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Retrofit suggestions from resilient design perspective in educational buildings lighting systems

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Abstract

Educational buildings need to be properly built and renovated because of the number of users served, the rate of usage, the potential for energy savings, and their number in public buildings. Physically, educational buildings that do not meet the essential comfort conditions cause more energy consumption, have a negative effect on academic performance of students and also cause disruptions in educational program applications. According to 2021 data, there are approximately 67,000 school buildings in Turkey. A major portion of these buildings were constructed before 2000 and are now nearing the end of their economic life. It is essential to renew the insufficient buildings make them suitable for the conditions of the age. In this context, resilient systems that continue to function in a variety of negative conditions while maintaining comfort conditions become a priority in the design of the created environment. The lighting arrangements of educational buildings that are directly connected to visual comfort, academic performance, and energy consumption are discussed in this study. Within the framework of resilient design, certain suggestions have been developed in light of the current lighting standards in effect regarding the processes to be followed before the retrofit works to be performed in the lighting arrangements of the school buildings. These suggestions were discussed in three categories as short-, medium-, and long-term periods, taking into consideration the duration of the improvement processes and without interfering with the existing activities during the school education period and it was aimed to create a guide for designers and practitioners with the improvement systematics to be made in these periods. In order to test these suggestions, a classroom from the Ministry of National Education's type school projects is used as an example. The existing situation of the natural and artificial lighting system of this classroom and short-, medium- and long-term improvement suggestions were estimated through the Dialux Evo program. According to the findings, the recommended improvements enhanced visual comfort criteria and resulted in a considerable reduction in energy consumption. With the help of the improvement calendar, it is possible to modify the lighting systems of existing school buildings and increase visual performance.

Keywords: school lighting design, retrofit, resilient lighting design, visual comfort, educational buildings

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1. Introduction

The subject of "Quality Education" is one of the titles determined by the United Nations in line with the "Sustainable Development Goals". The purpose here is to ensure that all students receive quality education in quality places (Nazar et al., 2018). In this regard, improving the physical facilities of schools is critical for fulfilling educational activities and increasing the academic success of students. Scientific studies have also shown that the schools that are unable to offer the required comfort conditions have a negative effect on academic performance of students.

School buildings, as well as their indoor and outdoor environments, should be handled, designed, and built in a way that contributes positively to student development while also making students and teachers happy to be there. For this reason, it is important to maintain the existing positive conditions without affecting the educational environment. Thanks to resilient designs, it is possible to maintain the current function in the event of natural disasters, power failures or extraordinary situations. The important issue here is the process of designing buildings, including their interior, exterior, and environment, to decrease the impact of these situations while taking negative conditions and other external dangers into consideration. In this context, it is necessary to take steps within a resilience framework in order to develop future educational buildings that are practical, durable, accessible, inclusive, and sustainable. Both the design of the new schools to be built in this manner and the enhancement of the physical facilities of the existing schools should be a priority for a good education.

In today's world, where the importance of sustainable designs is increasing day by day due to limited natural resources, school lighting systems that directly affect visual performance should be designed and improved within the context of sustainability (Çelik, 2019). Within the scope of resilience, several recommendations are made in this research to ensure that lighting systems in schools are managed and enhanced, taking the artificial and natural lighting requirements in the standards in the account. The aim of the study can be summarized as supporting individuals and institutions in relevant occupational groups for the systematic implementation of natural and artificial lighting system retrofitting in education buildings.

1.1. Retrofit In Lighting Design in Terms of Resilience

The term resilience can be defined as the ability to adapt to changing situations and preserve functionality or regenerate itself after an interruption. In simple terms, resilience the ability to recover after a disruption or interruption (Campos, 2022). According to the American Lighting Association, lighting systems in the context of resilient design are defined as lighting that has the ability to prepare, plan, endure, regenerate, and adapt more successfully against negative circumstances. The issue to be addressed in this context is the concept that lighting should be regarded as a system, designed, planned, and it does not focus on a single element.

Retrofit in lighting systems can be referred as replacing inefficient elements with new energy-efficient ones (IEA SHC, 2016). In this context, the retrofit process can be interpreted as a method of achieving resilient design in the lighting system in buildings.

It is possible to adapt to lighting technologies that are constantly changing with technology and to enhance systems that lost their efficacy over time using retrofit applications.

According to data of the International Energy Agency, artificial lighting consumes around 12% of electrical energy utilized in households and 25% -40% in non-residential usage. It is estimated that the energy spent for artificial lighting constitutes approximately 19% of the global electricity consumption. Energy consumption in the field of lighting is predicted to rise further in the next years as a result of easy access to lighting products, diversity of usage areas, and technical advancements. As a result, including systems that use energy more effectively through enhancing building systems in order to minimize the energy needed for artificial lighting has become a current issue.

Lighting systems in buildings are one of the most important application areas in retrofit, due to their energy saving potential. By replacing the old lighting elements, it is possible to save up to 50% in the energy consumed according to the usage area (Benya & Leban, 2011). Investments in energy-efficient lighting systems, according to studies, are one of the most cost-effective ways to increase energy efficiency and reduce CO2 emissions (Gentile et al., 2016). Research and field studies have shown that lighting retrofit applications are simple to implement and have a high economic return rate (Dubois et al., 2016). In addition, studies have shown that retrofit applications in the field of lighting in schools reduce the energy consumption for artificial lighting by 31% to 57% (Booysen et al, 2021; Clark, 2007).

Its aim is to provide visual comfort through new lighting technologies combined with improved practices, and to reduce electricity and maintenance costs arising from artificial lighting. The strengths, weaknesses, opportunities and potential threats of the improvement applications in lighting systems are summarized (SWOT analysis) in Table 1.

Table 1 Retrofit SWOT analysis (IEA SHC, 2016).

Strengths	• High energy savings that can be achieved with new lighting technologies and control systems • Short payback period of the system • More efficiency with less intervention compared to other retrofit issues
Weaknesses	• Lack of knowledge and inexperience in some areas (*reducing the level of illumination, not lighting according to the function, etc.)* • In some cases, the savings potential cannot be determined precisely and the reliability of some control systems is low (*use time, dimming, etc.)*
Opportunities	• Reducing energy consumption and supporting environmental sustainability by renewing existing buildings over time • The need to improve and modernize indoor environment quality with visual comfort • Obsolescence of existing lighting installations in developed countries
Threats	• The potential to increase the energy consumed for artificial lighting by 40% in 2030 • Consumption increase that may occur with the decrease in consumer expenses (*Rebound effect*)

Before carrying out the improvement processes in the lighting systems, it is essential to define the current situation well and to determine the appropriate solution proposals. The wrong steps from the beginning without proper planning may prevent the improvement process from providing the expected efficiency. In this regard, it is critical to ensure that lighting systems are kept up to date, particularly in locations such as school buildings that need continuous usage and which have a direct impact on the academic performance of students.

2. Educational Buildings Lighting Design Criteria

Studies have shown that both natural and artificial lighting affects people's health, mood, and alertness (Cajochen 2007; Van Bommel, et al 2004). For this reason, it can be said that the lighting systems of educational buildings directly affect the academic performance of students (Sleegers et al, 2013). In addition to serving as learning places for future generations, educational buildings play an essential role in the construction of public structures. According to the "2020-2021 National Education Statistics" of the Ministry of National Education, there are a total of 67,125 public and private (pre-school, primary, secondary and high school) school buildings in our country. The number of students studying in these schools is over 18 million. These structures, approximately 75% of which were built 20 years or earlier, have a total of 732,381 classrooms. Therefore, outdated technologies are still used in the lighting systems of some schools in parallel with the construction years or necessary improvement studies are not conducted.

Considering the number of users served by educational facilities, it is understood how large society and the physical environment they have an impact on, either directly or indirectly. Studies that will enable school buildings to use energy more efficiently and enhance physical comfort conditions have become important in this regard.

Before starting the improvement works in the field of lighting, the current situation should be analyzed and deficiencies should be determined in the light of the standards and regulations in force. In our country, the related "TS EN 12464-1 Light and lighting - Lighting of work places - Part 1: Workplaces in closed areas" and "TS EN 17037 Daylight in Buildings" are in force. In addition, there is some information on the lighting design of schools in the "Minimum Design Standards Guide for Educational Buildings" published by the Ministry of National Education for the design of school buildings.

Sufficient and appropriate lighting enables people to perform their visual actions efficiently and accurately. The visual and comfort needs required in various workplaces are determined by the type and duration of the action. According to TS EN 12464-1 Light and lighting - Lighting of workplaces - Part 1: the lighting requirements of indoor areas with different functions in the indoor workplace standard, Numerical values and special requirements depending on the function are presented under the following headings:

- Illuminance level (E_m, *horizontal, vertical and cylindrical planes*),
- Glare (R_{UGL}),
- The uniformity of the light distribution (U_0),
- Color rendering (R_a),

As an example of this information, the lighting requirements for classrooms in educational buildings are presented in Table 2.

Table 2 Lighting requirements for classrooms (TS EN 12464-1)

Type of task/activity area	E_m (lx)		U_0	R_a	R_{UGL}	$E_{m,z}$ (lx)	E_m (lx)	E_m (lx)	Specific requirements
	required	modified				U_0 > 0,10			
Classroom - General activities	500	1000	0,60	80	19	150	150	100	Lighting should be controllable for different activities and scene settings. For classrooms used by young children, an $\bar{E}_m$ required of 300 lx may be used by dimming. Ambient light should be considered.
Black, green and white boards	500	750	0,70	80	19	-	-	-	Vertical illuminances. Specular reflections shall be prevented. Presenter/teacher shall be illuminated with suitable vertical illuminance.

Daylight should be the primary lighting source for all spaces in terms of visual comfort, pleasure and energy use. TS EN 17037 Daylight in Buildings Standard encourages designers to use and evaluate daylight effectively in spaces. At the same time, it defines minimum performance standards for natural lighting design of spaces. The criteria presented for the daylight performance of spaces in this standard are:

- Providing sunlight,
- Providing an outside view,
- Exposure to sunlight
- Daylight dependent glare control

In the standards, general natural lighting parameters have been specified for all building types, not just for education buildings, it has been stated that daylight should contribute considerably to the lighting requirements of any typology structure.

It is aimed to determine the design criteria in educational buildings with the "Minimum Design Standards Guide for Educational Buildings" prepared by the Ministry of National Education. This guide aims to keep up with the changes that education systems will go through throughout time as a result of rapidly developing technologies and new needs. Suggestions regarding the amount of illuminance levels, window orientations and window area are presented for some spaces. The lighting recommendations for the classes in the guidebook are shown in Table 3.

Table 3 Lighting recommendations for classrooms

Type of activity	E_m (lx)	Area of windows	Additional Information
Classroom	300	**Windows area/floor area:** %25-%50	The classroom should be designed in such a way that daylight comes from the left side for students, and furnishings and door openings should be arranged accordingly.

The said standards and guides are also updated over the years depending on the changing terms of use, user characteristics and technology. In this regard, these developments should be followed and the researches in this field should be kept up-to-date.

3. Method

Within the scope of the research, an action plan has been developed to assist in the elimination of problems with artificial and natural lighting systems of educational buildings and their retrofit in terms of visual and energy performance. In the context of this action plan, an information and timetable has been created so that designers and practitioners can take action in a systematic way. While preparing improvement ideas for this plan, the current natural and artificial lighting standards and design guidelines in force in Turkey were taken into consideration.

For this purpose, it was aimed to create a theoretical infrastructure by first making a wide literature review; Design, lighting, retrofit, energy, etc. for educational buildings published by various institutions and organizations, with papers, articles and theses made on the subject at home and abroad. Guidelines and standards on the subjects were examined.

After the theoretical infrastructure is formed, the other steps followed in the study can be listed as follows:

- Creating an information (*What-Why-How*) table that will provide explanatory information to designers and practitioners in addition to the numerical information provided for educational structures in the standards and guides,
- Determining in which areas and at what time the improvement processes that can be done during the school education period can be made,
- Establishing a short, medium and long-term retrofit calendar in accordance with the determined improvement processes,
- Selection of the space for retrofitting and implementation of the suggested action plan for this space.
- Application of the proposed retrofit processes to the space and comparing the lighting performance of the existing and suggested situation with the lighting program,
- Analyzing the obtained data.

A case study was conducted to implement the action steps with the help of the information and timeline suggested from the study. In the case study, a classroom was chosen because it is a repetitive space in all schools and its total number. According to 2021 data, there are 732381 classrooms in schools. The selected classroom belongs to a type secondary school project with 24 classrooms implemented by the Ministry of National Education. Dialux Evo program was used to analyze the lighting performance of the existing and suggested situations.

4. Suggestion for Lighting Retrofit in Educational Buildings

There are numerical values and brief explanations for the lighting conditions of school buildings in the regulations and various guidebooks prepared to determine the lighting requirements. Apart from numerical values, it can be suggested that lighting design suggestions will be more descriptive and beneficial for both designers and users. In this context, short suggestions about what criteria presented in the lighting standards are, why they are essential and how they should be obtained are presented in Table 4.

Table 4 General information on lighting design criteria in educational buildings *(What-Why-How)*

What *(is it)*	**Why** *(it is necessary)*	**How** *(should it be)*	
		Natural lighting	**Artificial Lighting**
Illuminance level (E_m)	• Visual comfort • Visual performance • Academic performance • Energy consumption	• The windows should be oriented and designed in appropriate dimensions to make maximum use of natural lighting. • External obstacles that will prevent daylight entering the space should be avoided. • The reflection factors of the inner surfaces should be chosen at appropriate values.	• The most suitable light source should be chosen in terms of energy consumption and efficiency. • Devices with high light efficiency should be selected. • The reflection factors of the inner surfaces should be chosen at appropriate values.
The uniformity of the light distribution (U_0)	• Visual comfort • Academic performance • Energy consumption	• Windows should be designed and positioned in accordance with the space function and dimensions. • Furnishing-window relation should be arranged in accordance with the light distribution.	• The relationship between the furnishing and the lighting arrangement should be considered in accordance with the space and function. • Luminaires light distribution features (light intensity diagram) should be selected according to the function.
Glare (R_{UGL})	• Visual comfort • Academic performance	• The windows should not be positioned behind the students to avoid silhouette effects and glare. • The light should generally be placed on the left side so that students can see what they write. • Disturbing direct sunlight should be prevented from entering the space. • Solar control elements should be used when necessary.	• Lightings should be positioned considering the viewing direction and working area so that they do not cause glare. • Luminaires to be used in places should be chosen in a way that will not cause glare.
Color rendering (R_a)	• Visual comfort • Academic performance • Ability to distinguish colors	• In order to perceive the objects in their true colors, maximum use of daylight should be made in the spaces.	• Lamps with high color rendering should be preferred so that objects can be perceived in their true colors.
Daylight Factor (DF)	• Visual comfort • Visual performance • Academic performance • Energy consumption	• Window sizes, positions and orientation should be designed to take advantage of daylight.	-
Transparency Ratio	• Visual comfort • Visual performance • Academic performance • Energy consumption	• Window sizes, positions and orientation should be designed to take advantage of daylight.	-
Energy consumption (W/m^2, $W/m^2/100$ lx)	• Energy consumption	• The windows should be oriented and designed in appropriate dimensions to make maximum use of natural lighting. • Cleaning of windows and interior surfaces should be done at regular intervals.	• The most suitable light source should be chosen in terms of energy consumption and efficiency. • Luminaires should be maintained at regular intervals.

A lighting improvement calendar was designed, taking into account the lighting design standards and the time limit within the education period, without interrupting the activities.

In this context;

- Visual comfort criteria

- *Illuminance Level (E_m),*
- *Uniformity of the light distribution (U_0),*
- *Glare (R_{UGL}),*
- Daylight factor (DF)

- Energy consumption
  - Total power (W)
  - Lighting power density (W/m^2, W/m^2/100 lx)

are taken into account. The parameters were created by taking various constraints (time, cost, structural, etc.) into consideration. Table 5 presents suggestions for natural and artificial lighting and space features under the headings of “short (≤15 days), medium (≤90 days) and long-term (>90 days) improvements”, taking the implementation period of the improvement processes into account. These recommendations were created by taking the time intervals in the academic year into account.

Table 5 Retrofit suggestions in terms of lighting design criteria and time

Retrofit period		Lighting design criteria			
		Illumination level (*E*)	**Uniformity of illuminance (U_0)**	**Glare (UGR)**	**Energy comsumption (W/m^2, W/m^2/100 lx)**
Natural Lighting	**Short term improvements** (≤15 days)	• Maintenance and cleaning of windows • Trimming of plants and trees outside the building	• Changing the furnishing order	• Adding indoor solar control elements (curtains and blinds etc.)	• Maintenance and cleaning of windows • Trimming of plants outside the building
	Short term improvements (≤ 90 days)	• Improvement of glass and joinery properties	• Use of light shelf elements etc	• Adding solar control elements to the façade	• Replacement of glass and joinery
	Short term improvements (> 90 days)	• Rearrangement of size, position, number properties of windows • Redesign/change of building skin and transparent areas	• Redesign of the building envelope		
Artificial Lighting	**Short term improvements** (≤15 days)	• Maintenance and cleaning of lamps and luminaries • Lamp change (in terms of lm/W, color etc.)	• Luminaire change *(in terms of light intensity diagram)* • Luminaire replacement (in terms of reflector, mounting type, etc.) • Changing the furnishing order		• Lamp and luminaire maintenance and cleaning • Lamp and luminaire replacement
	Short term improvements (≤ 90 days)	• Change of lamp and luminaire types • Changing the location of luminaires			
	Short term improvements (> 90 days)	• Redesign of the lighting system			
Space specifications	**Short term improvements** (≤15 days)	• Cleaning, painting, changing the furnishing order of interior surfaces			
	Short term improvements (≤ 90 days)	• Arrangement of light reflection factors of interior surfaces and facings	• Arranging the lighting system according to the task areas	• Arrangement of light reflection factors of interior surfaces and facings • Arranging the lighting system according to the task areas	
	Short term improvements (> 90 days)	• Redesign of the interior			

The goal of the determined retrofit calendar is to regulate and improve the deficiencies in school lighting systems in a systematic manner.

4.1. Case Study

It is aimed to test the retrofit calendar and improvement suggestions created within the scope of the study on a sample classroom, taking the existing education conditions into account. First, a typical secondary school project implemented by the Ministry of National Education was selected and a classroom belonging to this school was modelled in the Dialux Evo 10.1 lighting simulation program. The natural and artificial lighting performance of the specified classroom was calculated seperately for the existing situation and the short-medium-long-term improvement ideas offered within the scope of the study.

The existing classroom is a volume of 7.60x7.70x3.10 m, with 3 windows measuring 1.50x1.70 m. The parapet height of the windows is 0.90 m. Window area/Floor area= 13.07%, The transparency ratio (Window area/Wall area with windows) is 32.47%. It's considered that the area is a highly dirty space with a five-year maintenance cycle (MF:0,57). The plan and sections of the classroom are presented in Figure 1.

Figure 1 Plan and sections of the sample classroom

The study areas in the classroom are divided into two parts, the desk surface and the blackboard surface, in order to evaluate the horizontal and vertical illuminance level and uniformity of the light distribution. The calculation plane for the area with the desks is positioned horizontally at a height of 0.80 m from the ground. A calculation area has been created in the vertical plane for the blackboard. For glare, a calculation surface was created at a height of 1.2 m from the ground in accordance with the field of view of the students (Figure 2).

Figure 2 Work planes for calculation

Daylight calculations were made for Adana on 15 December at 12:00 am, according to the closed sky conditions determined by the International Commission on Lighting (CIE).

The "short-term (15 days), medium-term (90 days), and long-term (> 90 days)" recommendations in Table 5 were taken into account while developing lighting recommendations for the sample classroom to be improved. In this context, the suggestions implemented in the short, medium and long-term time frame can be listed as follows:

Short-term lighting improvement suggestions;

- Maintenance and cleaning of windows,
- Cleaning, painting of interior surfaces,
- Maintenance and cleaning of lamps and luminaires,
- Lamp change (lm/W)

Medium-term lighting improvement suggestions;

- Enhancement of glass and joinery,
- Change of lamp and luminaire types,
- Arrangement of light reflection factors of interior surfaces and facings,

Long-term lighting improvement suggestions;

- Rearrangement of windows size, position, number, etc.
- Change of lamp and luminaire types,
- Changing the location of the luminaires,
- Arrangement of light reflection factors of interior surfaces and facings,

The existing situation of the sample classroom and the improvement suggestions for the natural lighting system are presented in Table 6.

Table 6 Existing situation and natural lighting improvement suggestions

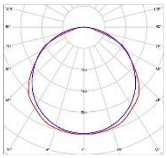
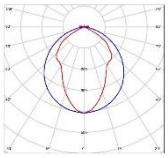
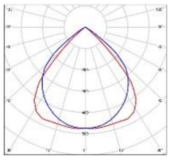
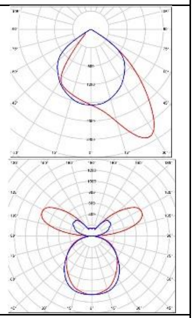
Specifications	Existing situation	Short term improvements	Mid term improvements	Long term improvements
Inner surface reflectance factors *(Floor/Wall/Ceiling)*	0,20/0,30/0,60	0,30/0,50/0,70	0,30/0,50/0,70	0,30/0,60/0,85
Glass light transmission factor *(t)*	%74	%80	%80	%80
Room maintenance factor *(MF)*	0,57 *(Dirty room)*	0,80 *(Clean room)*	0,80 *(Temiz oda)*	0,80 *(Temiz oda)*
Transparency Ratio	%32.47	%32.47	%32.47	%48.13

There is no any structural applications in the short and medium-term suggestions, but the window area was increased in the long-term suggestion.

The existing situation of the artificial lighting system of the sample classroom and the improvement suggestions are presented in Table 7.

Table 7 Existing situation and artificial lighting improvement suggestions

Specifications	Existing situation	Short term improvements	Mid term improvements	Long term improvements
Inner surface reflectance factors *(Floor/Wall/Ceiling)*	0,20/0,30/0,60	0,30/0,50/0,70	0,30/0,50/0,70	0,30/0,60/0,80
Room maintenance factor *(MF)*	0,57 *(Dirty room)*	0,80 *(Clean room)*	0,80 *(Temiz oda)*	0,80 *(Temiz oda)*
Number of luminaires	6	6	6	8
Light output ratio of luminaire	%76	%82	%87	%100
Lamp type	TL-D Fluorescence	TL5 Fluorescence	TL5 Fluorescence	LED

Number of lamps	12	12	12	8
Lamp power (W)	2 x 36 W	2 x 35 W	2 x 35 W	40 W / 31 W
Total system power (W)	432 W	462 W	462 W	302 W
Lamp luminous flux (lm)	6500 lm	6650 lm	6650 lm	5489 / 3773 lm
Lamp efficiency (lm/W)	68,5 lm/W	70,5 lm/W	75 lm/W	134,1 lm/W
Color rendering (R_a)	80	90	90	80
Type of luminaire	Bare	Bare	with louvre	with louvre / with opal diffuser
Luminaire image				
Light intensity distribution/lighting pattern				
	Direct	Direct	Direct	Direct / Semi-Direct

In the existing situation fluorescent lamps are used. While fluorescent lamps are used in short and medium-term improvement suggestions, LED lamps are used in long-term improvement.

5. Evaluation and Conclusion

The visual comfort and energy use performance of the current situation and suggested situations were determined using the Dialux Evo 10.1 software. Visual comfort criteria of the created improvement suggestions (horizontal and vertical illuminance level Eh, Ev, distribution uniformity of horizontal and vertical illumination; Uh, Uv, glare; UGR) and calculation results for energy use (W, W/m2, W/ m2/100 lx) are presented in Table 8. The classroom study areas are divided into two sections, the desk surface and the board surface, in order to determine the horizontal and vertical illuminance levels as well as the uniformity of the luminance distribution. The calculation plane for the area with desks is horizontally positioned 80 cm above the ground. Natural lighting calculations were made for Adana on 15 December at 12:00, according to the overcast sky conditions determined by the International Commission on Illumination (CIE).

All the data obtained for the existing situation and suggested scenarios are presented in Table 8.

Table 8. Lighting values of existing and suggested scenarios

Existing situation									
	E_h	**U_h**	**E_v**	**U_v**	**UGR**	**W/m²**	**W/m²/ 100 lx**	**P_t (W)**	**DF**
TS EN 12464-1	**500**	**0,6**	**500**	**0,7**	**19**	**-**	**-**	**-**	**-**
TS EN 17037 *(to exceed 500 lx)*	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**%2,6**
Artificial lighting	267	**0,75**	153	**0,76**	20,7	7,9	3,09	462	-
Natural lighting	145	0,18	75,1	0,44	<10	-	-	-	1,257

Integrated lighting	412	0,58	227	**0,71**	20,5	7,9	3,09	462	1,257
Short term improvements									
Type of lighting	**E_h**	**U_h**	**E_v**	**U_v**	**UGR**	**W/m²**	**W/m²/ 100 lx**	**P_t (W)**	**DF**
Artificial lighting	459	**0,74**	196	0,6	19,8	7,39	1,94	432	-
Natural lighting	151	0,2	68,9	0,43	<10	-	-	-	1,308
Integrated lighting	**609**	**0,64**	264	0,58	19,8	7,39	1,94	462	1,308
Midterm improvements									
Type of lighting	**E_h**	**U_h**	**E_v**	**U_v**	**UGR**	**W/m²**	**W/m²/ 100 lx**	**P_t (W)**	**DF**
Artificial lighting	**529**	**0,69**	189	0,46	**19**	7,39	1,68	432	-
Natural lighting	178	0,21	94,5	0,48	<10	-	-	-	1,554
Integrated lighting	**706**	**0,63**	282	0,52	**19**	7,39	1,68	462	1,554
Long term improvements									
Type of lighting	**E_h**	**U_h**	**E_v**	**U_v**	**UGR**	**W/m²**	**W/m²/ 100 lx**	**P_t (W)**	**DF**
Artificial lighting	**512**	**0,61**	**559**	0,62	**17,7**	5,17	1,02	302	-
Natural lighting	333	0,27	191	0,56	<10	-	-	-	**2,959**
Integrated lighting	**837**	0,49	**745**	**0,70**	17,7	5,17	1,02	302	**2,959**

Bold texts represent values provided by standards

When the findings are examined, it is seen that in all suggested conditions, all visual comfort and energy consumption measures improve progressively. When the criteria are examined one by one;

Short term improvements; In this suggested scenario, some advantages that can be obtained with improvements to be made in a very short time are aimed to be revealed. In this context, the interior surfaces, windows and fixtures are cleaned, and the maintenance factor *(MF)* and the window light transmission coefficient are increased. In addition, more efficient lamps are used to produce more luminous flux with the same energy.

It is seen that the average illuminance level *(Eh,v)* values in the horizontal and vertical planes have increased compared to the current situation. The horizontal illuminance level has approached the required values in the standards.

While the uniformity of illuminance can be achieved in the horizontal plane *(Uh),* it is close to the standard values in the vertical planes *(Uv).*

Although the glare *(RUGL)* values decreased compared to the current situation, the standard value could not be achieved.

Medium-term improvements; In this suggestion, it is aimed to reduce glare by using luminaires with louvres compared to the other two situations. In addition, more efficient lamps are used to produce more luminous flux with the same energy.

Although the average illuminance level *(Eh)* values in the horizontal plane are insufficient in terms of natural lighting, they have reached the standards in terms of artificial lighting. As a result of the reduction of window joinery thickness, the daylight level increased. Vertical illuminance *(Ev)* values did not reach the standards.

While the uniformity of illuminance could be achieved in the horizontal plane *(Uh),* it could not be provided in the vertical plane *(Uv).*

While the current lighting scheme causes glare, in the proposed case the Glare (RUGL) is below the required values.

Long-term improvements: In this suggestion, the artificial and natural lighting system was redesigned. LED lamps were preferred as artificial lighting elements, and window sizes were increased to increase daylight. In addition, the reflectivity factors of the interior surfaces have been increased *(Floor/Wall/Floor; 0.30/0.60/0.80).*

The average illuminance level *(Eh,v)* values in the horizontal and vertical planes provided the standards. Natural lighting values alone did not meet the standards.

The distribution of the illuminance has reached the standards in the horizontal and vertical planes *(Uh, v).*

The glare *(RUGL)* values provided the standard values.

While the daylight factor *(DF)* could not be provided (2.6%) in the current and other recommendations, this value was obtained (2.959%) by increasing window sizes without long-term improvement.

As a result, it can be said that the suggestions presented give successful results in terms of increasing the illuminance levels, reducing the glare value, improving the distribution uniformity and reducing the energy consumption. While short- and medium-term improvements are especially beneficial in terms of energy consumption and illuminance level, it is clear that a more comprehensive improvement process is needed to improve other visual comfort criteria. In this respect, it is an indication of this that more successful results are obtained in the long-term improvement proposal than in other suggestions.

Improvements should not only be considered as increasing the illuminance level and reducing energy consumption, but all other visual comfort criteria should be taken into account. Other improvement suggestions can be used depending on the need to improve a classroom with the features within the scope of the acceptances. Considering the results, it can be said that the proposed improvement proposals provide systematic solutions for the improvement of the lighting conditions in the classrooms.

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Resume

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