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The impact of color and materials selection on lighting design in classroom

Dersliklerde renk ve malzeme seçiminin aydınlatma tasarımına etkisi

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The Impact of Color and Material Selection on Lighting Design in Classrooms

Highlights

- *Classroom illuminance was evaluated per TS EN 12464:2021 via measurements and simulations.*
- *Wall colors and desk materials' effect on illuminance and light distribution were analyzed in Dialux.evo.*
- *A significant contribution to energy efficiency was demonstrated through the manipulation of color and material parameters within the scope of interior design.*

Graphical Abstract

The illuminance levels of classrooms were measured and evaluated according to the TS EN 12464:2021 standard. Simulations of warm/cool wall colors and desk material combinations were conducted in Dialux.evo to examine their effects on illuminance levels (lx) and light distribution at the work plane and focused surface.

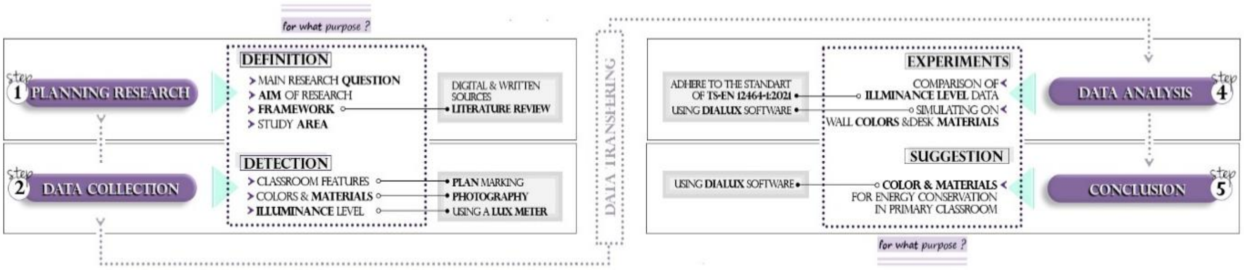

Figure. General methodology diagram

Aim

The aim of this study is to holistically address classroom lighting design in educational buildings and quantitatively reveal the impact of wall colors and student desk materials on energy-efficient lighting.

Design & Methodology

Following the assessment of existing illuminance levels in the classrooms, a series of lighting simulations were conducted using Dialux.evo software to evaluate the effects of various wall surface color and desk material combinations on energy-efficient lighting performance.

Originality

This study adopts a holistic approach to energy-efficient lighting design in classrooms, encompassing not only the quantitative and qualitative characteristics of lighting fixtures but also spatial factors such as color and texture, which play a crucial role in enhancing visual comfort and energy performance.

Findings

Simulations in Dialux.evo 12 using 6500K LED fixtures revealed that classrooms with 80% reflective warm-toned walls combined with PPC seating achieved the highest illuminance levels, while those with 50% reflective cool-toned walls and wooden seating exhibited the lowest.

Conclusion

The orientation of the space and the reflectance ratio notwithstanding, it was concluded that warm colors contribute to higher illuminance levels compared to cool colors. Changes in colors and materials within the space significantly affect not only the illuminance level but also the quality of light distribution, with the impact of color changes being greater on the work plane compared to the focused surface.

Declaration of Ethical Standards

The author(s) of this article declare that all necessary legal permissions related to the study were obtained from the relevant institutions.

The Impact of Color and Material Selection on Lighting Design in Classrooms

Araştırma Makalesi / Research Article

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ABSTRACT

This study addresses lighting design as a key factor for energy efficiency and sustainability. A significant portion of global energy consumption is electricity, much of which is allocated to building lighting. The large number of educational buildings and their year-round use require efficient lighting strategies to reduce energy consumption. In classrooms, proper lighting design not only ensures energy savings but also enhances visual comfort, thereby supporting efficiency in education. This study aims to examine lighting design in classrooms within a holistic and sustainability-oriented framework by revealing the impact of wall surface colors and student desk material properties on energy-efficient lighting design. In this context, current illumination levels in classrooms were measured and evaluated for compliance with standard, then illuminance calculations were carried out using DiaLux.evo software to suggest wall color and desk material recommendations. The research findings indicate that, regardless of room orientation and the reflectance coefficient of the color, warm colors contribute more to work plane illuminance compared to cool colors. In addition, it has been observed that changes in wall surface colors and desk surface materials significantly affect not only the level of illuminance on the work and focal surface but also the quality of light distribution.

Keywords: educational building, artificial lighting, efficient energy, visual comfort.

Dersliklerde Renk ve Malzeme Seçiminin Aydınlatma Tasarımına Etkisi

ÖZ

Bu çalışma, enerji verimliliğini sağlamaya yönelik ve sürdürülebilirliğin en önemli unsurlarından biri olan aydınlatma tasarımını ele almaktadır. Küresel enerji tüketiminin önemli bir kısmı elektrik enerjisi kullanımına dayanmaktadır ve bu enerjinin büyük bir bölümü bina aydınlatmasına ayrılmaktadır. Eğitim yapılarının sayıca fazla olması ve yıl boyunca aktif olarak kullanılması, enerji tüketimini azaltmaya yönelik etkin bir aydınlatma tasarımını zorunlu kılmaktadır. Dersliklerde doğru aydınlatma tasarımı, enerji tasarrufunun yanında, görsel konfor sağlayarak da eğitimde verimliliği desteklemektedir. Dersliklerde aydınlatma tasarımını bütüncül ve yapının sürdürülebilirliği bağlamında ele alarak, dersliklerin duvar yüzey renklerinin ve öğrenci sıralarının malzeme özelliklerinin enerji etkin aydınlatma tasarımına etkisinin ortaya koyulması amaçlanmıştır. Bu bağlamda, dersliklerde mevcut aydınlatma düzeyleri ölçülerek standarda uygunluğu belirlenmiş, ardından DiaLux.evo yazılımıyla dersliklerde tercih edilecek duvar yüzey renk ve sıra malzeme önerilerinin sunulmasına yönelik aydınlık düzeyi hesaplamaları yapılmıştır. Araştırma bulguları, mekanın yönelimi ve rengin yansıtma katsayısından bağımsız olarak, sıcak renklerin soğuk renklere kıyasla çalışma düzlemi aydınlık düzeyine daha fazla katkıda bulunduğunu göstermektedir. Bunun yanında duvar yüzeylerindeki renk ile sıra yüzeylerindeki malzeme değişiminin çalışma düzlemi ve odak yüzeyinde hem aydınlık düzeyi üzerinde hem de ışık yayılımında etkili olduğunu göstermektedir.

Anahtar Kelimeler: eğitim yapıları, yapay aydınlatma, etkin enerji kullanımı, görsel konfor.

1. INTRODUCTION

One of the fundamental principles of sustainable architecture is resource conser-vation. In this context, effective utilization of daylight is closely related to energy con-servation, among many other strategies, which primarily aim at resource preservation. Environmental issues alongside increasing population and consumption rate of energy underline the importance of efficient energy use in today's globalized world. Electric power consumption represents nearly 20% of the global energy demand, a substantial portion of which is attributed to lighting applications in high-occupancy environments such as educational buildings. According to IAE report which was published in 2022, with the widespread use of electrical devices caused of technological advancements, electricity demand is expected to increase 30% by 2030. According to the Stated Policies Scenario, electricity demand is projected to increase by 80% and by 120% according to announced Pledges Scenario in 2050. According to Net Zero Emissions Scenario electricity demand is pro-jected to increase by 150% in 2050 [1]. Lighting constitutes between 20% to 50% of global electricity demand worldwide [2]. It is observed that in Türkiye the use of electricity for lightning purposes has increased by 52.2%

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over the past decade from 2014 to 2024 [3]. Accordingly, lighting systems alone are responsible for approximately 56% of the total electricity consumption in buildings, underscoring their critical role in overall energy demand within the built environment [4]. Consequently, the deliberate specification and integration of lighting systems are recognized as critical strategies for mitigating energy consumption throughout the design, construction, and operational phases of buildings [5]. In the assessment of energy poverty and the formulation of energy-efficient strategies, lighting constitutes a critical component that necessitates an independent and detailed evaluation [6].

Current data in Türkiye shows that there are a total of 70,383 educational structures and 749,454 classrooms in public buildings [7], these numbers show that making educational facilities considerably more prevalent compared to other building catego-ries. Alongside the high number of buildings, considering the intensity of use, the ser-vices provided, and the necessity of ensuring visual comfort conditions in educational structures, the potential energy savings become significantly important [8,9]. Although the active usage periods of educational buildings are generally conducive to benefiting from daylight, artificial lighting systems are frequently utilized in classrooms to ensure the illuminance levels specified in international standards [10] and to achieve uniform lighting for visual comfort conditions.

Conscious design of lighting systems in educational buildings contributes not only to the preservation of eye health but also to ensuring the efficient continuation of education by providing visual comfort conditions and achieving significant energy savings. Additionally, proper design of lighting systems enables students to perceive each space correctly and perform their actions effectively without experiencing physical or mental discomfort in different functional areas such as classrooms, libraries, laboratories, cafeterias, and corridors [11-16]. Furthermore, it is an important design element that influences students through various ways unrelated to the visual perception of lighting [17-20].

In educational buildings, one of the requirements for conscious lighting design is its potential contribution to efficient energy use. While natural lighting is primarily utilized in educational buildings, artificial lighting fixtures are often employed to maintain a consistent level of illumination in classrooms due to Earth's daily movements. Bayer and Yazıcı (2019) reveal that, particularly during and after the pandemic period when remote working became prevalent, users placed significant importance on daylight in their home working environments. They found that the majority of modifications made to these spaces were aimed at maximizing the benefit from natural light. The findings of this study indicate the need for further research on the effects of daylight on workspaces [21]. In this context, in the artificial lighting design of educational buildings, selecting the appropriate luminaires and arranging them correctly makes it possible to reduce both electricity consumption and construction costs [22]. In achieving energy efficiency, the qualitative and quantitative characteristics of artificial lighting fixtures are as crucial as the color and material properties of the working plane, ceiling, floor, and wall surfaces within the space. Therefore, in energy-efficient lighting designs, consideration should also be given to the color and material properties of surfaces and furnishings in meeting the lighting conditions specified by standards [23-25].

It has been determined that energy-efficient lighting approaches in educational buildings involve integrated lighting systems that provide optimum conditions, with evaluations based on the type, location, and power of lighting fixtures. Typically, lighting design is considered independently of other physical parameters such as color and material in the space. This study discusses the effects of physical variables such as color and texture on achieving a homogeneous illumination level and energy savings in a space. Based on the analysis conducted in this study, information regarding effective color and material choices to achieve electricity savings in classroom design is provided.

2. COLOR, MATERIAL AND LIGHTING IN CLASSROOM

There are numerous studies about color selection in interior spaces. It is concerned in the literature that about the use of color in educational buildings, the focus has primarily been on the relationship between color and lighting. While some of these studies support each other's findings, others have conflicts with one another. This study is based on the premise that the selection of colors and materials on wall surfaces and furniture in classrooms not only effects visual comfort conditions and learning motivation but also plays a role in energy-efficient lighting design.

The colors to be used on interior walls, ceilings, and floors are effective parame-ters in the brightness level of the space. When selecting or using colors, it is important to consider all components related to color (hue, reflectance coefficient, color render-ing index, etc.) together. Surfaces exhibit different characteristics in terms of light reflectance properties, showing glossy, matte, and intermediate states. Light reflectance coefficients of light-colored surfaces are larger than those of dark-colored surfaces. Therefore, whether the surface color is light or dark affects the quality of shadows, the luminosity ratio of the space, and the brightness level. Light-colored interior surfaces and furnishings used in classrooms increase individuals' visual efficiency due to their high reflectance properties. In this context, there are determined values regarding the light reflectance coefficients of colors and materials to be used in classrooms [26]. High reflectance coefficients of surface colors and materials contribute to energy savings by providing visual comfort conditions. Reflectance values are recommended to be within the range of 70-90% for ceilings, 50-80% for wall surfaces, and 20-70% for large furnishings occupying significant space within the area [10]. For the floor covering materials, which form a secondary surface for the desks used in classrooms, a reflectance coefficient of 20-25% is required [23,27]. In energy-efficient lighting design, when the reflectance coefficient of surfaces is at least 70%, ceilings serve as a secondary light source for artificial lighting fixtures, supporting the conservation of energy expended for lighting [23].

In the first half of the 20th century, during a time when the increase in energy demand was just beginning, Hynds (1944) particularly evaluated the relationship between lighting efficiency and color for educational buildings. Hynds emphasized the necessity for wall surface colors in classrooms to contribute to lighting efficiency by having reflectance coefficients that enhance brightness [28]. For classrooms receiving more daylight than expected, Hynds recommended designing them with cool colors such as blue or green, while suggesting that classrooms with insufficient daylight should be designed with warm color tones like yellow, orange, or beige [29,30]. The surface colors used in classrooms should be selected in light tones to ensure compatibi-lity with achieving homogeneous brightness levels as per standards, thereby reducing the amount of energy expended for lighting purposes [26]. However, it is not sufficient to conscientiously select wall surface and furnishing colors; the color of light used in classrooms is also important due to its impact on the accurate perception of surface and material properties. If the wall surface color in classrooms is in shades of blue, lighting fixtures with artificial lighting elements should have cool daylight; if the wall surface color is in shades of orange, it is recommended that the lighting fixtures have a warm white lamp color temperature [30]. Additionally, using artificial lighting elements with daylight-like and high color temperature in classrooms helps students to be less affected by sudden changes in brightness levels and positively influences their participation in class [20,32,33].

Color is considered an important design element not only because of its psychological and physiological effects on students but also due to its impact on academic achievement[26, 34–37]. Excessive use of color in classrooms can lead to overstimulation of multiple senses simultaneously in students [38], while insufficient use of color may cause stress and aggression, resulting in an inefficient learning process [39]. Therefore, when selecting the surface color of the classroom in its design, attention should be paid not only to aesthetic concerns but also to its functional aspect, which contributes to facilitating focus and learning [35, 40]. When examining the relationship between color and students' learning performance in classrooms with walls painted in different colors, it has been found that warm color tones increase students' motivation and ease of focus compared to cool color tones or white [41]. On the other hand, another study found that cool color tones increased attention and memory performance to a greater extent compared to warm tones [42]. For the walls of primary school classrooms, it is recommended to use warm colors such as yellow, pink, or terracotta [30,43,44], preferably in the scale between skin color and sand color [35]. Similarly, the literature suggests that the use of soft/pastel green or blue tones on wall surfaces [35], particularly the blue color coded 5B 8/R in the Mussel Color System [37], will have positive effects on learning.

Color cannot be considered independently of materials. Therefore, material properties are as important in design as the color of surfaces abd furnishings. Materials can have different properties through processes such as texture, polished, etc. the texture of spatial components is defined by the material that makes up that component. Texture, which visually affects humans, alters the perception of color and shape. The surfaces with the same color are perceived in different colors and tones when different textures are used. Therefore in energy-efficient design in educational buildings, both the color and material properties of surfaces and furnishings should be considered together.

3. MATERIAL and METHOD

In this study, the significance of the consideration of color and material properties in indoor spaces for effective utilization of energy expended on lighting in educational structures is aimed to be highlighted. Towards this aim, the existing levels of illumination in primary education structures were measured, and alternative color and material options for energy-efficient lighting were tested using Dialux. evo software. Initially, onsite inspections were carried out in classrooms within this scope. During this phase, classroom dimensions, color and material characteristics, furniture features,

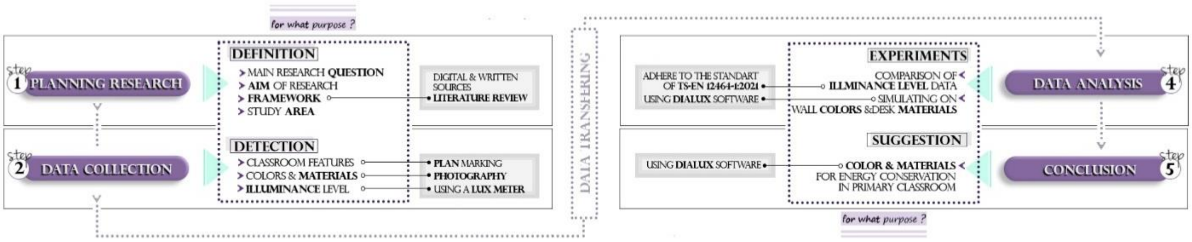


Figure 1. General methodology diagram

spatial organization, lighting, and shading elements were identified, and the current illumination levels in the classrooms were measured. Illumination level measurements were conducted in three different scenarios: natural, artificial, and integrated lighting. Firstly, the data regarding the conformity of the measured current illumination levels to the TS EN-12464:2021 Standard were presented. Based on the data obtained from the on-site inspections, all classrooms were simulated using Dialux.evo software, and the effects of different colors and materials on the illumination level on work and focus surfaces were calculated for walls and furniture (Fig.1).

3.1. Study Area

The study was conducted in a two-story primary school building located in Trabzon province (Fig. 2). The primary school is situated at 40.94 degrees latitude and 39.68 degrees longitude, in the GMT +2 time zone. The building consists of 4 primary school classrooms and 4 middle school classrooms. Primary school classrooms are sit-uated on the ground floor, with two classrooms facing north and the other two facing south. To evaluate the current levels of illumination in the classrooms and to select the period when artificial lighting is most intensively used, specific dates for measure-ments were determined based on data provided by the Meteorology General Directorate. Trabzon province is among the cities with the lowest solar energy potential, with an annual average of 1400-1450 KWh/m2, and an average sunlight duration of 4.5 hours per day. The closest season to closest season to these data is autumn, with sunlight durations of 4.9 hours in September, 4.5 hours in October, and 3.6 hours in November [45,46]. The decisive criteria for selecting the measurement days were ensuring clear sky conditions and choosing days when students do not attend school, such as holidays.

Figure 2. Study area

The illumination level measurements in the classrooms were conducted in three different ways: natural lighting, artificial lighting, and integrated lighting combining both. The measurement time interval was set from 10:00-11:00 a.m., chosen based on the criterion of classrooms receiving optimal daylight. During the measurement of natural lighting levels, the lights were turned off, and the curtains were left open. For the measurement of artificial lighting levels, artificial light sources were turned on, and the curtains were closed. In cases where both natural and artificial lighting were pre-sent, both curtains and artificial light sources were turned on. The room index (R) [10] of the classrooms was calculated as 1.136, and the measurements were carried out us-ing a DT-1309 lux meter at 16 different points in the classrooms, at 1.5-meter intervals, at a height of 80 cm above the working plane (measurement range 0.1 lux-0.1 Klux, margin of error ±5%). Except for essential furnishings such as desks, chairs, boards, and classroom cabinets, no other variables such as student clothing, books, or note-books were present in the classrooms during the measurements.

3.2. Simulating on Dialux.evo 12

Based on the findings obtained from the illumination level measurements in the classrooms, the aim was to provide recommendations for both visual comfort and energy savings in accordance with the values specified in the TS-EN 12464-1: Light and lighting - Lighting of work places - Part 1: Indoor work places. In order to assess the impact of colors and materials in the space on illumination levels for energy savings, Dialux.evo 12 software was used to simulate eight different scenarios by changing wall colors and furniture colors and materials in all classrooms (Classroom 01-02-03-04). Simulations are a critical tool not only for evaluating daylight performance but also for conducting accurate and comprehensive calculations in integrated lighting scenarios where both daylight and artificial lighting are considered simultaneously. In this context, the selection of simulation software varies depending on the purpose of the study and the required depth of analysis, with different platforms offering distinct capabilities [47, 48]. In the present study, Dialux evo was selected due to its ability to incorporate both daylight and artificial lighting in the computational process. For artificial lighting calculations in the software, the date (14.11.2023), time (11:00), and sky type (clear sky) were selected to account for daylight. Additionally, the latitude and longitude (40.94 and 39.68) of the primary school, time zone (+2 GMT), and north direction were processed in the software. Table 1 contains data related to the physical design parameters determined in Dialux.evo for the fixtures present in all classrooms.

As of the academic year 2023-2024, four LED fixtures are used as artificial lighting elements in the classrooms. The fluorescent fixtures have been replaced with LED fixtures, and the switch arrangement of the fixtures has been organized into two levels: window side and corridor side (Fig. 3). The usage duration of LED fixtures is considered to be 5 days a week, with an average of 7 hours per day. According to the EN12464-1 standard in the Dialux database, the annual energy demand of the fixtures ranges from 115 to 192 kWh, with CO2

Table 1. The structural and equipment features of the classrooms modeled in Dialux.evo 12 software

STRUCTURAL FEATURES								
	Plan Dimensions	Ceiling Height	Beam	Glazing Area	Windos Pieces	Window	Door	Floor
Size (cm)	680x650	280	40x680	13,44 m^2	6	140x160	100x200	60x120
Color& Materials	Concrete	Concrete	Concrete			#F6F6F6	Oak Wood	Granite
FURNITURE FEATURES								
	T's Desk	T's Chair	Bookcase	W. Board	Curtain	Store-1	Store-2	Board
Size (cm)	120x60x75	61x53x88	120x42x180	165x120	135x160	40x40x40	100x120	120x80x5
Color& Materials	Oak Wood	Black Fabric	Oak Wood	#E7E7E7	#EAE0C0	#FE6B0C	Teak Wood	Red &Blue Fabric

emissions ranging from 46 to 77 kg. The maximum annual savings cover 40% of the total energy demand, with a saving potential of 77 kWh. Within the scope of the study, eight different combinations were tested to determine the extent to which energy savings could be achieved through the selected wall surface colors and seating materials aimed at achieving maximum energy efficiency.

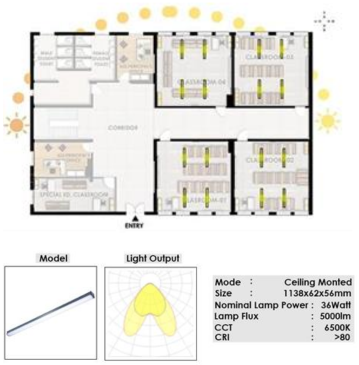


Figure 3. The electrical lighting fixture used in the classrooms is LED fixtures

surfaces were determined from the Munsell Color System, frequently utilized in the literature [49]. Student desks were chosen to be commonly preferred materials such as wood and PPC (Polypropylene Carbonate). Since the study aims to contribute to energy savings by enhancing illumination levels in classrooms, Munsell's colors were classified based on their reflectance rates using the 'chart' system. The purpose of using this system is to adhere to the TS-EN 12464-1 standard when evaluating illumination levels in the study. According to the standard, it is recommended that wall surfaces in classrooms have a reflectance of 50% to 80%. For the simulation, colors were selected from the warm and cool color groups with the lowest 50% reflectance and from the warm and cool color groups with 80% reflectance to determine the impact of color on illumination levels. Alongside these color combinations, the secondary variable is student desks. Table 2 presents the color and material combinations aimed at contributing to energy-efficient lighting design within the scope of the study. The combination labeled #06, enclosed within a frame, represents the simulated version of the current condition.

Table 2. Combination of Wall Color and Student Desk Materials Prepared for Energy-Efficient Lighting Approach (numerical data (%) for the reflection and reflection coating of student desk materials were obtained from the records in Dialux.evo 12.)

Co. Nu.	**WALL COLOR**			**DESK MATERIAL**			
	Mussel Color System		**Wall Color's HEX Code**	**Texture**	**Material**	**Reflectivity**	**Reflect Coating**
#01	%50 Chart	Warm	#8E805C		Beech Wood	%56	%2
#02	%80 Chart	Warm	#DECFBA		Beech wood	%56	%2
#03	%50 Chart	Warm	#8E805C		PPC	%70	%8
#04	%80 Chart	Warm	#DECFBA		PPC	%70	%8
#05	%50 Chart	Cold	#6A959B		Beech Wood	%56	%2
#06	%80 Chart	Cold	#C3CFCB		Beech wood	%56	%2
#07	%50 Chart	Cold	#6A959B		PPC	%70	%8
#08	%80 Chart	Cold	#C3CFCB		PPC	%70	%8

3.3. Determining Colors and Materials for Energy-Efficient Lighting

In the study aimed at identifying the impact of wall surface colors and material properties of student desks on illumination levels in the classrooms for energy-efficient lighting, the color options to be used on classroom wall

4. FINDING AND DISCUSSION

In the area study covering the primary school classrooms at Karlık Primary School, illumination level measurements were conducted at designated measurement reference points for each classroom. The provided tables represent natural lighting, ar-tificial lighting, and integrated lighting, which refers to the combined measurement of natural and artificial lighting. In this section of the study, the four classrooms where measurements were taken will be examined separately, considering their existing volumetric characteristics along with spatial design features such as materials and colors integrated with the lighting systems, all of which are included in the study for energy-efficient lighting design recommendations.

4.1. Classroom-01

Classroom-01 is the first of two classrooms situated in the northern direction of the educational structure (Fig.4). This classroom is consistently utilized for first-grade primary education.

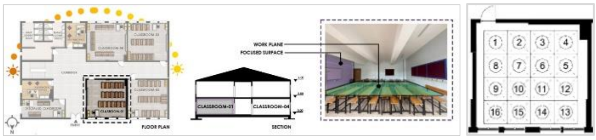


Figure 4. Classroom-01’s floor plan, section,photograph and measurement points

4.1.1. Current data of classroom-01

Graphs depicting the illuminance level measurements taken in September, October, November from 16 different reference points in Classroom-01 are provided in Table 3. Upon examining the measurement data, it is observed that the highest illuminance level was consistently measured near the windows during September, October, and November. According to the natural lighting data, it was determined that the illuminance level at reference points 13-16 in September, points 13-15 in October, and points 14 and 16 in November was at the standard level. According to the artificial lighting data, it was found that the illuminance level at reference points 9, 10, 13, and 14 in September, point 16 in October, and points 15 and 16 in November was at the standard level. Based on the integrated lighting data, it was determined that the illuminance level at reference points 13-16 in September, points 13-16 in October, and points 13, 14, and 16 in November was at the standard level. The data group exceeding the maximum illuminance level specified in the stand-ard was only measured in September, covering reference points 13-16 along the window edge in both natural and integrated lighting conditions. The highest illuminance level in Classroom-01, located in the north direction, was measured in September, while the lowest level was measured in November.

4.1.1. Simulation results for classroom-01

The average illuminance levels in the space, depending on different wall surface colors and seating materials simulated in Dialux.evo 12 for Classroom-01 (Table 4). In combination #04, where walls are painted with warm color tones with 80% re-flectance and seating materials are PPC, the highest illuminance level was achieved both on the working plane and the focus/learning plane. Conversely, in #05, which includes walls with cold color tones with 50% reflectance and seating materials made of wood, the lowest illuminance level was observed.

Table 3. Assessment of classroom-01’s measured illuminance levels for the months of September, October and November based on TS-EN 12464:2021

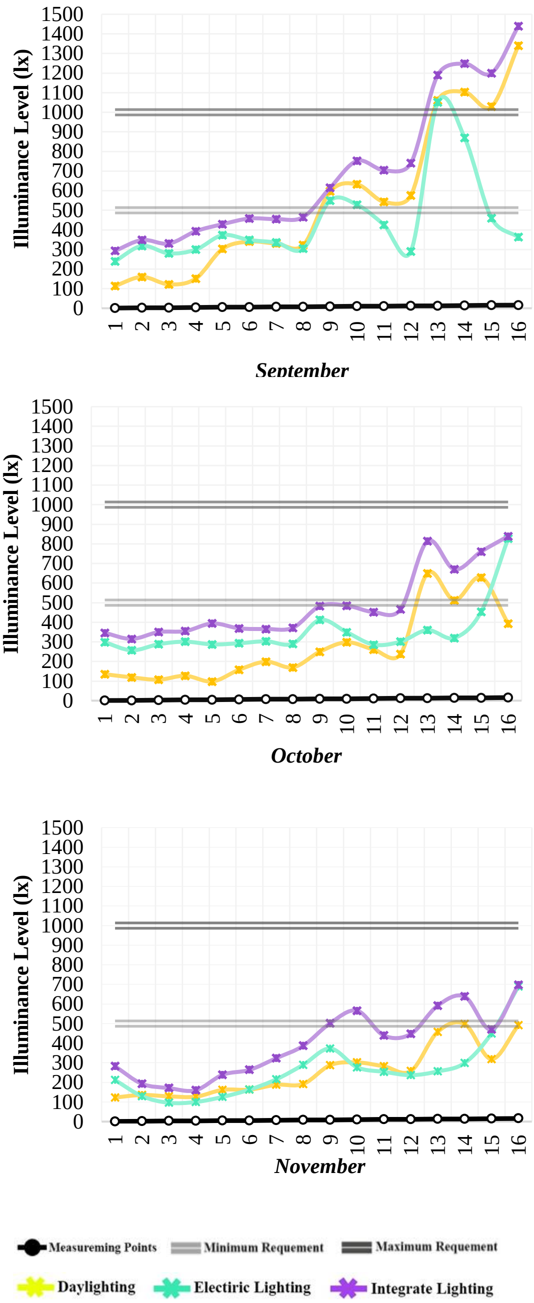
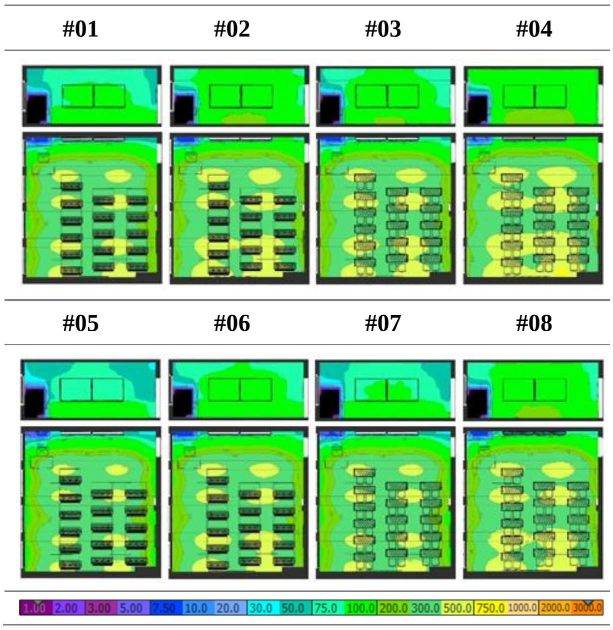


Table 4. Illuminance level (lx) distributions obtained by simulating classroom-01 on dialux.evo according to combinations



In combinations prepared with PPC student desks, the highest illuminance level is achieved with walls painted in warm color tones with 80% reflectance, while the lowest illuminance level is obtained with walls painted in cold color tones with 50% reflectance. In Classroom-01, an average illuminance level of 380 lux was achieved with a combination of walls painted in warm color tones with 50% reflectance and walls painted in cold color tones with 80% reflectance, along with PPC student desks.

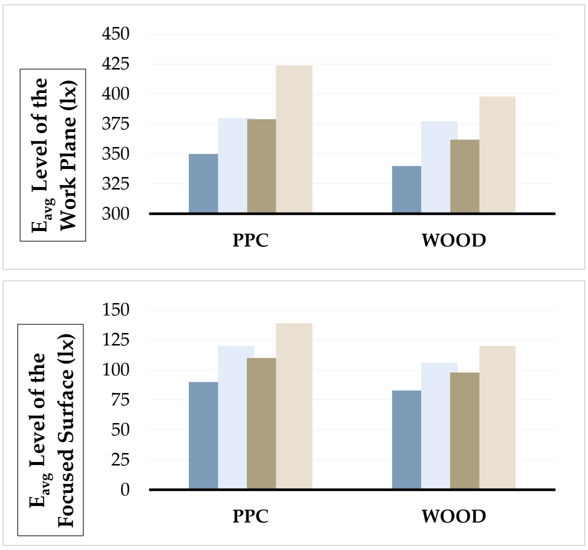


Figure 5. The luminance levels classified according to wall surface color and seating materials: (**a**) E_{ort} illumination level (lx) at the working surface; (**b**) Average illumination level (lx) at the focused surface.

4.2. Classroom-02

Classroom-02 is located in the northeast direction of the educational building (Fig. 6) and is consistently used for second-grade elementary school students.

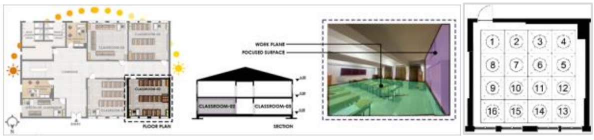
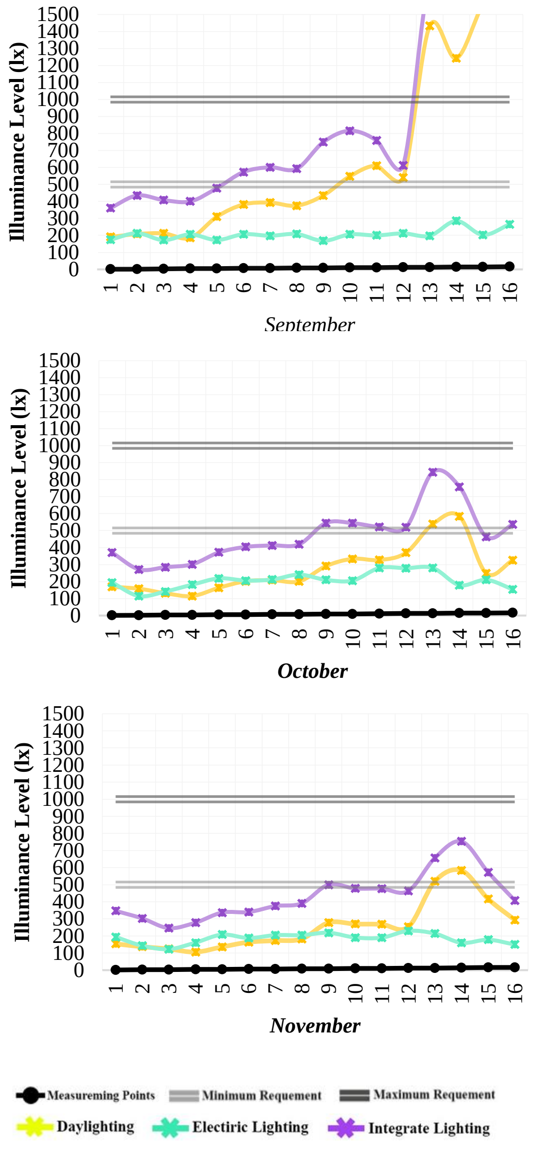


Figure 6. Classroom-02's floor plan, section,photograph and measurement points

4.2.1. Current data of classroom-02

In Classroom-02, located to the north and east of Classroom-1.

Table 5. Assessment of classroom-02's measured illuminance levels for the months of September, October and November based on TS-EN 12464:2021



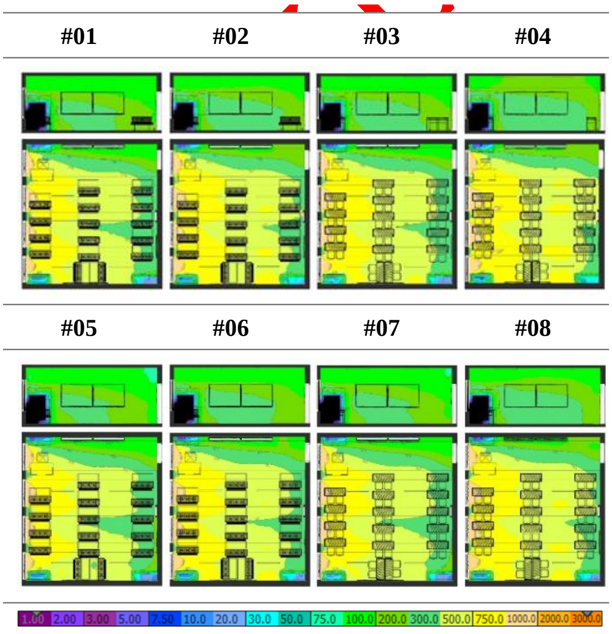
The highest illuminance levels were measured near the windows at 16 different reference points, as shown in Table 5. The highest illuminance level in Classroom-02, located to the north, was measured in September. The data group exceeding the maximum required illuminance level was measured only in September, covering reference points 13-16 along the window edge, in both natural and integrated lighting conditions.

According to the natural lighting data, it was found that in September measure-ments, the illuminance level at measurement points 10-12 met the required stand-ard level in October and November at measurement points 13 and 14. According to the artificial lighting data, it was determined that the required standard level was not met in any of the months measured, indicating that the lu-minaires in the classroom were inadequate. Based on the integrated lighting data, it was found that in September measure-ments, the illuminance level met the required standard level at points 6-11 and 12, in October at points 9-16, and in November at points 9, 13-15 (Table 5).

4.2.2. Simulation results for classroom-02

Classroom-02 was simulated using dialux.evo 12 software, and the average illu-minance levels in the space, depending on the wall surface and desk materials, have been compiled in Table 6. In combination #04, where walls are painted with a warm color tone and have an 80% reflectance rate, along with desk made of PPC material, the highest illuminance levels were achieved both on the working plane and the focused surface. Conversely, combination #05, which comprises walls with a 50% reflectance rate and a cool color tone, along with desk made of wood, resulted in the lowest illuminance levels.

Table 6. Illuminance level (lux) distributions obtained by simulating classroom-02 on dialux.evo according to combinations



When compared to Classroom-01, in the same combination of wall color and desk material, a 58% higher illuminance level was achieved on the working plane. This is attributed to the lower density of fixtures in this classroom and higher light transmittance of shading elements on the windows.

Both on the focused surface and the working plane, the highest illuminance level was achieved with walls painted in warm colors with an 80% reflectance rate, regard-less of the seating material, while the lowest illuminance level was obtained with a combination of walls painted in cool colors with a 50% reflectance rate (Fig. 7). In all combinations tested in Classroom-02, the average illuminance level specified for the working plane was reached. The combination of walls painted in warm colors with an 80% reflectance rate and PPC desk came closest to the standard with an average illuminance level of 268 lx on the focal plane. However, when the same wall color was paired with wooden desk, the illuminance level dropped to 236 lx, resulting in a 11,9% decrease in illuminance level.

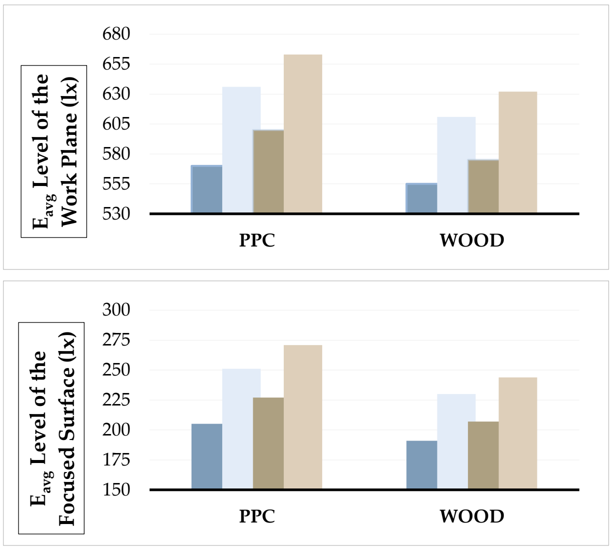


Figure 7. The luminance levels classified according to wall surface color and seating materials: (a) E_{ort} illumination level (lx) at the working surface; (b) Average illumination level (lx) at the focused surface.

In the classroom with walls painted in warm colors and positioned in the northwest direction, compared to the classroom positioned in the northeast direction, it created an illuminance level that was 35,8% higher on the working plane and 48,9% higher on the focused surface. The main reasons for this higher level are primarily attributed to the shape of shading elements and the orientation of the space. In Classroom-01 positioned in the northeast direction, it was determined that it created a higher illuminance level ranging from 2.65% to 4,8% on the working plane and from 8,2% to 15,49% on the focused surface. In Classroom-01 positioned in the northwest direction, it was de-termined that it created a higher illuminance level ranging from 2,65% to 4,8% on the working plane and from 7,15% to 10,94% on the focused surface.

4.3. Classroom-03

Classroom-03 is positioned in the southeast direction of the educational building (Fig. 8) and is consistently used for third-grade elementary school students.

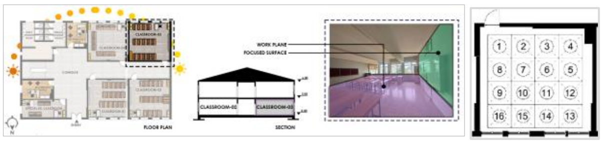


Figure 8. Classroom-03's floor plan, section, photography and measurement points

4.3.1. Current data of classroom-03

In Classroom-03, positioned to the south, measurements were taken at 16 different reference points, and graphs prepared for three different scenarios are compiled in Table 7.

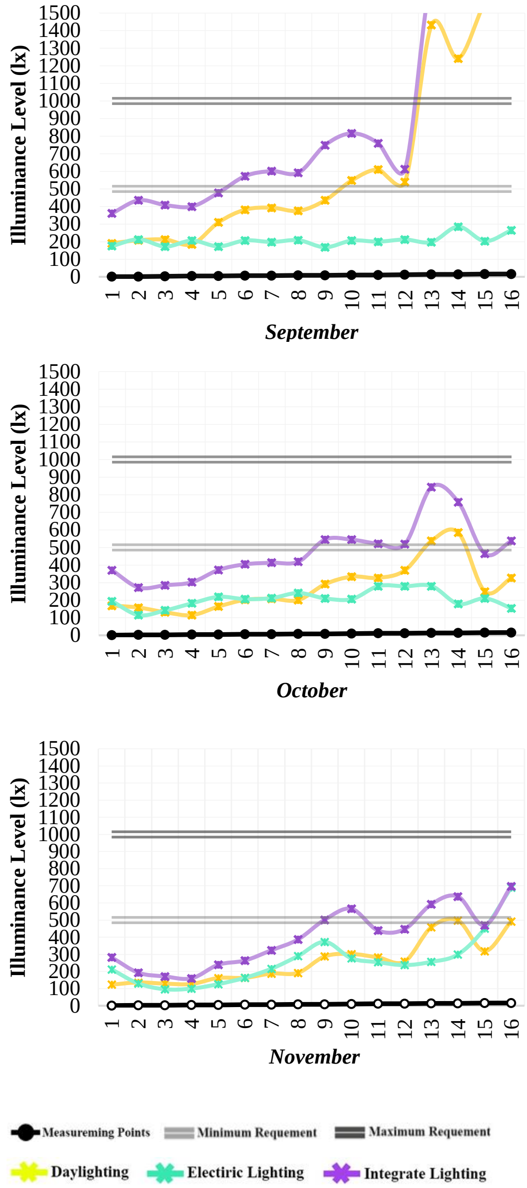
According to the natural lighting data, in September measurements, the measurement points along the window edges exceed the desired level. In October measure-ments, measurement points 1-5 are within the desired range. According to the data obtained in November, only measurement point 4 has an illuminance level within the desired range, while the illuminance level at all other measurement points is above the maximum level.

In the artificial lighting data, it was found that in September measurements, the luminaires were inadequate for the classroom, and only at measurement points 14-16 near the teacher's desk by the window, the desired illuminance level was achieved. In October, the desired illuminance level is observed up to measurement point 9, and in November, up to measurement point 6.

According to the integrated lighting data, in September measurements, except for the measurement points along the window edges, the illuminance level is within the desired range throughout the classroom. In October, only measurement points 3 and 4 are within the desired range. The desired illuminance level was not observed in November within the specified standard range.

Classroom-02 and classroom-03, excessive illuminance levels were observed near the windows, while artificial lighting was found to be insufficient. Overall illuminance levels were higher in September compared to the other months. In the south-oriented Classroom-03, the required standards were achieved at certain measurement points, whereas in the northeast-oriented Classroom-02, compliance was much more limited. Under integrated lighting conditions, Classroom-03 met the standards only in September, while Classroom-02 achieved acceptable levels at specific points in different months.

Table 7. Assessment of classroom-03's measured illuminance levels for the months of September, October and November based on TS-EN 12464:2021



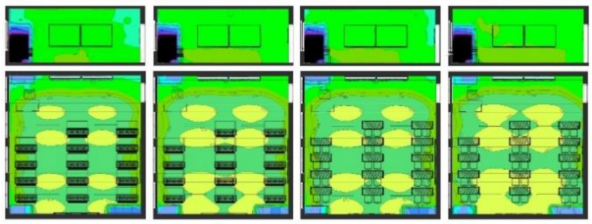
4.3.2. Simulation results for classroom-03

Classroom-03 was simulated using Dialux.evo 12 software, and the average illu-minance levels in the space, depending on the wall surface and desk materials, have been compiled in Table 8. Similar to Classroom-01 and Classroom-02, the combination #04, which consists of walls painted in warm colors with an 80% reflectance rate and PPC desk, achieved the highest illuminance levels on both the working plane and the focused surface. The lowest illuminance level was observed in the combination #05, which comprises walls painted in cool colors with a 50% reflectance rate and wood desk.

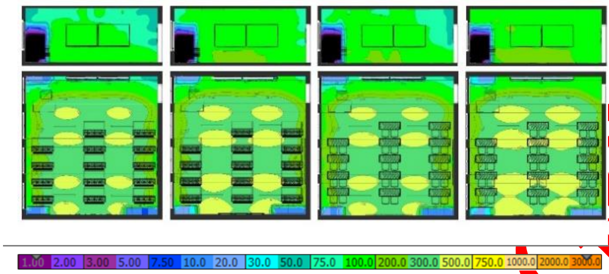
When comparing the average illuminance levels on the focal plane, although the combination with walls painted in warm colors with an 80% reflectance rate and PPC desk (#04) achieved the highest illuminance level, the uniformity ratio is higher in other combinations with warm-colored painted walls (#01, #02, #03) (Table 5). Calculations with walls painted in cool colors resulted in the highest uniformity ratio in combination #06, which consists of walls painted in cool colors with an 80% reflectance rate and wood desk.

Table 8. Illuminance level (lx) distributions obtained by simulating classroom-03 on dialux.evo according to combinations

#01	#02	#03	#04



#05	#06	#07	#08



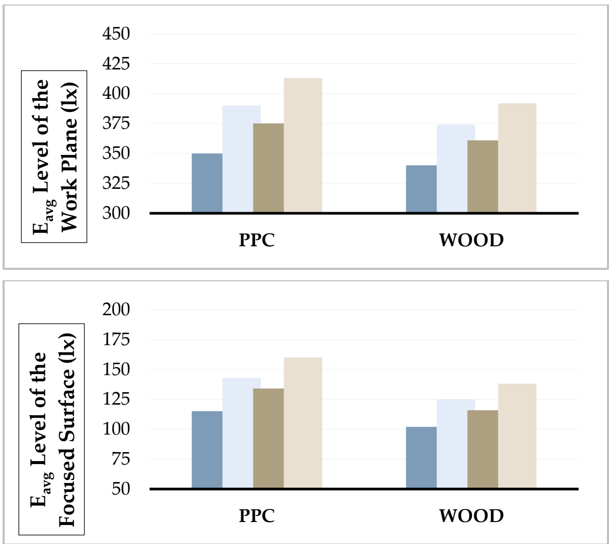


Figure 11. The luminance levels classified according to wall surface color and seating materials: (a) E_{ort} illumination level (lx) at the working surface; (b) Average illumination level (lx) at the focused surface.

Although the measured natural lighting in the southern classrooms is higher than the current situation, when the data of existing shading elements is inputted into the simulation, the illuminance level changes due to the high light transmittance of the shading elements. In this simulation, despite Classroom-03 being positioned to the south, it achieved 60% less illuminance compared to Classroom-02 facing north.

When the average illuminance levels on the focal/learning plane were examined, it was ob-served that the results were consistent with those on the working plane. When com-paring the combination #05, which resulted in the lowest illuminance level, with the combination #04, which achieved the highest illuminance level, a difference of 150% was found between them (Fig. 11).

4.4. Classroom-04

Classroom-04 is located in the northeast direction of the educational building (Fig. 12) and is consistently used for second-grade elementary school students.

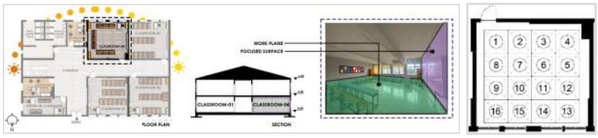
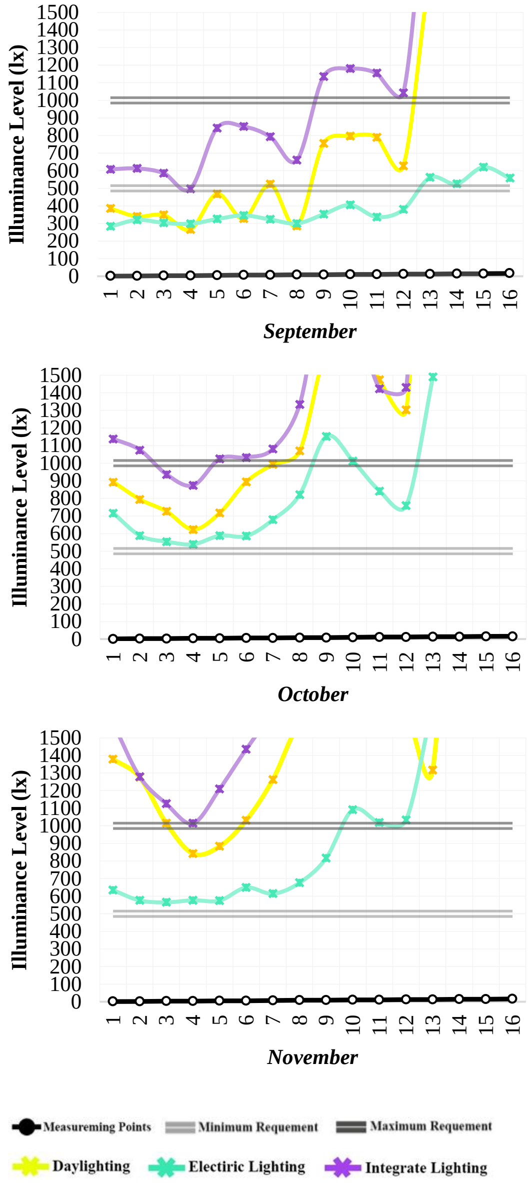


Figure 12. Classroom-04's floor plan, section and photograph

In Classroom-04, positioned to the south and west of Classroom-03, the highest illuminance levels were measured near the windows only in September, but in October and November, this high illuminance level exceeded the maximum desired level at every point in the classroom (Table 10).

According to the natural lighting data, in September measurements, points 9-12 had illuminance levels within the desired standard range. In October, points 1-7 and 8, and in November, points 4 and 5, had illuminance levels within the desired standard. In the artificial lighting data, t is determined that in September measurements, the illuminance level is within the desired standard at measurement points 13-16 along the window edges, in October measurements, at points 1-12, and in November meas-urements, at points 1-9. In the integrated lighting condition where both natural and artificial light sources were used, it was found that in September measurements, it was determined that the illuminance level did not meet the desired standard at measurement points 1-8, in October at points 3 and 4, and in November, no measurement point met the desired standard for illuminance level.

Table 10. Assessment of classroom-04's measured illuminance levels for the months of September, October and November based on TS-EN 12464:2021

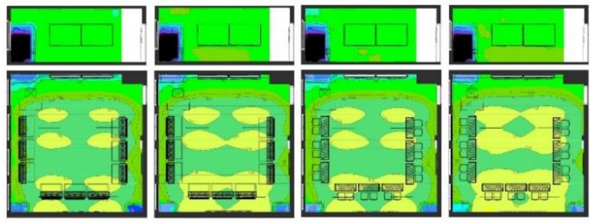


4.4.2. Simulation results for classroom-04

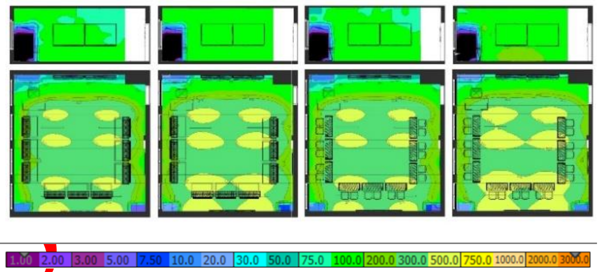
Classroom-04 was simulated using Dialux.evo 12, and the average illu-minance levels in the space, depending on the wall surface and seating materials, have been compiled in Table 11. When comparing the average illuminance levels on the focal plane, it was ob-served that although the highest illuminance level was achieved in combination #04, which consists of walls painted in warm colors with an 80% reflectance rate and PPC seats, the distribution was more uniform in combination #01, which consists of walls painted in warm colors with a 50% reflectance rate and wooden seats. Calculations with walls painted in cool colors resulted in the highest uniformity ratio in combination #06, similar to Classroom-03, which consists of walls painted in cool colors with an 80% reflectance rate and wooden seats. Conversely, the combination with the lowest uniformity distribution ratio was found to be combination #05, which consists of walls painted in cool colors with a 50% reflectance rate and wooden seats.

Table 11. Illuminance level (lx) distributions obtained by simulating classroom-04 on dialux.evo according to combinations

#01	#02	#03	#04



#05	#06	#07	#08



In Classroom-04, combination #08, where walls are painted with a cold color tone and have an 80% reflectance rate, along with PPC material desks, achieves the highest level of illumination both on the working plane and on the focus/learning plane. The lowest level of illumination is observed in combination #05, where walls have a 50% reflectance rate and are painted with a cold color tone, paired with desks made of wood material. When compared to the adjacent Classroom-03, there is a minimal difference in the illumination levels between the working plane and the focus/learning plane. However, when compared to Classroom-01, which faces north, Classroom-04 exhibits approximately 6,4% higher illumination on the working plane and 12,1% higher illumination on the focus/learning plane. The primary reason for this difference is the different orientations of the classrooms.

In the classroom situated with warm-toned painted walls and facing southwest, it generates approximately 0,52% to 2,34% higher illumination levels on the working plane compared to the classroom oriented towards southeast. However, on the focus surface, it exhibits approximately 1,58% to 5,3% lower illumination levels. Classroom-03, facing southwest, produces approximately 3,1% to 5,48% higher illumination levels on the working plane and about 4,25% to 9,56% higher illumination levels on the focus surface compared to classroom-04 facing southeast. In Classroom-04, oriented towards southeast, it generates approximately 1,94% to 4,8% higher illumination levels on the working plane and around 11,97% to 15,3% higher illumination levels on the focused surface.

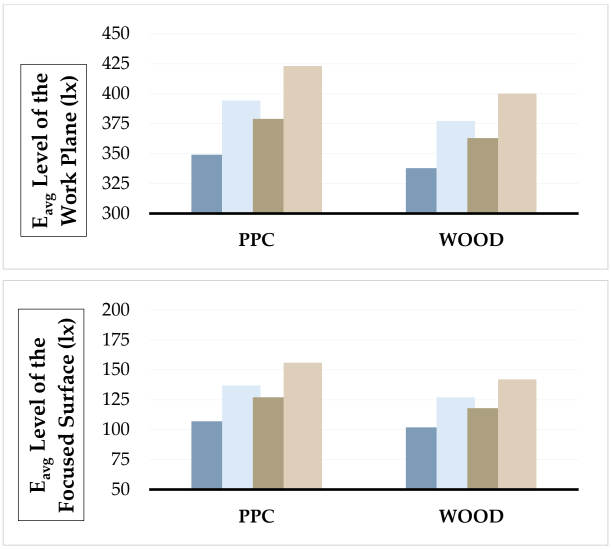


Figure 14. The luminance levels classified according to wall surface color and seating materials: (**a**) E_{ort} illumination level (lx) at the working surface; (**b**) Average illumination level (lx) at the focused surface.

The analyses indicate that orientation and furnishing characteristics directly influence not only the illuminance levels but also the uniformity ratio and energy efficiency. In this context, selecting only high-reflectance color and material combinations is not sufficient; instead, the orientation of the space, shading systems, furnishing density, and the surface properties of interior elements must be considered collectively. In designing an energy-efficient learning environment, qualitative aspects such as the distribution of light and visual comfort should be regarded as equally essential as the quantitative level of illuminance.

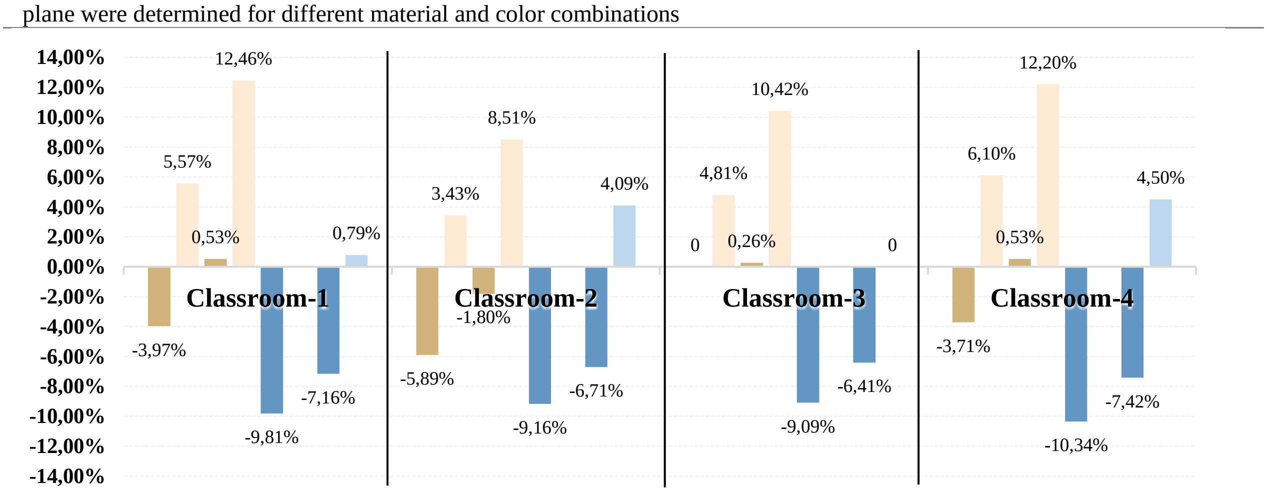
6. CONCLUSION

In the conducted area study, alternatives were generated to achieve sufficient brightness levels with improvements/changes that would be less costly without altering the existing lighting design. In this context, the effects of changing the colors of wall surfaces and furnishings in classrooms on the existing brightness level have been examined. In classrooms within educational buildings, the natural light level varies depend-ing on the direction from which natural light is received. Particularly when natural light is received from the south direction, the brightness level indoors is often higher than desired, necessitating the use of shading elements to achieve visual comfort. The use of shading elements decreases the brightness level, leading to increased reliance on artificial lighting. In cases where sufficient daylight cannot be obtained and artificial lighting is needed, energy-efficient lighting design becomes crucial for achieving energy savings. In energy-efficient lighting design, not only the position, number, and type of fixtures matter but also the color and textural properties of the space are influential. In this study, the effects of the color and material properties of wall surfaces and fur-nishings in classrooms on the brightness level have been examined.

Regardless of the orientation of the space and the reflectance coefficient of the color, it has been found that warm colors contribute to a higher brightness level compared to cool colors.

Classrooms were simulated with Dialux.evo 12 software with LED fixtures emitting light at 6500K, considering two warm and two cool color tones, and four different reflectance levels of these colors were altered to create eight different combinations. As a result, the highest brightness level in classrooms was achieved with the combination of walls painted in warm color tones with 80% reflectance and seating made of PPC material, while the lowest brightness level was obtained with the combination of walls painted in cool color tones with 50% reflectance and desk made of wood material.

Table 12. Based on the baseline condition (#06), positive and negative percentage variations in illuminance levels on the working plane were determined for different material and color combinations



Research findings indicate that painting classroom walls with warm or cool colors has a significant impact on illumination levels. The obtained data present, with reference to combination #06, the variation rates in illuminance levels on the work plane and focal surface for other combinations, shown on a classroom-by-classroom basis (Table 12).

Proper selection of seating materials in classroom design contributes to improving the illumination levels within the space.Regardless of the orientation of the space and the reflectance rate of the color, it has been found that warm colors contribute to higher illumination levels compared to cool colors. Additionally, the highest illumination level in classrooms was achieved with a combination of walls painted in warm tones with 80% reflectance and seats made of PPC material/light colors, while the lowest illumination level was obtained with a combination of walls painted in cool tones with 50% reflectance and desk made of wood material. A classroom with walls painted in warm color tones, using the same shading elements and positioned facing the north, creates a brightness level on the working plane approximately 1% to 2.6% higher compared to a classroom positioned facing the south. However, it generates a brightness level on the focal surface approximately 15% to 21% lower. The analyses indicate that, in all classrooms where the same row material was used, changes in wall surface color had a significant impact on the focal surface, ranging from 1.3% to 22.83%. The effect of color on the work plane illuminance was found to be up to 12.46%.The desks used in classrooms cover a significant area on the working plane, mak-ing the correct selection of desk materials one of the parameters that affect the bright-ness level in the space. This choice, especially depending on the reflectance or covering properties of the desk materials, affects the overall brightness level in the room. In this context, it has been determined that the use of light-colored desks can lead to higher brightness levels in classrooms.The use of light-colored (PPC) desks in all classrooms positively influences the brightness level both on the focal surface and on the working plane. When comparing their effects on the focal surface and the working plane, it has been concluded that their impact is more significant on the focal surface. This study investigated the influence of wall color and furniture material on indoor illuminance levels. In future studies, a more comprehensive evaluation can be conducted by incorporating additional parameters—such as lighting energy consumption and potential energy savings—within integrated simulation frameworks to support sustainable lighting strategies.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials andmethods used in their studies do not require ethicscommittee approval and/or legal-specific permission.

AUTHORS' CONTRIBUTIONS

Fatma Zişan YOLCU: Contributed to the design of the study, conducted the experiments, carried out data collection and curation, performed formal analyses, and prepared the initial draft of the manuscript, including figures and visualizations.

Tülay ZORLU: Contributed to the conceptualization and design of the study, supervised the research process, reviewed and edited the manuscript, and undertook overall project administration and funding acquisition.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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