

A DIALux-Based Comparative Analysis of Dental Clinic Lighting Design Based on National and International Standards

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Abstract

In Türkiye, the number of dentists is increasing faster than the population, leading to a rise in private dental clinics. Regulation No. 31975 outlines physical requirements for such clinics but vaguely defines lighting as merely needing to be "sufficient," resulting in practical neglect. This study compares international lighting standards with practices in Türkiye to emphasize the need for clearer regulations. Using DIALux simulation, artificial lighting in four operating dental clinics was analyzed. Illuminance and uniformity levels were evaluated against international standards (CIBSE, ISO 9680:2014) and Türkiye's TS-EN 12464-1. Results show that current lighting conditions fall short of these benchmarks. The study recommends replacing existing fixtures with compliant alternatives to improve clinic environments. Integrating detailed lighting criteria into national regulations will help align practices with international standards, ensuring healthier, more effective dental care spaces.

Keywords: Artificial lighting, healthcare environments, lighting standards, dental clinics.

Ulusal ve Uluslararası Standartlar Kapsamında Diş Klinikleri Aydınlatma Tasarımının DIALux Tabanlı Karşılaştırmalı Analizi

Öz

Türkiye’de diş hekimi sayısının nüfusa oranla daha hızlı artması, özel diş kliniklerinin sayısında da artışa neden olmuştur. Kliniklerin fiziksel koşulları 31975 sayılı Ağız ve Diş Sağlığı Hizmeti Sunan Özel Sağlık Kuruluşları Hakkında Yönetmelik’te tanımlansada, aydınlatma yalnızca “mekân yeterince aydınlatılmalı” şeklinde belirsiz bir ifade ile geçmekte ve bu durum uygulamada ihmal edilmektedir. Bu çalışma, uluslararası aydınlatma standartları ile Türkiye’deki uygulamaları karşılaştırmakta ve düzenlemelere özgül aydınlatma kriterlerinin eklenmesi gerekliliğini vurgulamaktadır. Dört faal diş kliniğinin yapay aydınlatma tasarımı DIALux simülasyonu ile analiz edilmiştir. Aydınlik düzeyi ve düzgünlük değerleri, uluslararası CIBSE, ISO 9680:2014 ve Türkiye’nin TS-EN 12464-1 standartlarına göre değerlendirilmiştir. Sonuçlar, mevcut kliniklerdeki aydınlatma koşullarının standartları karşılamadığını göstermektedir. Bu sorunları gidermek için mevcut armatürlerin, standartlara uygun aydınlatma elemanlarıyla değiştirilmesi önerilmektedir. Böylece hem hastalar hem de çalışanlar için daha sağlıklı mekânlar oluşturulabilecektir.

Anahtar kelimeler: Yapay aydınlatma, sağlık iç mekanları, aydınlatma standartları, diş hekimliği klinikleri.

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1. Introduction

The number of dentists is growing faster than the population, leading many dentists to open private clinics (Turkish Dental Association, 2024). The official gazette published a regulation titled "On Private Health Institutions Providing Oral and Dental Health Services" on 06.10.2022, which outlines the requirements for the physical infrastructure of dental clinics. This regulation encompasses a range of spatial requirements (Ministry of Health, 2022). The quality of the space is determined by elements such as planning-space organization, indoor air quality, acoustics, and lighting, which cater to various spatial needs (Kutlu, 2018). Lighting quality, quantity, spectrum, and intensity play important roles in the design of healthcare interiors (Billur & Billur, 2020). In the regulation regarding the opening of a dental clinic, such spatial needs are specified in detail. However, regarding lighting, it is only stated that "the place must be sufficiently illuminated," and the quality and quantity of these lighting criteria are not mentioned.

Lighting design encompasses various parameters, including color rendering index, illuminance, luminance, glare, etc. (Stork & Mathers, 2009). Lighting is a crucial factor in dental clinics to minimize errors and accidents by healthcare staff and ensure the successful completion of medical procedures. Yurtgün & Köse Doğan's (2024) study reports that investigations into potential problems in the areas that both patients and employees utilize have been conducted. Within the parameters of this investigation, the significance of providing sufficient illumination for patient and staff areas within the clinic's interior was emphasized. Well-illuminated spaces, including examination and operating rooms, are essential in these healthcare facilities. While some dentists used to rely on natural light from the North facade in examination rooms, modern color-corrected lamps have made this unnecessary. The primary consideration in operating rooms is to have shadowless lighting, ensuring that the operating lamp maintains the appropriate luminance (Hegland, 1982).

In dental clinics, in addition to general lighting, LED work/task lights are an important factor for dentists. These lights have both advantages and disadvantages. LED lights use less power and consume more energy compared to traditional bulbs, providing 25% more light with one-fifth of the power. This is crucial for reducing energy consumption and promoting sustainability. Another benefit of LED dental task lighting is that it does not emit radiant heat, creating a more comfortable working environment. With LED lighting design, glare and shadows can be reduced (Roy & Satvaya, 2022). Although the color rendering index (CRI) of LED lights has improved technologically, the performance advantage still lies with quartz-halogen bulbs/dichroic reflectors, which is a downside of LED dental task lighting. When selecting task lighting, it's important to consider its technical specifications (A-Dec, 2011).

1.1. General Lighting and Operation Room Lighting in Dental Clinics

Lighting design is important in areas such as hospital waiting areas, corridors, receptions, day rooms, operating rooms, etc. With a good lighting design, tasks can be completed correctly (Roy & Satvaya, 2022). Proper lighting in operating rooms is crucial for optimizing the efficiency of tasks performed during surgery. It is essential to implement necessary measures to address potential issues, such as power outages in these settings. The shadows cast by the surgeon, the surgical team, and the instruments must be managed to avoid excessive sharpness, and the heat generated by the lighting should not interfere with the working environment (Kılıçaslan, 2011). When planning the layout of a dental clinic, it is important to consider the lighting design, taking into account factors such as illuminance, uniformity, and color temperature to ensure user comfort (Yurtgün & Köse Doğan, 2024). LED lighting is a beneficial option for dental clinics due to its adjustability and cost-effectiveness compared to fluorescent lamps. It also allows for the creation of dimmer spaces. Additionally, LED lights offer improved viewing angles in treatment areas such as operating rooms and are more ergonomic as they generate less heat. Using lights that produce less heat in operating areas can enhance the comfort of dentists, patients, and assistants. The lighting in a dental clinic is tailored to suit the specific functions of different spaces, with operating areas being equipped with lighting fixtures that provide good visibility and emit less heat, while areas like waiting rooms can have adjustable lighting to reduce patient stress. It is important to avoid overly bright lighting, as it can negatively impact working comfort. Also, adequate lighting in the clinic helps to reduce possible

medication errors. Sometimes, medication labels can be misread as a result of poor lighting (Salonen, Lahtinen, Lappalainen, Nevala, Knibbs, Morawska & Reijula, 2013). In addition to general lighting, dentists also utilize operating lighting, such as dental task lights, in treatment areas. The consideration of all these factors as a whole is important, and it is vital to ensure that the lighting in operational areas and general lighting meets the required standards. The 'Code for Interior Lighting' book specifies the following standards: doctor's rooms should have a lighting level of 100-200 lux; regional illumination should be within the range of 400-800 lux; diagnosis rooms should have a general illumination of 250-1000 lux; and operating rooms should have a general illumination of 500-1000 lux; and the general illumination of the operating room should also be between 500-1000 lux (Tonyali, 2019).

In examination areas, it's important to select lighting with a high color rendering index and non-glare features. Some companies producing lighting fixtures specializing in lighting solutions suggest using LED panels in dental clinics as it meets these criteria and are ideal for such environments. Adjustable lighting is crucial for both general areas and examination areas, allowing for the intensity to be modified based on requirements. It's important to avoid glare from the general lighting, particularly in operation areas, as it can create visual discomfort and distractions and increase the likelihood of medical accidents. Therefore, selecting appropriate lighting fixtures needs to comply with specific standards (Zumtobel, n.d.). The LED panel recommended for dental clinics by Zumtobel, an Austrian company developed in lighting, provides these features and is recommended for use in dental clinics.

In addition to general lighting in a dental clinic, dental task lighting used in operation-examination areas is also an important part of dental clinics. Since dentists work inside the mouth, which is a dark area, lighting is very important for them to notice the details in this area. Therefore, insufficient lighting can cause serious problems (Van Boheemen, Albayrak, Molenbroek & Ruijter, 2021).

Dental task lighting should provide the best working environment for the dentist with maximum efficiency. It must provide light sources in sufficient quantity, consistency and quality for working comfort. In addition to general oral health, due to the increasing number of aesthetic dental operations today, it has become important and necessary for dental task lighting to provide quality performance. For this reason, when designing dental task lighting, care is taken to ensure that it is at a level that mimics daylight. The proximity of the light source to sunlight is an important factor for the dentist to accurately see the situation inside the mouth. LED is used in dental task lighting, and thanks to this LED-based technology, it provides the dentist with the best illumination of the oral cavity during the operation (A-Dec, 2011).

In summary, the lighting design, types of luminaires chosen, and illuminance levels all depend on the purpose of the area. When planning lighting design, these spatial requirements and usage scenarios should be taken into account. In the operation and examination areas, it is important to use suitable energy-efficient fixtures to minimize glare from surrounding equipment and ensure the comfort of the dentist, assistants, and patients. LED fixtures are preferred due to their lower heat emission compared to other lighting options, contributing to a more comfortable working environment. Adjustable lighting in these spaces is beneficial; for instance, general lighting can be tailored to specific needs based on the lighting requirements of dental equipment in the waiting or examination areas.

1.2. International Lighting Standards in Healthcare Environments and Dental Clinics

When discussing lighting standards, it's important to consider various parameters. Dental clinics, as part of healthcare interiors, are subject to international standards for artificial lighting illuminance values. The research focuses on examining illuminance values in the waiting area and examination/operation areas. Therefore, the standards for lighting in operation areas and waiting areas were addressed. In the CIBSE (Chartered Institution of Building Services Engineers) (Raynham, Boyce & Fitzpatrick, 2012), it is suggested that the appropriate illuminance level for general lighting in the examination area is 500 lux, while the recommended illuminance for dental task lighting is 1000 lux. In dental clinics, it's important that the task lighting used in operating areas doesn't exceed an illuminance value of 1200 lux on the patient, according to the standards outlined in ISO 9680:2014 (ISO, 2014) for dentistry operating lights. The European Committee for Standardization (2011) suggests

that waiting areas in dental clinics should have a light intensity of 200 lux. In addition, the same standard specifies that examination areas used for general purposes should have a light intensity of 500 lux (Table 1.).

Table 1. Ideal illuminance values of waiting - examination areas and dental task lighting in dental clinics within the scope of lighting standards. Sources: CIBSE (Raynham et al., 2012), in ISO 9680:2014 (ISO, 2014), The European Committee for Standardization (2011)

STANDARDS	Waiting Area General Lighting (lux)	Examination Room General Lighting (lux)	Dental Task Light (lux)
CIBSE	-	500	1000
ISO 9680:2021(E)	-	-	1200
EN-1264- 1:2011	200	500	-

As per the guidelines from CIBSE (Raynham et al., 2012), the general illumination level recommended for waiting areas in dental clinics is 200 lux, and for examination areas, it is 500 lux. CIBSE standards suggest that dental task lighting should be at 1000 lux for daily use in examination-operation spaces in dental clinics, and the maximum recommended level according to ISO 9680:2014 (E) (ISO, 2014) standards is 1200 lux.

1.2.1. Lighting regulations and standards in healthcare environments in dental clinics in Türkiye

The regulations for establishing a dental clinic in Türkiye encompass a range of requirements, including spatial dimensions, quantity survey data, and sterilization facilities related to the physical aspects of the building. However, the emphasis on lighting, a crucial element for healthcare environments, is not adequately addressed in these regulations. The criteria stating that "the building should be adequately illuminated and ventilated" lack detailed specifications. Although the regulation specifies the Turkish Standards Institute (2011) for light illumination values, these specific criteria are not included in the regulation.

The research aims to analyze the visual comfort conditions of currently used dental clinics based on the illuminance and uniformity in the waiting area and examination/operation rooms and to make recommendations within the scope of standards for dental clinics.

2. Material and Method

The objective of the research is to utilize both quantitative research methods and simulation techniques. Four private dental clinics were selected as case studies for this research. Before conducting spatial measurements, a consent document outlining the purpose and scope of the research was prepared. As part of the research, clinics were visited. However, a limitation of the study was that not all clinics permitted the research to be conducted while patients were present in the operating rooms and waiting areas. Therefore, clinics where approval could be obtained were prioritized, and permission was secured from four clinics. Additionally, newly designed and modern clinics were preferred, both to facilitate access to the brand and model information of the lighting fixtures and to ensure that these clinics opened according to current regulations. Moreover, the similarity of square meter values among the selected clinics was considered to provide a consistent basis for evaluation. Using the convenience sampling method, easily accessible locations were identified and included within the scope of the study. Drawings conducted by authors. The simulations were made based on these drawings. The fixtures utilized in the existing clinics were identified for simulating the illuminances and uniformity levels of current situations by using DIALux, which is a specialized lighting simulation software. There are many lighting simulation software, but one of the most well-known is DIALux. This software emphasizes surface-based computations rather than predetermined measurement points like in EN 12464-1. Results at measurement areas are either

interpolated from surface calculation data or additional calculation points are identified to fulfill standard requirements (Witzel, 2012). According to the results of a research, the DIALux software was found to be more rational with its scene modeling, fixture placement and graphic explanations compared to other lighting simulation programs (Shikder, Price & Mourshed, 2009). In another study, the DIALux software provided a good analysis of the simulation results. It has features such as photorealistic renderings, isocontours, false color maps, value charts, 2D plot summary reports (Fernandez-Prieto & Hagen, 2017).

In another study, the current illuminance values of the lighting in office environments were compared with the values obtained by simulating them with the DIALux program in the computer environment. It is emphasized that reliable results can be obtained by using DIALux. However, it has been argued that in order for the data in this program to be output correctly, the person using the program must have knowledge about lighting (Skarżyński & Rutkowska, 2020).

In another research, DIALux 4.12 simulation was used to create hospital lighting that best suits the standards in hospital environments (Perdahçı, Yüce & Ünsalan, 2017).

These simulation programs for calculating the lighting scenario of a designed and modeled building are used by many researchers, engineers, scientists and designers today. These software must comply with the standards and methods recommended by the International Lighting Commission (CIE). For this reason, the DIALux simulation, which was found to be valid in the research, was deemed worth using in the scope of this study. Subsequently, due to deficiencies in the obtained data, it is necessary to analyze the optimal lighting fixtures and corresponding illuminance levels. Based on the results of the simulations, proposals were made to enhance the visual comfort of these particular cases.

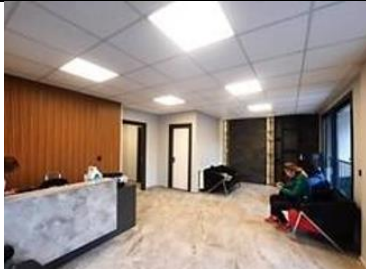
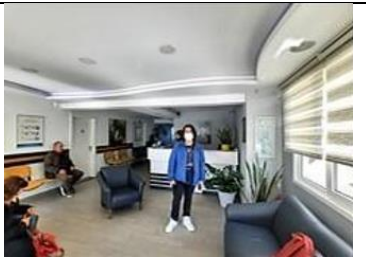
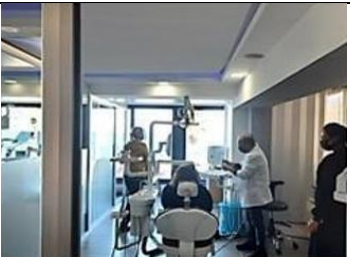
3. Findings and Discussion

Proper lighting is crucial for dental clinic design, as it significantly impacts the doctor's visual capabilities (Darses, Falzon & Béguin 1996). A recent investigation into dental clinics in educational institutions adhered to Brazilian standards (Brazilian Association of Technical Standards, 2013). According to these standards, an illumination level of 500 lux is required in operational areas as defined by NBR ISO/IEC 8895-1 ABNT 7. Additionally, this standard advises against excessive contrast, glare, and distracting reflections in the areas where dental operations occur. Within the studied sample, the dental schools' clinics revealed issues with their lighting fixtures, and the illuminance levels were deemed inadequate. Consequently, they proposed the implementation of a new lighting system equipped with updated fixtures in their findings (Simões, Santos, De Oliveira, Vila Nova & Fabio Barbosa De Souza, 2019). Measurements of spatial dimensions were conducted at four distinct dental clinics in Türkiye, and modeling was carried out using DIALux software. Information about the brand and model of the lighting fixtures utilized in these clinics was gathered. The current lighting fixtures were positioned and simulated within the DIALux program. The study focused on the illuminance and uniformity values of the waiting areas and operating rooms. Waiting areas and operating rooms in four different selected clinics were assessed. According to the findings obtained as a result of the research, the illuminance and uniformity values in the clinics were not found to meet the standards. If lighting standards had been explicitly included in the regulations for establishing dental clinics, more detailed guidance could have been provided, making compliance measurable and enforceable. However, the regulations do not specify numerical values for these standards but instead state that 'the space must be sufficiently illuminated.' As a result, clinic owners, lacking clear standards, have been unable to develop lighting scenarios that adhere to appropriate guidelines.

3.1. Lighting Simulations of Current Situations in Selected Dental Clinics

The research focused on studying the waiting areas and operation areas of selected dental clinics. The images below show the waiting areas and operating areas of four different clinics. (Table 2).

Table 2. Photographs were taken from the waiting area and operating area of 4 clinics. Source: İrem Hidir archive (2023)

CASE STUDIES	WAITING AREA	OPERATION AREA
Clinic 01		
Clinic 02		
Clinic 03		
Clinic 04		

The materials used in four dental clinics are defined, with a focus on their role in ensuring accurate lighting simulations. In the first clinic, the waiting area has matte 30x90 cm ceramic tiles, painted walls, and a wood-patterned PVC MDF panel on the back wall of the information desk. The desk features glossy gray porcelain and matte anthracite MDF-Lam, with matte white American panel interior doors. The examination area includes white MDF-Lam cabinets, a rock wool suspended ceiling, and five 60x60 LED panel lights. The second clinic uses glossy 60x120 cm ceramic tiles for the waiting area floor, painted walls, and a lacquered white information desk. White matte artificial leather seating is used throughout. The examination area shares the same materials as the waiting area. The third clinic has dark glossy 60x60 cm ceramic tiles in the waiting area, with a glossy porcelain-clad information desk and wall. Other walls are painted, and light-colored matte leather chairs are used. The operation area mirrors the waiting area's materials. In the fourth clinic, parquet-like ceramics cover the floor, with generally painted walls. The operation area has darker secondary paint. Matte orange leather seats are in the waiting area, and anthracite fabric seats are used elsewhere. The materials' light reflection properties were considered in simulations to ensure accurate lighting calculations and reliable assessment, complying with required standards.

The brand and quantity of lighting fixtures have been identified. Using these data, they have simulated the current usage of the clinics using the DIALux software. The lighting fixtures currently utilized in the simulated clinics have been incorporated. As a result, the visual below presents the photometric details of the lighting fixtures in each clinic (Table 3), (Table 4).

Table 3. Visuals and photometric information of the luminaires currently used in waiting areas. Source: DIALux simulation software (2024)

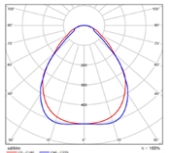
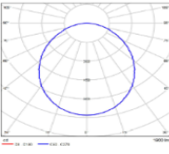
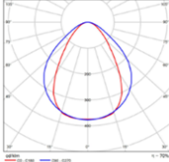
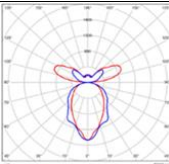
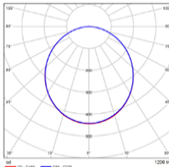
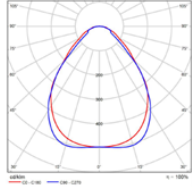
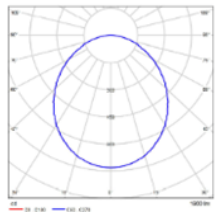
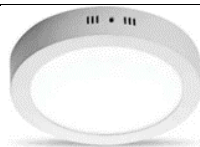
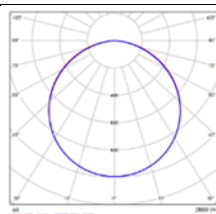
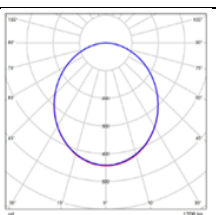
LIGHTING FIXTURES CURRENTLY USED IN THE WAITING AREA			
NO	BRAND INFO(S)	PRODUCT IMAGE(S)	LIGHT DISTRIBUTION CURVE(S)
CLINIC 01	Lemvigh Müller-Ledvance Biolum Hcled-60x60cm- 43W-2700K-3960lm		
CLINIC 02	NVC - NLED9688M 24W- 4000K-1900lm		
	TYPE1: RIDI-VENICE-E- F1x154-11-NE+G-F154- NDWS-400B840+ZMPS 25W-4000K-2812lm		
CLINIC 03	TYPE 2: FAGERHULT- Appareo G2 white 4000K CLO-40W-5360lm		
CLINIC 04	Oppl: LED MTD0700712/23- HaoYi-16W-3000K- 1200lm		

Table 4. Visuals and photometric information of the luminaires currently used in operation areas. Source: DIALux simulation software (2024)

LIGHTING FIXTURES CURRENTLY USED IN THE OPERATION AREA			
NO	BRAND INFO(S)	PRODUCT IMAGE(S)	LIGHT DISTRIBUTION CURVE(S)
CLINIC 01	Lemvigh Müller-Ledvance Biolux Hcled-60x60cm- 43W-2700K-3960lm		
CLINIC 02	NVC - NLED9688M 24W- 4000K-1900lm		
CLINIC 03	NVC - NLED4403LG 36W- 600x600-5700K-2880lm		
CLINIC 04	Opplé: LED MTD0700712/23-HaoYi- 16W-3000K-1200lm		

The lumen values of the lighting fixtures in the waiting areas of the current clinics are between 1200 and 5360. In the operating area, these values vary between 1200 and 5700 lumens. While the same lighting fixture was used in the waiting area and the operation area of clinics numbers 1, 2, and 4, two different lighting elements were used in the waiting area of clinic number 3, and a different lighting element was used in the operation area. The current lighting used in each clinic is LED lighting. These lighting fixtures were simulated using DIALux software. As a result, the illuminance values and uniformity values of the waiting area and operation areas of 4 clinics were obtained (Table 5).

Table 5. Point Illumination level values of the current situations in selected four different dental clinics. Source: Generated by Authors using DIALux simulation software (2024)

CASE STUDIES	WELCOMING AREA				OPERATION AREA			
	Area (m ²)	Ceiling Height (cm)	E (Nominal) (≥ 200)	U (Nominal) (≥ 0.40)	Area (m ²)	Ceiling Height (cm)	E (Nominal) (≥ 500)	U (nominal) (≥ 0.60)
Clinic 01	30.9	252	476 lux (✓)	0.15 (x)	11.4	252	435 lux (x)	0.15 (x)
Clinic 02	30.8	264	1969lux (✓)	0.11 (x)	18.1	254	2009 lux (✓)	0.66 (✓)
Clinic 03	21.5	283	347 lux (✓)	0.41 (✓)	14.5	283	198 lux (x)	0.48 (x)
Clinic 04	47.6	242	191 lux (x)	0.31 (x)	22.3	240	115 lux (x)	0.009 (x)

Within the framework of the clinic lighting standards, the illuminance value in the waiting areas should be ≥ 200 lux and the uniformity value should be ≥ 0.40 . The illuminance in the operating area should be ≥ 500 lux, and the uniformity value should be ≥ 0.60 . The illuminance value in the waiting area of the clinics is between 347 and 1969 lux. In the operation area, it is calculated between 115 and 2009 lux. According to the current lighting simulation data, the illuminance of clinics 1, 2, and 3 in the waiting areas comply with the standards. However, since the illuminance value in clinic 2 is 1969 lux, it is considerably high, although it meets the standards. In clinic number 4, the illuminance value was calculated as 191 lux, which was below the standards, and the uniformity value here was calculated as 0.31, although it should have been 0.40.

In clinics 1 and 2, the uniformity values were 0.15 and 0.11, respectively, and do not comply with the standards. In clinic number 3, the illuminance and uniformity values are the most compliant with the standards compared to those in other clinics. The illuminance levels in Clinics 1, 3, and 4 were 435 lux, 198 lux, and 115 lux, respectively. The standards indicate that these values should be at least 500 lux. The results show that the illuminance levels in these clinics' operating rooms do not exceed standards. Although the illuminance value in Clinic 2 appears to fulfill standards at 2009 lux, it is rather high. The uniformity value in the operation areas should be ≥ 0.60 according to the standards. However, according to DIALux results, the uniformity value was calculated as 0.15 in Clinic 1, 0.48 in Clinic 3, and 0.009 in Clinic 4. While the uniformity value in Clinic 2 complies with the standards with 0.66, clinics 1, 3, and 4 do not meet the standards (Table 6).

Table 6. Values for point illumination levels and light distribution curves derived from DIALux simulations of the examination room and the waiting area of four dental clinics. Source: Generated by Authors using DIALux simulation software (2024)

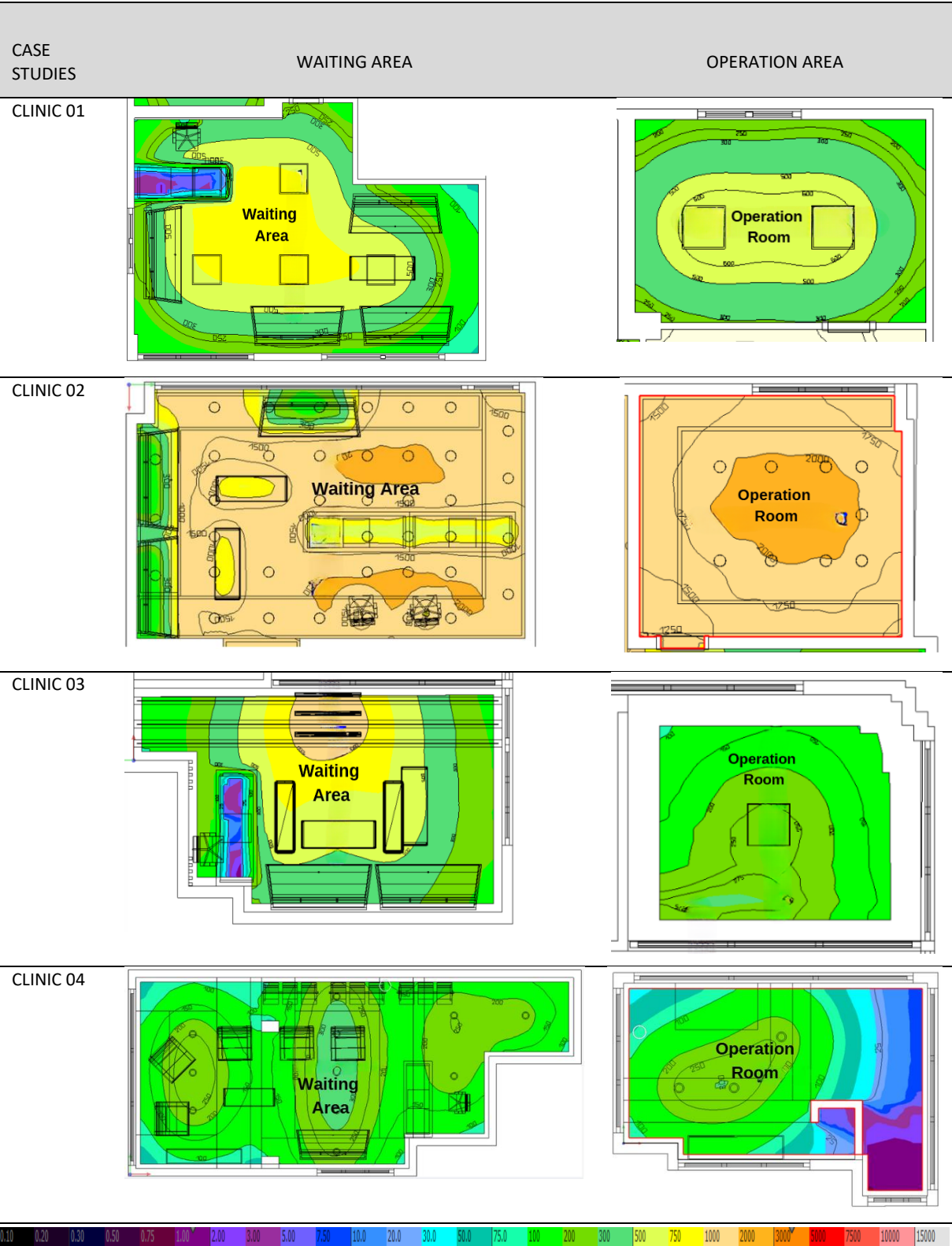


Table 6 shows the point illumination levels and light distribution curve values obtained from the results of the current situation of selected clinics in the DIALux simulation. The waiting area and operating area in each clinic are shown in this image. Based on the collected data, the adequacy of the current lighting fixtures will be analyzed concerning the established standards, and a proposal will be developed in response to the findings.

3.2. Recommended Lighting Simulations of Selected Dental Clinics

The current lighting situation in the waiting and operation areas of the 4 selected clinics was simulated. According to this data, most of the clinics do not comply with the standards. Therefore, an attempt was made to obtain a result that complies with the standards of the lighting fixtures recommended for these clinics. "NOKALUX/IIR 95 LED 3000 840, 35.2W, 3362lm" lighting fixture was placed in place of existing fixtures in clinics 1, 2, and 3. "NLED9688M" was installed in the waiting areas of Clinics 2 and 3, replacing the existing luminaires. The nominal power of this luminaire is 24W, the color temperature is 4000K, and the luminous flux is 1900 lumens. In the waiting area of Clinic 1, unlike the operation area, the "ES-SYSTEM 5712001, 11W, 1100lm" lighting fixture is recommended. In Clinic 4, the "LUG Light Factory - SOFT BASIC LED 56W 3200lm 3000K IP20 white" lighting fixture was used in both the waiting area and the operation area, and the scenario where the same type of fixture was used in both spaces was tested (Table 7), (Table 8).

Table 7. Visuals and photometric information of the recommended luminaires in waiting areas. Source: DIALux simulation software (2024)

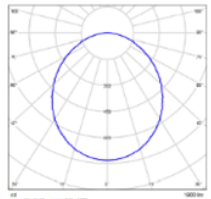
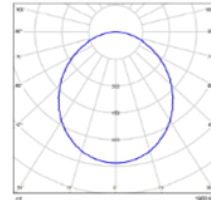
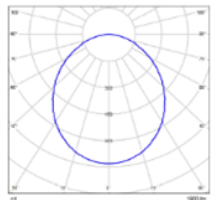
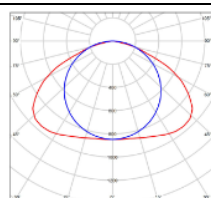
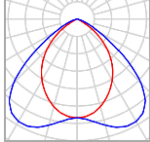
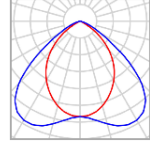
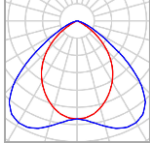
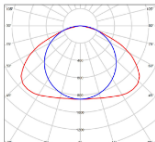
RECOMMENDED LIGHTING FIXTURES IN WAITING AREAS			
NO	BRAND INFO(S)	PRODUCT IMAGE(S)	LIGHT DISTRIBUTION CURVE(S)
CLINIC 01	ES-SYSTEM-PRIMA LED 240. LED 830-11W-1100lm		
CLINIC 02	NVC - NLED9688M 24W-4000K-1900lm		
CLINIC 03	NVC - NLED9688M 24W-4000K-1900lm		
CLINIC 04	LUG Light Factory - SOFT BASIC LED 56W 3200lm 3000K IP20 white		

Table 8. Visuals and photometric information of the recommended luminaires in operation areas. Source: DIALux simulation software (2024)

RECOMMENDED LIGHTING FIXTURES IN OPERATION AREAS			
NO	BRAND INFO(S)	PRODUCT IMAGE(S)	LIGHT DISTRIBUTION CURVE(S)
CLINIC 01	NOKALUX-IR 95 LED 3000 840-35.2W-3362lm		
CLINIC 02	NOKALUX-IR 95 LED 3000 840-35.2W-3362lm		
CLINIC 03	NOKALUX-IR 95 LED 3000 840-35.2W-3362lm		
CLINIC 04	LUG Light Factory - SOFT BASIC LED 56W 3200lm 3000K IP20 white		

In total, 4 different lighting fixtures were used to comply with the standards with different lighting design simulations. In the first scenario, two different lighting fixtures were used in the waiting and operation areas. In the second scenario, this situation was tested by using two different brand fixtures in the same spaces. In the third scenario, simulation data were obtained with the same lighting fixture in both the waiting area and the operation area (Table 9).

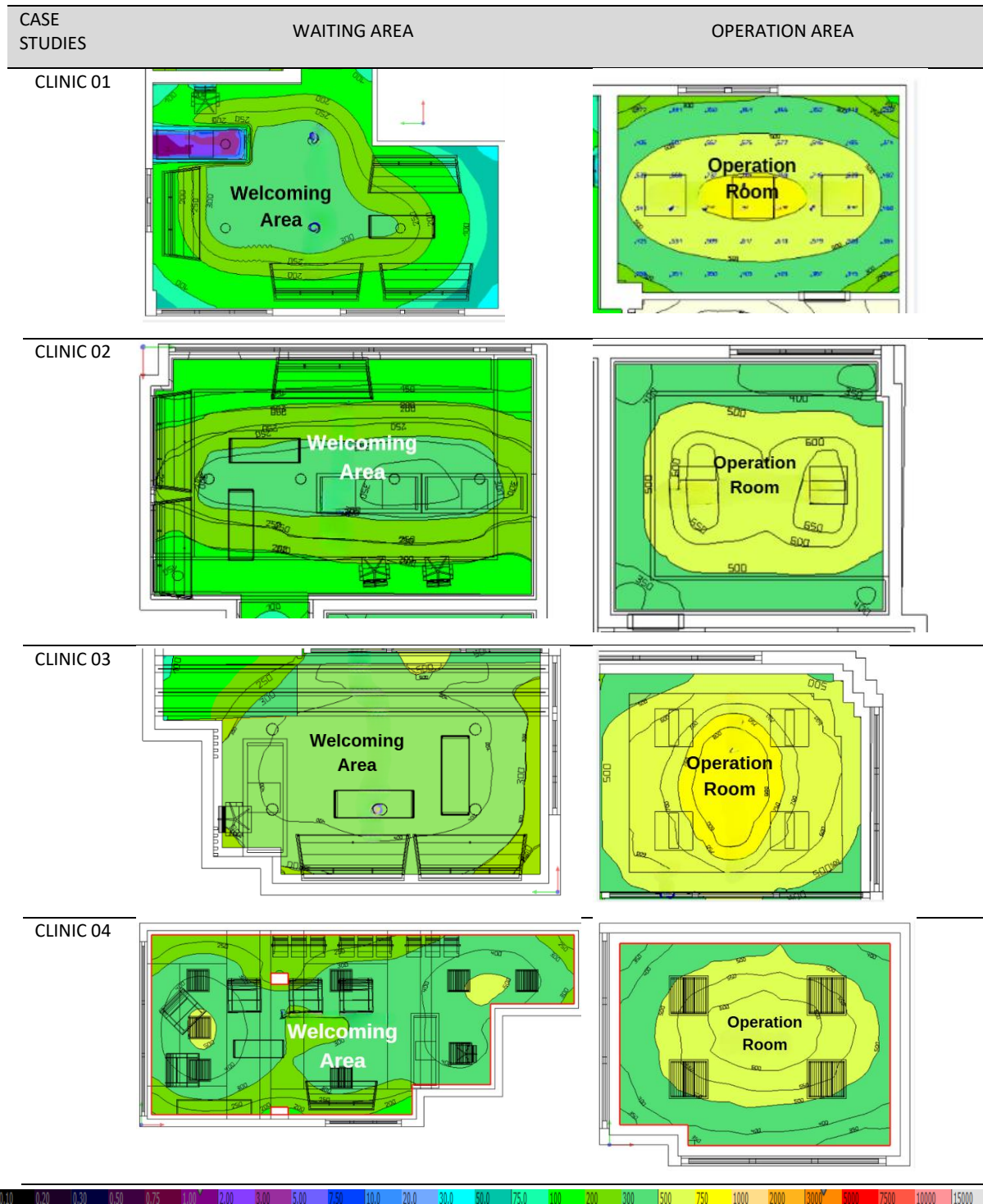
Table 9. Point Illumination level values of the recommended simulation in selected four different dental clinics. Source: Generated by Authors using DIALux simulation software (2024)

-CASE STUDIES	WELCOMING AREA		OPERATION AREA	
	E(Nominal)	U(Nominal)	E(Nominal)	U(nominal)
	(≥ 200)	(≥ 0.40)	(≥ 500)	(≥ 0.60)
Clinic 01	233 lux (✓)	0.36 (x)	609 lux (✓)	0.67 (✓)
Clinic 02	236 lux (✓)	0.48 (✓)	521 lux (✓)	0.64 (✓)
Clinic 03	395 lux (✓)	0.40 (✓)	657 lux (✓)	0.62 (✓)
Clinic 04	344 lux (✓)	0.42 (✓)	500 lux (✓)	0.60 (✓)

The DIALux simulation shows that the waiting spaces have illumination ratings ranging from 233 to 395 lux. According to the standards, the level of illumination in waiting areas should be 200 lux. The illumination values in the waiting areas in the proposed scenarios meet the required standards. The uniformity values in the waiting area are expected to be ≥ 0.40 within the framework of the standards. They were calculated as 0.48, 0.40, and 0.42 for clinics 2, 3, and 4, respectively. A value of 0.36 was obtained in clinic number 1, which is close to the standards. The illuminance value in the operation areas should be ≥ 500 and the uniformity value should be ≥ 0.60 . With the recommended lighting fixture in Clinic 4, the illuminance value was calculated as 500 lux and the uniformity value as 0.60. In clinics 1, 2, and 3, the illuminance value is between 521 and 657 lux. The uniformity values are between 0.62

and 0.67. Figure 6 shows the point illumination levels and light distribution curve values obtained from the recommended lighting scenario results of the DIALux simulation in clinics (Table 10).

Table 10. Values for point illumination levels and light distribution curves derived from DIALux simulations of the examination room and waiting area of four dental clinics with the recommended lighting fixtures. Source: Generated by Authors using DIALux simulation software (2024)



The existing lighting fixtures in four different selected clinics were replaced with the lighting fixtures suggested above. Different lighting fixtures were proposed in 4 different clinics, and the requirements of the standards were met. The ceiling of Clinic 3 was different from the ceiling of the other clinics. The beams were visible, and there were suspended ceiling applications at different levels. Therefore, in the lighting fixture proposal, the ceiling of Clinic 3 was redesigned as a flat plasterboard ceiling to prevent shadow formation due to these different levels (Figure 1).

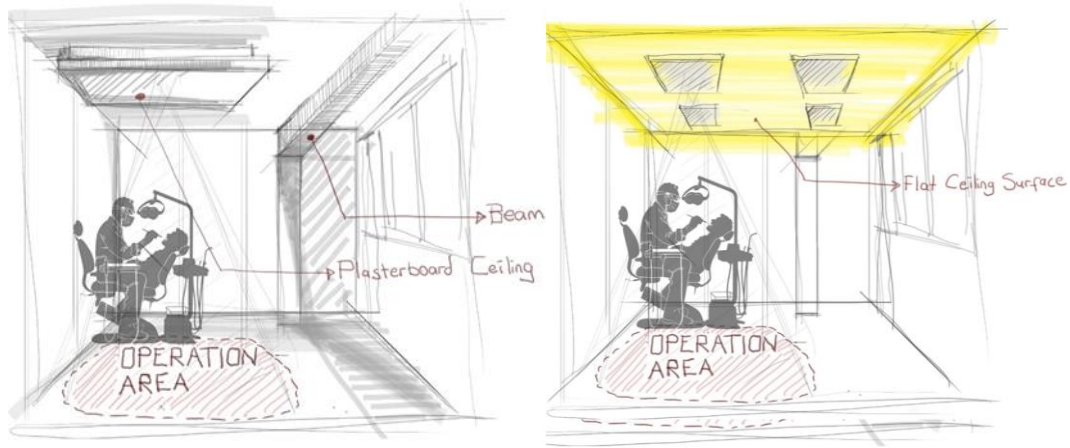


Figure 1. The first sketch is the current suspended ceiling and beams of Clinic 04. The second sketch is the designed version with the proposed plasterboard flat ceiling. Source: drawn by İrem HİDIR

In the current Clinic 3, the illuminance and uniformity values did not comply with the standards due to shadow formation on the ceiling. As Roy and Satvaya (2022) stated, shadows should be prevented in areas in healthcare buildings. Therefore, they proposed a lighting design with LED lighting fixtures in their study. In our study, we equalized the levels on the ceiling to prevent glare and shadows and recommended LED lighting fixtures. Accordingly, values following the standards were obtained.

4. Conclusion and Suggestions

The Turkish Dental Association has stated that the number of dental clinics is also increasing due to the increase in the number of dentists. Accordingly, many private dental clinics have been opened. However, the regulations published for opening dental clinics do not include the values of lighting standards in dental clinics. Lighting affects recovery rates in healthcare facilities and is therefore an important design factor. Additionally, the design of lighting should be taken into account to highlight the work performed in healthcare environments. A lighting scheme developed according to established standards impacts the motivation of staff, physicians, and the spirits of patients. When a design meets these standards, efficiency is enhanced (Perdahçı et al., 2017). According to Mehrotra Basukala & Devarakonda (2015), artificial lighting in health interiors is a crucial factor for employee performance, patient psychology, and error prevention in medical procedures. There are regulations for opening a dental clinic, and these regulations include physical conditions for space design. In the regulation published for opening a dental clinic in Türkiye, an article states, "The space must be sufficiently illuminated and ventilated." However, no information about qualification criteria is included in this regulation. Within the scope of the study, the illuminance and uniformity values of artificial lighting in waiting and operation areas of dentistry clinics, which are one of the health structures, were examined. The illuminance and uniformity values of artificial lighting currently used in 4 different dentistry clinics in Türkiye were calculated with DIALux simulation. Then, the compliance of these data with the standards was examined, and suggestions were made. According to the CIBSE (Chartered Institution of Building Services Engineers) SLL Code for Lighting (Raynham et al., 2012) and the European Committee for Standardization (2011), the illuminance value in waiting areas in clinics must be ≥ 200 and the uniformity value must be ≥ 0.40 . The illuminance value in operation areas must be ≥ 500 and the uniformity value must be ≥ 0.60 .

According to the data calculated in the DIALux simulation of the existing lighting fixtures in the 4 clinics selected as case studies, the illuminance level in Clinic 1's waiting area was determined to be 476 lux (≥ 200), while the uniformity value was 0.15 (≥ 0.40). In the operation area, the illuminance level was recorded at 435 lux (≥ 500), with a uniformity value of 0.15 (≥ 0.60). For Clinic 2, the existing lighting arrangements were evaluated, and the illuminance levels and uniformity values were assessed through simulation. The illuminance level in the waiting area was 1969 lux (≥ 200), with a uniformity value of 0.11 (≥ 0.40). The operation area exhibited an illuminance level of 2009 lux (≥ 500) and a uniformity value of 0.66 (≥ 0.60). In Clinic 3, unlike the others, two distinct types of lighting fixtures were utilized

in the waiting area. Following the simulation of these fixtures, the illumination level in the waiting area was measured at 347 lux (≥ 200), and the uniformity value was 0.41 (≥ 0.40). In the operation area, the illumination level was 198 lux (≥ 500), and the uniformity value was 0.48 (≥ 0.60). In Clinic 4, the waiting area's illumination value was found to be 191 lux (≥ 200), while the uniformity value was 0.31 (≥ 0.40). The operation area had an illumination value calculated at 115 lux (≥ 500), with a uniformity value of 0.009 (≥ 0.60).

According to Darses et al. (1996), lighting is a crucial factor in dental clinic design for doctors, as the quality of lighting directly impacts their vision. Eye fatigue has been found to be linked to physical fatigue, with 25% of overall body fatigue associated with eye strain. To prevent this and ensure working comfort, lighting design must comply with established standards. Referring to a similar study in this field, dental clinics in dental schools were examined following Brazilian standards (Ministry of Labor and Employment [MLE], 2019). The illumination level of the operating area is expected to be 500 lux according to the standards set by NBR ISO/IEC 8895-1 ABNT 7 (Brazilian Association of Technical Standards, 2013). In agreement with this standard, excessive contrast, glare, and eye-disturbing reflections should be avoided in dental operation areas. In the sample study, clinics in dental schools were examined, malfunctions in the lighting fixtures used in these clinics were detected, and the illuminance values were not found to be sufficient. Thereupon, they suggested a new lighting system with new fixtures in their study (Simões et al., 2019).

Similarly mentioned in the studies above, in our study, the current lighting system was compared and examined within the scope of international standards: CIBSE (Chartered Institution of Building Services Engineers) SLL Code for Lighting (Raynham et al., 2012), European Committee for Standardization (2011), and Turkish Standards Institute (2011). When we compare these international standards and the lighting standard for dental clinics in Türkiye, it is seen that the same values are present. The illuminance value in waiting areas should be ≥ 200 lux and the uniformity value should be ≥ 0.40 , and the illuminance value in operating areas should be ≥ 500 lux and the uniformity value should be ≥ 0.60 . It was observed that the four clinics selected as cases in our study were not compliant with the framework of the standards (Table 11), (Table 12).

Table 11. Point Illumination level values of the current situations in selected four different dental clinics. Source: Generated by Authors using DIALux simulation software (2024)

A. Point Illumination level values of the current situations in selected four different dental clinics						
CASE STUDIES	WELCOMING AREA			Ceiling Height (cm)	OPERATION AREA	
	E (Nominal) (≥ 200)	U (Nominal) (≥ 0.40)	Area (m ²)		E (Nominal) (≥ 500)	U (nominal) (≥ 0.60)
Clinic 01	476 lux (✓)	0.15 (x)	11.4	252	435 lux (x)	0.15 (x)
Clinic 02	1969lux (✓)	0.11 (x)	18.1	254	2009 lux (✓)	0.66 (✓)
Clinic 03	347 lux (✓)	0.41 (✓)	14.5	283	198 lux (x)	0.48 (x)
Clinic 04	191 lux (x)	0.31 (x)	22.3	240	115 lux (x)	0.009 (x)

Table 12. Point Illumination level values of the recommended situations in selected four different dental clinics
Source: Generated by Authors using DIALux simulation software (2024)

B. Point Illumination level values of the recommended simulation in selected four different dental clinics				
CASE STUDIES	WELCOMING AREA		OPERATION AREA	
	E(Nominal)	U(Nominal)	E(Nominal)	U(nominal)
	(≥ 200)	(≥ 0.40)	(≥ 500)	(≥ 0.60)
Clinic 01	233 lux (✓)	0.36 (x)	609 lux (✓)	0.67 (✓)
Clinic 02	236 lux (✓)	0.48 (✓)	521 lux (✓)	0.64 (✓)
Clinic 03	395 lux (✓)	0.40 (✓)	657 lux (✓)	0.62 (✓)
Clinic 04	344 lux (✓)	0.42 (✓)	500 lux (✓)	0.60 (✓)

Unlike the current situation, the ceiling of clinic number 4 has a different design than the other clinics. There is a ceiling at different levels, and beams are visible. This has caused poor results in the illuminance and uniformity values in the space. The desired results cannot be obtained in this ceiling type with the luminaires we selected while making the recommendation. According to our analysis, a flat and smooth ceiling should be obtained to provide proper light distribution in dental clinics, as in the other 3 clinics. Thus, as stated in the standards and similar studies, harsh contrast values, shadows, and reflections are avoided. Consequently, a new lighting system was designed using 4 different lighting fixtures, and the operation area of clinic number 3 was covered with plasterboard as a flat ceiling, unlike its current situation. Then, according to the DIALux simulation results obtained with the suggested fixtures, the lighting design complies with the standards. The article "The clinic should be sufficiently illuminated" in the regulation to open a dental clinic in Türkiye should be detailed, and these standards should be included in the regulation. Thus, the lighting factor in dental clinics, which are one of the health spaces, can be designed most healthily and following the standards for the comfort of working doctors and patients.

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Author Contribution and Conflict of Interest Declaration Information

All authors contributed equally to the article. There is no conflict of interest.

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