Integration of Natural and Artificial Lighting in Office Spaces to Promote Sustainability

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Received: 23.05.2025 Accepted: 10.07.2025

Abstract- The study examines the methods and technologies employed in integrating natural and artificial lighting in office environments with a focus on sustainability. It explores how artificial lighting can be effectively activated when the illuminance level—an essential aspect of visual comfort—cannot be met by natural light during the day. An example of how natural lighting—defined as a variable light source—can be made energy efficient through automated control systems, when supplemented by artificial lighting, a constant light source, is evaluated in a case study. An office with a renewed spatial organization and an updated automation system was selected for the case study. The analysis focuses on changes in spatial planning, ceiling lighting arrangements, the use of presence and light sensors, and zoning in spatial lighting. The natural lighting is analyzed using computer simulations that compare the previous office layout, PLT 1, with the later layout, PLT 2. Additionally, a partitioned office space is investigated as a preliminary assessment of glare. The evaluation, analysis, and comparisons yield significant findings. Consequently, important insights have been gained regarding the integration of natural and artificial lighting in an office space that has undergone spatial changes and where the automation system has been updated.

Keywords- Office lighting, integrated lighting, daylighting, artificial lighting, lighting performance

Ofis Alanlarında Sürdürülebilirliğe Yönelik Doğal ve Yapay Aydınlatma Entegrasyonu

Öz- Çalışma, sürdürülebilirliğe odaklanarak ofis ortamlarında doğal ve yapay aydınlatmanın bütünleştirilmesinde kullanılan yöntem ve teknolojileri incelemektedir. Gün içinde doğal ışık, görsel konforun temel bir unsuru olan aydınlatma seviyesini karşılayamadığında yapay aydınlatmanın nasıl etkili bir şekilde etkinleştirilebileceğini araştırmaktadır. Değişken ışık kaynağı olarak tanımlanan doğal aydınlatmanın, sabit ışık kaynağı olan yapay aydınlatma ile desteklendiğinde otomatik kontrol sistemleri aracılığıyla nasıl enerji açısından verimli hale getirilebileceğine dair bir örnek, bir vaka çalışmasında değerlendirilmektedir. Yenilenmiş bir mekansal organizasyona ve güncellenmiş bir otomasyon sistemine sahip bir ofis, vaka çalışması için seçilmiştir. Analiz, mekansal planlamadaki değişikliklere, tavan aydınlatma düzenlemelerine, varlık ve ışık sensörlerinin kullanımına ve mekansal aydınlatmada bölgelere ayırmaya odaklanmaktadır. Doğal aydınlatma, önceki ofis düzeni PLT 1' i sonraki düzen PLT 2 ile karşılaştıran bilgisayar simülasyonları kullanılarak analiz edilmektedir. Ek olarak, bölmeli bir ofis alanı parlama için ön değerlendirme olarak incelenmektedir. Değerlendirme, analiz ve karşılaştırmalar önemli bulgular ortaya koymaktadır. Sonuç olarak, mekansal değişime uğrayan ve otomasyon sistemi güncellenen bir ofis mekanında doğal ve yapay aydınlatmanın entegrasyonu konusunda önemli bilgiler elde edilmiştir.

Anahtar Kelimeler- Ofis aydınlatması, bütünleşik aydınlatma, doğal aydınlatma, yapay aydınlatma, aydınlatma performansı

1. Introduction

In contemporary architecture, lighting serves not only to fulfill the basic illumination needs of a space but has also evolved into a design tool that enhances user health, comfort, and performance. Office workers spend a substantial portion of their lives in their work environments. Research indicates that lighting in offices significantly influences workers' well-being and productivity, in addition to its functional role [1, 2]. Maximizing the use of natural light can positively impact human health and performance while also contributing to energy conservation.

Today, advanced technologies that are responsive to user needs and enhance energy efficiency are at the forefront of lighting design. Thanks to light and motion sensors, automated lighting systems can optimize both the intensity and color of light based on the usage of the space [3, 4]. These systems not only reduce energy consumption but also improve visual comfort by making artificial lighting resemble natural lighting in terms of color and intensity [5, 6]. Through building automation, control over the quantity and timing of lighting in a space can be achieved, allowing customization according to user needs while effectively utilizing artificial lighting [7].

In addition, the division of lighting according to spatial needs (zoning) enhances both environmental quality and user experience. Effective zoning, combined with the use of sensors to integrate natural and artificial lighting in office spaces, can lead to significant energy savings [8, 9]. In office environments, desktop task lighting can help employees maintain focus, while ambient lighting can provide a wide and uniform light distribution in common areas [10, 11]. These technological solutions not only conserve energy but also enhance user satisfaction by allowing for personalized lighting options. Implementing such systems in lighting design represents a contemporary approach that promotes both individual comfort and collective efficiency [5, 6, 12]. Studying the various types of natural and artificial lighting, understanding the distinctions between these two forms, and learning the control methods are essential for creating an effective design that meets the lighting needs of a given space.

The use of natural and artificial lighting in buildings involves various design processes. Natural lighting influences a space in different ways, depending on the time of day and the direction of the light. When natural lighting fails to provide the minimum required illumination for a space, it becomes necessary to supplement it with artificial lighting at varying levels. Generally, natural lighting is categorized into two types: side lighting and top lighting. In contrast, artificial lighting is classified into three types: ambient lighting, task lighting, and accent lighting [10, 13]. Regarding control systems, fixed or movable sunshades are commonly used for natural lighting, while manual or automatic control systems are employed for artificial lighting [13, 14].

The primary challenge is to determine how to achieve the minimum illuminance necessary for visual comfort in spaces that utilize both types of lighting simultaneously. The focus of this study is on integrating these two lighting types in office environments. The research hypothesis posits that the combination of time-varying natural light and controllable artificial lighting, through various methods, can not only ensure the required visual comfort but also enhance energy efficiency in a sustainable manner. Furthermore, these methods and technologies can assist designers and yield valuable insights regarding energy efficiency and human health. Therefore, the aim of this study is to examine the methods used to integrate both types of lighting through a case study. Some of the sub-objectives include identifying relevant design parameters, performance measurement methods, challenges and their solutions, as well as the advantages and limitations of each approach. The lighting performance of the offices analyzed in the case study is evaluated using computer simulations.

2. Materials and Methods

Lighting plays a crucial role not only as a design element but also as a factor that supports health and visual comfort in the workplace. The type of work performed influences the minimum required illuminance [15]. To enhance the productivity and comfort of employees, careful attention should be given to the lighting layout in an office. Visual comfort is generally defined as a subjective response to the quantity and quality of light in a specific space at a particular time. Light levels that fall above or below the required illuminance for a space can lead to visual discomfort [16]. The values necessary for ensuring visual comfort in lighting design are outlined in various international standards, such as EN 12464-1, CIE (International Commission on Illumination), and IES (Illuminating Engineering Society). CIE documents establish standards, relevant regulations, and current research on indoor lighting. It is beneficial to review specific parameters when evaluating integrated lighting [17, 18]. Analyzing the factors that influence visual comfort in office environments and providing general definitions of integrated lighting will help define the scope of the field study to be conducted. It is essential to discuss the topic within the limitations identified from this analysis.

2.1. Factors Affecting Visual Comfort Conditions in Offices

The factors that contribute to visual comfort conditions are defined as illuminance, luminance, and color [19]. The evaluation indices related to this definition are presented in Table 1. According to international standards, the minimum illuminance level for offices should be 300 lux [17]. Comfortable lighting in office spaces is believed to enhance employee performance. When ambient lighting and task lighting are used simultaneously in an office, the average illuminance in non-working areas should not be less than half of the illuminance in the working area. Additionally, the illuminance of the corridor adjacent to the office is expected to maintain a certain proportion of the average illuminance of the office [20]. Otherwise, significant contrasts in luminance levels within the office can lead to visual discomfort or fatigue for workers. The uniformity of the illuminance level within the visual field, specifically the consistent distribution of illumination, significantly impacts visual comfort conditions [21]. The parameters influencing the uniformity factor include the lowest measured illuminance level and the average of the measured illuminance levels [15]. In interior spaces, the distribution of luminance across volume surfaces is a crucial factor for visual comfort. To mitigate the negative effects of luminance distribution and to create an environment conducive to visual perception, specific ratios must be maintained between the luminance of various surfaces and objects within the visual field, ensuring these values remain within established limits [22, 23]. Each surface in the space exhibits different light reflection rates based on its material properties. Some materials produce a brighter appearance by reflecting light at a high rate, while others absorb light significantly, resulting in lower luminosity. This plays a crucial role in the balanced distribution of illuminance within a space [24]. The amount of visible light transmitted through the glazing system is expressed as a percentage. A low visible light transmittance (VLT) is beneficial for glare control, while a high degree of transmittance is preferred to maintain natural lighting [25, 26]. Several factors influence VLT. Glass coatings can reduce VLT by reflecting and absorbing some of the visible light. Similarly, the use of colored glass diminishes VLT by absorbing or reflecting light. The thickness of the glass is also a significant factor; thicker glass absorbs more light, resulting in a lower VLT compared to thinner glass [27].

Table 1: Visual comfort conditions and evaluation indices in a space [28, 29]. (Table is created by the authors)

Visual Comfort Conditions	Evaluation Index
Illuminance Level	• Minimum required illuminance level (lux)
	• Uniformity ratio (U_0)
Glare	• Surface reflectance ratios used in the space (ρ)
	• Visible light transmittance (VLT) value for glass surface
	• Glare index (UGR)
Color	• Color rendering index (CRI)

In architectural design, offices are categorized into three main types: traditional (cellular) offices, open-plan offices, and group offices as co-working space [30]. The differences in architectural design among these office types also influence artificial lighting design, necessitating distinct solutions. For instance, in open-plan offices, ambient lighting is often designed to provide minimum required illumination for workspaces, which inadvertently illuminates the surrounding circulation areas to the same degree. However, these circulation areas may not require such high levels of illumination. This situation highlights the need for a combination of ambient and task lighting [30]. Furthermore, in traditional (cellular) offices, where spaces are typically smaller, it may be more effective to utilize general lighting throughout the entire area.

Each of the indices presented in Table 1 represents an area that requires individual examination. In a field study, it is considered more appropriate to evaluate one or more of these indices rather than all of them simultaneously. In this context, given the widespread use of computer simulations to assess natural lighting performance, prioritizing the analysis of illuminance levels in any field study is advisable. Additionally, preliminary assessments of glare can be included alongside the sample analysis.

2.2. Definitions of Integrated Lighting

The combination of natural and artificial lighting is referred to as integrated lighting. This definition encompasses the hours during which spaces are actively used throughout the day, excluding the period after sunset when only artificial lighting is employed. Integrated lighting applications are primarily found in public buildings and offices, but they can also be implemented in residential settings. This study focuses specifically on offices as a building type. The primary objective is to ensure that the minimum illuminance levels in offices are achieved through natural lighting during daytime working hours. In instances where natural lighting is inadequate, artificial lighting is employed to supplement and enhance illumination.

Table 2: Overview of integrated lighting (Table is created by the authors).

Light Sources	Features	Controllability	Targets	Challenges
Natural	Dynamic (climate-based)	Difficult (fixed or moving shading device can be used)	Achieving a defined threshold (e.g., DF 2-5% range)	Values above and below the defined threshold are obtained.
Artificial	Static (manual or automatic control system / can be adjustable by occupant)	Easy (by occupancy and daylight sensor and applying zoning in a space)	Supplementing natural light when it fails to meet the desired minimum illuminance level.	The need to implement a building automation system arises from the inefficiency of manual systems.

The artificial lighting used to complement natural light provides a consistent light source. Light sensors, which will be installed in the space, will provide real-time readings of variable parameters related to natural lighting, depending on the time of day and sky conditions [31]. In addition, the brightness level of artificial lighting can be adjusted through dimming [32]. Zoning can also be implemented within the space, allowing for a controllable process regarding when, how much, and in which areas artificial lighting will complement natural lighting [33]. As part of the control system, both manual and automatic controls are prominent. However, compared to the capabilities offered by automatic control, manual control is less effective. This is because manual control lacks instantaneous illuminance level measurement and the ability for rapid intervention in artificial lighting, as seen in automatic control [14]. There are various types of automatic control systems [3, 4]. In this study, the focus is narrowed to a centralized automation system, presence sensors, and photocell sensors [8, 32, 34]. An overview of integrated lighting is presented in Table 2.

3. Evaluation of Integrated Lighting Applications in a Sample Office

An evaluation has been conducted on a sample office for the application of integrated lighting. The evaluation criteria are based on the information presented in Table 1 and Table 2 in the second section. Table 1 includes the minimum required illuminance conditions and preliminary assessments of glare. Furthermore, the general evaluation of integrated lighting in Table 2 is illustrated through the sample office discussed in this study.

The building analyzed in this case study is located in Istanbul and consists of thirty floors (see Fig. 1). Constructed in 1998, it was originally designed as an office building. However, following a change of ownership in the late 2010s, the building was repurposed for use as a university facility (refer to Fig. 1). This transition necessitated modifications to the spatial layout of the building, transforming it into a mixed-use structure that accommodates both educational and office functions. Consequently, the interior design required reorganization, leading to the conversion of some open-plan offices into traditional (cellular) offices or co-working spaces. Due to this transformation, the old office layout on the 18th floor is referred to as PLT 1 in this study, while the new layout is designated as PLT 2. PLT 1 represents the open-plan office configuration, whereas PLT 2 corresponds to the small co-working space (see Fig. 2). In PLT 2, the group of divided offices is primarily designed as shared spaces for multiple academicians to collaborate. PLT 1 originally included four traditional cellular offices and one large open-plan office. In contrast, PLT 2 has reconfigured the open-plan office into fourteen individual offices, all of which have been converted into small co-working spaces (see Table 3).

Figure 1: Left: K block tower (Google Earth, 2025); Center: General view of the building [35]; Right: 18th floor before renovation (Istanbul Gelisim University Department of Construction Affairs).

In the previous automation system, the ceiling lights across the three floors of the tower building were controlled simultaneously. This approach resulted in excessive energy consumption for the building's lighting. Additionally, managing the lighting for all three floors together created challenges in usability. For the University, which is committed to fostering a sustainable campus, it became essential to revise the control of the ceiling lighting on each floor of the tower to reduce energy costs and enhance user comfort. Consequently, the existing automation system was upgraded. Motion and photocell sensors were integrated into the new lighting control system, establishing an automatic lighting solution. Furthermore, zoning was implemented in the design of the system.

A curtain wall glass facade system is employed on the exterior of the K Block Tower building. The primary source of natural light examined in this study is provided by a side window designed in an arc shape in the plan. Spandrel parts cover both the beam and the parapet surface. Beneath the parapet, there are office cabinets and radiators for the heating system. The gray-blue color of the glass surfaces used in the vision parts of the curtain wall facade harmonizes visually with the color of the sky and optimizes natural light transmittance. To utilize natural light efficiently in buildings, the VLT value is typically selected within a range of 70% to 90%. In this project, a VLT value of 85% is anticipated. This value provides high light transmittance, creating a bright and comfortable environment in the offices. Fig. 2 illustrates the interior view of the curtain glass facade system utilized in the project. Both manual and automatic curtains can be employed for natural lighting control. In automatic systems, light intensity is detected using photocell sensors, which adjust the curtains to open, close, or remain half-open as needed. In contrast, manual systems require user intervention for opening and closing the curtains. Such manual curtains can pose challenges in public spaces, which typically experience high user density. In the tower building, manual curtains were implemented, potentially leading to some issues. However, during the plan revision, these problems were mitigated by reducing the size of the offices and decreasing the number of users in each space (see Fig. 2). In the interior of the PLT 2 plan type, the office partition walls were constructed using transparent glass, with a matte foil applied to the glass surface. These partition walls extend to the full height of the space. This design choice was made during the automation system renewal process, which involved not only updates to the artificial lighting but also the creation of partitions for ventilation supplied from the ceiling. This approach allows for the separation of indoor air control in the offices. However, this aspect is beyond the scope of this study. The matte foil applied to the interior glass partitions was installed up to the average person's eye level, leaving the upper portion of the glass partition wall transparent to maximize light transmission.

Table 3: PLT 1 and PLT 2 plan types and spatial utilization of the 18th floor of the K block tower building (The plans were obtained from the Istanbul Gelisim University Building Works Department (The table is reproduced from the first author's thesis).

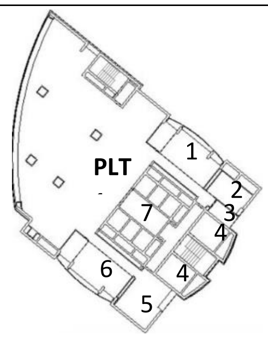
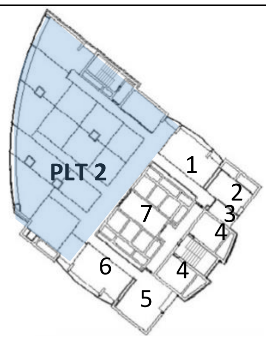
PLT1	**PLT2**	**Spatial Use**	
		**1**	Office for academician
		2	
		3	Kitchen
		4	Restroom
		5	Office for academician
		6	
		7	Elevator lobby
		PLT1	Open office
		PLT2	Co-working space

Figure 2: The left side features an interior view of the curtain glass facade utilized in the project on the 18th floor. In the center and to the left, roller blinds are employed in the offices. (Photograph by Nahid Babaei)

Table 4: Features of glass partition walls used in the installation of co-working spaces (Photograph by Nahid Babaei)

Glass Partition Wall Features		
Glass type and thickness	4mm single pane	
Type of use	Clear and frosted glass (mixed)	
Light transmittance	85% VLT	
Wall height	260 cm	
Frosted glass height	150 cm	
Transparent glass top band height	110 cm	
Frame material	Aluminum	

Generally, the websites of glass manufacturers indicate that the VLT of frosted glass ranges from 30% to 90%. Low VLT values, such as 30%, offer high privacy while significantly reducing light transmission. In contrast, higher VLT values, such as 90%, allow more natural light to enter, brightening the space but diminishing privacy levels. Medium matte glass, with a VLT of 60%, does not provide complete privacy but permits more natural light to pass through compared to lower VLT alternatives. However, to minimize light loss, a matte glass with a VLT of 85% was selected instead of medium matte glass. This choice enables sufficient privacy within the office while allowing natural light to efficiently penetrate the space [36]. This predicted value will be utilized in the analyses conducted as a preliminary assessment. The specifications of the glass partition walls used in the installation of the group office / co-working space are presented in Table 4.

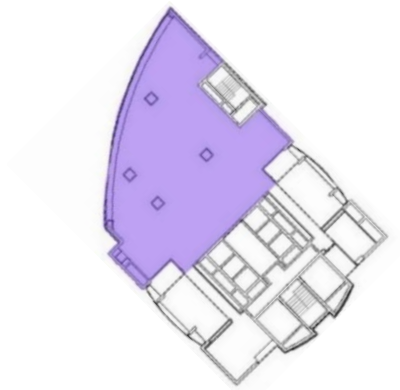
In the remainder of the study, firstly, there are findings on artificial lighting that highlight the differences and changes between PLT 1 and PLT 2. These findings focus on ceiling lighting design, control systems, sensor utilization, and zoning. Then, the performance evaluation of natural lighting, which also addresses the differences between PLT 1 and PLT 2, is discussed. Here, the natural lighting is analyzed through computer simulations. Finally, the analysis and evaluation of a group office / co-working space selected from PLT 2 is presented.

3.1. Findings on Artificial Lighting

In the PLT 1 plan layout, a general lighting scheme was implemented in the open office areas without taking into account the interior design and furniture arrangement. The lighting was designed to ensure a uniform distribution throughout the entire space, with no differentiation made between work areas and transitional spaces, such as corridors.

In the PLT 2 plan layout, group office / co-working space were designed, and corridors were created to provide access to these offices. The artificial lighting was zoned, dividing the space into fifteen distinct areas, and the ceiling lighting scheme was restructured. Corridors were designated as a separate zone, with lighting controls implemented to accommodate various usage scenarios. With the renewal of the automation system, presence and illuminance sensors were installed in individual offices, ensuring the integration of natural and artificial lighting. This resulted in the creation of an automatic control system connected to the automation system, which receives real-time data from the spaces and can manage artificial lighting accordingly. Additionally, an independent manual control unit was added for each office, allowing users to adjust the artificial lighting based on their specific needs. This approach aims to enhance user comfort while improving energy efficiency. Thanks to the zonal control units, unnecessary energy consumption is minimized, and the lighting system becomes more adaptable Table 5. illustrates how artificial lighting is segmented in the PLT 1 and PLT 2 plan layouts.

Table 5: Zoning of artificial lighting in the PLT 1 and PLT 2 plan layouts (The plans were obtained from the Istanbul Gelisim University Building Works Department. The table is reproduced from the first author's thesis).

PLT 1	PLT 2
	

In the PLT 2 plan layout, the placement of ceiling luminaires has been redesigned and optimized to accommodate the specific lighting requirements and furniture arrangements of the offices. As a result, a more efficient lighting design has been developed, enhancing both visual comfort and energy efficiency. The layout of the ceiling luminaires for artificial lighting in the PLT 1 and PLT 2 layouts is presented in Table 6.

Each office is equipped with a separate wall-mounted switch that allows users to manually control the lighting system. Additionally, the system is designed to respond to the amount of natural light present and features a photo sensor that automatically activates or deactivates the lights based on the ambient light levels. This functionality helps to prevent unnecessary energy consumption, leading to more efficient lighting management. In group offices (co-working spaces), lighting control can be performed both manually and automatically. Users can adjust the lighting using the wall-mounted switch according to their preferences, while the photo sensor monitors the natural light levels and automatically turns the system on or off as needed. The details and operational principles of the lighting control mechanism are presented in Table 7.

In the PLT 2 plan layout, each office is divided into two lighting zones to enhance visual comfort and ensure energy efficiency: luminaires near the windows and those located within the interior. When adequate natural light is available in the space, the lights are automatically turned off, preventing unnecessary use of artificial lighting. It is established that the minimum illuminance at desk level should be 300 lux to maintain visual comfort. If the level of natural light exceeds this threshold, the luminaires closest to the windows are turned off first, optimizing the use of direct daylight. Conversely, if the level of natural light falls below the threshold, artificial lighting is activated, and the interior luminaires are turned on. This system provides both automatic and manual control, allowing users to adjust the lighting levels according to their personal preferences. Consequently, a balanced and comfortable lighting environment is created, which helps prevent eye fatigue and minimizes reflections and contrast differences.

Table 6: The layouts of ceiling luminaires for artificial lighting in the PLT 1 and PLT 2 plans (The plans were obtained from the Building Works Department of Istanbul Gelisim University. The table is reproduced from the first author's thesis).

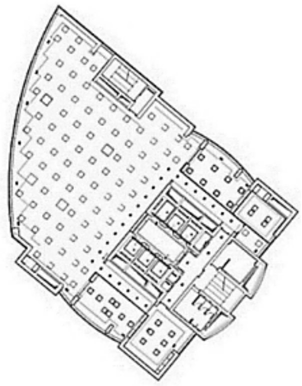
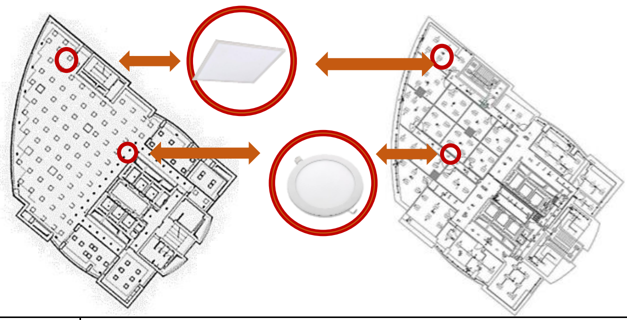
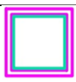
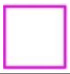
PLT 1	PLT 2
	

Table 7: Wall switch for artificial lighting (left) and identification of switch control modes (right). (Photo by Nahid Babaei. The table is reproduced from the first author's thesis.

	Switch Options	Function
	1	On / Off
	2	Photoelectric sensor
	3	Region changes
	4	Automatic dimming
	∧∨	Manual dimming

Table 8: Luminaire models used on the ceiling (Plans were obtained from Istanbul Gelisim University, Department of Construction Affairs. The table is reproduced from the first author's thesis).

PLT 1	PLT 2	
		
		**At the entrance, in the corridors and near the window** 18W recessed round LED panel luminaire
		**Group offices (co-working spaces)** 60x60 40W recessed square panel luminaire
		**Open offices** 60x60 24W recessed square panel luminaire

Three models of luminaires were utilized in the PLT 1 and PLT 2 plan layouts. Round lamps were installed at the entrance, in the corridors, and near the windows, while square lamps were employed in the open office and the group offices (co-working spaces). The specifications of the lamps are detailed in Table 8. In the PLT 2 plan layout, round luminaires were implemented throughout all corridors, and 40 W, 60×60 cm square luminaires were preferred for the group offices (co-working spaces). The previous lighting design was revised, and the lighting for each office was designed individually. In the entrance corridor, direct lighting was used on one side, while indirect lighting was applied on the opposite side. Round luminaires were installed in the corridors to ensure adequate illumination throughout the space (see Figure 3).

Figure 3: Ceiling lighting in the corridors of the PLT 2 office layout (Photograph by Nahid Babaei)

3.2. Analyzes of Natural Lighting

In this study, the daylighting performance of PLT 1 and PLT 2 plan types was evaluated through simulations. For the PLT 1 plan layout, the distribution and homogeneity of daylight in the open office spaces were analyzed, along with the impact of natural lighting on the workspaces. In PLT 2, the daylight factor (DF), a static metric, and illuminance, a dynamic (climate-based) metric, were analyzed separately after the open office was converted into group office / co-working space and corridors were established. Since the offices are divided into independent zones, the natural lighting performance of the spaces was comparatively analyzed for both layouts. Simulations for both plan layouts were conducted to assess the efficient use of daylight, determine the need for artificial lighting, and implement optimizations to ensure visual comfort. The data obtained allowed for an evaluation of the effects of different lighting strategies on energy efficiency and user comfort, as well as guidance on how to interpret these findings.

In order to analyze the natural lighting in the offices, the layouts of PLT 1 and PLT 2 on the 18th floor were first modeled using Autodesk Revit. Subsequently, performance evaluations were conducted on the models using the lighting analysis plugin integrated into Autodesk Revit.

3.2.1. DF analysis

The daylighting factor (DF) analyses for the PLT 1 and PLT 2 plan layouts are presented in Table 9. In the PLT 1 plan layout, the average daylight factor (ADF) was calculated to be 3% as a result of the simulation. According to lighting principles, an ADF value in the range of 2% to 5% is considered to provide a sufficient light level. However, artificial lighting may be necessary at certain times. Table 9 displays the illuminance levels for both plan layouts. The total area examined for illuminance levels is 892 square meters. Of this area, 15% falls within the defined thresholds (136 m²), 18% exceeds the threshold (159 m²), and 67% is below the threshold (597 m²). In the PLT 2 plan layout, the ADF was calculated to be 2.8% as a result of the simulation. In this layout, 13% of the area is within the threshold (120 m²), 17% is above the threshold (149 m²), and 70% is below the threshold (623 m²).

There is a 0.2% difference in the ADF value between the PLT 1 and PLT 2 plan layouts. The ADF value is lower in the PLT 2 layout, which is associated with a reduction in the level of natural lighting in the environment. This decrease is attributed to the presence of frosted glass partitions and the limited diffusion of daylight through the glass partition panels (see Table 10).

Table 9. Comparison of DF analysis results across different plan layouts (The table is reproduced from the first author's thesis).

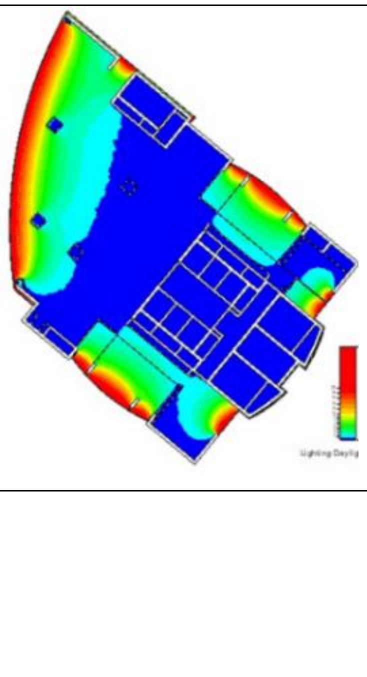
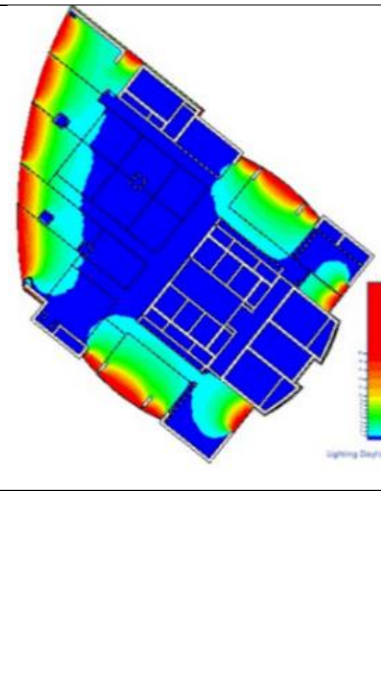
PLT 1	PLT 2
	

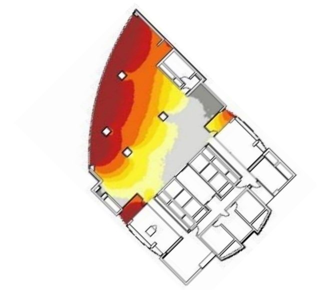
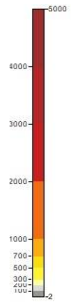
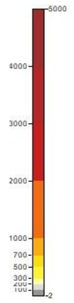
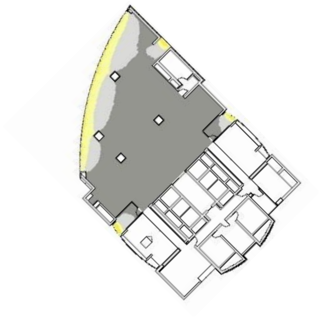
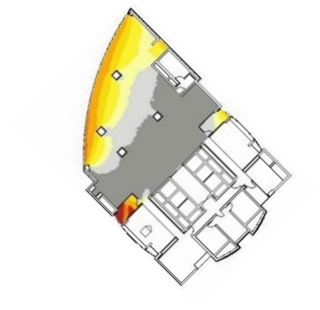
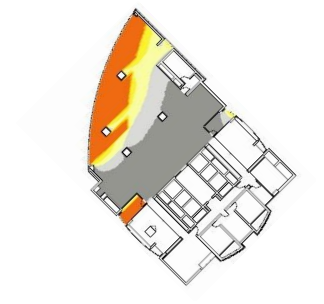
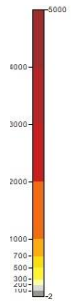
Table 10. Comparison DF analysis data (The table is reproduced from the first author's thesis).

Type of the Plan	ADF	Targeted Threshold		
		Within	Above	Below
PLT 1	%3	%15	%18	%67
PLT 2	%2,8	%13	%17	%70

3.2.2. Illuminance level analysis

The illuminance analysis for PLT 1 and PLT 2 plan types is presented in Tables 11 and 12. To evaluate natural lighting, analyses were conducted on March 21, June 21, and December 21 at 09:00, 12:00, and 15:00. The lighting analyses considered the time periods of 09:00-12:00, 12:00-15:00, and 15:00-18:00 to accurately assess light changes throughout the day. These time periods were selected to observe and analyze variations in natural lighting conditions based on the sun's position. Consequently, the indoor illuminance levels and shaded area distributions at different times can be analyzed more comprehensively.

Table 11: Illuminance level analysis of natural lighting for PLT 1 plan layout (lux) (The table is reproduced from the first author's thesis).

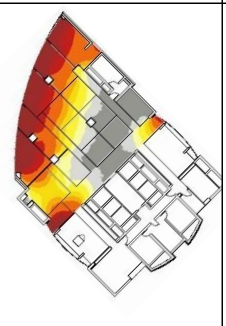
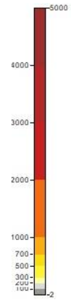
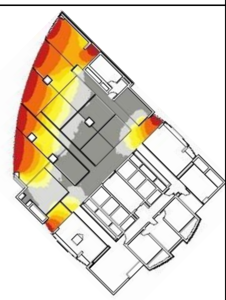
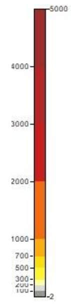
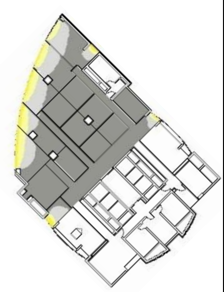
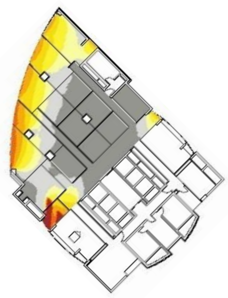
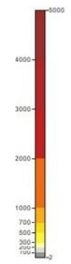
<table>
<tr><td rowspan="2"></td><td colspan="3">PLT 1</td><td></td></tr>
<tr><td>9:00</td><td>12:00</td><td>15:00</td><td></td></tr>
<tr><td>March 21</td><td></td><td></td><td></td><td>
</td></tr>
<tr><td>June 21</td><td></td><td></td><td></td><td>
</td></tr>
<tr><td>December 21</td><td></td><td></td><td></td><td>
</td></tr>
</table>

"Perez All-Weather Sky" model is utilized as the sky model in the lighting analysis conducted with Autodesk Revit software. This model is favored for its ability to provide a realistic sky distribution that encompasses all weather conditions. Its capacity to accurately represent sky brightness and light distribution across various atmospheric conditions allows for reliable results in natural lighting analysis. Specifically, it facilitates a more thorough evaluation by considering factors such as cloud cover, atmospheric conditions, and light variations at different times of the day.

The primary difference between PLT 1 and PLT 2 in this analysis lies in the distribution of light within the space, primarily due to the presence of glass partitions. In the PLT 1 model, light is distributed more uniformly, allowing it to reach areas farther from the window. Conversely, in the PLT 2 model, the partitions partially obstruct the flow of light, leading to a more uneven distribution throughout the space. This results in a greater reliance on artificial lighting in the PLT 2 model. The uneven distribution of natural light within the interior space heightens the dependence on artificial lighting, particularly in areas distant from windows, which consequently leads to increased energy consumption.

Visual comfort is a crucial factor for the productivity and well-being of employees in office environments. In the PLT 1 layout, the larger windows and deeper open office spaces are likely to result in higher levels of glare, particularly in the center near the building core where the elevators are located. Conversely, the PLT 2 layout is expected to have more limited glare levels due to the smaller windows in the group office / co-working space. This situation necessitates conducting detailed glare analyses separately to ensure user comfort. To maintain visual comfort, especially in work areas, it is essential to establish appropriate strategies for controlling daylight.

Table 12: Illuminance level analysis of natural lighting for PLT 2 plan layout (lux) (The table is reproduced from the first author's thesis).

	PLT 2			
	9:00	12:00	15:00	
March 21				
June 21				
December 21				

In both plan layouts, high illuminance levels and increased glare effects are typically observed in offices situated near windows. This can adversely impact the visual comfort of employees. Therefore, it is essential to implement lighting control strategies and appropriate shading systems, such as roller blinds. Roller blinds assist in managing daylight, reducing excessive and uncomfortable glare, thereby creating a more pleasant visual environment. Further analyses are necessary to confirm this point conclusively; however, these additional analyses fall outside the scope of this thesis. Future studies could involve detailed luminance assessments on various days and under different weather conditions to investigate high illuminance levels and potential discomfort caused by glare at the windowsill in a more comprehensive manner.

In both plan layouts, a significant decrease in natural lighting levels is observed in December. This occurs because the sun's rays strike the building at lower angles during the winter months. Consequently, there is an increased reliance on artificial lighting in areas where adequate illumination cannot be achieved through natural light alone. This may necessitate further adjustments to enhance energy efficiency and visual comfort. Among the simulations conducted for various days and times, one was chosen as a representative example, specifically the data from March 21 at 15:00, which fell within the target threshold. The findings from this analysis yield significant insights into lighting performance and regional light distribution. The results and associated data are presented in Table 13.

As a result of the analysis, the areas of the PLT 1 and PLT 2 plan layouts that fall within the target threshold values have been evaluated. In the PLT 1 plan layout, 190 m² of the total area of 415.73 m² was found to be within the threshold values, resulting in a ratio of 45.70%. In the PLT 2 plan layout, the area evaluated within the target threshold value is 174 m², which corresponds to a ratio of 41.85% of the total area.

This data illustrates the distribution of natural and artificial lighting within the space and how the illumination levels in both zones correspond to the established thresholds. The PLT 1 plan layout demonstrates a higher ratio within the target threshold value, resulting in reduced reliance on artificial lighting in this area. In contrast, the PLT 2 plan layout is anticipated to require increased artificial lighting due to its lower target threshold value. This assessment aids in optimizing the lighting design efficiently, ultimately enhancing user comfort.

Table 13: Comparison of luminance level analysis data for the PLT 1 and PLT 2 plan layouts on March 21 at 15:00 (The table is reproduced from the first author's thesis).

Type of the Plan	Area	Targeted Threshold	
		Area	%
PLT1	415,73 m²	190 m²	%45,70
PLT2		174 m²	%41,85

3.3. Analyses and Evaluations of a Group Office / Co-working Space

In the revised plan layout, PLT 2, one independent office has been selected as a case study to analyze the integration of natural and artificial lighting. An office located in the northwest corner of the building, featuring windows on both sides, was chosen for the investigation of lighting levels (see Fig. 4). The simulations utilized specific dates—March 21, June 21, and December 21—at the times of 09:00, 12:00, and 15:00 as parameters for both day and hour. Additionally, the "Perez All Weather Sky" model was employed in all analyses. The objective is to determine the illuminance levels and to make preliminary assessments regarding glare.

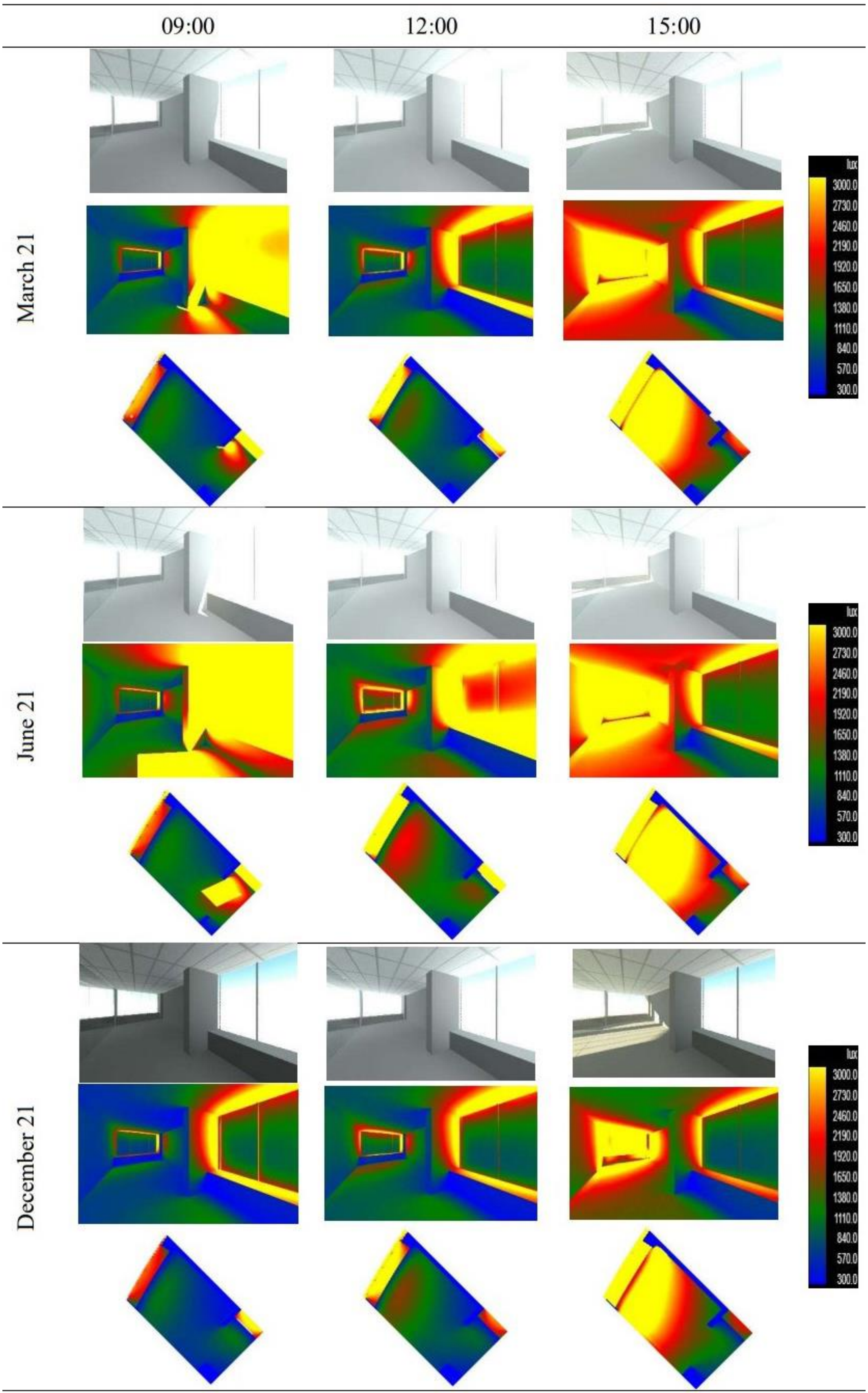
The selected office features two windows: one facing northeast and the other facing northwest. According to Table 14, the northeast window experiences higher illuminance levels in the morning, while the northwest window has greater illuminance levels in the afternoon. The analysis indicates that the selected office has lower illuminance levels in December, resulting in a higher demand for artificial lighting compared to other months. Due to the northwest orientation of the office, it receives more natural light between 15:00 and 18:00 among the three different time periods, which can lead to levels that may cause uncomfortable glare.

When the minimum required illuminance cannot be achieved through natural lighting alone, artificial lighting becomes necessary. The office selected as an example is equipped with a photocell sensor that detects natural light levels continuously. When adequate natural lighting is present, the artificial lighting is automatically turned off. However, if the illuminance level drops below a specific threshold, the system automatically activates and turns on the luminaires.

Figure 4: Lighting design of the sample office (The table is reproduced from the first author's thesis).

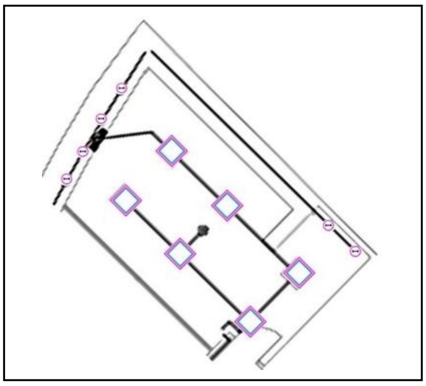
For artificial lighting, six square lamps are utilized, arranged in pairs across three rows. These lamps can be operated manually or controlled by a motion sensor and photocell (see Table 15).

Table 14: Illumination level and glare analysis of the sample office (The table is reproduced from the first author's thesis).



The lighting fixtures in the office are divided into two sections to ensure efficient and balanced illumination. The first section, situated near the windows, receives the most natural light. The second section is located in the central area of the office, where natural light is minimal. This arrangement enhances visual comfort in the workspace and increases efficiency by reducing unnecessary energy consumption. By optimizing the use of both natural and artificial lighting, this approach not only improves the user experience but also promotes energy efficiency, contributing to sustainability (Fig. 5).

Table 15: Luminaire models used in sample group office / co-working space (The table is reproduced from the first author's thesis).



		60x60 40W recessed square panel luminaire
		18W recessed round LED panel luminaire
		Photocell light and motion sensor

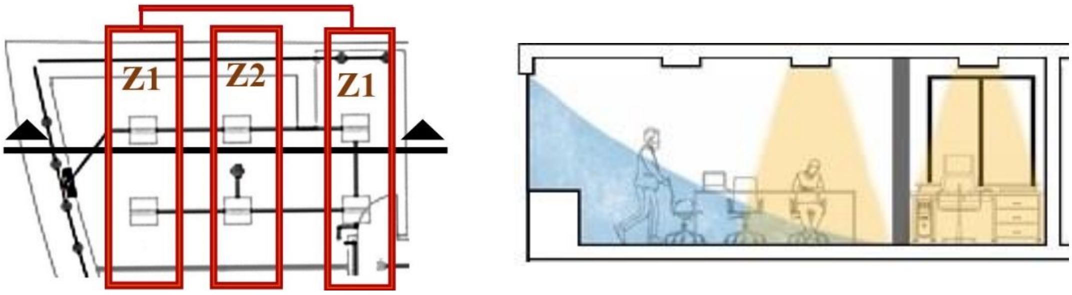


Figure 5: Zoning for the ceiling lighting in the cellular office: the plan of the group office / co-working space is shown on the left, while the section of the group office / co-working space is displayed on the right (The figure is reproduced from the first author's thesis).

On November 18, 2024, two distinct status determinations were made for the group office / co-working space, which was examined through preliminary physical photography. One photograph was taken with the artificial lighting activated, while the other was captured with the lighting deactivated. The images presented in Table 15 offer preliminary data regarding the integration of the artificial lighting system used in the examined group office / co-working space with natural lighting, as well as its interaction with the photocell sensor.

Table 16: A preliminary assessment of natural and artificial lighting in the individual office under review is presented. The left image shows the office with natural lighting only, while the right image displays the office with both natural and artificial lighting (Photograph by Nahid Babaei).

Only with natural lighting (November 18, 2024 – 14:00)	**With natural and artificial lighting (November 18, 2024 – 16:00)**
	

In the left photo of Table 16, it is evident that when natural lighting is adequate, the photocell sensor activates, turning off the lights and conserving energy. In the right photo, it is clear that when natural lighting is insufficient, the photocell sensor activates, turning on the lights to ensure the space is adequately illuminated and providing a uniform light distribution. These images demonstrate the effectiveness of integrating natural and artificial lighting and highlight the benefits in terms of visual comfort and energy efficiency.

4. Findings from Case Study

DF analyses conducted on the PLT 1 and PLT 2 plan layouts reveal the levels of natural light provided. In the PLT 1 plan layout, the ADF was calculated to be 3%, indicating that natural lighting is generally sufficient, although artificial lighting may be necessary at times. In the PLT 2 plan layout, the ADF was calculated at 2.8%, suggesting an increase in areas that cannot be adequately illuminated by natural light. This indicates a lower level of natural lighting and performance in the PLT 2 plan layout.

In the open-plan offices of PLT 1, excessive light entering from the edges of the windows creates disturbing glare for users in those areas. As less natural light penetrates deeper into the open office, the disparity between the minimum and maximum illumination levels—near the windows—widens, resulting in an increased glare rate. Conversely, in PLT 2, the division of offices reduces the depth of individual workspaces, thereby decreasing the difference between the minimum and maximum illumination levels near the windows. Consequently, the contrast effect and, subsequently, the glare rate diminish. In the centrally located offices, although the natural illumination level is lower, the glare issue is less pronounced, and the light distribution is more balanced. This finding is significant for optimizing lighting strategies and enhancing visual comfort.

In the light level analyses, simulations conducted on different dates (March 21, June 21, and December 21) during specific times of the day reveal how natural light levels in the interior space fluctuate. The analyses assessed whether the light levels in the PLT 1 and PLT 2 plan layouts met the established threshold values. While the PLT 1 plan layout achieved a higher percentage of target threshold value areas (45.70%), the PLT 2 plan layout recorded a rate of 41.85%. This discrepancy suggests that additional artificial lighting is necessary for the PLT 2 plan layout.

Analysis conducted at various times of day reveals how natural light levels fluctuate based on the sun's position. In December, in particular, there was a notable decrease in natural light levels in offices facing northwest due to the lower angles of the sun. This resulted in a greater dependence on artificial lighting, especially in areas distant from windows.

The luminance analyses conducted in the PLT 1 and PLT 2 layouts indicate elevated lux levels and increased glare effects in areas adjacent to the windows. This situation may adversely impact the visual comfort of the workers and requires closer monitoring. It is expected that the glare effect will be more pronounced in the PLT 1 layout due to its larger windows and deeper space, whereas in the PLT 2 layout, glare may be reduced because of the smaller windows and shallower space.

Simulations were conducted to evaluate the effect of sunlight on interior spaces on March 21, June 21, and December 21, at three different times: 09:00, 12:00, and 15:00. The analyses revealed that sunlight penetrates more evenly in the morning and afternoon on March 21 in the PLT1 and PLT2 layout designs. Consequently, this period is considered the most suitable for office use. During midday, however, natural light reaches the center of the plan more limitedly. On June 21, due to the sun's high angle in the sky, the natural lighting level in the space is at its peak. This increase in sunlight can lead to visual comfort issues, such as reflections and glare, as well as heightened thermal loads. Therefore, it is recommended to incorporate shading elements, such as curtains and sunshades, as well as reflective glass. In the PLT 1 plan layout, there is high light intensity throughout the day near the windows. Additionally, the absence of partition panels allows for better distribution of natural light to the interior. In contrast, the PLT 2 plan layout experiences high light intensity only near the exterior facade, resulting in insufficient natural light reaching the interior areas. On December 21, the natural lighting level in the space is at its lowest, with areas that receive adequate light being limited primarily to those close to the north facade. During this time, the demand for artificial lighting increases. To enhance lighting efficiency, it is important to consider the use of light-colored interior surfaces and the strategic placement of furniture.

It was determined that the highest illumination level occurred at 15:00 on March 21st, while the lowest illumination level was recorded at 09:00 on December 21st in both plan layouts. Simulations conducted for March 21st, June 21st, and December 21st revealed that the spaces received more natural light in the afternoon, with the peak illumination level consistently reached at 15:00 among the analyzed hours. A general comparison of illumination levels in the PLT 1 and PLT 2 plan layouts is presented in Table 17.

Table 17: General comparison of lighting in PLT 1 and PLT 2 layouts (The table is reproduced from the first author's thesis).

Features	PLT 1	PLT 2
Light Distribution	Wider and more homogeneous	Limited and concentrated around windows
Area Usage	Large open office, fewer partitions	Small cellular office, more partitions
Efficiency of Natural Light	Medium-low	Medium-low
Brightness of Central Areas	Medium level	Low level

Based on the daylight analyses conducted, it is recommended to incorporate external shading elements to manage the high light intensity in south-facing spaces during the summer months. Simultaneously, an effective natural ventilation system and appropriate thermal insulation should be implemented to prevent overheating that may occur during this period. In the winter months, due to the low levels of natural light, light-colored and reflective surface materials should be favored in interior spaces, and artificial lighting should be strategically planned to enhance illumination levels.

Additionally, considering that daylight is limited in the central areas of the plan, priority should be given to the design of artificial lighting in these regions. The design recommendations should focus on mitigating the negative impacts of seasonal light variations on user comfort, energy efficiency, and overall interior quality. In the PLT 2 variant, the division of office spaces into sections results in offices located far from windows receiving less natural light. Consequently, it was determined that artificial lighting is necessary in all analyzed time zones within these spaces.

In order for natural light to reach the space more effectively, glass with a higher visible light transmittance (VLT) should be preferred over materials with low light transmittance, such as frosted glass. This is particularly important in offices located in the center of the layout, where natural light is limited. Additionally, using artificial lighting with a color temperature and light quality that closely resemble natural light enhances visual comfort for employees and reduces fatigue.

Conclusion

By utilizing dynamic systems that adjust according to the time of day and seasonal changes, offices can provide appropriate lighting for employees at all times. Technologies such as photocells and motion sensors minimize unnecessary energy consumption, ensuring that only the areas in use are illuminated. Achieving energy savings through efficient lighting is a crucial step toward a sustainable future. To maximize the benefits of natural daylight, the placement of windows and the depth of the space should be carefully considered in office designs. In both open office layouts and group office / co-working space configurations, positioning windows on different planes enhances the distribution of natural light, creating a more balanced environment. If the space is equipped with artificial lighting to achieve adequate brightness, dividing ambient lighting into zones is crucial in integrated lighting design. It is essential to provide solutions tailored to the specific lighting needs of each zone. For instance, ambient lighting can be designed differently for areas near windows compared to those farther away. Additionally, focused solutions, such as task lighting in high-traffic work areas, can be combined with ambient lighting to enhance functionality.

The minimum brightness requirements vary depending on the intended use of the spaces. In interior design, various strategies are employed to achieve the desired brightness levels across different surfaces. By considering employee preferences, the intensity, color temperature, and arrangement of lighting can be optimized. Furthermore, a healthier and more comfortable environment can be established by utilizing human-centered lighting systems that support the biological clock and replicate the effects of natural light. Computer-aided simulations can be employed during the planning phase of lighting designs. These simulations help minimize design errors by visualizing the impact of light sources and materials on the space in advance.

This research demonstrates that natural and artificial light can be effectively integrated through various technologies and methods to enhance visual comfort in office environments. However, more comprehensive studies are necessary to thoroughly analyze visual comfort. Specifically, the levels of brightness and glare in each office, along with their effects on visual comfort, should be examined in greater detail. The choice of materials significantly impacts the lighting efficiency of interior spaces. The ability of surfaces to absorb or reflect light can directly influence the distribution of natural light within the area and overall visual comfort. Additionally, the effects of materials used—such as those for floors, walls, and ceilings—on light reflection, as well as the role of this reflection in determining the general brightness level of the environment, should also be taken into account. Therefore, it is beneficial to examine the light reflection properties of the materials used, the effects of lighting conditions on the space, and overall visual comfort. Additionally, a more detailed analysis of how light is distributed in various areas and the impact of this distribution on users can be conducted. These supplementary analyses can enhance office designs and lighting strategies, providing crucial data to improve the user experience. It has been established that more in-depth analyses are necessary regarding glare, another aspect of visual comfort. Furthermore, comparing the energy loads of the sample office building after the automation system has been updated with its previous state will serve as a significant assessment of energy efficiency. Consequently, these additional analyses recommended for future studies can positively contribute to achieving optimal visual comfort and the development of sustainable lighting solutions.

Information Notes

This article is based on the MSc. thesis of the first author at Istanbul Gelisim University, Institute of Graduate Studies, Architecture Master of Science Program, under the supervision of the second author.

The lighting analysis for the case study discussed in the article was conducted by using Autodesk Revit®. The software mentioned is legally used by the authors for educational purposes.

There is no need for ethics committee approval in this article.

Declaration of Conflicting Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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