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Editorial

Lighting in Buildings

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1. Introduction to This Special Issue

Lighting in the built environment has evolved since the rapid uptake of solid-state lighting (SSL) devices. In the last few decades, energy efficiency has played an important role in lighting research, application, and standardization. However, the improvements in the efficiency of individual luminaries are reaching a plateau. The growing understanding of human visual and non-image forming (NIF) effects of light necessitates balancing occupants' needs with energy efficiency goals [1]. Sensors and advanced controls now enable intelligent building lighting systems to meet these often-competing goals through technological development [2–4]. Despite the advent of LEDs, energy savings can be increased further through the intelligent use of lighting controls [5–10]. New parameters are considered during the design process, such as user and equipment needs [11–13], use of daylight [14–16], biophilic design [17,18], and providing adequate lighting when and where needed [19–21] to increase wellbeing and productivity for occupants. In light of the recent progress, this Special Issue aims to provide insights into the research on new approaches for building lighting systems and their implications for occupants.

In this "Lighting in Buildings" Special Issue, eight research papers [22–29] were published with 31 contributing authors from four countries (Australia, China, New Zealand, and the USA). Research topics included integrative (sometimes colloquially termed human-centric) lighting [22], visual perception and lighting [23], nocturnal lighting [24], spatial luminance distribution [25], luminance imaging [26], pupillary light reflex and NIF effects [27], field study of interior lighting [28], and façade design for daylighting [29]. All of these topics can be classified into three categories: integrative lighting, indoor lighting, and daylighting.

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2. Integrative Lighting

The study of integrative lighting systems is primarily concerned with occupant wellbeing, performance, and comfort. In this Special Issue, several studies contributed to this domain. For example, the framework developed by Jalali et al. [22] leverages current knowledge to offer a structured method for incorporating circadian lighting design throughout various project phases through close collaboration among team members. By defining project objectives and performing site analyses, architects can pinpoint both opportunities and limitations related to lighting and natural daylight. This study also highlights the importance of incorporating circadian entrainment considerations into the architectural design process early on to allow architects to devise solutions that prioritize occupant health.

Other studies were more experimental in nature. In Wang et al.'s study [24], five hours of continuous lighting interventions were administered at night to investigate the effects of lighting on melatonin levels, sleepiness, sleep quality, and performance during nighttime work in a confined space. The findings indicated that exposure to bright light significantly suppressed melatonin, resulting in the lowest levels of subjective sleepiness and increased morning sleepiness. Rapid increases in subjective sleepiness were observed under dim lighting conditions, which also provided the best sleep quality and melatonin suppression, given that the light exposure was sufficiently prolonged. For shift work, low-stimulation lighting that is suitable for visual tasks was preferred to minimize disruptions to sleep rhythms. For tasks requiring higher levels of illumination, moderate light enhanced performance while avoiding severe sleep disturbances. Although high illuminance reduced subjective fatigue, it did not significantly improve cognitive task performance and severely disrupts circadian rhythms and sleep, making it neither economical nor energy efficient.

In another controlled study, Wang et al. [27] examined the action spectra of pupillary light reflex, an essential marker of autonomic nervous system function, and a noninvasive tool in neuroscience research, physiological, and psychological clinical diagnosis. Past studies in humans [30–32] have reached partial agreement on the sources of signals that mediate the initial pupil constriction and the post-illumination pupil response. However, the exact mechanism by which the intrinsic and extrinsic signals of intrinsically photosensitive retinal ganglion cells (ipRGCs) regulate steady-state pupil size under continuous lighting is still unclear. Wang et al. [27] presented two experiments that reached three key findings. Firstly, both intrinsic and extrinsic signals contributed to regulating pupil size under continuous lighting conditions, challenging previous reports that underestimated the role of extrinsic signals [33–35]. Secondly, the influences of these signals may vary with melanopic radiance. At higher values of melanopic radiance, the intrinsic signal alone determined pupil size under sustained light exposure, which aligns with data from a previous study [36]. Finally, the experiments proposed and verified a hypothesis regarding melanopsin's potential role in regulating cone sensitivity.

Advancements in data collection technologies enhance the ability to gather substantial response and stimulus data in realistic settings. However, the complexity of hypothesis testing in real-world environments remains a significant challenge, as stated by Collier et al. [28]. Previous office studies suggest that architectural lighting can significantly impact some occupant responses, such as daytime sleepiness and sleep quality, although it does not seem to significantly affect mood and stress. Collier et al. [28] also examined the experimental protocols utilized in studies on the circadian impact of office lighting, and they investigated occupant responses through a field study. In this study, 23 office occupants spent 12 weeks under both static and dynamic lighting conditions, evaluating their alertness, mood, lighting and environmental satisfaction, and sleep quality. The results indicate that while occupants were generally satisfied with the lighting and environmental conditions, dynamic lighting did not significantly affect their alertness, mood, lighting satisfaction, or sleep quality.

3. Indoor Lighting

Improving the environmental quality of public and private indoor spaces plays a significant role in shaping occupants' experiences and emotions. The impact of lighting conditions on human emotions is multidimensional, as supported by research published in this Special Issue. For example, Wei et al. [23] found that exposure to different colors of light influences customer emotions and satisfaction with the environment. Their results suggest that perceived service quality can be managed through the color of light, all other things being equal.

In other research, Wu et al. [25] demonstrated the effectiveness of improving spatial luminance distribution across various dimensions, such as luminance distribution, object lightness, visual appeal and load, and light-shadow. By optimizing the visual appeal and visual load of spatial luminance distribution, this study proposed a restorative spatial luminance distribution (SLD) pattern suitable for various restorative reserve levels in the environment. Experimentally, the research showed the potential of lighting luminance distribution to enhance the restorativeness of hotel rooms. There were several key findings. Firstly, SLD of lighting significantly improved environmental restorativeness by 30.9%, despite an equal reduction ratio. Secondly, SLD enhanced the restorative perception potential, negatively correlated with the restorative reserve level of the environment. Furthermore, eye-movement data highlighted the role of visual perception in improving environmental restorativeness through spatial luminance distribution, showing an opposing yet coexisting relationship between visual appeal and visual load. Lastly, common characteristics of restorative spatial luminance distribution include a single highlight with uniform light and no stray light transition, a consistent highlight shape within groups, an ordered highlight sequence between groups, and an appropriate illumination effect of a single bright object.

Finally, Bishop and Chase [26] developed a luminance imaging device using a low-cost device and sensor, along with minimal calibration equipment. The developed device shows accuracy comparable to other custom devices that use higher-cost technologies and more extensive calibration equipment, proving effective for indoor lighting measurements. However, there are opportunities for improvement, with several suggestions to enhance device accuracy and measurement range. This study shows that accurate luminance imaging can be achieved at a very low cost. A no-equipment calibration procedure was also presented, effectively linearizing highly non-linear sensors. This enables the use of affordable sensors with a highly non-linear response for luminance imaging, instead of expensive alternatives with a linear response. The procedures outlined eliminate the need for expensive calibration equipment, reducing both device and calibration costs.

4. Daylighting

The desire to incorporate daylight into indoor spaces extends beyond merely helping to complete specific tasks. It is crucial to evaluate daylight distribution concerning perceived brightness, sustainable design approaches, visual comfort, and ambiance. In recent years, new lighting metrics have been developed to define daylight distribution and harvesting, but no existing metrics are linked to interactions with facade design. Thus, designing facades that maximize light transmission for both sustainability (energy efficiency) and human comfort (thermal and visual) remains challenging. To address these challenges, Sawyer et al. [29] introduced a new approach, facade photometry, for measuring light penetration through facades. This approach connects the facade's structure with its impact on light transmittance, allowing facade photometry to guide facade design and local adjustments. This linkage helps achieve energy-efficient indoor lighting that satisfies occupants' visual and thermal comfort.

5. Conclusions

The studies included in this "Lighting in Buildings" Special Issue cover several topics relevant to lighting research. The half of the papers are focused on integrative lighting and factors that affect the occupant well-being, such as pupillary light reflex and other NIF effects. Today, humans spend more than 90% of their time indoors and in many cases the workplace is located in a dense urban environment, resulting in the biological effect of natural light being limited [37]. Thus, the examination of the NIF effects of indoor lighting is an important contribution of this Special Issue. However, there is room for improvement. Considering individual differences in response to light, future research should use larger sample sizes and carefully screen participants' sleep types. Age and gender differences should also be taken into account. Since real-world occupational settings cannot be fully replicated in labs, long-term studies in realistic environments and post-occupancy evaluations are necessary. In addition, research on the pupillary light reflex might offer an easy way to assess the impact of different lighting scenarios within integrative lighting approaches. Developing a standard protocol for pupillometry could facilitate the direct assessment of ipRGC function in healthy and diseased retinas.

Studies published in this Special Issue also investigated the effect of lighting color on people's emotions in indoor spaces. Many studies of spatial luminance distribution used limited luminance levels in indoor environments; thus, more research with empirical validation is needed. Today's smartphones have advanced imaging capabilities, high-quality sensors, various shutter speeds, and onboard image processing, but their accuracy should be investigated further. More advanced and calibrated imaging techniques could enhance accuracy and performance while reducing costs [38–40]. Shading systems with specular characteristics are important for glare analysis. Future research should investigate façade lighting for specular reflections, which cannot be detected without photon mapping techniques.

A final note for this editorial is a call for papers for a follow-up Special Issue, "Lighting in Buildings—2nd Edition" (https://www.mdpi.com/journal/buildings/special_issues/850FPNEZ88, accessed on 18 August 2024). As the guest editors, we are inviting researchers to submit papers focusing on topics including but not limited to the following: adaptive, intelligent lighting systems; human visual response to lighting; human NIF response to lighting; modeling and evaluating energy efficiency and lighting application efficacy; daylight in buildings; lighting and color in virtual reality (VR) and augmented reality (AR) applications; novel applications of SSL devices in buildings; and policy, building standards, and recommendations.

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