GREEN BUILDING CONFERENCE
INNOVATIVE SOLUTIONS FOR A GREENER BUILT ENVIRONMENT

DOI: **10.5937/greenb26058D**
Research paper

AN APPROACH TO SMART DAYLIGHT CONTROL IN MEMBRANE-COVERED SPORTS FACILITIES

Snežana Đorić-Veljković[1], Jelena Stevanović[2], Dragan Kostić[3], Miomir Vasov[4], Milan Gocić[5], Vuk Milošević[6]

Abstract

The importance of daylight for occupant health and well-being and requirements for reduction of energy consumption has led to the development of innovative and sustainable solutions. In recent years, membrane structures have become increasingly popular for covering sports halls, and various other facilities due to their high daylight transmittance, fast construction, and lightweight. Unlike conventional roofs (which are generally solid and opaque), membrane envelopes, particularly those made of high-performance membrane materials, offer the possibility of using natural daylight as a primary light source during building operation . However, unwanted daylight penetration can also cause visual discomfort, glare, and an increased load on the cooling system if not managed appropriately. Accordingly, integrating smart daylight control strategies with membrane-covered structures represents a promising approach to energy-efficient and sustainable sports facilities. Based on the literature, intelligent daylight management systems could be a promising solution for improving the performance of membrane-covered sports halls. The integration of real-time environmental monitoring with adaptive lighting control can enhance visual comfort, optimize daylight utilization, and reduce energy consumption. Studies indicate that smart daylighting strategies applied in membrane facilities provides significant potential for improving indoor environmental quality and promoting the sustainable design of sports facilities. Given that numerous membrane-covered sports facilities have become popular in the last two decades, it is necessary to become familiar with innovative possibilities for controlling the optimal use of daylight and consequently optimal energy consumption. In this context, the present study aims to provide a methodological foundation for the implementation and quantitative validation of intelligent lighting control strategies, based on sensing occupancy detection and lighting control, in both existing and newly constructed sports facilities with membrane roofing systems.

Key words: *Daylight control, Membrane facilities, Smart lighting, Energy efficiency*

[1] PhD, Full Professor, Faculty of Civil Engineering and Architecture, University of Niš, Serbia, snezana.djoric.veljkovic@gaf.ni.ac.rs, ORCid 0000-0003-0475-040X
[2] PhD Student, Teaching Assistant, Faculty of Civil Engineering and Architecture, University of Niš, Serbia, jelena.stevanovic@gaf.ni.ac.rs, ORCid 0009-0008-1239-4509
[3] PhD, Full Professor, Faculty of Civil Engineering and Architecture, University of Niš, Serbia, dragan.kostic@gaf.ni.ac.rs, ORCid 0000-0001-6927-4155
[4] PhD, Full Professor,Faculty of Civil Engineering and Architecture, University of Niš, Serbia, miomir.vasov@gaf.ni.ac.rs, ORCid 0000-0002-4525-9644
[5] PhD, Full Professor, Faculty of Civil Engineering and Architecture, University of Niš, Serbia, milan.gocic@gaf.ni.ac.rs, ORCid 0000-0001-8398-6570
[6] PhD, Associate Professor, Faculty of Civil Engineering and Architecture, University of Niš, Serbia, vuk.milosevic@gaf.ni.ac.rs, ORCid 0000-0003-1211-215X

1. INTRODUCTION

It is well established that light influences the behavior well-being, and visual performance of occupants. It enables the perception of space, shapes, and colors and provides the visual conditions necessary for performing a wide range of visual tasks. The benefits of using daylight include energy savings, reduced CO_2 emissions (CO_2 footprint) and health-related reasons [1-3]. Daylight distribution in facilities is mostly determined by structural and envelope characteristics, and daylighting design is a complex multidisciplinary task which requires balancing visual comfort, energy performance, and well-being of occupants [4,5]. Although natural daylight represents the most efficient and environmentally friendly light source, there are some disadvantages. Namely, its availability of daylight constantly changes across seasons, times of day, and weather conditions, making fixed lighting strategies insufficiently efficient. Also, excessive daylight may produce glare, non-uniform illuminance, overheating, and increased cooling loads, especially during summer periods. Design of daylight in sports halls therefore requires a balance between natural and artificial light, with particular attention to glare control, uniform illuminance, and solar heat gains [6].

On the other hand, the concept of smart building exists for several decades. It was created due to the growing need for improved occupant comfort, resource efficiency, and more effective building operation [7,8]. A key objective is the rational use of energy and other resources, which has become increasingly important because of rising energy demand and environmental concerns [9]. Buildings account for a substantial share of global energy consumption, while lighting represents an important component of electricity demand. Sports facilities are particularly demanding because they require appropriate illuminance levels over large indoor spaces and may operate from early morning until late evening [10,11]. Consequently, reducing electricity consumption associated with artificial lighting has become an important objective of sustainable building design [12].

The emergence of membrane structures represents a significant innovation, opening up new possibilities for the use of daylight. Given that these structures combine architectural flexibility with lightweight construction, they can be widely applied to various sports facilities. Unlike conventional opaque roofs, membrane envelopes transmit a considerable portion of visible light while maintaining structural efficiency [13]. These envelopes, particularly those made of high-performance membrane materials such as polytetrafluoroethylene (PTFE) or ethylene tetrafluoroethylene (ETFE), offer the possibility of using natural daylight as the primary light source during the operation of building. ETFE cushions may achieve visible light transmittance exceeding 90%, as it is presented in Figure 1 [14], whereas PTFE-coated fiberglass membranes typically provide diffuse transmission between 10% and 40%, depending on material composition and coating characteristics [14-16]. Despite these advantages, membrane-covered facilities present specific lighting and thermal challenges. Consequently, modern membrane-covered sports facilities increasingly integrate intelligent lighting systems, that enable the dynamically balancing natural and artificial lighting according to actual environmental conditions.

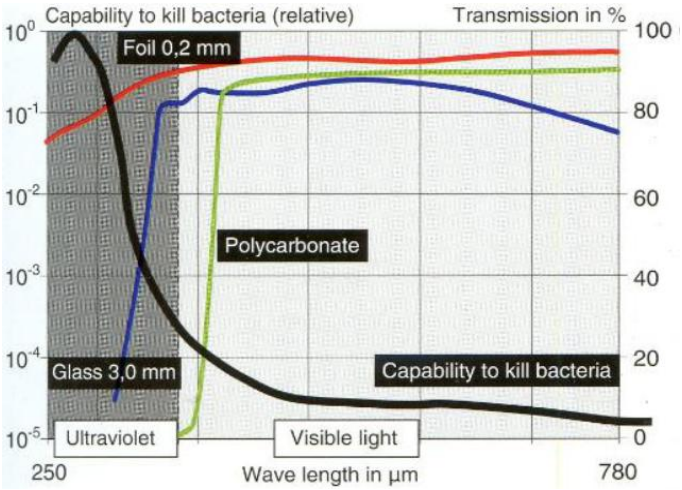


Figure 1. Light Transmittance of ETFE and Other Transparent Materials [14]

It should be emphasized that recent advances in sensing technologies, used for Internet of Things (IoT) devices, wireless communication, and Building Management Systems (BMS) have enabled the development of smart daylight control systems [17,18]. These systems can continuously monitor indoor illuminance, occupancy, weather conditions, and solar radiation and automatically adjust artificial lighting to maintain the required illumination levels while reducing unnecessary electricity consumption [17-21].

The application of daylight-control technologies is also influenced by geographical conditions, building use, user requirements, and applicable standards [11, 12]. Therefore, this paper focuses on the potential application of smart daylight control to membrane-covered sports facilities under real-world operating conditions. The study first reviews the principal characteristics of membrane sports facilities and relevant daylight-control technologies and then synthesizes these findings into a conceptual framework for integrating membrane architecture with intelligent lighting technologies. The proposed framework is intended as a conceptual basis for future implementation and quantitative validation rather than as an experimentally validated control system.

It should be emphasized that this study uses a focused narrative literature-review approach to identify and synthesize knowledge relevant to daylight control in membrane-covered sports facilities. Practically, the literature was organized into four thematic groups: (i) daylight, visual comfort, and human well-being; (ii) daylighting performance and membrane materials, with particular attention to ETFE and PTFE systems; (iii) intelligent lighting, occupancy sensing, IoT, and BMS-based control; and (iv) adaptive building-envelope and daylight-control technologies. Sources were selected according to their direct relevance to daylight performance, sports-facility lighting, membrane-envelope behavior, or intelligent control. The reviewed findings were compared qualitatively and then used to identify the functional components and information flows required for a conceptual smart daylight-control strategy.

2. MEMBRANE-COVERED SPORTS FACILITIES

In addition to computational structural analysis and fabrication technologies, improvements in polymer materials enabled significant development of membrane structures during the last three decades. The most frequently applied membrane materials include ETFE foil cushions, multi-layer pneumatic membrane systems, PTFE-coated fiberglass fabrics and PVC-coated polyester fabrics. The properties of ETFE make it mostly suitable for sports facilities requiring natural lighting [13,16,19]. This material is well suited due to its high optical transparency, low weight, chemical resistance, and long service life. ETFE cushions weigh less than 1% of equivalent glass surfaces while transmitting more than 90% of visible daylight.

However, the transmitted light depends not only on membrane material properties but also on solar altitude, curvature, orientation, contamination, aging, environment and surrounding reflections [13,19].

It should be mentioned that PTFE membranes typically produce highly diffuse illumination, reducing direct glare but transmitting less daylight overall. On the other hand, ETFE cushions allow considerably higher daylight penetration while maintaining excellent transparency. This property makes ETFE particularly attractive for large stadium roofs and enclosed arenas where maximizing natural lighting is desirable. Nevertheless, maximizing daylight transmission alone is not sufficient. High daylight availability may result in excessive illuminance levels exceeding recommendations specified in EN 12193 (also SRPS EN 12193:2019) for sports lighting, especially during clear summer days [12].

To overcome solar heat gains, modern membrane systems increasingly employ advanced solutions. Recent studies have investigated climate-adaptive ETFE facades. It is demonstrated that switchable ETFE systems can dynamically modify daylight transmission according to solar conditions, thereby simultaneously improving daylight availability and reducing glare [22]. Such adaptive envelope technologies represent an important step toward intelligent building envelopes capable of actively interacting with environmental conditions rather than functioning as passive structural elements.

3. SMART DAYLIGHT CONTROL SYSTEMS FOR MEMBRANE-COVERED SPORTS FACILITIES

The primary purpose of a smart daylight management system is to maximize the use of available natural daylight and also ensure that the illuminance required for different sports activities remains within the prescribed range. Unlike conventional lighting systems, which may operate at a constant output regardless of environmental conditions, an intelligent daylight-control system adjusts the artificial-light contribution according to measured indoor daylight, occupancy, and relevant environmental conditions [22-24]. This approach has been made possible by the development of IoT technologies, wireless sensor networks, and BMS systems, which enable (support) continuous monitoring of environmental parameters, rapid data processing, and automatic lighting adjustment without continuous user intervention [22-24].

In membrane-covered sports facilities, daylight availability is highly dynamic because membrane transmittance and solar exposure allow substantial changes in indoor illuminance. Consequently, intelligent lighting control can be particularly beneficial. A typical smart daylight-control system consists of four principal components: (a) a daylight-sensing subsystem, (b) occupancy monitoring, (c) an intelligent control algorithm, and (d) a dimmable LED lighting system, as presented in Figure 2.

Within the smart daylight-control system, indoor daylight sensors continuously measure horizontal illuminance on the playing surface or at representative measurement points. The measured daylight illuminance is transmitted to the lighting controller, which determines the required level of artificial lighting to maintain the illuminance specified for the relevant sports activity. If daylight is sufficient to meet the target, artificial lighting can be reduced to its minimum operating level or switched off when appropriate. During cloudy conditions or evening hours, the controller increases LED output to compensate lack of daylight.

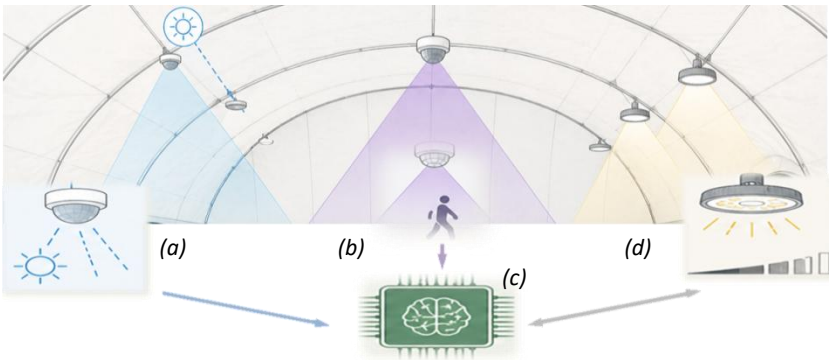


Figure 2. Typical smart daylight control system consists of four principal components: (a) daylight sensing subsystem, (b) occupancy monitoring, (c) intelligent control algorithm, (d) dimmable LED lighting system

Unlike conventional on/off control, continuous dimming allows for gradual transitions between lighting levels, preventing sudden changes that could distract athletes or spectators. It is evident that the use of a smart daylight control system can significantly reduce electricity consumption for lighting. However, the potential reduction in electricity consumption depends on climate, building orientation, membrane optical properties, occupancy, operating schedules, and the characteristics of the lighting system. Therefore, a specific percentage of savings should not be assumed without quantitative validation.

Another important fact is that sports halls are rarely in continuous use throughout the day. Instead, their operation generally involves alternating periods of intensive activity, maintenance, training, and the complete absence of users. Therefore, occupancy sensors represent another essential element of intelligent lighting systems which provide an additional control input. Commonly used technologies include: passive infrared (PIR) sensors, ultrasonic detectors, microwave sensors, camera-based occupancy estimation, and image-processing systems using artificial intelligence, as presented in Figure 3. When no occupancy is detected, the lighting system can reduce

its output to a predefined standby level or switch artificial lighting off, provided that the remaining illumination is appropriate for the intended activity.

It is important to mention that the really fast development of LED technology has fundamentally transformed sports lighting during the last two decades. Compared with metal-halide sources previously used in many sports facilities, LED systems offer high luminous efficacy, rapid switching, dimming capability, long service life, lower maintenance requirements, improved color rendering, and high operational reliability.

For daylight-control applications, one of the most significant advantages of LED technology is continuous dimming rather than operation only at full power. Modern dimmable LED luminaires equipped with appropriate electronic drivers can regulate luminous flux over a wide range [25]. Consequently, artificial lighting can supplement only the portion of the required illuminance that is not provided by daylight. In the proposed framework, the required artificial lighting contribution can be conceptually expressed as $E_{art} = E_{req} - E_{dl}$, where E_{req} is required illuminance, while E_{dl} is measured value of illuminance provided by daylight. Obviously, according to this mathematical expression, the smallest value of E_{art} is 0, because artificial lighting cannot have a negative value if the daytime brightness is higher than required. On the other hand, the normalized LED dimming command can be represented as E_{art} / E_{LEDmax} , where E_{LEDmax} represents the maximum illuminance that can be provided by the artificial lighting system. These relationships represent the control principle, but their coefficients and calibration would need to be determined experimentally for a particular sports hall.



(a) *(b)* *(c)* *(d)* *(e)*

Figure 3. Element of intelligent lighting systems: (a) passive infrared (PIR) sensors, (b) ultrasonic detectors, (c) microwave sensors, (d) camera-based occupancy estimation, and (e) image-processing systems using artificial intelligence

4. PROPOSED CONCEPTUAL SMART DAYLIGHT CONTROL STRATEGY

It is obvious that the introduction of innovative approaches in the control of daylighting in membrane-covered sports facilities has the potential to improve the utilization of natural light and reduce unnecessary operation of artificial lighting. Such a strategy could be incorporated during the design of new facilities and, subject to

compatibility with the existing electrical and BMS infrastructure, could also be introduced progressively into existing structures. The concept may therefore be relevant to existing school sports facilities, such as the physical education facility at the "Ivan Goran Kovačić" Elementary School (Figure 4) in the Nikola Tesla suburb of Niš.



(a) (b)

Figure 4. View of the physical education sport facility (a) exterior and (b) interior

Based on the reviewed literature, a conceptual smart daylight control strategy suitable for membrane-covered sports facilities is proposed. The framework integrates four information sources: indoor daylight sensors, an outdoor weather station, an occupancy monitoring system, and the BMS. The controller uses these inputs to determine whether the hall is occupied, estimate the available daylight, identify relevant environmental conditions, and adjust the artificial-light contribution accordingly.

The proposed control architecture is shown in Figure 5. An outdoor weather station can provide global solar irradiance, solar position, cloud-cover information, and outdoor temperature. Simultaneously, indoor sensors designed for continuous operation can measure horizontal illuminance on the playing surface or at representative points within the sports hall. Occupancy information determines whether the hall is in active use. The BMS provides operating schedules and interfaces with the lighting system. All sensor data are transmitted to a central controller, where the daylight-control algorithm calculates the required artificial-light contribution.

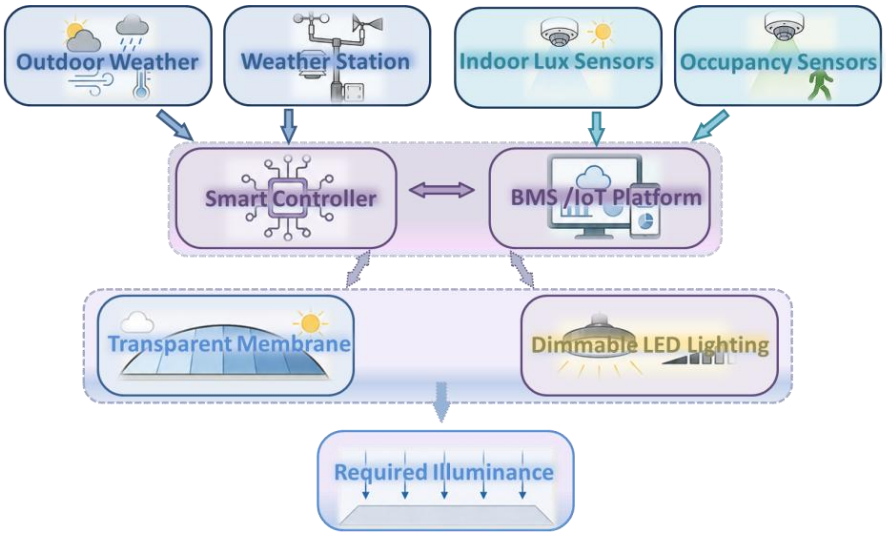


Figure 5. Conceptual smart daylight control strategy suitable for membrane-covered sports facilities

For occupied periods, the controller compares measured daylight with the target illuminance specified for the relevant sport or activity and adjusts the dimmable LED system accordingly. A short time delay or hysteresis should be incorporated to prevent rapid switching or oscillation caused by temporary fluctuations in daylight.

Furthermore, future implementations could utilize artificial intelligence algorithms capable of predicting daylight availability some time in advance, using weather forecasts and environmental data. Such predictive control may further improve the coordination of natural and artificial lighting, but its performance would need to be assessed experimentally and compared with simpler control strategies.

Although the proposed framework has not yet been quantitatively validated as a complete control system, in the future investigation it would be usefull to providesimultaneous long-term measurements of indoor illuminance, occupancy, and electrical lighting consumption under controlled comparison conditions. In addition, it would be useful to present calibrated simulations that quantify annual energy savings or improvements in visual comfort. Consequently, the potential benefits of the proposed strategy should be interpreted as a conceptual assessment based on the reviewed literature rather than as experimentally demonstrated performance. Quantitative validation should include multi-point illuminance measurements on the playing surface, outdoor solar irradiance and weather data, occupancy schedules, LED electrical power, and indicators of visual comfort such as illuminance uniformity and glare. Measurements should be conducted under representative seasonal and weather conditions and compared with a baseline operating mode without daylight-responsive control. Calibrated daylight and energy simulations could be used to extend th e assessment to annual performance and to test alternative membrane properties, sensor locations, control thresholds, and operating schedules.

5. CONCLUSION

Membrane-covered sports facilities have become an increasingly attractive architectural and structural solution because of their lightweight construction, rapid creation, and potential for extensive daylight diffusion. However, effective utilization of daylight requires control strategies capable of responding to continuously changing environmental and occupancy conditions. In this paper, an intensive literature review was used to recognize the principal requirements and technologies relevant to smart daylight management in membrane-covered sports facilities. Based on the studied indication, a conceptual control framework was developed that integrates indoor daylight sensors, occupancy detection, outdoor weather monitoring, dimmable LED luminaires, and BMS integration. The proposed conceptual strategy for smart daylight management defines a control principle for dynamically balancing natural and artificial lighting based on target illuminance levels and occupant presence. Future experimental and simulation-based validation is required to quantify energy performance, illuminance uniformity, visual comfort, and the influence of membrane optical properties. The framework can potentially be applied to both new and existing sports facilities as a basis for improving daylight utilization and lighting energy efficiency.

ACKNOWLEDGMENT

This research was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, under the Agreement on Financing the Scientific Research Work of Teaching Staff at the University of Niš, Faculty of Civil Engineering and Architecture - Registration number: 451-03-34/2026-03/200095 dated 05/02/2026 and supported by the Science Fund of the Republic of Serbia, Grant No. 7363, Improvement of functional, energetic, lightening and structural characteristics of closed and semi closed halls covered by structural textile membranes - BALLOON-HALL-Optima. Also, this research aligns with the Sustainable Development Goals, particularly SDG 11: Sustainable Cities and Communities.

LITERATURE

[1] Mardaljevic, J. (2021). The implementation of natural lighting for human health from a planning perspective. Lighting Research & Technology, 53(5), 489–513. https://doi.org/10.1177/14771535211022145

[2] 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. 10.1016/S0378-7788(02)00107-X

[3] De Luca, F., Simson, R., Voll, H., & Kurnitski, J. (2018). Daylighting and energy performance design for single floor commercial hall buildings. Management of Environmental Quality: An International Journal, 29(4), 722–739., https://doi.org/10.1108/MEQ-10-2017-0110

[4] Wirz-Justice, A., Skene, D. J., & Münch, M. (2021). The relevance of daylight for humans. Biochemical Pharmacology, 191, 114304. https://doi.org/10.1016/j.bcp.2020.114304

[5] Edwards, L., & Torcellini, P. (2002). A literature review of the effects of natural light on building occupants. National Renewable Energy Laboratory. Colorado

[6] Tzempelikos, A., & Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. Solar Energy, 81(3), 369–382. https://doi.org/10.1016/j.solener.2006.06.015

[7] Sport Scotland, The national agency for sport, Understanding daylighting of sports halls. https://sportscotland.org.uk/media/ni2ao5tp/understandingdaylightsc.pdf

[8] Authority Network America – ANA, Intelligent Lighting Control Services for Smart Buildings, Smart Building Authority. https://smartbuildingauthority.com/

[9] International Commission on Illumination. CIE S 008/E:2001, (2021) Guide on Interior Lighting. https://cie.co.at/publications/guide-interior-lighting

[10] VELUX Commercial. (n.d.). Designing daylight solutions for sports facilities, Building Design. https://commercial.velux.com/blog/building-design/designing-daylight-solutions-for-sports-facilities

[11] International Commission on Illumination. (2002). Lighting of work places—Part 1: Indoor (ISO 8995-1:2002(E)/CIE S 008/E:2001). https://www.cie.co.at/publications/lighting-work-places-part-1-indoor

[12] SRPS EN 12193:2019 – Light and Lighting – Sports Lighting, Institute for standardization of Serbia, 2019. https://iss.rs/en/project/show/iss:proj:60454

[13] Gürlich, D., Reber, A., Biesinger, A., & Eicker, U. (2018). Daylight Performance of a Translucent Textile Membrane Roof with Thermal Insulation. Buildings, 8(9), 118. https://doi.org/10.3390/buildings8090118

[14] Bessey, R. P. (2012). *Structural design of flexible ETFE atrium enclosures using a cable-spring support system* [Master's thesis, Brigham Young University]. BYU ScholarsArchive. https://scholarsarchive.byu.edu/etd/3811

[15] Suo, H., Angelotti, A., & Zanelli, A. (2015). Thermal-physical behavior and energy performance of air-supported membranes for sports halls: A comparison among traditional and advanced building envelopes. *Energy and Buildings, 109*, 35–46. https://doi.org/10.1016/j.enbuild.2015.10.011

[16] Pavlović, A., Đorić-Veljković, S., & Karamarković, J. (2018). The importance of ethylene-tetrafluoroethylene for building daylighting. *Facta Universitatis, Series: Architecture and Civil Engineering, 16*(3), 355–374. https://doi.org/10.2298/FUACE171129014P

[17] Mundo-Hernández, J., Rutherford, P., & Chilton, J. C. (2006). Daylighting prediction in sports buildings with membrane structures: Physical and computer modelling. In *New Olympics New Shell and Spatial Structures, IASS/APCS Symposium*, Beijing, China.

[18] Raphael, B. (2011). Active control of daylighting features in buildings. *Computer-Aided Civil and Infrastructure Engineering, 26*(5), 393–405. https://doi.org/10.1111/j.1467-8667.2010.00692.x

[19] International Commission on Illumination. (2006). *CIE 171:2006: Test cases to assess the accuracy of lighting computer programs*. https://www.cie.co.at/publications/test-cases-assess-accuracy-lighting-computer-programs

[20] International Commission on Illumination. (1989). *CIE 083:1989: Guide for the lighting of sports events for colour television and film systems*. https://www.cie.co.at/publications/guide-lighting-sports-events-colour-television-and-film-systems-3rd-edition

[21] Bueno Unzeta, B., de Boer, J., Delvaeye, R., Deroisy, B., Fontoynont, M., Neves Pimenta, D., Reinhold, P., Stoffer, S., & Weitlaner, R. Editor: Marc Fontoynont (2021). *Review of lighting and daylighting control systems*. International Energy Agency Solar Heating and Cooling Programme, IEA SHC Task 61 / EBC Annex 77. https://doi.org/10.18777/ieashc-task61-2021-0002

[22] Flor, J.-F., Liu, X., Sun, Y., Beccarelli, P., Chilton, J., & Wu, Y. (2022). Switching daylight performance prediction of climate adaptive ETFE façade based on weather conditions. *Building and Environment, 209*, 108650. https://doi.org/10.1016/j.buildenv.2021.108650

[23] Belany, P., Sedivy, S., Roch, M., & Budjac, R. (2026). A fast two-stage analytical framework for real-time daylight simulation in smart buildings. *Electronics, 15*(1), 19. https://doi.org/10.3390/electronics15010019

[24] de Rubeis, T., Ragnoli, M., Leoni, A., Ambrosini, D., & Stornelli, V. A. (2024). Proposal for a human-in-the-loop daylight control system—Preliminary experimental results. *Energies, 17*(3), 544. https://doi.org/10.3390/en17030544

[25] Rea, M. S. (Ed.). (2011). *The lighting handbook: Reference and application* (10th ed.). Illuminating Engineering Society (IES)