Resilient Solar Energy for Climate Action: Mitigation and Adaptation in the Built Environment

Berta García Fernández[1]

[1] ETSI Montes, Forestal y del Medio Natural, Dpto. de Ingeniería y Gestión Forestal y Ambiental, Universidad Politécnica de Madrid, Madrid (Spain)

Lighting systems account for a significant share of global electricity consumption and greenhouse gas emissions, making them a key target for decarbonization in the built environment. Solar lighting technologies, particularly photovoltaic systems integrated into buildings and urban infrastructures, can reduce energy demand while strengthening resilience. However, research on solar technologies, daylighting strategies, and adaptive architectural design is often addressed separately, limiting integrated approaches that support both mitigation and adaptation. To address this gap, this study develops a conceptual framework for climate-responsive solar lighting in the built environment. The research is based on an analytical synthesis of technological and architectural strategies identified in scientific literature and international reports. The results highlight the potential of integrating photovoltaic systems, daylighting design, and smart lighting technologies to support resilient and low-carbon built environments.

Keywords: Solar energy; Lighting; Climate change; Mitigation and adaptation; Sustainable building design.

Introduction

Climate change presents urgent and multifaceted challenges that demand robust mitigation and adaptation strategies within the built environment. Replacing all the world inefficient lighting with energy efficient alternatives would cut the global share of electricity used for lighting by 50% and lead to a 5% reduction in total global electricity consumption (UNFCCC, 2023). Lighting systems account for approximately 15% of global electricity consumption and contribute nearly 5% of greenhouse gas (GHG) emissions, highlighting the critical importance of transitioning toward energy-efficient and low-carbon alternatives (IEA, 2020). Among these, solar lighting technologies, particularly photovoltaic (PV) systems, represent a sustainable pathway by reducing dependence on fossil fuels and enhancing energy resilience. Recent studies also emphasize that integrating daylighting metrics and adaptive lighting strategies can enhance both energy performance and human comfort, linking operational efficiency with resilience indicators such as Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) (Mukherjee, 2025; Almesbah, 2025). These technologies directly support the United Nations Sustainable Development Goals (SDGs 7, 11, and 13), promoting clean energy access, sustainable urban development, and climate action (IEA PVPS, 2021; UNDP, 2022).

Strategies developed for sustainable and resilient built environments, such as solar energy integration and adaptive design, can be adapted to forest-dependent communities, creating synergies between urban and forested contexts in addressing climate change and enhancing resilience (Broto, 2024). The accelerating impacts of climate change on forest ecosystems present complex challenges for both environmental sustainability and community well-being. Rising temperatures, shifting precipitation patterns, and increased frequency of extreme events threaten forest biodiversity, exacerbate deforestation, and disrupt the livelihoods of forest-dependent populations. These challenges underscore the urgent need for integrated climate action strategies that address both mitigation and adaptation objectives (Djoudi, 2022). Solar energy solutions offer a resilient pathway to achieve these goals by providing decentralized, low-carbon energy access while supporting ecosystem conservation (Yu, 2019).

Despite their potential, significant barriers remain, including regulatory gaps, limited financing mechanisms, and a lack of public and institutional awareness. The performance and reliability of solar energy systems are also inherently influenced by climatic and environmental factors such as solar irradiance, atmospheric composition, and land use patterns. Atmospheric aerosols and cloud cover can reduce PV efficiency, a phenomenon evidenced by observed global "solar dimming" trends (Kaufman et al., 2002; Bond et al., 2013). Conversely, recent temporary improvements in air quality such as those recorded during COVID-19 lockdowns correlated with measurable increases in solar energy generation (Song, 2021). Furthermore, the intensification of extreme weather events and greenhouse gas concentrations underscores the growing need for resilient and adaptive solar lighting infrastructures capable of

10.18086/swc.2025.08.20 Available at http://proceedings.ises.org

maintaining functionality under climate stressors (Seneviratne et al., 2021).

Although research on solar energy systems, daylighting technologies, and sustainable lighting design has expanded significantly in recent years, these topics are frequently addressed independently in the scientific literature. Many studies focus primarily on the mitigation potential of solar technologies through improvements in energy efficiency and emission reduction, while others emphasize adaptation strategies related to thermal comfort, building resilience, or environmental performance. However, fewer studies examine how solar-based lighting systems can simultaneously contribute to both mitigation and adaptation objectives through the integration of technological solutions, passive architectural strategies, and climate-responsive design within the built environment.

This paper therefore seeks to bridge the gap between technological, architectural, and resilience-oriented perspectives on solar lighting in the built environment.

The objective of this study is to analyze how solar lighting systems can support climate action by integrating mitigation and adaptation strategies in buildings and urban infrastructures. In particular, the research aims to identify key solar lighting technologies and passive daylighting strategies, evaluate their contribution to energy efficiency and environmental performance, and develop an integrated conceptual framework linking solar lighting technologies, adaptive design approaches, and resilience indicators.

The study is based on the synthesis and analysis of technological, architectural, and environmental strategies identified in scientific literature and international reports related to solar energy systems, daylighting technologies, adaptive building envelopes, and climate-resilient infrastructure. Through this analytical synthesis, the research develops a conceptual framework for climate-responsive solar lighting systems in the built environment.

The remainder of the paper is structured as follows. Section 1 examines the integration of solar energy into climate action strategies in the built environment. Section 2 discusses mitigation and adaptation lighting strategies. Section 3 explores natural and passive lighting approaches and their role in improving environmental performance and occupant comfort. Finally, Section 4 presents the conclusions and outlines future research directions.

1. Integrating Solar Energy into Climate Action Strategies in the Built Environment

The integration of solar energy technologies into the built environment is increasingly recognized as a key strategy for addressing both climate mitigation and adaptation objectives. Photovoltaic (PV) installations on rooftops and building façades substantially contribute to achieving Net-Zero Energy Building (NZEB) standards by offsetting operational energy use through on-site, clean electricity generation (UNEP, 2022; IPCC, 2022). Passive solar design strategies, such as daylighting, optimized building orientation, and solar control, further reduce electricity demand, reinforcing mitigation objectives by lowering greenhouse gas emissions (IEA, 2021). Integrating advanced sensor systems and behavior-based lighting controls has also been shown to significantly improve operational efficiency and adaptive performance, creating buildings that respond dynamically to both environmental conditions and occupant needs (Arshi & Mondal, 2023).

Integrated strategies combine mitigation measures, such as reducing deforestation, lowering carbon emissions, and promoting sustainable energy use, with adaptation measures that enhance energy access, increase community resilience, and support biodiversity preservation. Practical implementations include solar-powered nurseries, rooftop solar panels, and agrovoltaic systems for mitigation, alongside solar microgrids, solar-powered water pumps, and community-based solar projects for adaptation (Fig. 1). These technologies not only provide reliable energy but also foster sustainable livelihoods, strengthen social cohesion, and enhance ecosystem stewardship.

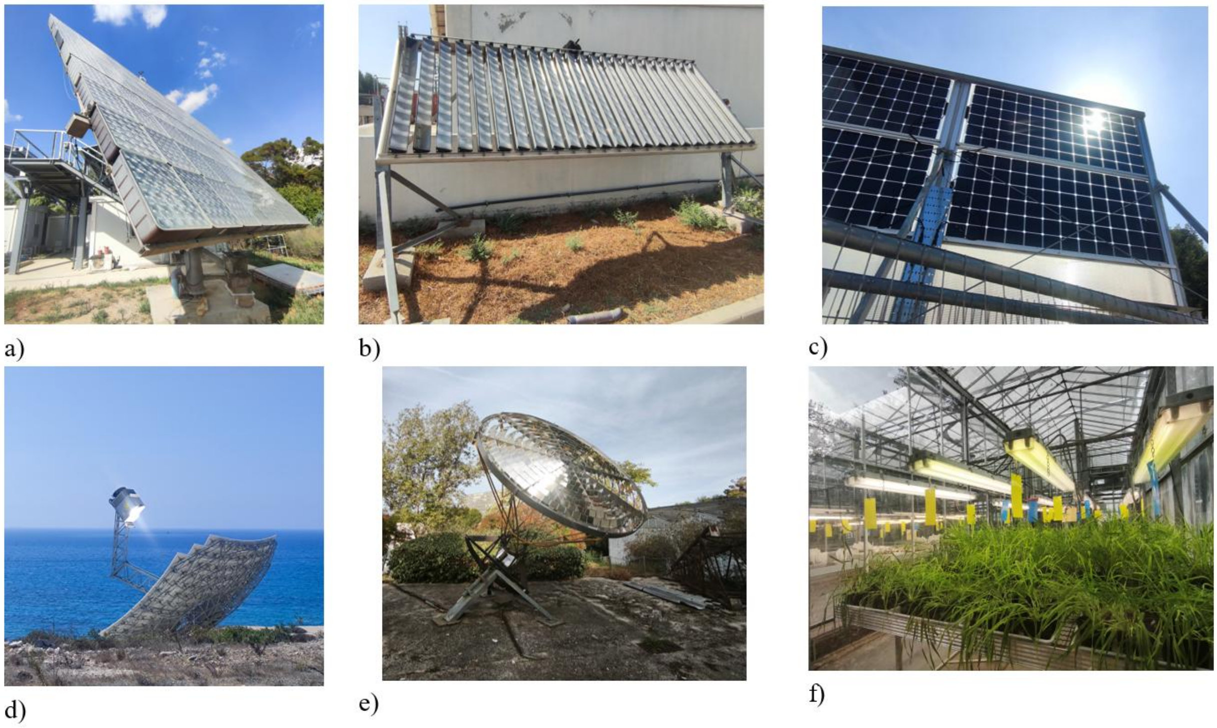

Figure 1. Practical applications of solar energy and climate-responsive lighting technologies. a) Concentrator photovoltaics. b) Solar thermal collector. c) Photovoltaic (PV) Panels. d) Sunrise CSP's core technology. e) Solar Concentrator. F) Plant growth under a controlled environment.

From an adaptation perspective, PV systems integrated with battery storage enhance energy autonomy and ensure reliable electricity supply during grid disruptions or extreme weather events. Passive cooling techniques, including solar chimneys and ventilated façades, have proven effective in mitigating urban heat stress while improving indoor thermal comfort. Modular and decentralized solar solutions also demonstrate strong potential for rapid deployment in off-grid or disaster-prone regions, thereby strengthening infrastructure resilience and ensuring access to essential services (Fthenakis et al., 2008).

Lighting technologies represent another critical area for climate-responsive innovation. On the mitigation side, energy-efficient LED systems, especially when powered by solar energy, significantly reduce electricity consumption and extend system lifespan. Smart solar-powered LED networks dynamically respond to ambient conditions, optimizing energy use and maintaining functionality during blackouts (Shankar et al., 2021). These innovations also advance adaptation goals by improving public safety and urban comfort under climate stressors such as heatwaves or storms (Santamouris et al., 2017). Natural lighting technologies, including daylighting systems, skylights, and smart glazing, further reduce dependence on artificial lighting while improving indoor environmental quality (García-Fernandez et al., 2023). Electrochromic glazing adapts to varying light intensities, optimizing daylight penetration and reducing cooling loads (Tavares et al., 2016). Additionally, photovoltaic glass integrates energy generation with daylight provision, and green roofs enhance insulation while mitigating urban heat island effects (Berardi et al., 2014). The combination of these natural and smart lighting strategies positions the built environment as a platform for both energy mitigation and climate resilience, supported by measurable performance indicators (Mukherjee, 2025; Almesbah, 2025; Arshi & Mondal, 2023). Collectively, these integrative strategies, combining active and passive solar systems, embody bioclimatic design principles and provide an effective framework for addressing both climate change mitigation and resilience within the built environment.

2. Mitigation and Adaptation Lighting Strategies in the Built Environment

As the global community faces the interconnected challenges of climate change and the growing demand for energy-efficient solutions, lighting design within the built environment emerges as a strategic driver of sustainability. Lighting systems influence not only the energy balance of buildings and cities but also their capacity to adapt to evolving climatic conditions. Integrating mitigation and adaptation principles into lighting design represents a crucial step toward achieving resilient, low-carbon, and human-centered environments. Lighting stands at the intersection of technology, design, and climate resilience. Its evolution toward energy-efficient, renewable, and adaptive systems represents a tangible pathway for cities to meet global climate objectives. By embracing both mitigation through decarbonization and efficiency, and adaptation through resilience and flexibility, lighting becomes an active agent in shaping sustainable urban futures.

2.1 Mitigation Strategies: Efficiency and Decarbonization

Mitigation strategies focus on reducing greenhouse gas (GHG) emissions through enhanced energy efficiency, the transition to renewable energy sources, and the optimization of lighting operations. In the built environment, lighting can account for 15–25% of total electricity consumption, particularly in dense urban areas (IEA, 2020). Therefore, innovations in lighting technology play a decisive role in achieving global climate targets.

The widespread transition to Light Emitting Diode (LED) technology represents one of the most effective and mature solutions for energy efficiency in the lighting sector. LEDs consume up to 80% less electricity and last ten times longer than conventional lamps (IEA, 2020). When integrated with smart controls, such as occupancy sensors, daylight harvesting, and adaptive dimming, LED systems provide additional energy savings and operational intelligence, enabling dynamic responses to human presence and environmental conditions. These systems not only reduce emissions but also advance intelligent urban management.

The implementation of solar-powered lighting systems offers another sustainable pathway to decarbonization. By harnessing photovoltaic (PV) energy, these systems eliminate direct emissions and alleviate dependence on fossil fuel-based grids. These systems provide reliable illumination without extensive infrastructure, making them ideal for rural, off-grid, or remote areas with limited energy access. Beyond environmental benefits, solar lighting contributes to energy equity by providing clean, renewable illumination to underserved communities, thereby improving safety and quality of life. Hybrid solar lighting installations that combine PV modules, LED luminaires, and energy storage systems can reduce operational CO_2 emissions by up to 60% while ensuring off-grid reliability (Pratama et al., 2023,). This dual functionality, high efficiency and autonomous operation, positions hybrid lighting as a cornerstone technology for both decarbonization and resilience.

2.2 Adaptation Strategies: Resilience and Climate Responsiveness

Adaptation strategies address the capacity of lighting systems to endure and perform effectively under the stresses imposed by climate change. This includes designing infrastructures that respond to temperature fluctuations, extreme weather events, and changing daylight patterns, ensuring functionality and safety across diverse climate scenarios.

The Urban Heat Island (UHI) effect, resulting from heat absorption and retention in dense built environments, can be mitigated by energy-efficient and low-heat-emitting lighting, particularly LEDs and solar systems. These technologies reduce radiative heat output, contributing to cooler urban microclimates (Santamouris et al., 2017). The integration of reflective materials and shading elements into lighting design further reduces local thermal stress and complements broader urban cooling strategies.

Adaptive lighting systems exemplify climate-responsive design by employing environmental sensors and predictive analytics to regulate illumination based on temperature, humidity, daylight availability, and seasonal variations. Such systems reduce energy waste while ensuring visual comfort and operational continuity during extreme events (Kim et al., 2018). By adjusting brightness and spectral composition in real time, adaptive lighting enhances comfort, safety, and energy performance. Moreover, by minimizing waste heat and supporting thermal balance, these systems contribute to the mitigation of UHI effects and overall climate resilience.

In regions prone to floods, storms, or prolonged heat waves, resilient lighting infrastructure relies on weatherproof materials, robust luminaire enclosures, and autonomous power solutions such as solar batteries or hybrid backups (Samatar et al., 2024). This redundancy ensures continuous operation during grid failures and enhances the resilience of critical public infrastructure.

2.3 Technological Innovation in Climate-Responsive Lighting

Recent advances in lighting technologies are driving a dual transition toward mitigation through energy efficiency and renewable integration, and toward adaptation through robustness and resilience. Smart street lighting integrates sensors, automation, and data-driven controls to dynamically adjust illumination according to pedestrian presence, traffic density, and ambient light levels. By reducing unnecessary operation, these systems achieve substantial energy savings while maintaining safety and visual comfort (Agramelal et al., 2023). The integration of renewable energy, particularly solar power, ensures continuous operation during grid disruptions (Hamed & Alshare, 2022), positioning smart lighting as a key component of climate-resilient urban infrastructure. Importantly, these innovations can also be implemented through retrofitting strategies in existing lighting networks and building façades, enabling the modernization of urban infrastructures without large-scale reconstruction. Retrofitting with solar-LED and adaptive control systems not only extends the lifespan of conventional installations but also accelerates the transition toward low-carbon, resilient cities.

Hybrid solar-LED systems further enhance this integration. Combining PV modules, LED luminaires, and smart control technologies, they ensure uninterrupted performance during power shortages or extreme conditions. Advances in storage capacity, sensor integration, and automation have improved their adaptability and reliability (Agramelal et al., 2023). From a mitigation perspective, these systems substantially reduce greenhouse gas emissions through renewable generation and high efficiency. From an adaptation standpoint, their autonomy and robustness under variable environmental conditions make them essential for resilient urban and rural infrastructure (Hamed & Alshare, 2022).

2.4 Integrated Framework for Sustainable Lighting

An effective climate strategy for lighting must integrate both mitigation and adaptation components, recognizing their mutual reinforcement. A holistic framework combines energy-efficient technologies (LEDs, smart controls) with renewable generation (solar PV, hybrid systems) and adaptive design measures (resilient materials, predictive maintenance). Integrated lighting systems exemplify this synergy: for instance, solar-powered smart streetlights can reduce electricity consumption by up to 70% while maintaining functionality during climate-related disruptions (Bachanek et al., 2021).

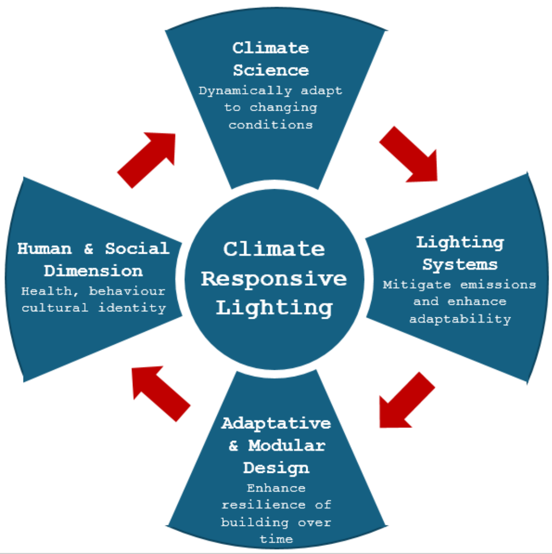

Figure 2. Conceptual framework of Climate Responsive Lighting.

Coupling adaptive lighting algorithms with climate data and IoT-based monitoring enables real-time optimization of energy performance, enhancing the resilience of urban infrastructures. These integrated systems form a cornerstone of sustainable urban planning, reducing emissions, improving energy equity, and strengthening the adaptive capacity of buildings and public spaces. Lighting thus emerges not merely as a technical component but as an active agent of climate strategy, bridging technology, resilience, and human-centered design for the cities of the future (Fig. 2).

3. Natural and Passive Lighting Strategies for Climate Adaptation and Mitigation

Natural and passive lighting strategies complement technological solutions by leveraging architectural design and environmental conditions to optimize daylight use, minimize energy demand, and enhance visual and thermal comfort. Unlike mechanical or electronic systems, passive lighting relies on spatial configuration, materials, and geometry to modulate sunlight within the built environment. These strategies not only reduce energy consumption but also contribute to climate resilience by improving building performance under varying environmental conditions.

3.1 Daylighting Design and Architectural Integration

Architectural innovations such as light shelves, solar chimneys, and atrium-based daylighting systems amplify the diffusion of natural light while controlling glare and overheating (Fig.3). The integration of reflective surfaces, light diffusers, and adjustable louvers allows dynamic modulation of daylight according to seasonal and climatic variations. These design principles exemplify climate-responsive architecture, transforming natural illumination into an adaptive environmental resource.

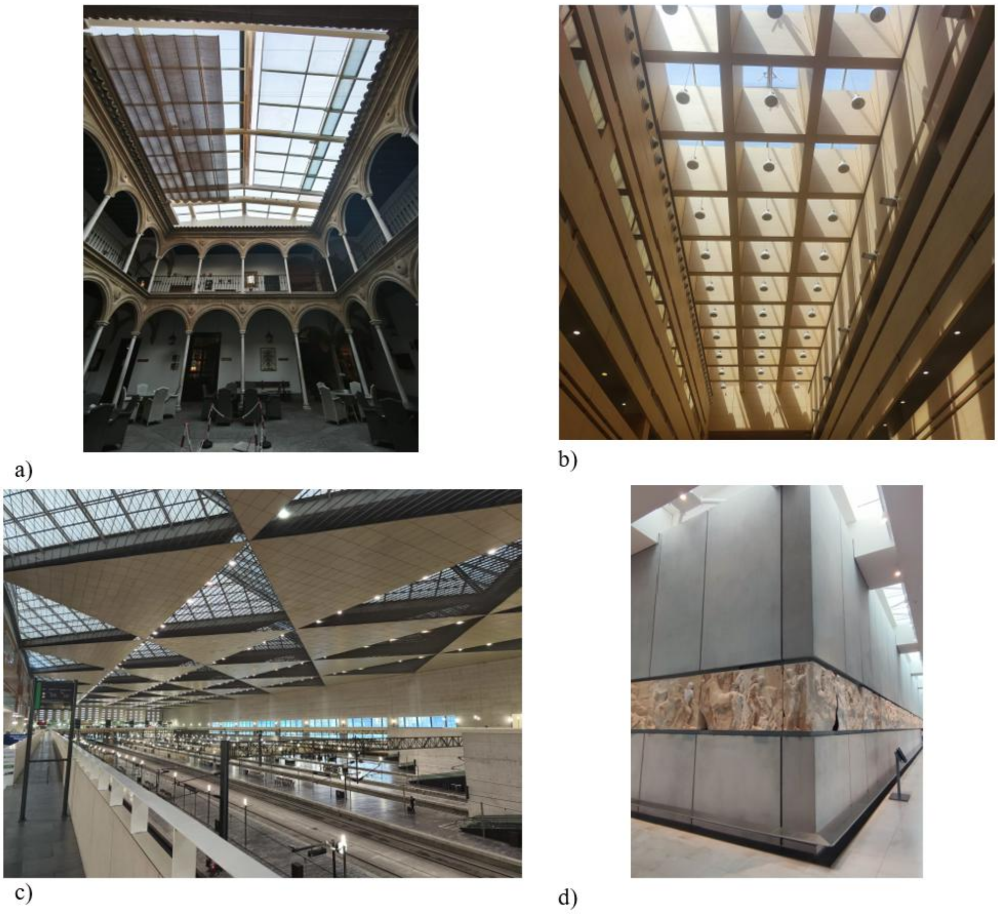

Figure 3. Examples of climate-responsive natural lighting systems in architecture, including light shelves and atrium-based daylighting strategies. a) Dean Ortega Palace, Úbeda, Spain . b) Multipurpose Building Universidad Complutense de Madrid, Spain. c) Zaragoza train station, Spain. d) Acropolis Museum in Athenes, Greece .

Daylighting design represents one of the most effective passive strategies for achieving both mitigation and adaptation goals (García-Fernandez et al., 2023). By optimizing the penetration of natural sunlight through windows, skylights, light tubes, and reflective surfaces, daylighting reduces reliance on artificial lighting and the associated electricity consumption. Studies show that well-designed daylighting can offset up to 40–60% of lighting energy use in commercial buildings, particularly when combined with dynamic shading and sensor-based control systems (Lee et al. 2024).

From a mitigation perspective, daylighting directly decreases GHG emissions linked to power generation. From an adaptation standpoint, it enhances thermal comfort and visual wellbeing by regulating interior light levels and reducing heat gains through careful façade orientation and glazing selection. Moreover, daylighting fosters psychological benefits such as improved circadian rhythm alignment and occupant productivity, reinforcing its relevance for sustainable and healthy design. Case studies in commercial buildings have demonstrated energy savings of up to 58.6% when light shelves and skylights are strategically implemented (Xue & Liu, 2023).

3.2 Passive Lighting strategies and Synergies

Daylighting strategies are intrinsically linked to passive cooling measures. By coordinating natural light entry with shading devices, reflective roofs, and thermal mass, buildings can achieve a balance between illumination and temperature control. In warm climates, external shading and high-reflectance materials prevent excess solar gains, reducing cooling loads and contributing to urban heat island mitigation (Santamouris et al., 2017). Conversely, in colder regions, solar-oriented fenestration enhances heat retention and daylight availability, reducing heating energy demand.

Green roofs and vertical gardens contribute to climate-responsive urban design by improving insulation, reducing heat island effects, and promoting natural light diffusion. When combined with reflective surfaces or light-directing features, these systems optimize daylight distribution in adjacent interior spaces. As a mitigation measure, they lower energy consumption for heating and cooling by improving the building envelope's performance. From an adaptation standpoint, they enhance urban resilience through microclimate regulation, biodiversity support, and stormwater management. The Chicago City Hall green roof is a well-documented case, achieving up to 30% reductions in cooling costs through the combined effects of insulation and daylight optimization (Berardi et al., 2014).

Integrating natural lighting with passive ventilation systems creates synergies that further reduce energy consumption and improve indoor environmental quality. Strategic placement of windows, vents, and light wells enhances both daylight penetration and natural airflow, minimizing dependence on mechanical systems. In terms of mitigation, these integrated designs reduce total energy use by maximizing the availability of natural resources. From an adaptation standpoint, they improve indoor air quality, occupant well-being, and comfort, particularly in densely built environments exposed to heat stress or pollution. The One Central Park development in Sydney exemplifies this integration, combining daylighting and ventilation strategies to create a high-performance, climate-responsive urban complex (Baker & Steemers, 2020).

3.3 Materials, Reflectivity, and Building Envelope Optimization

Material selection plays a decisive role in passive lighting performance. High-reflectance interior surfaces, translucent façades, and light-colored materials maximize daylight distribution while reducing the need for artificial lighting. Advanced glazing technologies, such as spectrally selective coatings and electrochromic glass, enable real-time adaptation to external conditions, filtering heat while transmitting visible light (Wilson et al., 2020).

Innovations in window design and glazing technologies, such as electrochromic, thermochromic, and photochromic systems, are transforming daylight management in modern architecture. These smart glazing materials adjust transparency or tint in response to solar intensity, enabling precise control over light and heat transmission. Their mitigation potential lies in optimizing solar gain and reducing the need for artificial lighting and cooling. For adaptation, smart glazing enhances occupant comfort by preventing glare and overheating, particularly in climates with high solar exposure. High-performance buildings employing electrochromic glass have demonstrated significant reductions in energy demand for both air conditioning and artificial lighting (Bertoldi et al., 2016).

Photovoltaic (PV) glass integrates solar cells within transparent or semi-transparent glazing materials, allowing daylight penetration while simultaneously generating renewable electricity. This dual-function design supports the transition toward zero-energy buildings and energy-autonomous façades. The mitigation benefits of PV glass lie in its capacity to offset grid-based electricity use and reduce carbon emissions. From an adaptation perspective, PV glass moderates solar gain and internal temperatures, improving thermal comfort and reducing cooling loads. The SolarLeaf project in Hamburg, Germany, exemplifies this synergy by incorporating PV glass façades that both produce power and enhance indoor lighting quality (Seyfang et al., 2019).

The building envelope, when designed with appropriate insulation and reflective properties, acts as both a lighting modulator and a thermal buffer. Integrated façade systems that combine daylighting apertures, shading, and PV panels can serve dual purposes, harnessing sunlight for energy and illumination while mitigating heat gain and glare. This multifunctional approach aligns with the circular design principles of resource efficiency and environmental responsiveness.

3.4 Toward an Integrated Passive–Active Lighting Framework

The next frontier in sustainable lighting lies in the integration of passive and active systems. Hybrid configurations that couple daylighting with smart controls, sensors, and renewable energy generation offer optimal performance across diverse climatic contexts. For instance, daylight-linked dimming systems automatically adjust artificial lighting according to natural light availability, reducing energy consumption by up to 70% without compromising comfort (Li et al. et al. 2003).

By combining architectural daylighting with technological innovation, such as solar-powered smart luminaires and adaptive algorithms, buildings can operate as self-regulating systems that respond intelligently to environmental dynamics. This integrated paradigm embodies the essence of climate-responsive design: achieving decarbonization through efficiency while enhancing resilience through adaptability and passive intelligence.

4. Conclusions and Future Work

This study demostrates that solar lighting constitutes a pivotal strategy for advancing both climate change mitigation and adaptation within the built environment. By integrating daylighting, adaptive façades, and hybrid photovoltaic–thermal systems, solar-based illumination reduces energy demand, enhances thermal comfort, and improves the overall environmental performance of buildings and cities.

The proposed framework links lighting performance indicators, such as daylight autonomy, useful daylight illuminance, and energy flexibility, to resilience-oriented metrics including occupant well-being. Incorporating smart sensors, dynamic envelopes, and behavior-responsive controls further enhances the adaptability and operational intelligence of lighting environments.

At the urban scale, solar-driven and hybrid systems contribute substantially to global decarbonization goals, particularly when integrated with clean energy transitions and building retrofitting. Life-cycle analyses confirm that these technologies can significantly reduce the carbon intensity of urban infrastructure while fostering comfort, safety, and equity.

Importantly, the findings illustrate that innovative active and passive lighting strategies are complementary pathways toward climate-resilient design. While active systems leverage digitalization and renewable integration, passive strategies, such as daylighting, green façades, and smart glazing, capitalize on natural resources to minimize energy use and strengthen adaptive capacity. Their synergy defines the next generation of low-carbon and human-centered urban environments.

By extending this framework to forest and rural contexts, the study reveals how solar-based solutions can also support sustainable forest management, energy equity, and community resilience, aligning with global Sustainable Development Goals. In these settings, solar illumination not only reduces carbon footprints but also fosters biodiversity conservation and social inclusion through decentralized, low-impact infrastructure.

Future research should prioritize the long-term monitoring of adaptive solar lighting systems under diverse climatic conditions, the standardization of resilience-based performance metrics, and the integration of lighting systems with digital twin technologies and renewable microgrids. Advancing this agenda will require interdisciplinary collaboration among engineers, architects, environmental scientists, and behavioral researchers to translate conceptual advances into scalable, context-sensitive, and climate-resilient architectural solutions.

Acknowledgments

The author gratefully acknowledges the support of the Universidad Politécnica de Madrid.

References

Agramelal, F., Sadik, M., Moubarak, Y., & Abouzahir, S. (2023). Smart street light control: a review on methods, innovations, and extended applications. Energies, 16(21), 7415. https://doi.org/10.3390/en16217415

Almesbah, M. (2025). Review of dynamic building envelope systems and technologies utilizing renewable energy resources. Journal of Engineering, 9(2), 41. https://doi.org/10.3390/designs9020041

Arshi, O., & Mondal, S. (2023). Advancements in sensors and actuators technologies for smart cities: A comprehensive review. Smart Construction and Sustainable Cities, 1, 18. https://doi.org/10.1007/s44268-023-00022-2

Bachanek, K. H., Tundys, B., Wiśniewski, T., Puzio, E., & Maroušková, A. (2021). Intelligent street lighting in a smart city concepts—A direction to energy saving in cities: An overview and case study. *Energies*, *14*(11), 3018. https://doi.org/10.3390/en14113018

Baker, N., & Steemers, K. (2020). Daylight Design of Buildings. Routledge.

Berardi, U., GhaffarianHoseini, A. H., & GhaffarianHoseini, A. (2014). State-of-the-art analysis of the environmental benefits of green roofs. Applied Energy, 115, 411–428. https://doi.org/10.1016/j.apenergy.2013.10.047

Bertoldi, P., Zangheri, P., & Castellazzi, L. (2016). Improving the energy performance of buildings: Trends, policies and technologies in the EU. European Commission, JRC Science for Policy Report.

Bond, T. C., Doherty, S. J., Fahey, D. W., Forster, P. M., Berntsen, T., DeAngelo, B. J., … & Zender, C. S. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres, 118(11), 5380–5552. https://doi.org/10.1002/jgrd.50171

Broto, V. C. (2024). Community Energy and Sustainable Energy Transitions. Palgrave Macmillan, Cham.

Djoudi, H., Dooley, K., Duchelle, A. E., Libert-Amico, A., Locatelli, B., Balinga, M. B., Brockhaus, M., Colloff, M. J., Djenontin, I. N. S., Dirk, C., Duguma, L., Baa, O. E., Fedele, G., Gitz, V., Kachamba, D., Kanninen, M., Lavorel, S., Mbow, C., Mertz, O., Meybeck, A., Minang, P. A., Mugabowindekwe, M., Munera-Roldan, C., Pramova, E., Shackleton, S., Sonwa, D. J., Soto Pinto, M. L., & Wabbes Candotti, S. (2022). Leveraging the power of forests and trees for transformational adaptation. Climate Policy Initiative. https://doi.org/10.2139/ssrn.4268299

Fthenakis, V. M., Kim, H. C., & Alsema, E. (2008). Emissions from photovoltaic life cycles. Environmental Science & Technology, 42(6), 2168–2174. https://doi.org/10.1021/es071763q

García-Fernández, B., & Omar, O. (2023). Sustainable performance in public buildings supported by daylighting technology. Solar Energy, 264, 112068. https://doi.org/10.1016/j.solener.2023.112068

Hamed, T. A., & Alshare, A. (2022). Environmental impact of solar and wind energy-a review. Journal of Sustainable Development of Energy, Water and Environment Systems, 10(2), 1–23. https://doi.org/10.13044/j.sdewes.d9.0387

IEA. (2020). Energy Efficiency 2020. International Energy Agency. https://www.iea.org/reports/energy-efficiency-2020

IEA. (2021). Solar PV Global Market Outlook. International Energy Agency. https://www.iea.org/reports/solar-pv

IPCC. (2021–2023). Assessment Reports (AR6). Intergovernmental Panel on Climate Change. Cambridge University Press.

Kaufman, Y. J., Tanré, D., & Boucher, O. (2002). A satellite view of aerosols in the climate system. Nature, 419(6903), 215–223. https://doi.org/10.1038/nature01091

Kim, I. T., Kim, Y. S., Nam, H., & Hwang, T. (2018). Advanced dimming control algorithm for sustainable buildings by daylight responsive dimming system. *Sustainability*, *10*(11), 4087. https://doi.org/10.3390/su10114087

Lee, J. H., & Kang, J.-S. (2024). Study on lighting energy savings by applying a daylight-concentrating indoor louver system with LED dimming control. *Energies, 17*(14), 3425. https://doi.org/10.3390/en17143425

Li, D. H., & Lam, J. C. (2003). An investigation of daylighting performance and energy saving in a daylit corridor. Energy and buildings, 35(4), 365-373. https://doi.org/10.1016/S0378-7788(02)00107-X

Mukherjee, B. (2025). A case for effective circadian daylighting metrics. Energies, 15(3), 315. https://doi.org/10.3390/buildings15030315

Pratama, S. G., Alissa, R. A. D., Nafis, R. F., Arrayyan, A. Z., & Putra, K. T. (2023). Implementation and feasibility study of solar-powered streetlighting systems in rural community area. E3S Web of Conferences, 425, 05007. https://doi.org/10.1051/e3sconf/202342505007

Reinhart, C. F., & Andersen, M. (2016). *Daylighting design and simulation.* In J. A. Clarke & J. W. Hand (Eds.), *Building Performance Simulation for Design and Operation* (2nd ed., pp. 307–340). Routledge.

Shankar, A., Vijayakumar, K., & Chitti Babu, B. (2021). Energy saving potential through artificial lighting system in PV-integrated smart buildings. *Journal of Building Engineering, 44*, 103080. https://doi.org/10.1016/j.jobe.2021.103080

Samatar, A. M., et al. (2024). Performance analysis of hybrid off-grid renewable energy systems in rural areas: A case study. Renewable Energy, 259, 258–270. https://doi.org/10.1016/j.ecmx.2024.100780

Santamouris, M., Papanikolaou, N., Livada, I., Koronakis, I., Georgakis, C., Argiriou, A., & Assimakopoulos, D. N. (2001). On the impact of urban climate on the energy consumption of buildings. Solar Energy, 70(3), 201–216.

https://doi.org/10.1016/S0038-092X(00)00095-5

Seneviratne, S. I., Zhang, X., Adnan, M., Badi, W., Dereczynski, C., Di Luca, A., Ghosh, S., Iskandar, I., Kossin, J., Lewis, S., Otto, F., Pinto, I., Satoh, M., Vicente-Serrano, S. M., Wehner, M., Zhou, B., & Allan, R. (2021). Weather and climate extreme events in a changing climate. In V. Masson-Delmotte, P. Zhai, A. Pirani, & S. L. Connors (Eds.), Climate Change 2021: The Physical Science Basis. Working Group I contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1513–1766). Cambridge University Press. https://doi.org/10.1017/9781009157896.013

Seyfang, G., Haxeltine, A., Hargreaves, T., & Longhurst, N. (2010). Energy and communities in transition: Towards a new research agenda on agency and civil society in sustainability transitions.

Song, Z., Li, L., & Xu, Y. (2021). Air pollution and soiling implications for solar photovoltaic power generation: A comprehensive review. Applied Energy, 298, 117247. https://doi.org/10.1016/j.apenergy.2021.117247

Tavares, P., Bernardo, H., Gaspar, A., & Martins, A. (2016). Control criteria of electrochromic glasses for energy savings in Mediterranean building refurbishment. Solar Energy, 134, 236–250. https://doi.org/10.1016/j.solener.2016.04.022

UNDP. (2022). Sustainable Development Goals Progress Report 2022. United Nations Development Programme. https://www.undp.org/publications

UNEP. (2022). Global Status Report for Buildings and Construction 2022. United Nations Environment Programme.

UNFCCC. (2015). Paris Agreement. United Nations Framework Convention on Climate Change. https://unfccc.int/sites/default/files/english_paris_agreement.pdf

UNFCCC. (2023). Global Climate Action | UNFCCC

Wild, M. (2009). Global dimming and brightening: A review. Science, 324(5923), 1247–1250. https://doi.org/10.1029/2008JD011470

Xue, Y., & Liu, W. (2023). A study on the optimization of atrium daylight and energy performance through skylight and shading design in commercial buildings in cold zones. Buildings, 13(1), 228. https://doi.org/10.3390/buildings13010228

Yu, M., Zhang, J., & Liu, H. (2019). Improved control of forest microgrids with hybrid complementary energy storage. *Applied Sciences*, *9*(12), 2523. https://doi.org/10.3390/app9122523