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Research Article

Daylighting in High-Rise Office Buildings: A Comprehensive Review

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ABSTRACT

This article is a detailed review of the significance of daylighting in high-rise office buildings and its importance to the energy performance, visual comfort and productivity of building occupants. Due to increased urbanization globally, high-rise buildings are becoming prevalent in cities, the need for sustainable design approaches, maximize the use of daylight, eliminating glare and increase productivity. Historical background and overview of day lighting systems are discussed, as well as the current techniques and new technologies for passive and active daylight systems. The article also treats some daylighting problems related to buildings, such as glare, regulatory compliance, daylight deprivation, non-uniform daylight distribution. Case studies of projects implemented with exceptional daylighting are introduced. Significant findings on integrating new technologies, self-sufficient buildings, adaptive shade, and the impact of layout in a space to achieve the desired daylighting were also discussed. The potential impact of green rating systems such as LEED and WELL on sustainable daylighting is also highlighted in the review. The future of day lighting with innovative dynamic materials such as electrochromic glass, and climate responsive controls are also discussed to provide a balance between energy savings, productivity and aesthetics.

1. INTRODUCTION TO DAYLIGHTING IN HIGH-RISE OFFICE BUILDINGS

The significance of daylighting in high-rise office buildings is discussed in this section. In modern architectural designs, daylighting is a leading design element, bringing together environmental, economic, and social aspects. Daylighting has been described as a straight-forward and yet highly multifaceted concept . It enhances not only the amount of natural light but also the overall aesthetic, feelings, and environmental quality of the interior spaces. Open buildings, or buildings with large windows, have been appreciated throughout the history of architecture. There is a growing concern for integrating effective daylighting in high-rise buildings as the world rapidly urbanizes. As of recent years, more than half of the global population is living in urban environments, consuming over 75% of the world's energy, and pumping out over 75% of the greenhouse gas emissions [1].

Despite the challenges brought by high-rise structures in a dense urban setting, the proliferation of high-rise buildings also presents opportunities for innovative designs and sustainable solutions. A high-rise building greatly impacts the surrounding environment as it changes the flows of sun, wind, and other natural resources. In some cases, it might block access to nature and create an undesirable environment for the pedestrians, which raises questions about the point of building a high-rise. Given the increasing density of urbanization, there is a need for vision and strategy to use high-rise buildings to positively affect the urban context, instead of merely filling the skyline with isolated objects. Current high-rise designs and regulations are too focused on maximizing the floor space, which often results in unnecessary setbacks and awkward shapes. Design guidelines to improve the building's performance from multiple perspectives are critically needed.

Efficient daylighting in high-rise office buildings has always been an art as well as a science. On the one hand, turned and shaped glass panes, and interesting shading devices are often designed to create stunning architectural aesthetics. On the other hand, uneven daylighting often occurs, leading to energy wastage and adverse comfort levels. Therefore, it is essential to look at some formalized and parameterized approaches in seeking efficient daylighting designs [2].

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2. HISTORICAL DEVELOPMENT AND IMPORTANCE OF DAYLIGHTING IN ARCHITECTURE

As humanity emerges from the burdens of a pandemic, the focus now turns towards creating a more humane world. A world where social fairness, cultural acceptance, and environmental resilience play vital roles in shaping future systems, be it economic, political, or educational. Underlying philosophical frameworks that promote holistic consideration of human involvement and dependency are central to addressing global concerns. Since the dawn of civilization, human beings have continuously transformed their natural surroundings to create artificial habitats. Over time, a specific response to these constructed environments has emerged, known as architecture, which encompasses a wide range of cultural interpretations. Despite cultural diversity, habitats share common ecological contexts. In light of this, the quest for future architectural systems should incorporate lessons learned from historical precedents. Recent technological advancements have significantly optimized artificial environmental control systems, enabling tighter control over temperature, air quality, and illumination levels. However, these have also become a source of concern and new problems. The economic burden of maintenance, construction, and energy expenditure has risen exponentially as global progress prioritizes economic growth over equity and nature. Artificial systems, while insightful, have limitations and drawbacks. Observations of historical habitats reveal a reliance on passive, natural, or "free" systems to create comfort zones. These historical habitats demonstrate a sophisticated understanding of holistic environmental control systems, considering relationships between form, materiality, accessibility, and behavior. Though techniques may vary, the fundamental approach should be re-examined in light of contemporary challenges. Daylighting, the deliberate control of sunlight, presents a semi-natural system where human intervention shapes spatial and material arrangements, allowing nature to dictate other variables. Like all natural light sources, sunlight is a variable agent, constantly fluctuating in intensity, direction, and color. This variability can be a nuisance, requiring mitigation strategies, or embraced as an opportunity to highlight architectural form. Variable agents necessitate diverse responses, accommodating mitigation and embrace strategies. Yet, most buildings ignore daylight variability, offering static responses dependent on artificial control systems. This is surprising considering the prehistoric understanding of daylight and complementary academic progress on its benefits, especially in containing private spatial arrangements. While history reveals changing attitudes and techniques regarding daylight, high-rise habitats seem resistant to the ephemeral qualities of natural light. Thus, an investigation of high-rise design strategies focusing on daylighting is conducted. The first chapter outlines the methodology and approach, followed by a comprehensive historical review from diverse cultures and locales, demonstrating changing attitudes towards daylighting across time periods [3].

3. BENEFITS OF DAYLIGHTING IN HIGH-RISE OFFICE BUILDINGS

The high-rise office building is the modern building typology. It has grown rapidly in the past decades, especially in developing and newly industrialized countries. Office buildings are the major building type in the worldwide construction market. The global floor area of office buildings will double by 2030. Good design of high-rise office buildings is crucial for a pleasant, healthy, and productive workplace for many office workers. A good design should satisfy the end users' needs while considering various design constraints. Daylighting, the availability and penetration of natural light, is essential in high-rise office buildings [4]. High-rise office buildings often provide a great opportunity for effective daylighting design. Daylighting affects numerous aspects in the built environment, particularly on the health and well-being of the building occupants. Exposing to natural light helps improve mood, reduce fatigue and headache, and ease stress. The overall satisfaction increases notably, with the building occupants exposed to more daylight. Daylighting is closely related to energy efficiency. More than one third of the total energy use in commercial buildings is attributed to lighting. Implementing effective daylighting strategies in new office buildings can help save up to 80% of the lighting energy use. Since the introduction of the energy crisis in the late 1970s, energy-saving has been the most concerned issue in the building research community. The safety, health, and productivity of the building occupants are easily overlooked in most energy-conservative buildings. However, there is no guarantee that energy savings will result in enhanced productivity and performance of office workers. Natural light is vital for the health and well-being of the building occupants. A workplace with no window may feel stuffy. Therefore, a thorough investigation on the interplay between the employee's well-being, energy savings, and productivity enhancement is wanted in high-rise office buildings. Empirical data and quantitative studies are used to build the case for daylighting, rather than simply anecdotal evidence and qualitative discussion. The validity of the data-driven claims has often been questioned. Daylighting provisions and analysis for high-rise office buildings in the world and recent case studies are presented to give supporting evidence for the priori claims. Awareness has increased that the built environment can and should do more than just provide shelter. It is widely accepted that well-designed workplaces can enhance the productivity of the employees and therefore the performance of the organization. Numerous studies have concluded that landscaping, artworks, scenery views, and the aesthetic considerations can significantly improve the productivity rates. However, these provisions are often costly and involve complex maintenance requirements. What is needed is a simple and easily applicable solution that has the potential to enhance productivity in a cost-effective manner. Daylighting design in the workplace is often overlooked in most intensive office environments despite the numerous prior researches on the benefits of good daylighting design. Its agencies the productivity enhancement while alleviating the eye-strain discomfort for the intensive computing operations [5].

3.1 Health and Well-being

Daylighting has often been considered as a means to enrich the aesthetics of a space and minimize energy use. However, there is strong evidence that it is vital to health and well-being as well. The effects of daylighting on health and well-being in high-rise office buildings, specifically focusing on the mental health, thoughts, and perception of occupants, have been reviewed. As one of the primary environmental sources, natural light has significant psychological and physiological effects in office settings. It is observed that an adequate amount of daylighting in the workplace alleviates stress and enhances feelings of comfort and connection to the outdoor environment, thereby improving mental health [2]. An explanation of the science behind circadian rhythms is provided, along with the significance of exposure to natural light to regulate the cycle of sleeping and alertness. In modern office buildings, where the proportion of designated spaces for work without hindering privacy is higher, windows are usually precluded in most enclosed meeting rooms. This potentially curtails the exposure of daylight and natural view, which in turn restricts the connection with the outside world and makes it more difficult for one's mind to wander out of the confining space [6]. During the long hours spent indoors, feasible daylighting strategies can help in keeping the mind outward and thus lead to lower rates of absenteeism, and higher job satisfaction and productivity. Research finds a significant association between access to daylight and employee focus, as well as cognitive function, thus providing a basis for designing workplace environments with effective daylighting.

In addition to boosting productivity, it is also found that workplace environments with ample daylight prove to create healthier indoor air quality by facilitating the ventilation. Overall, daylighting is deemed essential in promoting a healthy space for working and thus efforts are made to advocate daylighting design principles as a prerequisite for building health standard [7].

3.2 Energy Efficiency

Daylighting, the art and science of allowing natural light into buildings, plays a significant role in the enhancement of energy efficiency in high-rise office buildings. Office spaces have been noted to be "daylight critical" environments where effective daylighting can diminish the dependency on artificial lighting and subsequently save energy. Daylighting has been estimated to account for a maximum of about 90% of the possible energy reductions for the lighting system alone in some typical office buildings. Taking into account the greater involvement of electric lighting within the building design scenario, the reduced energy cost in comparison to the total energy cost is still about 14%. It has been shown in various case studies that the economic benefit associated with energy reductions could exceed the construction and maintenance cost of the daylighting systems. The role of building orientation and window placement in maximizing the daylight penetration while minimizing the heat gain has also been assessed [8]. Strategizing the daylighting systems and appropriately integrating them into the energy modeling would generally assist in developing the building design scenario. Simulation software has become the predominant tool in the building design process and most of the energy modeling programs feature a daylighting module either built-in or as an auxiliary option. The designed daylighting systems could be modeled along with a set of building geometry, materials and weather data inputs. The performance of daylighting systems could then be predicted either in terms of the illuminance level on the working plane or the daylighting factor. Doulos et al. 2020 [9] investigated the impact of daylighting and lighting control systems on user satisfaction, visual comfort, and energy efficiency in three office buildings in Athens, Greece. Using post-occupancy evaluations, they assessed user preferences, illuminance levels, and control options. Building A used a closed-loop system with T8 lamps, achieving optimal illuminance levels in most areas. However, limited daylight penetration led to overuse of artificial lighting, with moderate user satisfaction due to the lack of manual control. Building B employed an open-loop system with compact fluorescent lamps, delivering good illuminance levels but some over-lit areas (>900 lx). This system achieved high energy efficiency, although user satisfaction was constrained by the inability to override the automated system. Building C utilized an integral reset system with T5 lamps but underperformed, with many areas falling below the recommended 500 lx. Despite lower energy savings, Building C allowed manual control, improving user satisfaction compared to the other buildings. Findings revealed that daylight harvesting systems in Buildings A and B improved energy efficiency through effective dimming, while Building C's system underperformed due to a suboptimal control algorithm. Users expressed a strong preference for combining daylight with artificial lighting and emphasized the importance of manual control for optimal satisfaction. Table I summarizes the key findings, and the suggested image highlights user preferences and system performance.

TABLE I. THE INTEGRATION BETWEEN DAYLIGHT AND ENERGY EFFICIENCY FOR DIFFERENT TYPES OF BUILDING

Aspect	Building A	Building B	Building C
Control Algorithm	Closed-loop	Open-loop	Integral reset
Illuminance Levels	Optimal in most areas, some over-lit	Generally good, some areas over-lit (>900 lx)	Many areas under-lit (<500 lx)
Energy Efficiency	Moderate, with frequent overuse of luminaires	High efficiency due to better dimming	Low efficiency due to poor control algorithm
User Satisfaction	Moderate visual comfort	Better visual comfort	Manual control improved user satisfaction

The impact of daylighting strategies on energy consumption could be computed simultaneously along with the thermal and energy performance analysis. Daylighting could dramatically enhance the natural light intake of the interior space resulting in a more comfortable and pleasant working environment. Nevertheless, care should be exercised in the application of daylighting due to the potential drawbacks. Excessive daylighting might produce glare discomfort, and overheating and thus the balance between these factors should be analyzed. Effective solutions have been suggested including the use of various shading devices, tilting windows and the arrangement of interior partitions. It is widely recognized that the careful design of the daylighting systems could yield more than one benefit by incorporating the features of both energy saving and thermal comfort [10].

3.3 Productivity and Performance

Research on high-rise office buildings and the rationale behind their popularity has been deliberated upon in many studies. Some factors influencing the choice and continued use of high-rise buildings for office space have been highlighted, including the socio-political landscape, land availability, and the desire for open views and better access to natural light [11]. Much research has been conducted on the effect of natural light on job performance and how jobs done away from natural light can lower concentration and attentiveness levels. The design of high-rise offices often compromises on the availability of natural light reaching the core spaces. Despite such issues, studies have revealed that "Daylighting" can significantly improve productivity in high-rise offices as compared to window-less low-rise offices. Daylighting refers to "the provision of sunlight or daylight to a space by means of a window, skylight or other aperture". Natural light during the day is an important element of the design of buildings used for working, creative, or scholarly purposes. This has been amply illustrated by research, with an emphasis on office environments. A number of studies have shown how a well-lit environment can enhance creativity and collaboration among employees.

Research has shown that working in spaces enhanced by daylight can help reduce fatigue, improve mood, and add to a sense of identity and ownership of a space. Such psychological findings are crucial in planning spaces for job functions that require diligent attention as well as creativity. Time spent in artificially-lit spaces has been seen to bring about negative consequences with an increasing concentration of such spaces. Spaces bathed in, or viewed from, natural light tend to have better psychological effects and yield increased productivity. This is supported by a claim that "productive" employees yield higher returns. In fact, a mere 1% increase in productivity has the potential to return millions to a multi-national corporate business, given the amount spent on the salaries of employees performing tasks in the office spaces of such businesses. Productivity gains in high-rise offices due to effective daylighting have been evidenced with the help of case study buildings that have undergone post-occupancy evaluation. This emphasizes the need for dealing with how the workplace is designed, instead of going into the intricacies of the design, detailing, and construction of the high-rise buildings themselves. Above all, the focus is on "daylighting", with a plea to see daylighting as a catalyst for greater performance in today's office settings [12].

4. CHALLENGES AND CONSIDERATIONS IN IMPLEMENTING DAYLIGHTING IN HIGH-RISE BUILDINGS

Dedicated efforts in high-rise office buildings towards maximizing daylighting can be obstructed by a few issues that need to be carefully evaluated during design. Although daylighting has numerous advantages, glare and visual comfort are two of the most destructive issues hindered by daylight. Building orientation, façade design, and structural design significantly influence and mitigate glare overshadowing considerations [13]. Excessive daylighting in both afternoon and morning hours can cause high internal temperatures and contribute to glare discomfort in the office spaces. Therefore, careful consideration of spatial design and layout design can greatly minimize glare discomfort while maximizing daylight utilization. Other structural design measures can excessively limit the prospect views of the building spaces. Aside from compliance with natural lighting-related requirements in building codes, an informative summary of daylighting-related design considerations in high-rise buildings under the effects of local weather conditions is discussed. Generally, codes will state the required design consideration for natural lighting in a numerical manner [14]. Clearly, legislative requirements on natural lighting with local building codes significantly affect building design strategies. However, daylighting regulatory requirements are usually not considered in the design charters of office or commercial buildings. To bridge this gap, a series of necessary actions need to be taken by natural lighting advocates, policy-makers, architects, and builders at different levels with priority given to the policy-makers who influence law enactment and practice. The daylighting-related issues in high-rise office buildings environments are discussed, and a number of solutions and best practices for minimizing these issues are suggested. Action items that assist designers in meeting daylighting goals without compromising comfort are also suggested. Overall, the integration of daylighting will necessitate thorough planning. This paper aims to provide a coherent overview of the key challenges that need to be engaged with during the planning of the integration of daylighting.

4.1 Glare and Visual Comfort

Focusing on glare and visual comfort, there is a plethora of research investigating the effects of daylight on office environments; the perceived benefits of daylighting indoors tended to decrease with the increase of sunlight. Excessive sunlight entering interiors was found to hinder the visual comfort, thermal comfort, and overall performance of the occupants by overpowering the benefits of daylighting. Glare, the lighting condition that results in loss of visual comfort due to excessive contrast of luminance, was found to be the main cause of discomfort in daylit places [9]. A whole variety of definitions and classifications of glare exist in research. Per an overview of glare's characterizations, glare can simply be considered one out of several factors affecting the comfortability of a space. Like an inharmonious sound would impede the sense of hearing, glare hinders the comfort of a person's vision, as objects and spaces become hard to see. This impediment could also generate other discomforts and distractions felt by other faculties. Consequently, the productivity and comfortability of the occupants would be affected [15].

Nonetheless, glare is not a problem exclusive to daylighted spaces. Artificial lights can generate glare as well, and thus other daylit spaces have become focused on eliminating glare conditions, which seem to be more troublesome and difficult to control than artificial lights. Particularly in office buildings, a great variety of different work activities could be done within the same space, and glare caused by natural light differs from that by artificial light for the same viewing direction. As a result, many case studies regarding office buildings daylit by window arrangements are found in research. Since it is still possible to have control on how the windows are placed and how the space is arranged at the design stage, a review of strategies for controlling glare in daylit offices is attempted. Here, strategies to control glare are analyzed in two contexts: the design of the building itself and the interior design within. For each context, basic strategies to limit glare and some related case studies are presented. Finally, some recommendations are proposed on how lighting and other design choices could be integrated to best mitigate glare effects.

4.2 Spatial Design and Layout

Spatial design and layout are critical considerations for the effective application of daylighting strategies in high-rise office buildings. To ensure the efficient penetration of natural light into the interior space of a building, attention needs to be paid not only to the form of the building envelope and window design but also to the optimization of its interior layouts. It is often found that the degree of space utilization in buildings and the degree of access to daylight are globally correlated. This suggests that careful spatial design is necessary to achieve successful daylighting performance [16].

Various design methodologies are found that strongly encourage flexibility in the arrangement of workspaces in office buildings and other types of high-rise commercial structures, while still minimizing the obstruction of light by interior partitions. The arrangements of office spaces which are primarily dependent on predetermined design layouts tend to restrict the penetration of natural illumination within the interior spaces. In addition to having a significant impact on building energy performance, it is important to note that the arrangement of enclosed office spaces can considerably affect the comfort of employees working in them. Therefore, either an integrated approach among architects and interior designers or careful consideration by solely the architectural designer is necessary to ensure that the spatial arrangement enhances the accessibility of natural illumination. As case references, some successful spatial designs in high-rise office buildings that facilitate daylight exposure are examined, and the critical role of spatial organization in the effective application of daylighting strategies is highlighted. Figure 1 shows the seasonal solar variations affecting daylight availability, with longer daylight hours in summer (sunrise at 5:00 AM, sunset at 7:00 PM) and shorter hours in winter (4 hours less). Annual cloud cover averages 2.98 oktas, with mostly clear skies enhancing daylight. These factors are critical for optimizing daylighting strategies to improve comfort and energy efficiency [10]. Thoughtful spatial organization is found to be essential in achieving effective daylighting in addition to the expected importance of form design, window design, and shading devices. Factors considered in the assessment of spatial design include the aspect of employee comfort in relation to spatial arrangement and its significance towards productivity, types of workstations, temporal change of daylight availability, and the effect of orientation of workstations relative to windows. Special attention is paid here to how spatial arrangement affects the comfort of employees working in a close controlled climate and artificially illuminated environment under the perspective of architectural design alone [17].

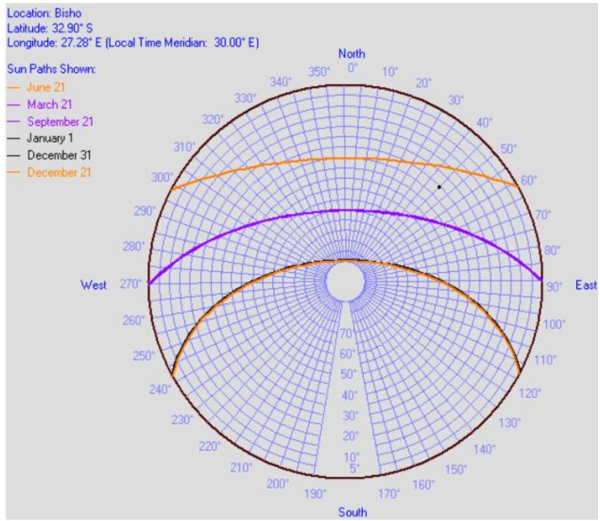

Fig 1. Sun path diagram [18]

The aim is to present consideration points for office buildings and other space types in which the comfort of employees is largely determined by the effectiveness of spatial arrangement. The arrangement of individual offices and the effect on the comfort of employees working in them is chosen as an example for thorough examination, although a number of other arrangements are possible. With regard to the motivation of designers, the significance of spatial organization in daylighting design is not always readily apparent.

4.3 Regulatory Requirements

This section addresses the regulatory requirements surrounding daylighting in high-rise office buildings, emphasizing their impact on design practices. An overview of the various building codes and standards that mandate minimum daylighting provisions is provided. These regulations aim to promote integrated design while giving architects and building managers some degree of flexibility on how to achieve compliance. Nevertheless, a common challenge for many architects is how to meet regulatory criteria for daylighting without compromising aesthetic appeal. Hence, a selection of case studies is included, showing how several recent high-rise office buildings have achieved excellent daylighting, while also complying with the relevant building regulations. The inclusion of both a plan and a plot showing regulatory compliance for each case study also highlights how the criteria can be met in different ways [19]. Finally, potential future changes in the legislation are discussed, as higher standards for energy efficiency may bring some elements of daylighting regulation into question [8]. This section acts as a guide to understanding and adhering to the critical legal aspects of daylighting in high-rise office buildings. On one hand, the design and building codes of many states and cities now contain provisions for daylighting. On the other hand, the recent prioritization in the United States of Leadership in Energy and Environmental Design (LEED) certification for new publicly funded buildings, as well as growing interest in such certification within the private sector, has elevated the importance of compliance with daylighting regulations. For building planners unfamiliar with the codes, an overview of the requirements is provided, along with how recent advances in modeling daylighting can facilitate compliance. For those already planning in accordance with the codes, practical advice for navigating the regulatory process and integrating compliance into design plans is provided [20].

5. DAYLIGHTING STRATEGIES AND TECHNOLOGIES FOR HIGH-RISE OFFICE BUILDINGS

Daylighting strategies and technologies are explored in this section with particular focus on high-rise office buildings. A building’s performance is significantly determined by its form and design. Specifically, the building envelope is the outer skin of a building enclosing the interior spaces containing users and equipment and influencing energy performance. Various passive design techniques relying on natural elements have been utilized to achieve effective integration of daylight within buildings. These techniques include proper building orientation, window placement, reflective surfaces, light shelves, skylights, and overhangs [21]. Passive systems are intended to maximize daylight penetration in the deep interior while avoiding glare and other potential problems. Beyond passive solutions, there are many available active systems and controls. Active systems are those cutting-edge technologies that can actively adjust to the changing light conditions. Controls can optimize the performance of both passive and active devices, where control strategies can range from fully automated to manually controlled devices, with automated shading systems being one of the most common active daylighting strategies . Automated shading systems are claimed to effectively prevent glare, promote spatial uniformity of daylight distribution, and improve user satisfaction with respect to the indoor lighting conditions found by subjective assessments. Meanwhile, smart controls combining shading and electric lighting have also shown great potential in reducing energy use compared to fixed systems. There are a number of excellent building designs utilizing these implemented daylighting strategies and technologies. A successful building design can be innovative daylighting solutions that significantly improve user experience and energy performance at the same time. The widely agreed definition of sustainability is "to meet the needs of the present without compromising the ability of future generations to meet their own needs," which indicates a balance between social, environmental, and economic concerns. Adaptive technologies within the context of the built environment may include building controls and other adjustable systems responding to the changes in the exterior or interior environment. Some potential sustainability implications of these adaptive technologies are generally acknowledged [22].

5.1 Passive Design Techniques

Focusing on passive design techniques, this section argues that the best methods of harnessing the natural light involve no mechanical systems. A passive system is defined as one that alters the built environment by simply adding space, shape, or materials to it without the addition of any new mechanical devices, appliances, or systems. The simplest passive systems are the classical design principles of site orientation, window sizing, and window placement, which broadly defined are the foundational elements for most daylighting systems. Once these basic elements are in place to maximize daylight, the designer can move into more active systems that would be in the spirit of the paper. A good example of this might be overhangs or light shelves which control glare while allowing for ample daylight penetration. Another good example is material selection, where a choice between reflective versus absorptive surfaces helps control uniformity in the space. Case studies are drawn from buildings in traditional and/or passive design communities which have successfully employed these techniques. Passive design systems are typically thought to have the greatest merit in regions with limited financial resources. However, it is also these areas that most often have the greatest access to natural resources, e.g. sunlight. Thus, the merit of passive design systems expands from simply an economic or social merit to one of environmental sustainability. By their very design, passive systems inherently avoid waste, and thus are a fundamental step towards promoting environmental sustainability. However, it is cautioned that building designers be careful not to overly compartmentalize passive systems into their own category. A good passive design is a good design overall, and like any good system, it must be integrated with the building's overall architectural vision. Thus, the merits of passive designs must reside beyond simply their inherent benefits in promoting environmental sustainability. The techniques discussed here involve only the simplest passive measures but are nonetheless critical to any successful attempt at harnessing daylight. Finally, as a comprehensive review, this section attempts to provide a guide to the passive techniques which now exist for attempting to daylight new buildings [23].

5.2 Active Systems and Controls

This section examines the various active systems and controls that enhance the daylighting potential of buildings. Shading systems are extensively used both externally and internally to control the daylighting impact. While passive systems are non-mechanical and can provide some degree of control, active shading systems are responsive to the varying state of light and thus need to be controlled. The automated shading systems respond to the daylighting performance for some variables. According to passive systems, the shape and geometry of shading devices are determined before construction and remain constant. The active systems can operate mechanically to enhance performance based on external and internal parameters affecting daylight. Systems like louvres are traditionally used to protect from excessive daylight and have been proven to improve daylight penetration in deep building zones. Besides windows, other openings can be used with louvres for better daylight performance. For a fixed aperture opening, the effectiveness of louvres is based on their angle of inclination. At the desired angle, the ratio of daylight illuminance inside the room to outside is maximized which controls excessive light and glare. Advanced glazing, window blinds, and their automation can significantly improve the daylighting performance of building fa9ades [24]. Despite improvements, uniformity of daylight distribution remains a challenge in most buildings. To overcome this challenge, a combination of widely used systems and newly developed technologies is proposed. Data from several field studies suggest that daylighting can enhance productivity and satisfaction of building users through improved visual performance, lower fatigue, and enhanced view of the outside environment. Effective control of daylighting can ensure reduction in glare and thermal overheating. Generally, three approaches can be used to control daylighting actively; one is the use of advanced optical devices that enhance the effectiveness of daylight and remove drawbacks. The second method utilizes complex computation algorithms to optimize lighting systems either for fixed or variable conditions. Finally, the design of integrated lighting systems that combine several technologies is improved. Action research has shown that appropriate interventions may improve visual comfort and control of the environment. Here, lighting systems were improved in two educational and office buildings. Technological interventions included the incorporation of movable components to the existing installations and the improvement of automated control procedures. The results show that glare can be reduced by the systematic application of technical measures, and attention to control procedures is as important as the technology itself. Generally, there are three groups of systems used for active control of daylighting; automated shading systems are widely used to control the daylighting impact in buildings and have been developed to either maintain a fixed state of light or to optimize the daylighting. Simple controls include the manual operation of shading devices, and in the absence of occupants, these systems require a reliable control strategy for a deterministic state. Automated devices can also be used to control the electrochromic glass, which regulates the transmittance of solar radiation through a changeable layer of a transparent electrochromic material when a voltage is applied. These advancements allow a variety of control strategies based on external conditions, and a good strategy considers temperature, transmitted insulation, and illuminance as variables. Changes in these variables with time can be dynamically predicted using neural networks and time series approach. Through appropriate integration of active systems, the daylighting potential can be maximized and users' experience improved in office buildings. Several typically used active systems are discussed here, and it is crucial to choose appropriate systems that would complement passive strategies already in use. A number of conducted experiments in different settings demonstrate the significant contribution of developed active controls to the daylighting quality of altered spaces. Participating buildings include offices, educational workplaces, and cultural spaces [25-28].

6. CASE STUDIES OF SUCCESSFUL DAYLIGHTING IMPLEMENTATION IN HIGH-RISE OFFICE BUILDINGS

A growing number of high-rise office buildings are making successful daylighting improvements one at a time or collectively. All of them are exemplary cases that have experimented with efforts to improve daylighting. Some have involved extensive renovation of existing buildings, while others have been built from scratch. Some buildings are very new and on the cutting edge of architectural design, while others are older but have been remodeled effectively. Selected buildings also reflect different geographical locations and cultural backgrounds as well as different architectural styles. Although buildings may differ in their fundamental language of architecture or approach to sunlight, there are also many similarities in the experimentation of various daylighting methods and their positive effects on occupancy and operational effectiveness [29]. They are a useful reference for architects and planners to visualize the real application of what has been discussed previously in the text.

The buildings have been analyzed one by one for their unique design strategies and technologies, how they provide optimum accessibility to natural light, and what specific problems they address. The goal is to distill as many lessons as possible so that they can be successfully adopted in future daylighting projects. Basic information is provided about each building, including built years, floor area, and a brief overview of the design strategy that relates to daylighting. In addition, the numerical daylighting and energy performance evaluated by the building designer, along with occupants' metrics and feedback, are presented wherever possible to emphasize the advantage of good daylighting. Some buildings may include several interesting daylighting provisions but only one or two are picked for detailed analysis because of the space limit. The buildings selected for case studies are: 101 Park Drive, Boston, USA; Johnson Controls, Milwaukee, USA; National Oceanic and Atmospheric Administration, Maryland, USA; San Mateo County Office Building, Redwood City, California, USA; Tsim Sha Tsui Centre/Empire Centre, Hong Kong, China; The Hong Kong and Shanghai Bank Headquarters, Hong Kong, China; and Bank of China Tower, Hong Kong, China [30].

7. SUSTAINABILITY AND GREEN BUILDING CERTIFICATIONS

Sustainability in the context of daylighting in buildings is often associated with energy and environmental concerns of the community. The global sustainability concept of buildings may be extended to substantial systems like cities. A green sustainable building is a concept of producing a structure that is in harmony with the surrounding ecosystem and is able to meet humans' needs. Large cities contain about half of the worldwide population and account for fifty percent of the energy and resource consumption, whereas they release the same amount of greenhouse gases. The urban settlement type consumes the most energy and other resources; as such, urban development has an important impact on the world environment. The organization and angle of orientation of buildings have a considerable influence on energy, natural ventilation, and daylighting, which are the main drivers for building development in terms of sustainability.

Green building certification provides proof or assurance of sustainable development. Several behavioral and economic measures are followed for the appropriate management of sustainability in office buildings to increase the effectiveness of workers' performance, reduce energy use, and offer comfort and health within the surroundings of the building. Both developed and developing countries have implemented building certification systems. The certification system is one of the globally acknowledged systems that have been applied in diverse nations. The green building certification process is generally less costly than conventional construction, and the building is released for operation sooner with fewer contractors' claims about the quality. Building designers and occupants believe that green building criteria are valuable for environmental benefits, reduction of natural resources, and increased energy efficiency, which is necessary for both developing and established nations [31].

7.1 LEED Certification

Leadership in Energy and Environmental Design (LEED) is a recognized rating system designed to influence the development of more sustainable buildings. It emphasizes environmental and human health. The principles of the LEED rating system are defined as setting the context, maintaining the certification process, and establishing minimum building performance. LEED has several ratings for new construction and major renovations, but to date, the main focus has been on new construction.

LEED points are the measures of building operations and strategies that have the most positive impact on the environment and for building occupants. Each LEED credit is translated into a specific quantified point value. To be LEED certified, a building must also meet mandatory requirements. LEED-NC is a rating system for new construction and includes eight general categories: sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, innovation in design, and regional priority. At present, more than 10,000 projects are registered and certified under the LEED rating system, representing over 4.4 billion square feet in all 50 states and 114 countries.

New construction and major renovation projects are tracked, including government and publicly financed construction. After the completion of several construction phases, the design team registers a project of interest with LEED. When a project registers, it is assigned a LEED coordinator for project management purposes. LEED pre-qualified professionals can be used to ensure a comprehensive understanding of the LEED certification process. Out of the listing of specific office building properties, building owners and managers can use EBOM to track environmental performance across a broader portfolio. Finally, the LEED software provides ongoing benchmarking and performance measurement for existing building managers [32].

There are many benefits of LEED-certified buildings, such as increased property values, reduced operating costs, increased leasing demand, heightened occupancy rates, and a better indoor living environment with increased daylight and improved thermal comfort. In hard economic times, there are fewer building devaluations and a lower tendency to reduce rents for high-rated properties. LEED has investigated the impact of sustainable building features on office rent and occupancy rates. In this case, the monthly rent and occupancy share are highest for Class A office building purchasers. Buildings with a 100% view of a daylighted scene rent for a 12% premium, and those with 50% views rent for a 7.5% premium. There are several limitations of the study, including failure to control for part-time or mini-location measurements. However, tenants aren't any more likely to pay premiums for green buildings in other areas. For these reasons, tenants prefer to be in green-certified buildings, but at the current time, the advantages of the market are reaped by owners rather than tenants. Finally, in terms of building performance, green construction is also healthier for tenants. Green construction includes building systems, such as low-emissivity materials and natural ventilation, which allow for superior outdoor air distribution. Green construction uses uncommon source control and better performance management, minimal air contaminants, lower levels of adverse material pollutants, and enhanced indoor comfort. Green buildings benefit the environment by promoting sustainable building practices, conserving natural resources, reducing landfill waste, stimulating quality improvements, and optimizing cost-effective design [33].

7.2 WELL Building Standard

The WELL Building Standard can be implemented in the post-occupancy phase as it mainly addresses the indoor environmental quality of a building. Also known as WELL, it is a certification program that assesses the impact of the built environment on human health and well-being.

In terms of daylight performance, WELL v1.0 included a feature credit where projects could earn points if 75% or more of the regularly occupied, enclosed floor area was within 25 ft. of vision glazing. The vision glazing should also provide a clear view of the outdoor environment. In the latest version, new strategies are added to meet the task-ambient light ratios at workstations, remove barriers to daytime lighting controls, and ensure good daylight at the core of the building. In addition to these strategies, an assessment of visual acuity, occupants' overall satisfaction with the indoor environment, and light environment will also be considered. These strategies help ensure good quality light for occupants and contribute to human health and mood while indoors. With increased digital reliance on work and workspace, it is crucial to ascertain better indoor environmental design. By rewarding projects for the provision of daylight in these buildings, the WELL Standard encourages the building industry to foster stronger awareness of personal health and well-being [34].

8. FUTURE TRENDS AND INNOVATIONS IN DAYLIGHTING FOR HIGH-RISE OFFICE BUILDINGS

This chapter continues to investigate future trends and innovations in daylighting, specifically for high-rise office buildings. Focus is placed on emerging technologies and concepts that were either in their infancy or not yet widely adopted. One key trend is the desire to keep up with growing technologies such as dynamic glass, energy-efficient windows, and coatings that reflect or absorb select wavelengths of light. These advancements aim to maximize the benefits of natural light while minimizing unwanted heat energy use. Another advancing aspect relates to fixed interior or exterior shading devices, emphasizing the importance of integrating the concepts of smart home systems that automatically adjust windows, shades, or artificial lighting based on the occupancy and time of day. As global awareness of climate change rises, concerns about extreme weather events and their effect on traditional daylighting strategies also arise. Thus, adaptability should become a governing quality of new designs instead of relying solely on historical precedents. Trends in architectural practices regarding daylighting techniques often center on the use of virtual reality and computer simulations in combination with physical modeling or the refinement of computer simulations with measured data. On the other hand, innovations in materials that enhance light diffusion and distribution through a space also become a growing concern for many designers. Some cutting-edge ideas worth highlighting include various patterns or nanostructured films that can be adhered to glass surfaces, causing the light to either explode in a uniform manner through space or redirect the beam only in one direction while avoiding hotspots on surfaces. Furthermore, biophilic innovations that embed living elements in the façade design, exploiting both the light channeling properties of certain plants and the health benefits of adding greenery to the interior, remain experimental. Finally, international legislations are being examined to see how future daylighting standards could be influenced by the expansion of the EU, thus affecting the quality of daylighting outside current city centers [35].

9. CONCLUSION

Daylighting is a vital consideration in the design of high-rise office buildings. With the rise of tall structures in urban centers, it is essential to explore how to maximize the benefits of daylight while minimizing its drawbacks. By looking at the basics and importance of daylighting, and delving deeper into the challenges, strategies, technologies, and future possibilities of daylighting in high-rise office buildings, a comprehensive understanding is gained. Daylighting offers numerous benefits, including energy savings, health improvements, mood enhancement, productivity increases, and economic advantages that extend beyond mere numbers. However, it is not a cure-all solution. Issues such as solar heat gains, glare, excess brightness, uneven light distribution, and even darkness must be addressed to create a comfortable, productive, and efficient environment. This is especially pertinent for high-rise and deep-plan buildings, where achieving the best performance from daylight is more complex than in low-rise structures .

Nevertheless, the challenges posed by high-rise structures can be addressed effectively. Strategic planning at the site, building, and floor levels can significantly influence how daylight enters a space. A variety of design solutions, technologies, and retrofits are available to improve building and office performance concerning daylight. In looking at the future possibilities of daylighting in high-rise office buildings, factors such as building orientation, the relationship between façade design and building depth, and anticipated improvements in daylighting design can enhance the overall design process and address the performance issues of buildings as dictated by regulations and expectations. Daylighting has a long and rich history in architecture and building design. Presently, there is a renewed focus on daylighting as sustainability becomes increasingly prioritized. Sustainability regulations and requirements also demand consideration of energy use, artificial lighting, and daylighting. Finally, as a key consideration in modern buildings and a fundamental aspect of design, daylighting is a current focus, along with the exploration of new technologies and methods.

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