ATATÜRK ÜNİVERSİTESİ YAYINLARI
ATATURK UNIVERSITY PUBLICATIONS

Research Article *Araştırma Makalesi* DOI: 10.54864/planarch.1549649

Estimating Energy Savings in Office Lighting: The Impact of Illuminance Distribution and Fixture Types of Luminaires

Ofis Aydınlatmasında Enerji Tasarrufunun Tahmini: Aydınlatma Dağılımı ve Armatür Türlerinin Etkisi

Narmin HASANOVA [1]
[1]Department of Interior Architecture and Environmental Design, Faculty of Architecture, Yaşar University, İzmir, Türkiye

İlknur UYGUN [2]
[2]Department of Interior Architecture and Environmental Design, Faculty of Architecture, Yaşar University, İzmir, Türkiye

This research was produced from the non-thesis program conducted by the first author, under the supervision of the second author, at Yaşar University, Department of Interior Architecture and Environmental Design.

Received / Geliş Tarihi	18.09.2024
Revision Requested / Revizyon Talebi	27.10.2024
Last Revision / Son Revizyon	05.03.2025
Accepted / Kabul Tarihi	06.03.2025
Publication Date / Yayın Tarihi	15.03.2025

Corresponding author / Sorumlu Yazar: İlknur UYGUN

E-mail: ilknur.uygun@yasar.edu.tr

Cite this article: Hasanova, N. & Uygun, İ. (2025). Estimating Energy Savings in Office Lighting: The Impact of Illuminance Distribution and Fixture Types of Luminaires. *PLANARCH - Design and Planning Research*, 9(1), 99-108. DOI:10.54864/planarch.1549649

ABSTRACT

Artificial lighting is a crucial component of office environments and a significant energy consumer. Effective lighting design in offices must balance the well-being and visual comfort of workers with energy efficiency. Therefore, designers need more focus on lighting design for providing more eye-comfort space for workers who spend most of their time in office. This study examines various artificial lighting distributions and fixtures concerning their potential for energy savings and visual comfort. Utilizing a quantitative research approach, both literature review and simulations were conducted. Four recommended lighting fixtures, each with similar power and flux and different shapes from different brands, were selected for analysis. Small, medium, and big office rooms were modelled using the room index formula for diverse office layouts. The simulations of the offices with varied lighting fixtures were carried out in DIALux Evo 11. This study aims to find the optimal lighting fixture for energy saving in the workplace. The findings from the simulation indicated that as the room index increased, there was a slight reduction in both the illuminance levels and uniformity. While the illuminance levels remained above the standard, the uniformity fell short of the required standard. In accordance with the results of the analysis, the optimal choice for lighting in the rooms is a square lighting fixture, which fulfills the necessary standards across various room sizes. Based on simulation results, the recommended artificial lighting fixtures of brands can provide an energy-consuming environment, but they do not consistently ensure visual comfort across all office layouts.

Keywords: Energy saving, artificial lighting, illuminance distribution, lighting fixture.

ÖZ

Yapay aydınlatma, ofis mekanlarının önemli bir bileşeni ve aynı zamanda önemli bir enerji tüketicisidir. Ofislerde etkili aydınlatma tasarımı, çalışanların refah ve görsel konforunu enerji verimliliği ile dengelemelidir. Bu nedenle tasarımcıların, zamanlarının çoğunu ofiste geçiren çalışanlar için daha fazla göz konforu sağlayacak bir ortam sağlamak adına aydınlatma tasarımına daha fazla odaklanmaları gerekmektedir. Bu çalışma, enerji tasarrufu ve görsel konfor potansiyelleri açısından farklı tiplerdeki yapay aydınlatma armatürlerinin ışık dağılımlarının etkisini incelemektedir. Nicel bir araştırma yaklaşımı kullanılarak literatür taraması ve simülasyonlar yapılmıştır. Analiz için her biri benzer güç ve ışık akısına sahip, farklı şekillerde ve farklı markalardan ofisler için önerilen dört aydınlatma armatürü seçilmiştir. Oda indeksi formülüne göre küçük, orta ve büyük olarak tanımlanan ofis odaları, farklı ofis yerleşim düzenleri modellenmiştir. Farklı aydınlatma armatürlerine sahip ofislerin simülasyonları DIALux Evo 11 programında gerçekleştirilmiştir. Bu çalışma, iş yerinde enerji tasarrufu sağlayacak en uygun aydınlatma armatürünü bulmayı amaçlamaktadır. Simülasyondan elde edilen bulgular göstermektedir ki; oda endeksi arttıkça hem aydınlatma seviyelerinde (E) hem de düzgünlük değerinde (U) hafif bir azalma olmaktadır. Aydınlatma seviyeleri standardın üzerinde kalırken, düzgünlük değeri önerilen standardın altında kalmaktadır. Analiz sonuçlarına göre, farklı oda boyutlarına sahip ofislerde aydınlatma için en uygun seçim, gerekli standartları karşılayan kare aydınlatma armatürüdür. Sonuçlar, markalar tarafından ofisler için önerilen yapay aydınlatma armatürlerinin enerji tüketimini azaltan bir ortam sağlayabileceğini, ancak farklı ofis düzenlerinde görsel konforu tutarlı bir şekilde garanti etmediğini göstermektedir.

Anahtar Kelimeler: Enerji tasarrufu, yapay aydınlatma, ışık dağılımı, aydınlatma armatürü.

Introduction

The effect of artificial lighting on visual comfort is a well-known fact around the world. The parameters of the artificial lighting have impact on the visual comfort of the users. Researchers have focused extensively on aspects of the lamp type, fixture type, number of fixtures, illuminance distribution, artificial lighting control, and energy efficiency of the artificial lighting (Viitanen et al., 2013; Soori & Alzubaidi, 2011; Takei, 2009; Uygun, 2018; Hsieh, 2012; Jang et al., 2024; Soori & Vishwas, 2013). Additionally, substantial research has explored the relationship between artificial lighting and office environments. However, there is limited research on the effects of different forms of artificial lighting and varying illuminance distributions on visual comfort and energy consumption in office settings. Further studies are needed to investigate these specific variables.

This research aims to assess the energy saving potential in offices through visual comfort, based on the impact of the different illuminance distributions and lighting fixture forms. It is hypothesized that artificial lighting fixtures' illuminance distribution and shape affect the energy saving potential. Energy savings potentials for lighting loads in the offices may be achieved by selecting appropriate artificial lighting fixtures according to their shape and illuminance distribution.

This paper focuses on artificial lighting design in offices, intentionally excluding daylight factors from the model. While space organization aspects like plan schemes and dimensions are pertinent to lighting design, this study considers office dimensions but disregards openings due to daylight. The primary objectives are to evaluate illuminance, the uniformity of illuminance distribution, glare, and energy efficiency as key parameters of visual comfort. In a comparison of different types of lighting fixtures based on photometrical properties of lighting distribution, their shape, luminous flux, and energy consumption were considered, while the correlated color temperature (CCT) of light sources, and color rendering index (CRI) are also disregarded for evaluation. EN 12464-1:2021 guides with its standards about visual comfort will be restricted criteria for workers' comfort conditions.

Literature Review

Visual Comfort of Workers

Artificial lighting in office environments significantly impacts productivity, health, and well-being. Viitanen et al. (2013) underline the importance of lighting in facilitating visual tasks. Boyce et al. (2006) highlight that while lighting quality might not directly impact immediate performance, subtle long-term effects are evident. Providing workers with individual control over lighting, as suggested by Chraibi et al. (2017), enhances satisfaction and can reduce energy use by encouraging lower desired illuminance levels. Jang et al. (2024) point out the significance of uniform illuminance distribution to prevent discomfort caused by sudden changes in lighting levels.

Energy Savings in Artificial Lighting

Artificial lighting consumes approximately one-third of the energy in commercial buildings (Soori & Vishwas, 2013). The adoption of energy-efficient solutions, like LEDs, has drastically reduced consumption while improving durability and cost-effectiveness (Montoya et al., 2017). Mattsson and Laike (2015) demonstrated the benefits of integrated lighting controls, including daylight-responsive dimming and occupancy-based systems, which optimize energy use without compromising visual comfort. Hsieh (2012) further revealed that uniform illuminance distributions not only reduce energy consumption but also improve perceived brightness, emphasizing the value of strategic luminaire placement.

Room Size and Lighting Effects

The interaction between room size and lighting is crucial for both energy efficiency and visual comfort. Studies by Pracki (2018) and Uygun (2018) show that personalised luminaire layouts based on room index values optimize lighting performance. Pracki (2020) demonstrated that reducing luminaire power through careful design can lead to substantial energy savings without losing lighting quality. Uygun's (2018) model proposes layouts for achieving uniform work plane illuminance, particularly in office settings, to balance visual comfort and energy efficiency effectively.

As highlighted in various studies referenced above, efficient artificial lighting design integrates energy-efficient technologies, personalized control systems, and room-specific layouts to enhance both sustainability and user satisfaction. By addressing parameters such as illuminance, glare, and uniformity while considering room size and lighting distribution, designers can optimize visual comfort and productivity. Research emphasizes the importance of constant lighting systems energy-saving goals. Advanced layouts and luminaire placements, further contribute to achieving balanced lighting environments that support well-being and operational efficiency.

Visual Comfort Parameters and Lighting Standards

Artificial lighting design in interiors involves several critical parameters which must be carefully considered to provide an optimal visual environment. This research focuses on three key parameters: illuminance, glare, and uniformity. Each of these elements plays a significant role in creating a comfortable and efficient lighting scheme.

Illuminance, the amount of light on a surface, is fundamental to lighting design and is measured in lux (lumens/m^2) (Benya et al., 2001). Adequate illuminance ensures that spaces are well-lit enough for their intended tasks, which can range from general lighting to more detailed work.

Glare, on the other hand, is a factor which can significantly impact visual comfort. Glare occurs when a part of the interior is significantly brighter than the general illumination level, causing discomfort or even impairing vision (CIE, 1995). Glare is quantitatively assessed using the Unified Glare Rating (UGR) which is internationally recommended for estimating the discomfort glare from indoor lighting installations but it is not suitable for daylight glare estimation (Tuaycharoen, 2020). Appropriate luminaire design and placement can help minimize glare effects (Suriyothin, 2021).

Uniformity in lighting is another crucial parameter, which refers to the ratio of the minimum illuminance to the average illuminance on a given surface. Uygun (2018) highlights that uniformity helps in understanding the distribution of light within a space. High uniformity can be important for spaces like offices or classrooms to avoid eye strain and ensure comfort.

Different standards and regulations guide the evaluation and implementation of these lighting parameters. Organizations such as the Chartered Institution of Building Services Engineers (SLL

Code for Lighting, 2022), the International Organization for Standardization (ISO 8995-1, 2002), and the European Norm (EN 12464-1, 2021) provide comprehensive guidelines for lighting design. These standards ensure that lighting systems meet safety, efficiency, and comfort criteria. Additionally, lighting design software like DIALux incorporates various international standards, including those from Japan, the USA, and Europe, allowing designers to tailor their projects to meet specific regional requirements.

In Türkiye, the TS EN-12464-1:2013 standard is widely used to ensure visual comfort and appropriate lighting design parameters are met. This standard helps in creating environments that are both functional and comfortable, supporting the well-being of workers by addressing issues related to illuminance, glare, and uniformity.

By adhering to these standards and thoroughly evaluating key lighting parameters, designers can create interior spaces that enhance visual comfort, efficiency, and overall user satisfaction.

Photometric Data of Luminaires

Artificial lighting elements such as lamps and luminaires come with photometric data. This data includes candle power distribution graph, power, and luminous flux, all of which are crucial for designing effective lighting systems.

Lighting distribution refers to the pattern in which light from a fixture spreads across a surface. The IES (Illuminating Engineering Society), defines a lighting distribution or intensity curve as a graphical representation of how a lamp or luminaire's luminous intensity varies in a plane that goes through the center of the light (URL-1). The candle power distribution graph complements this by illustrating the distribution of luminous flux, whether it is directed upwards or downwards, and whether it is symmetric or asymmetric (Uygun, 2018).

Artificial lighting has different distribution graphs, providing detailed information about its luminous characteristics. These graphs are essential for designers to choose the right lighting fixtures for specific applications, ensuring that light is distributed effectively and appropriately within a space (Uygun, 2018).

Luminous efficacy is another critical measure in lighting design. Luminous efficacy refers to the ratio of the total amount of emitted luminous flux to the total electrical power input of the source, expressed in lumens per watt (lm/W) (URL-2). It indicates how efficiently a light source converts electrical power into visible light, which is crucial for energy-efficient lighting solutions.

The luminous flux is the rate at which radiant energy is emitted over time, evaluated based on a standardized visual response (URL-3). This physical quantity depends on both the power of the light source and its ability to produce light visible to humans. It is measured in lumens (lm) and represented by the symbol Φ (Uygun, 2018).

Incorporating these photometric data points into the lighting design process ensures that the artificial lighting elements chosen will not only meet the required illuminance, glare, and uniformity standards but also operate efficiently and effectively in various environments. Understanding these parameters and data helps designers create lighting schemes that are both functional and aesthetically pleasing, contributing to the overall visual comfort and energy efficiency of interior spaces.

Data Collection

The number of artificial lighting fixtures needed for different size offices varies, depending on the size of the office. In order to determine energy-efficient lighting fixtures for different office sizes the room index formula is used. The room index formula is used for the comparison of the lighting fixtures, visual comfort, and energy consumption in rooms with different dimensions (eq. 1). The room index approach was used in different researches for defining energy efficacy, illuminance distribution, wall, and ceiling illumination (Stockmar, 2002; Ceelen, 2002; Pracki et al., 2020; Pracki, 2018).

$$K=(L \times W)/(Hm\,(L+W)), \qquad \text{(eq. 1)}$$

where K is the room index, L is room length, W is room width, and Hm is the mounting height of fitting from the working plane (Zanker,1980).

Ghisi and Tinker (2001) discovered that room dimensions had a nonlinear, parabolic connection with lighting performance. According to their findings, the effect of room dimensions on illumination levels is greatest at lower room index values—specifically, between 0 and 1.5—and decreases as the room index rises. This emphasizes the significance of selecting realistic room sizes for lighting studies by including room index values in the 0–1.5 range. To explore energy-efficient lighting solutions, rooms with dimensions of 3x4 m, 4x6 m, and 8x10 m were selected, corresponding to room indices of 0.57, 0.80, and 1.48, respectively. A 3 m ceiling was maintained, and layouts for furniture were offered based on the size and function of the space (Figure 1). In addition to reflecting actual room sizes, these measurements were selected to give priority to the crucial 0–1.5 range that Ghisi and Tinker (2001) found.

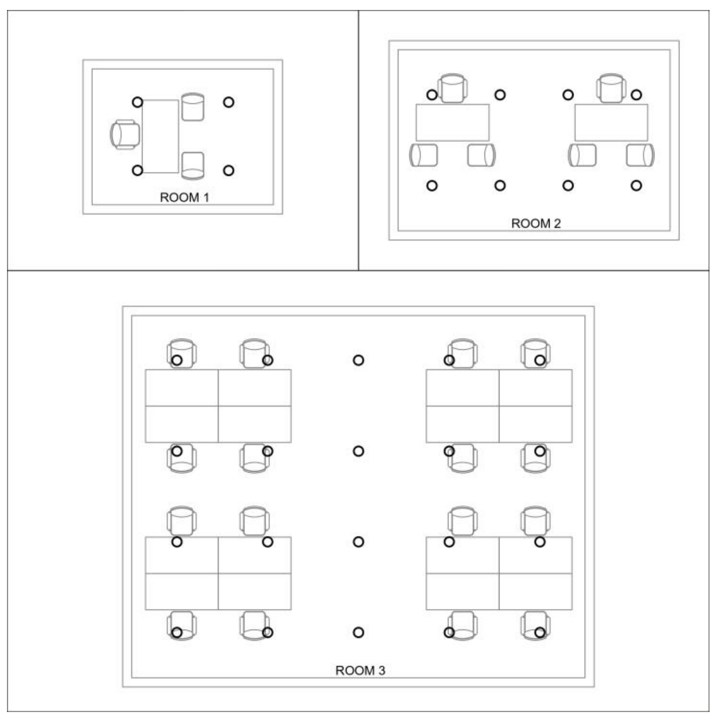


Figure 1. The layout of the rooms 1, 2, and 3.

Furniture layouts are offered for rooms based on their size, as determined by the room index formula (Figure 1). Furniture configurations were developed based on room index values. For instance, the furniture layout was designed for a single worker in a room with a room index lower than 1. Two workers could be accommodated in a room with a room index near 1, and several workers could be accommodated in a room with a room index between 1 and 1.5.

While these configurations serve as proposals, they are not built-in furniture layout solutions; alternative layouts can be adapted to suit different circumstances. Therefore, lighting quality assessments in this study were prepared considering the entire volume of the room, ensuring flexibility in addressing diverse spatial and functional requirements. This approach ensures that the relationship between energy use, lighting design, and space proportions is accurately represented, emphasizing the necessity of lighting design solutions that address both energy savings and visual comfort effectively.

The simulations of three rooms were carried out by using the DIALux software and the quantitative data was collected and analyzed. The reflectance factors of all the rooms are set to have a ceiling reflectance of 70%, wall reflectance of 50%, and floor reflectance of 20% which are (Table 1). These values were selected from the recommendation of the European Committee for Standardization (European Committee for Standardization, 2021). Using these standard values ensures consistency and comparability across different simulations, providing a reliable baseline for analysis.

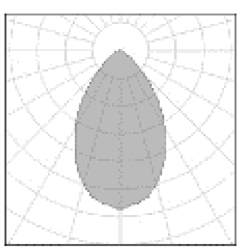
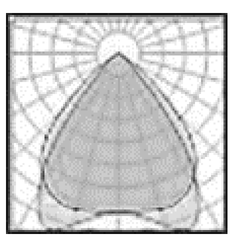
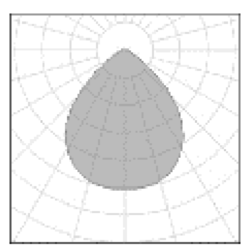
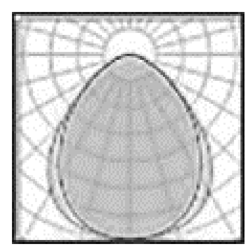
Table 1. Reflectance factors of the room.

Rooms	Reflectance Factor		
	Ceiling	Walls	Floor
1,2,3	70%	50%	20%

According to the EN 12464-1:2021 standard used in DIALux software, the minimum recommended illuminance for offices where writing, typing, reading, and data processing tasks are performed is 500 lux. Additionally, the uniformity standard for these offices should not be less than 0.60, while the maximum allowed glare should be 19 or lower.

Four different artificial lighting fixtures with varied illuminance distribution were selected from the recommendations of the different brand's websites for the offices (Table 2.). The artificial luminaires were selected with similar power and flux in order to see the effects of the lighting distribution and the shape of artificial lighting in the energy.

Table 2. Photometric Data of Selected Lighting Fixtures for Simulations.

Brand	Philips	Fagerhult	Philips	Fagerhult
Model	LUXSPACE, RECESSED DN571B 1 XLED38S/TWH-5000 F DN570B	NOTOR 36 BETA NANO REC 1200 HL 840 WHITE SINGLE CLO 16087-20036	POWERBALANCE GEN2 RC463B SRD W31L125 1 XLED28S/BU840 OC RC460B-2	MULTILUME SLIM DELTA HB 600X600 4000K DALI WIELAND CLO 23494-528
Fixture Form	 Circular	 Linear	 Rectangular	 Square
Illuminance Distribution				
Size (mm)	d=214, h=121	l=1189, w=56, h=51	l=1247, w=310, h=70	l=595, w=595, h=23
Power (W)	23.5	22	23	22
Luminous Efficacy (lm/W)	115	122	122	133
Flux (lm)	2700	2684	2800	2917
CCT (K)	3000	4000	3000	3000
CRI (%)	100	80	100	80

While designers may select different luminaire shapes for aesthetic reasons, it is crucial to ensure that shape-driven choices lead to appropriate lighting designs. Aesthetic preferences can sometimes be misleading if the selected luminaires do not align with the visual needs of the space. Therefore, selecting luminaires should balance both visual appeal and adherence to lighting standards to achieve optimal results.

Four ceiling recessed fixtures were selected from Philips and Fagerhult brands. Circular and rectangular artificial lighting fixtures were selected from Philips. The dimensions of the circular lighting fixture are 214 mm in diameter, with a height of 121 mm. The rectangular lighting fixture has a length of 1247 mm, a width of 310 mm, and a height of 70 mm. While the rectangular fixture has 23 W power, the circular has 23.5 W. The luminous efficacy of circular and rectangular artificial lighting is 115 lm/W and 122 lm/W. The flux of the circular and rectangular fixtures are close to each other, with 2700 lm and 2800 lm. The Correlated Color Temperature (CCT) and Color Rendering Index (CRI) of both the circular and rectangular fixtures are the same, with 3000 K of CCT and 100% of CRI.

On the other hand, from the Fagerhult brand, the linear and square-shaped lighting fixtures were selected. The linear lighting fixture has a length of 1189 mm, a width of 56 mm, and a height of 51 mm. The square lighting fixture has a length of 595 mm, a width of 595, and a height of 23 mm. The power of linear and square lighting fixtures is the same (22 W). The luminous efficacy of the linear lighting fixture is 122 lm/W, while the luminous efficacy of the square fixture is 133 lm/W. The flux of the linear and square lighting fixtures is 2684 lm and 2817 lm, respectively. Meanwhile, the CCT of the square is the same as in the Philips fixtures (3000 K), the CCT of the linear fixture is 4000 K. The CRI values of linear and square fixtures are similar, with 80%.

Methodology

In this study, a comprehensive literature review was carried out to explore the visual comfort of workers, energy saving of artificial lighting design in offices, effects of artificial lighting parameters, room size, and lighting effects on energy saving. The literature review was conducted using Google Scholar which is a platform offering access to a wide array of peer-reviewed studies and academic sources. Key topics explored included the correlation between lighting quality and worker productivity, strategies for reducing energy consumption through efficient lighting designs, and the role of specific lighting parameters, such as illuminance levels, luminaire layouts, etc. in achieving these outcomes.

Furthermore, studies examining the impact of room size and geometry on lighting efficacy and energy efficiency were evaluated. Priority was paid to identifying approaches employed in earlier research, such as computational models, experimental setups, and field studies. This assessment provides critical insights into the connection between lighting design, workplace ergonomics, and sustainability, laying the groundwork for the succeeding stages of this research. The papers and thesis with theoretical and numerical data were reviewed.

The search is conducted through a simulated work environment using DIALux EVO 11, which is cost and time-efficient. DIALux is a widely used lighting design software by designers, consultants, and engineers for its robust simulation capabilities and user-friendly interface, enabling detailed and accurate analysis of lighting scenarios. The simulated work environment was used to understand the influence of the lighting fixture forms and illuminance distribution effects on energy saving. Moreover, three rooms with different dimensions were identified by using the room index formula. The rooms were decorated randomly with furniture to create working space. By using the lighting generator of the software, the lighting fixtures were placed.

Glare values were determined for each room type based on a rectangular space with varying dimensions and a surface-to-height ratio (SHR) of 0.25. The viewing angles considered ranged from 0 to 360 degrees, allowing for a comprehensive assessment of glare in both horizontal and vertical planes. The glare parameters were calculated using the Unified Glare Rating (UGR) method, incorporating the impact of background luminance and the observer's viewing direction. This approach ensured that the glare evaluation reflected realistic user conditions and provided insights into visual comfort levels across different room configurations.

Illuminances were calculated based on a reference area set at 0.80 m above the floor, ensuring that the illuminance distribution was calculated according to standard office conditions.

In total, 12 simulation results were obtained from the software. The obtained results of the simulation were analyzed by using descriptive statistical analysis.

Simulation and Results

Room 1

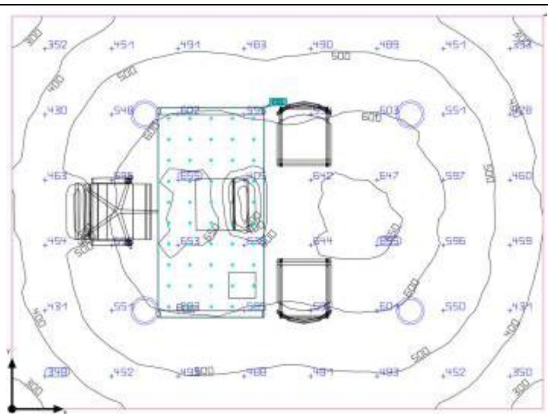
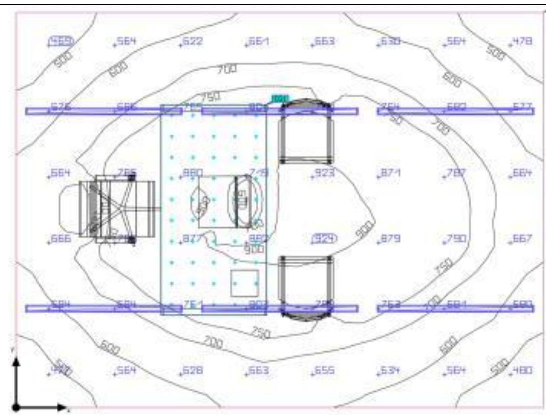
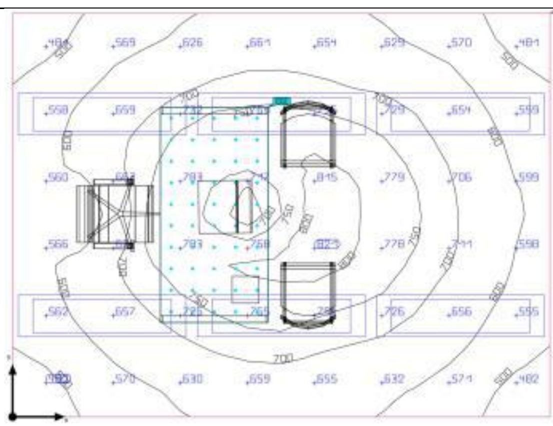
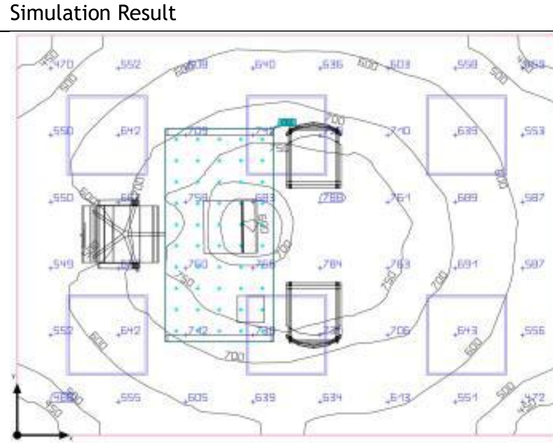
According to the DIALux program, a 3 m × 4 m room consumes 450 kWh/a. It recommends the same number of lighting fixtures for linear, rectangular, and square designs, while it suggests four fixtures for a circular design. Table 3 indicates that energy consumption remains below 342 kWh/a. Out of the four lighting fixtures, the energy usage of the linear and square lighting fixtures is the same, with 327 kWh/a. The circular lighting fixture is the least energy-consuming lighting, and it uses 233 kWh/a. In contrast, the rectangular lighting fixture is the highest energy-consuming lighting, which is 342 kWh/a.

The simulation results show that all lighting fixtures meet the required illuminance for Room 1. The circular lighting fixture provides the minimum illuminance (518 lx), meanwhile, the linear lighting fixture gives the maximum result for the illuminance (692 lx). The results of the rectangular and square lighting fixtures for the illuminance are 655 lx and 637 lx. In general, the linear lighting fixture is more suitable in terms of illuminance for Room 1.

It is clear that the glare results of the circular, rectangular, and square lighting fixtures are equal and under the maximum glare. The linear lighting fixture is over 19, which is over the required glare. The result of the circular lighting for glare is in the upper limit (19). In terms of glare, rectangular and square lighting fixtures are better, with 15 glare values.

The uniformity of the circular and linear fixtures is lower than the required uniformity (0.51 and 0.58), but the rectangular and square fixtures meet the standards, scoring 0.67 and 0.65. The rectangular fixture is the most efficient regarding uniformity.

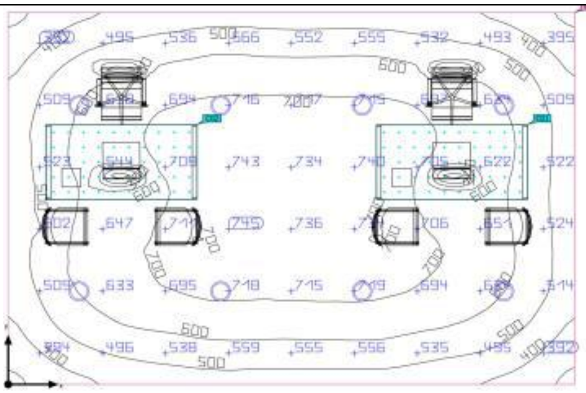
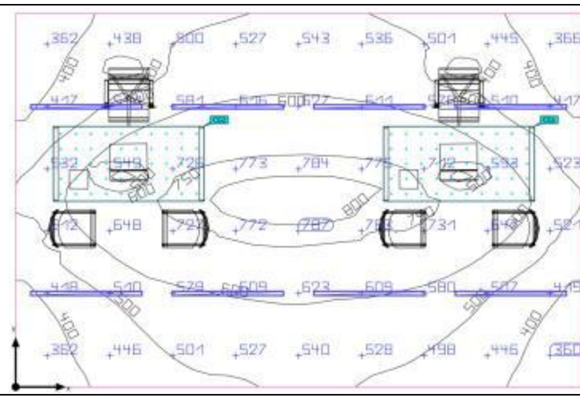
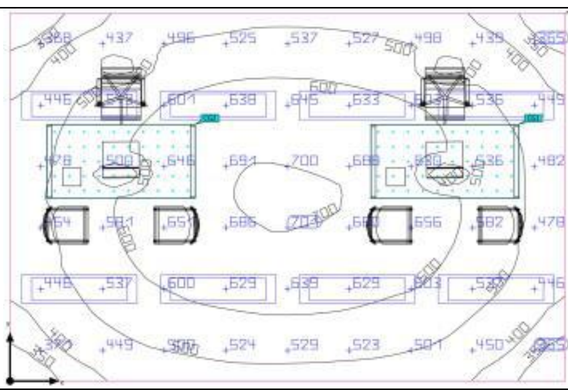
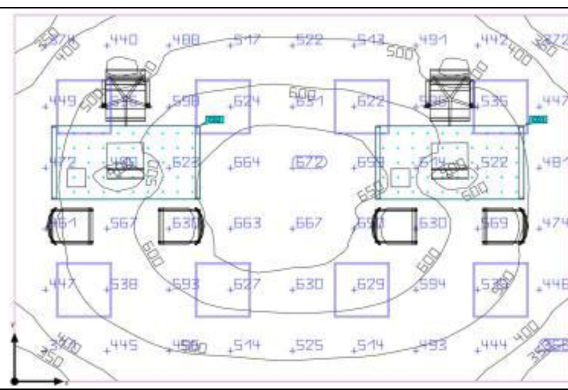
Overall, the rectangular lighting fixture is more suitable in terms of illuminance, glare, and uniformity.

Table 3. Simulations and results of the Room 1			
Circular Lighting Fixture		**Linear Lighting Fixture**	
Number of Fixtures	**4**	Number of Fixtures	6
Illuminance Level ≥ 500 lx	518 lx	Illuminance Level ≥ 500 lx	692
Glare ≤ 19	19	Glare ≤ 19	*21*
Uniformity ≥ 0.60	*0.51*	Uniformity ≥ 0.60	*0.58*
Energy Consumption (kWh/a)	**233 kWh/a**	Energy Consumption (kWh/a)	327 kWh/a
Simulation Result		Simulation Result	
			
Rectangular Lighting Fixture		**Square Lighting Fixture**	
Number of Fixtures	6	Number of Fixtures	6
Illuminance Level ≥ 500 lx	655 lx	Illuminance Level ≥ 500 lx	637 lx
Glare ≤ 19	15	Glare ≤ 19	15
Uniformity ≥ 0.60	0.67	Uniformity ≥ 0.60	0.65
Energy Consumption (kWh/a)	342 kWh/a	Energy Consumption (kWh/a)	327 kWh/a
Simulation Result		Simulation Result	
			

Room 2

The room measures 4 m x 6 m, resulting in consumption of 850 kWh/abased on DIALux. The lighting fixture generator in DIALux placed 8 lighting fixtures, an equal number of fixtures for each selected lighting fixture scenario (Table 4). The results of the energy consumption are alike, ranging from 436 kWh/a to 465 kWh/a. The circular fixture uses the most energy at 465 kWh, while both linear and square fixtures use the least at 436 kWh each. Meanwhile, the rectangular lighting fixture consumes 455 kWh/a. The illuminance of all lighting fixtures fulfils the required illuminance target (Table 6). The circular lighting fixture provides the highest illuminance at 595 lx, while the square fixture has the lowest at 532 lx. The results of the illuminance of the linear and rectangular lighting fixtures are 558 lx and 541 lx. Excluding the linear lighting fixture from the glare results, the results of the other lighting fixtures satisfy the glare requirement. The circular lighting fixture resulted in a maximum required glare, of 19. The most satisfying result for the glare belongs to rectangular lighting fixture. On the other hand, the square lighting fixture glare result is 16. The result of the linear lighting fixture for the glare exceeds the target glare (21). All lighting fixtures do not meet the required uniformity standard (0.60). Only the result of the square lighting fixture is closer to the target uniformity (0.58). The circular lighting fixture uniformity result is the lowest with 0.47, which is the worst result for uniformity. Linear and rectangular fixtures perform similarly (0.55), while the square fixture performs better in illuminance, glare, and uniformity.

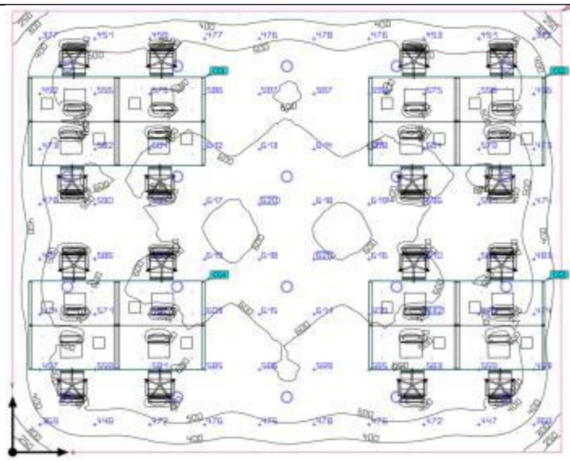
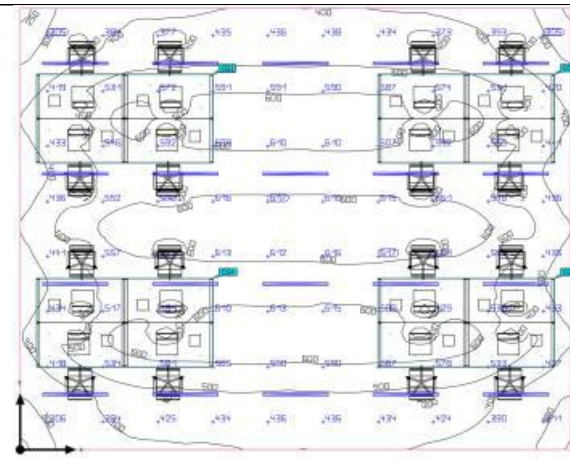
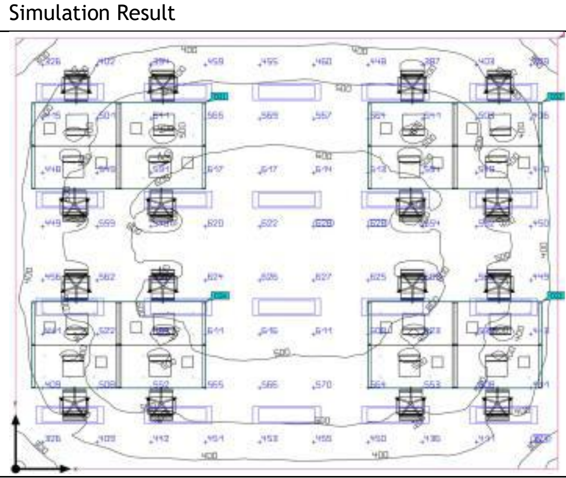
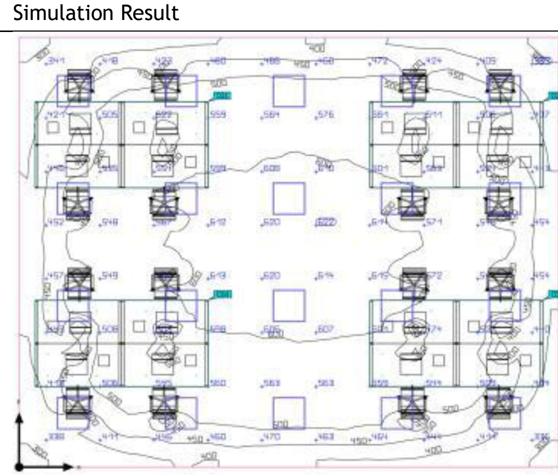
Table 4. Simulations and results of the Room 2.

Circular Lighting Fixture		**Linear Lighting Fixture**	
Number of Fixtures	8	Number of Fixtures	8
Illuminance Level ≥ 500 lx	595 lx	Illuminance Level ≥ 500 lx	558 lx
Glare ≤ 19	19	Glare ≤ 19	*21*
Uniformity ≥ 0.60	*0.47*	Uniformity ≥ 0.60	*0.55*
Energy Consumption (kWh/a)	465 kWh/a	Energy Consumption (kWh/a)	**436 kWh/a**
Simulation Result		Simulation Result	
			
Rectangular Lighting Fixture		**Square Lighting Fixture**	
Number of Fixtures	8	Number of Fixtures	8
Illuminance Level ≥ 500 lx	541 lx	Illuminance Level ≥ 500 lx	532 lx
Glare ≤ 19	15	Glare ≤ 19	16
Uniformity ≥ 0.60	*0.55*	Uniformity ≥ 0.60	0.58
Energy Consumption (kWh/a)	455 kWh/a	Energy Consumption (kWh/a)	**436 kWh/a**
Simulation Result		Simulation Result	
			

Room 3

The maximum energy consumption for Room 3 is 2850 kWh/a. For each lighting scenario, DIALux software placed 20 fixtures (Table 5). The energy consumption of situations is very similar, ranging from 1089 kWh/a to 1163 kWh/a. The least energy-consuming lighting fixtures are linear and square lighting fixtures, which consume 1089 kWh/a. Nevertheless, the greatest energy consumption is seen in circular lighting fixtures, which use the most energy at 1163 kWh/a, while rectangular lighting fixtures use 1139 kWh/a.The results of the illuminance of all lighting fixtures meet the required illuminance standard. The results of the linear, rectangular, and square lighting fixtures for the illuminance are similar, with 508 lx, 509 lx, and 507 lx. The circular lighting fixtures' illuminance result is the most appropriate, with 526 lx. The glare result of the linear lighting fixture is over the needed glare (21), while the circular, rectangular, and square lighting fixtures have resulted in the required standard of glare (19, 15, and 17). Among these, the rectangular lighting fixture is the best choice, as it demonstrates the lowest glare level (15). Unfortunately, none of the selected lighting fixtures achieved the required uniformity. The circular, linear, and rectangular lighting fixtures results are lower than 0.50. While the uniformity results of the linear and rectangular lighting fixtures are the same (0.48), the result of the circular lighting fixture is the lowest, with 0.41, and not suitable for Room 3. Nevertheless, the square lighting fixture result is a little bit more than 0.50 (0.52). The square lighting fixture meets the required standards for illuminance, glare, and uniformity. Overall, the square lighting fixture meets the required standards for illuminance, glare, and uniformity more effectively than the others.

Table 5. Simulations and results of the Room 3.

Circular Lighting Fixture		**Linear Lighting Fixture**	
Number of Fixtures	20	Number of Fixtures	20
Illuminance Level ≥ 500 lx	526 lx	Illuminance Level ≥ 500 lx	508 lx
Glare ≤ 19	19	Glare ≤ 19	*21*
Uniformity ≥ 0.60	*0.41*	Uniformity ≥ 0.60	*0.48*
Energy Consumption (kWh/a)	1163 kWh/a	Energy Consumption (kWh/a)	**1089 kWh/a**
Simulation Result		Simulation Result	
			
Rectangular Lighting Fixture		**Square Lighting Fixture**	
Number of Fixtures	20	Number of Fixtures	20
Illuminance Level ≥ 500 lx	509 lx	Illuminance Level ≥ 500 lx	507 lx
Glare ≤ 19	15	Glare ≤ 19	17
Uniformity ≥ 0.60	*0.48*	Uniformity ≥ 0.60	0.52
Energy Consumption (kWh/a)	1139 kWh/a	Energy Consumption (kWh/a)	**1089 kWh/a**
Simulation Result		Simulation Result	
			

Discussion and Conclusion

This research aimed to thoroughly examine the energy-saving potential of artificial lighting in three office spaces of varying sizes, with a focus on sustaining visual comfort. By investigating the impact of different illuminance distributions and lighting fixture shapes, the study aims to understand how these factors influence both energy efficiency and the well-being of office workers. Given that the office environment is where workers spend the majority of their time, providing a visually comfortable setting throughout the workday is crucial. For that reason, interior architects should pay more attention to lighting design solutions.

In earlier studies, researchers emphasized comparing luminaires (Viitanen et al., 2013; Soori & Alzubaidi, 2011; Takei, 2009; Muneeb et al., 2017). Our focus, however, was on LED luminaires, building on studies conducted by Uygun (2018), Pracki (2018), and Pracki et al. (2020). We utilized the room index formula to compare the impact of different illuminance distributions and lighting fixture forms in different room sizes for energy savings in offices. The findings from this study indicate that the choice of lighting fixtures can differ when balancing energy consumption with visual comfort.

For Room Index 1, circular fixtures were the most energy-efficient, but rectangular fixtures offered the best combination of adequate illuminance, controlled glare, and uniformity, making them the most suitable choice. This suggests that while energy efficiency is important, it must be considered alongside factors such as glare and uniformity to ensure a comfortable working environment. Interestingly, Viitanen et al. (2013) found similar trends, where LED luminaires generally maintained luminous efficacy better when dimmed compared to traditional luminaires, offering advantages for variable lighting needs.

In Room Index 2, all lighting fixtures displayed similar energy consumption, with the circular fixture providing the highest illuminance. However, the square fixture delivered better overall performance, particularly in terms of meeting glare and uniformity standards. This is consistent with Viitanen et al. (2013), who highlighted that the glare ratings were influenced by illuminance levels, and higher illuminance levels often resulted in higher glare perception. These findings underscore the importance of balancing illuminance and glare control as room size increases, emphasizing a more holistic approach to lighting design.

For the largest space, Room Index 3, the results highlighted that the square lighting fixture provided the most consistent performance across all evaluated criteria. Although the circular fixture offered the highest illuminance, its higher energy consumption and poor uniformity made it less suitable for larger spaces. Similarly, Viitanen et al. (2013) observed that user evaluations favored lighting setups with balanced glare and uniformity, as these factors significantly impacted visual comfort, particularly in larger spaces.

Overall, as the room index increased, illuminance levels slightly decreased, as did uniformity results. However, in the study conducted by Pracki et al. (2020), the increase in room index was associated with an improvement in uniformity. Despite these discrepancies, the current study and earlier findings agree on the need for lighting solutions which prioritize user comfort. For example, Viitanen et al. (2013) observed that 600 lx was consistently rated as the optimal illuminance level for office tasks, balancing visual comfort with energy efficiency. This study reinforces that recommendation, as both energy efficiency and subjective preferences converge at this illuminance level.

The square lighting fixture emerged as the most adaptable option, consistently meeting the necessary standards across different room sizes. This aligns with the findings of Uygun (2018), which also indicated that rectangular LED lighting is more energy-efficient. Moreover, Viitanen et al. (2013) emphasized the advantages of LED luminaires in maintaining luminous efficacy and user satisfaction across varying settings. These shared insights underscore the importance of considering multiple factors, including energy efficiency, visual comfort, glare control, and uniformity, when designing office lighting systems.

In conclusion, the findings highlight the necessity for a holistic approach to lighting design in office spaces. The interplay between energy efficiency and visual comfort must guide fixture selection, ensuring that office environments support both productivity and sustainability.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – İ.U.; Design - İ.U.; Supervision - İ.U.; Resources – N.H.; Materials - N.H.; Data Collection and/or Processing - N.H.; Analysis and/or Interpretation - İ.U., N.H.; Literature Search - N.H.; Writing Manuscript - İ.U., N.H.; Critical Review - İ.U.

Ethics Committee Approval Certificate: The authors declared that an ethics committee approval certificate is not required.

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

References

Benya, J., Heschong, L., McGowan, T., Miller, N., Rubinstein, F. (2001). Lighting Design Considerations. In *Advanced lighting guidelines* (pp. 4-1-4-33). New Buildings Institute, Inc. [CrossRef]

Boyce, P., Veitch, J. A., Newsham, G. R., Jones, C. C., Heerwagen, J., Myer, M., & Hunter, C. M. (2006). Lighting quality and office work: two field simulation experiments. *Lighting Research & Technology*, 38(3), 191–223. [CrossRef]

Ceelen, E. (2002). The luminaire efficiency factor for professional luminaires. Right Light 5 Conference, p. 307–309. Nice, France.

Chraibi, S. S., Lashina, T. T., Shrubsole, P., Aries, M. M., Van Loenen, E. E., & Rosemann, A. A. (2016). Satisfying light conditions: A field study on perception of consensus light in Dutch open office environments. *Building and Environment*, 105, 116–127. [CrossRef]

Chraibi, S. S., Crommentuijn, L., Van Loenen, E. E., & Rosemann, A. A. (2017). Influence of wall luminance and uniformity on preferred task illuminance. *Building and Environment*, 117, 24–35. [CrossRef]

EN 12464-1, 2021. Light and lighting – Lighting of work places – Part 1: Indoor work places. European Committee for Standardization.

Ghisi, E., & Tinker, J. (2001). Optimising energy consumption in offices as a function of window area and room size. Proceedings of Building Simulation 2001: 7th Conference of IBPSA, p. 1307–1314. [CrossRef]

Hsieh, M. (2012). The energy-saving effect and prediction method under various illuminance distribution types. *Building and Environment*, 58, 145–151. [CrossRef]

Hsieh, M. (2015). Effects of illuminance distribution, color temperature and illuminance level on positive and negative moods. *Journal of Asian Architecture and Building Engineering*, 14(3), 709–716. [CrossRef]

ISO 8995-1, 2002. Lighting of work places – Part 1: Indoor. International Organization for Standardization, Geneva, Switzerland.

Jang, S., Baik, Y.-K., & Kim, S. (2024). Analyzing the effects of illuminance variations on workers' visual perceptions to determine permissible dimming controls of lighting in a small office. *Building and Environment*, 254, 111322. [CrossRef]

Mattsson, P., & Laike, T. (2015). Optimal office lighting use: a Swedish case study. *Facilities*, 33(9/10), 573–587. [CrossRef]

Muneeb, A., Ijaz, S., Khalid, S., & Mughal, A. (2017). Research Study on Gained Energy Efficiency in a Commercial Setup by Replacing Conventional Lights with Modern Energy Saving Lights. *Journal of Architectural Engineering Technology*, 06(02). [CrossRef]

Pracki, P. (2018). Impact of Direct Lighting Luminaires' Luminous Intensity Distribution on Lighting Quality in Interiors. 2018 VII. Lighting Conference of the Visegrad Countries (Lumen V4). [CrossRef]

Pracki, P., Dziedzicki, M., & Komorzycka, P. (2020). Ceiling and wall illumination, utilance, and power in interior lighting. *Energies*, 13(18), 4744. [CrossRef]

SLL Code for Lighting, 2022. Society of Light and Lighting (CIBSE).

Soori, P. K., & Alzubaidi, S. (2011). Study on improving the energy efficiency of office building's lighting system design. IEEE Conference Publication | IEEE Xplore. [CrossRef]

Soori, P. K., & Vishwas, M. (2013). Lighting control strategy for energy efficient office lighting system design. *Energy and Buildings*, 66, 329–337. [CrossRef]

Spunei, E., Piroi, I., & Chioncel, C. P. (2017). The experimental determination of the luminous flux emitted by a few types of lighting sources. IOP Conference Series, p. 163, 012023. [CrossRef]

Stockmar, A. (2002). Luminaire efficiency factor system for general lighting. Right Light 5 Conference, p. 311–318. Nice, France.

Suriyothin, P. (2021). Landscape Luminaire Design for Part of the Conservation of Chudhadhuj Royal Residence, Sichang Island. *Nakhara: Journal of Environmental Design and Planning*, 20(3), Article 117. [CrossRef]

Takei, Y. (2009). Energy Saving Lighting Efficiency Technologies. *Science & Technology Trends: Quarterly Review*, No.32. [CrossRef]

Tuaycharoen, N. (2020). An Investigation of a Modified Formula of Daylight Glare and Limiting Daylight Glare Indices in the Thai Elderly. *Nakhara: Journal of Environmental Design and Planning*, 18, 83–96. [CrossRef]

TS EN 12464-1, 2013. Light and lighting – Lighting of work places – Part 1: Indoor work places. Turkish Standards Institute, Ankara, Türkiye. (in Turkish)

URL-1. Intensity (Candlepower) Distribution Curve, retrieved from https://www.ies.org/definitions/intensity-candlepower-distribution-curve/ (last access: 05.12.2024).

URL-2. Luminous Efficacy of a Source, retrieved from https://www.ies.org/definitions/luminous-efficacy-of-a-source/ (last access: 05.12.2024).

URL-3. Luminous Flux, retrieved from https://www.ies.org/definitions/luminous-flux/ (last access: 05.12.2024).

Uygun, İ. (2018). An Optimization Model for Luminaire Layout Design in Office Spaces: OptimLUM. Doctoral dissertation, Izmir Institute of Technology, Architecture, Izmir. [CrossRef]

Viitanen, J., Lehtovaara, J., Tetri, E., & Halonen, L. (2013). User preferences in office lighting: A case study Comparing LED and T5 lighting. *LEUKOS*, 9(4), 261–290. [CrossRef]

Xu, Y. (2019). Nature and source of light for plant factory. M. Anpo, H. Fukuda, & T. Wada (Ed.). *Plant factory using artificial light* (pp. 47–69). Elsevier. [CrossRef]

Zanker A. (1980) Calculation of room index and estimation of coefficient of utilisation of luminaires by means of a nomograph. *Lighting Research & Technology*, 12(2), 107-109. [CrossRef]