provides robust support for thermal & energy simulations, and SketchUp's user-friendly interface simplifies the creation of complex structures. Combining the two makes this an ideal setup for research that requires architectural precision and advanced performance analysis. (Figure 6.).

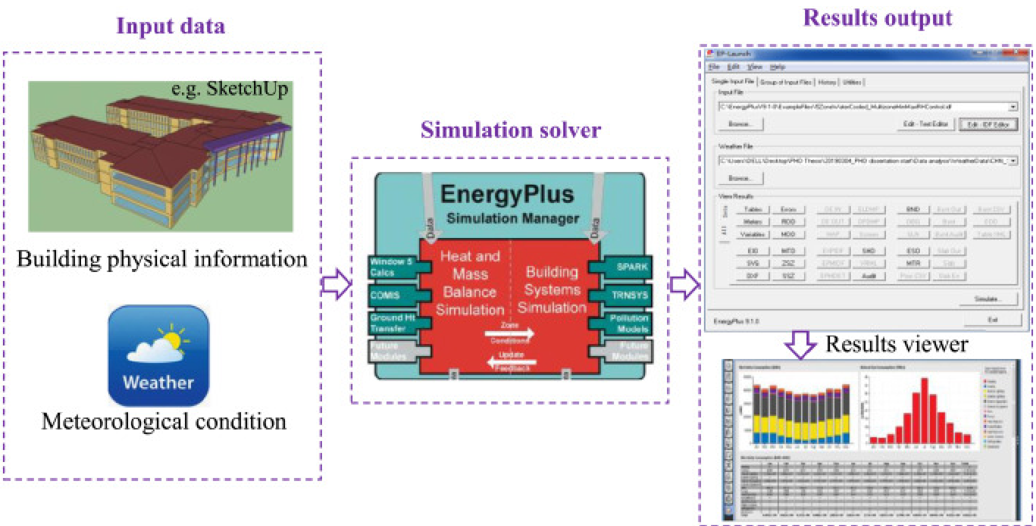

Figure 6. Building performance simulation tools [14]

Cooling demands and electricity consumption were analyzed under seasonal and site-specific climatic conditions (weather data files for Herceg Novi, Montenegro). The role of brise-soleil was assessed to reduce cooling loads and enhance EE.

The modeling process started with a geometric model in SketchUp created down to the detail and was then exported to EnergyPlus. All construction elements were defined carefully based on key material properties, including thickness, density, thermal conductivity, and specific heat. These layers' opaque and transparent surfaces were assigned correctly, so thermal performance representation was accurate.

Each construction's physical and thermal properties are specified in text-based input files (.idf) EnergyPlus uses. All layers, from exterior facades to interior surfaces, were included in the simulation, reflecting real-world conditions. This study uses the 3D model shown in Figure 7, which shows the integration of material properties and shading devices necessary for simulating how the building interacts with its environment.

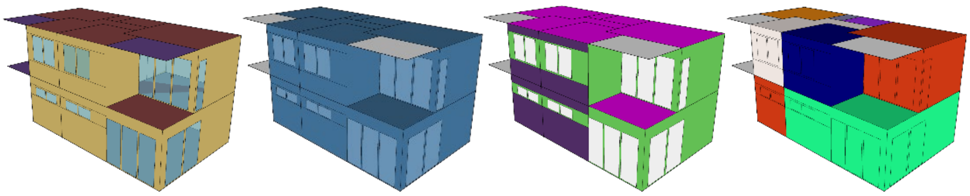

Figure 7. Energy models created in the Open studio plugin in SketchUp

Electricity consumption for cooling was analyzed, and a comparison between scenarios with and without brise-soleil was made using both percentage differences and absolute energy savings. This approach allowed for a clear understanding of the effectiveness of the brise-soleil in reducing cooling energy demand, with a specific focus on seasonal variations and peak months.

5. RESULTS AND DISCUSSION

5.1. Impact on Total Energy Consumption

The results show that brise-soleil is key in reducing cooling EC by controlling solar exposure during the warmer months, with solar gains reduced by up to 25%, leading to a 31% decrease in cooling energy demand during peak summer months.

Nevertheless, to limit beneficial solar heat gains, cooling EC was slightly increased by brise-soleil during cooler months (March to mid-June). This observation is in accord with Alhuwayil et al.'s findings that passive shading strategies may decrease thermal efficiency in climates or seasons with limited sunlight [15]. Their study highlighted how shading devices, while effective in reducing cooling loads in hot climates, can limit beneficial solar heat gains during cooler periods, similar to the slight increase in cooling energy consumption in May due to reduced beneficial solar gains, observed in our study.

However, despite this, brise-soleil was highly effective after July, when peak ambient temperatures occurred. July showed the highest monthly reduction, with energy savings of approximately 24.9%. In July, the configuration without brise-soleil consumed nearly 200 kWh, compared to around 150 kWh with the system installed. These results agree with Koç and Maçka Kalfa [16], who found substantial cooling load reductions from shading devices in Mediterranean regions with high solar exposure. Cooling energy consumption between May and October totaled 639.59 kWh without brise-soleil and 462.21 kWh with it, reflecting a 27.7% reduction. A monthly comparison of cooling EC between configurations with and without brise-soleil is shown in Figure 7, with significant reductions during peak summer months (Figure 8).

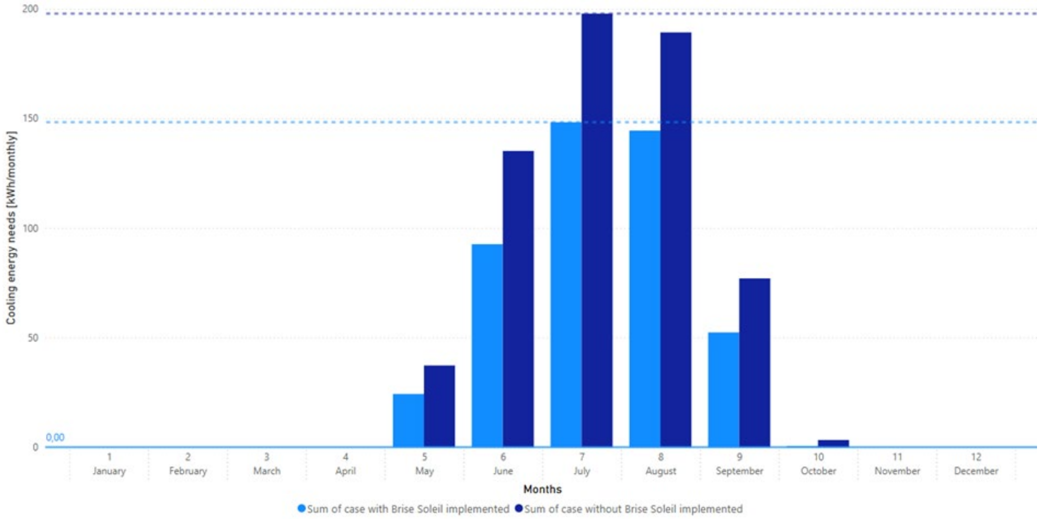

Figure 8. Comparison of monthly cooling energy consumption for brise-soleil and non-brise-soleil configurations

Furthermore, brise-soleil and other shading devices may contribute to sustainable design by decreasing peak cooling demand during heat-intensive periods. This reduces operational costs and conserves the environment by decreasing energy use and emissions, as Mohammed et al. [17] found in high-sun regions, which saw cooling load reductions via shading strategies. In climates with significant seasonal temperature variations, brise-soleil effectively reduces cooling energy needs and greenhouse gas emissions by improving energy performance.

6. CONCLUSION

Brise-soleil systems are increasingly proving to be a practical solution for improving the EE of residential buildings in warm climate zones, where rising global temperatures pose a serious challenge. This study confirms their key role in reducing EC and improving the aesthetics of architectural solutions. The results showed that brise-soleil can reduce monthly cooling EC by up to 31% in the hottest periods while annual savings amount to 12%. This makes them an extremely effective tool for lowering EC and carbon dioxide emissions.

Installing bridge-soleil systems in architectural projects improves EE and functionality and raises the aesthetic quality of buildings. These systems enable adaptable and flexible designs that maximize natural lighting, reduce indoor overheating, and significantly improve building comfort. At the same time, their role in adding dynamic and striking elements to the facades contributes to creating a unique visual identity of the buildings.

The results of this study confirm the key component of sustainable architecture: that brise-soleil systems have significant potential in residential projects to reduce cooling energy consumption by orders of magnitude during the hottest months. Integration of these systems allows urban planners and designers to design projects that fit given climatic conditions, which take energy efficiency, aesthetics, and reduction of carbon dioxide emissions into account. Beyond enhancing the energy performance of buildings, brise-soleil also brings to buildings their visual identity, supporting sustainable development goals. Future research could be directed to developing adaptive brise-soleil systems responding to different climatic challenges and integrating modern technologies, such as solar panels, to enhance energy sustainability in architecture.

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