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Araştırma Makalesi

Improving Natural Lighting Performance in Historical Education Venues: Ulugazi Primary School

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Abstract

Natural lighting is an essential factor in the design of educational buildings, as it creates an environment that provides psychological satisfaction, increases motivation, encourages healthier conditions and saves energy. Using the same finishing materials in classrooms facing different directions and sizes in educational buildings causes natural lighting effects of different quantity and quality. This situation creates psychological, physiological and cognitive inequality among students. This negativity can be annihilated by changing facade elements, the ratio of the transparent surface and the materials. However, these applications should be made with minor interventions in the historic structure. Within the scope of this study, which aims to determine the current natural lighting performance of the classrooms in Ulugazi Primary School, a historic school building in Kocaeli, the scenarios are designed with approaches that will have the most negligible impact on the building identity.

In this context, with the Climatestudio analyzes were conducted for four classes with different characteristics. Visual comfort problems were determined with the Spatial Daylight Autonomy (sDA) that evaluate the illuminance level annually and with the Annual Sunlight Exposure (ASE) that reveal the glare probability, within the scope of Leed V4.1. Furthermore, scenarios were created with the choice of finishing materials and curtains with different optical properties for the interior wall surfaces and ceiling, which have lost their authentic value, based on the same metrics. Thus, it has been revealed to what extent the quantity, quality and distribution of natural lighting in classrooms have changed. According to the simulation results, it was determined that there were significant glare problems in two of the four classes, with ASE ranges ranging from 0% to 31.4%. Class B facing south and east, has the most significant glare potential. In addition, all classrooms spatially provide the sDA value. However, more illuminance levels are required in the back corners of the classrooms.

Keywords: Natural Lighting, Glare, Illuminance, Finishing Material

Tarihi Eğitim Mekanlarında Doğal Aydınlatma Performansının İyileştirilmesi: Ulugazi İlköğretim Okulu

Öz

Doğal aydınlatma, psikolojik olarak memnuniyet hissettiren ve motivasyon arttıran ortam yaratması, daha sağlıklı koşulları teşvik etmesi ve enerji tasarrufu sağlaması nedeniyle eğitim binalarının tasarımında önemli bir faktördür. Bunun yanı sıra görsel konforun öğrenme üzerindeki etkisi büyüktür. Eğitim binalarında farklı yönlere bakan ve farklı boyutlardaki sınıflarda aynı bitirme malzemelerinin kullanılması farklı nicelik ve nitelikte doğal aydınlatma etkilerinin oluşmasına neden olmaktadır. Bu durum da öğrenciler

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arasında psikolojik, fizyolojik ve bilişsel olarak eşitsizliğe neden olmaktadır. Bu olumsuzluk cephede kurgulanacak elemanlar, saydam yüzey oranı ve malzemelerinin değişimi ile iyileştirilebilir. Ancak bu uygulamaların tarihi yapıda en az müdahale ile yapılması gerekmektedir. Kocaeli'nde tarihi bir okul binası olan Ulugazi İlköğretim Okulu'nda sınıfların mevcut doğal aydınlatma performansının tespit edilmesinin hedeflendiği bu çalışma kapsamında senaryolar bina kimliğine en az etkide bulunacak yaklaşımlarla kurgulanmıştır.

Bu bağlamda Rhinoceros 7 ile çalışan Climatestudio yazılımı ile farklı özelliklere sahip dört sınıfın Leed V4.1 kapsamında yıllık olarak aydınlık seviyesini değerlendiren sDA ve kamaşma olasılığını ortaya koyan ASE metrikleri üzerinden gerçekleştirilen analizler ile görsel konfor sorunları belirlenmiştir. Ardından aynı metrikler üzerinden özgün değerini kaybetmiş iç duvar yüzeyleri ve tavanda optik özellikleri farklı bitirme malzeme ve perde seçimleri ile kurgulanan senaryolar üzerinden sınıflardaki doğal aydınlatma nicelik, nitelik ve dağılımının ne ölçüde değiştiği ortaya konulmuştur. Simülasyon sonuçlarına göre Annual Sunlight Exposure (ASE) aralığı %0 ile %31,4 arasında değişen dört sınıfın ikisinde önemli ölçüde kamaşma sorunları olduğu belirlenmiştir. En fazla kamaşma potansiyeline sahip olan güney ve doğu yönlerine bakan B sınıfıdır. Bunun yanı sıra bütün sınıflar mekansal olarak Spatial Daylight Autonomy (sDA) değerini sağlamakla birlikte sınıfların arka köşelerinde yetersiz aydınlık düzeylerine rastlanmaktadır.

Anahtar Kelimeler: Doğal Aydınlatma, Kamaşma, Aydınlık Düzeyi, Bitirme Malzemesi

1. Introduction

Fry (2008) emphasized the necessity of providing all the comfort parameters related to the human senses in the classrooms since the learning process occurs through hearing, seeing, and feeling by touching.

Studies show that providing indoor climatic, visual and acoustic quality is essential as it directly affects the performance and health of students in their learning processes (Lee et al., 2012, p. 243; Korsavi, Montazami and Mumovic, 2020, p. 12; Zhang, Ortiz and Bluyssen, 2019, pp. 265-266). Significantly, during the primary stage of the learning process of seeing, the visual performance of the students varies depending on the size, forms, facade-transparent surface ratio, location, interior surface material optical properties, different brightness levels, distribution, and quality of classroom spaces (Heschong, 1999, pp. 7-29).

The appropriate level and quality of natural light with homogenous distribution depend on the characteristics of the solar rays acting on the space changing due to the sky conditions. Natural lighting is a primary method to be preferred in providing optimal interior visual comfort conditions to minimize energy consumption. Artificial lighting is used when natural and alternative natural lighting systems are insufficient. According to the report published by the International Energy Agency (IEA), artificial lighting is responsible for 14% of electricity consumption in the European Union (Economidou et al., 2011; URL-1). Therefore, using natural lighting is crucial for energy reduction and promoting environmental awareness (Phocas, Michael and Fokaides, 2011, p. 937; Michael and Phocas, 2012, p.195).

The usage of daylight and artificial lighting systems are significant parameters to be addressed from the first stage of building design. However, there are many existing school buildings where the parameters such as building orientation, transparent surface organization, and interior surface material selection have not been considered appropriately during the design phase. In these buildings, strategies such as variation of window glasses and frames, interior surface materials, and integration of alternative natural and artificial

lighting systems may be implemented to provide visual comfort conditions and energy efficiency within threshold value ranges (Boafo et al., 2019, pp. 10-11). However, due to the necessity of performing the refurbishments to the historical buildings by limited methods with minimum impact on the authentic identity of the building, it also offers a determinate option of interventions for lighting requirements (Doukas and Bruce, 2017, pp. 78-79; Khodeir, Aly and Tarek, 2016, pp. 260-264). In addition, in line with the spatial requirements brought by the current developments in the field of education, inadequate conditions for lighting may occur even in historic school buildings that continue with their original function. Optimal visual comfort threshold values prescribed by current standards are also provided by minimal intervention.
In addition to external factors, the quality and quantity of light, which changes due to internal factors such as the location of the student in the classroom, the physical characteristics and optical properties of the interior surface materials, the type and amount of the indoor artificial lighting system, and the time intervals in which it is active, determine the visual comfort levels of the students in the classrooms. Frequently, every classroom is organized similarly with ignorance of the quantity and quality of daylight usage in schools that affects students' cognitive performance and psychological and physiological states. (BS 8206-2, 2008). Visually inadequate conditions hinder the right of all students to benefit from information equally in the classroom located at different orientations of school.

Leed V4.1 (Leadership in Energy and Environmental Design Version 4.1) credits daylight usage in schools with a range of 1-3 points. The main aim is the usage of daylight effectively with a minimum requirement of artificial lighting by considering students' circadian rhythms and visual connection with the outdoors. In order to achieve daylight compatibility, LEED v4.1 emphasizes the use of simulations for daylight studies and encourages the Annual Sunlight Exposure (ASE) and Spatial Daylight Autonomy (sDA) criteria. A balance between sDA and ASE is required for LEED v4.1 compliance. Leed V4. 1 provides directives for glare control by manual or automatic systems in places such as classrooms, used at regular intervals. The Annual Sunlight Exposure (ASE1000/250) helps examine the level of glare problem and identifies the potential for visual discomfort in interior workspaces. According to the directive, direct sunlight at illuminance levels of 1000 lux and above can occur with a maximum rate of 10% of the space area and for a maximum of 250 operating hours per year. The other measurement, Spatial Daylight Autonomy (sDA), corresponds to the time rate as %55, 300 lux illumination level of daylight recommended for the classrooms is met at the reference locations. An increase in the rate of time provides higher points. sDA calculations are based on annual, climate-based simulations of thousands of different sky conditions throughout the year.

A point-in-time simulation is a measurement that looks at specific light levels on a given day and time, using localized sky conditions to study lighting design and glare. It is recommended to be between 300 and 3000 lux. Daylight levels less than 100 lux are often insufficient for most tasks. 100–300 lux is adequate, although some tasks require artificial lighting. In most cases, 300–3000 lux is considered a desirable level of illuminance. Illuminance levels greater than 3000 lux are undesirable as they can cause visual and thermal discomfort (URL-2; URL-3).

Zomorodian and Tahsildoost (2019, p. 679) evaluated daylight performance and visual comfort by a longitudinal subjective survey with 842 total responses and simulation-based metrics in four classrooms in two LEED™ silver certified buildings during a year. The results of the survey were reviewed by the results of Spatial Daylight Autonomy (sDA300/ 50% and Useful Daylight Illuminance (UDI300-3000/50%) metrics. The study indicated a robust correlation between students' perceptions and the calculated climate-based daylight metrics.

Lo Verso, Giuliani and Caffaro (2021, pp. 15-16) investigated the daylight quantity and quality in different Italian universities with the ad-hoc survey administered to students to find out how they perceived daylight conditions in their classroom. They carried out numerical simulations on different types of daylight metrics consisting of average and spatial daylight factor, daylight autonomy, continuous daylight autonomy, spatial daylight autonomy, annual sunlight exposure, and annual light exposure. Additionally, the study considered circadian metrics EML calculated only for the specific time steps when the survey was filled (point-in-time analyses), during both the spring and the fall/winter sessions. The comparison of the results of daylight metrics presented that the highest correlation was obtained with the average daylight factor DFm and the Annual Lighting Exposure ALE. In addition, Samiou, Doulos, and Zerefos (2022, pp. 1-2) aimed to identify daylighting design approaches that, given the climatic data for Greece, may maximize the visual environment in preschool classrooms. The study also evaluates climate-based daylight modeling metrics as an assessment tool throughout the daylighting design process. However, neither study looked at the effect of finishing materials on natural lighting.

In this study, visual comfort conditions of 4 classrooms on different orientations in Ulugazi elementary school in İzmit-Turkey is compared by the “Annual Sunlight Exposure”, “Spatial Daylight Autonomy” and “Point-in-Time” measures in the context of Leed V4.1. Furthermore, the study aims to improve interior visual comfort above a certain threshold level for each class with minimal intervention to the historic building by choosing interior shading elements and materials with different optical characteristics for ceilings, walls, and furniture.

2. Method

The study investigates the variation of daylight effects in different classrooms with proposed daylight control strategies with a simulation process with Rhinoceros 7(URL-4) and ClimateStudio for the historical Ulugazi primary school building in Kocaeli. This newly developed add-on is built on EnergyPlus and uses a new "Radiance" based path-tracking technology. It is a fast, advanced environmental performance analysis tool. Kocaeli IWEC climate data is used for the simulations. ClimateStudio calculates sDA, using dynamic shading and the latest LM-83 standards. The explanation of the case and the simulation assumptions are below (URL-5).

2.1. School building and classrooms

Ulugazi Primary School, located in Kocaeli-İzmit, was built in 1932 and continues to be used as a school today. It has three floors consisting basement, ground floor, and first floor. Figure 1 shows the classrooms on the ground floor, evaluated within the scope of this study. The building is modeled based on building survey drawings. Table 1 presents the spatial characteristics of the classes. The simulation process considers the effect of both the shadow effects of neighbor buildings and trees around the school.

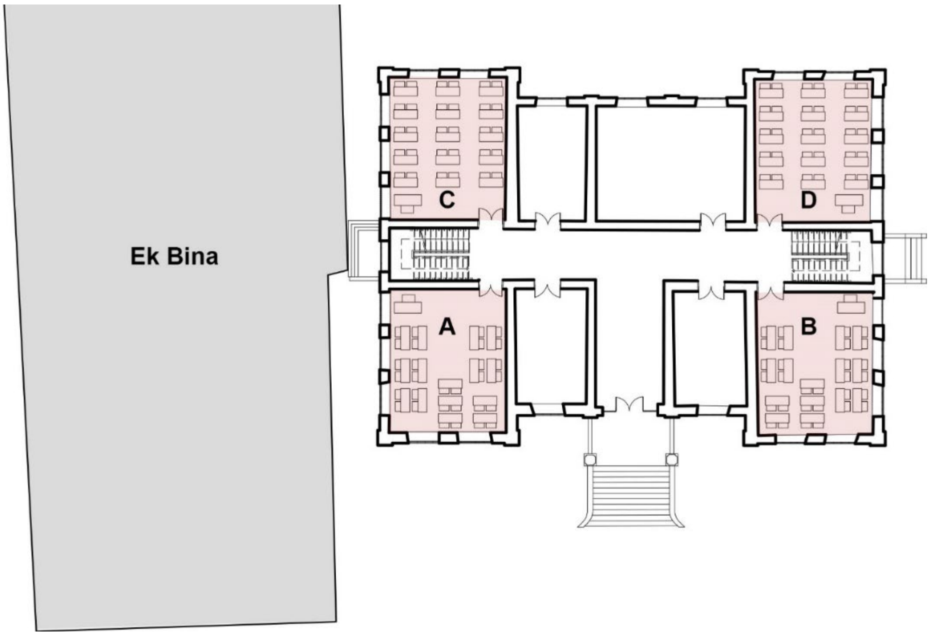

Figure1. Gorund floor (Abusamhadana and Türkmenoğlu, 2018, p. 193).

Table 1. Spatial characteristics of the classrooms

Classroom	Dimension (m)	Window area (m^2)	Facade Orientation
A	7,9*6,4*3.81	2.57*1.70*5	South
B	7,8*6,5*3.81	2.57*1.70*5	South
C	7,8*6,5*3.81	2.57*1.70*5	North
D	7,9*6,5*.3.81	2.57*1.70*5	North

2.2. Simulation parameters

Weather data is obtained by TUR_KC_Cengiz-Topel.AP.172005_TMYx.2007-2021 file (URL-6). Table 2 presents the daylight simulation parameters that remained the same during all simulations. The "Point-in-time" metric is calculated for specific hours of 9:30, 12:30, and 15:30 for the 15th day of October, January, and March, which represents the typical day of each for the fall, winter, and spring months. The study does not comprise the summer months as the education period does not proceed.

TS EN-12464 (2013) standard gives specific measurements of the grid system as a basis for the simulation process. According to the standard and simulation time, the distance among the grids is determined as 0.6 m. The height of the grid is 0.8 due to the sitting elevation on the desk.

Table 2. Daylight simulation parameters

Parameter	**Description**

Imported Weather Data File	TUR_KC_Cengiz-Topel.AP.172005_TMYx.2007-2021
Radiance parameters (ambient bounces, ambient samples)	6, 6400
Sensor grid height	0,8 m

2.3. Simulation scenarios

Due to the historical building status, the intervention points to the space are limited, so the interior features are discussed only on specific parameters.

There is a reflection of 50% for office furniture, 80% for ceilings, 50% for walls, and 20% for floors on interior surfaces in the existing classrooms (Table 3-table 4). Interior finishing materials from the ClimateStudio database are used for the simulations. The reflectance ratios of the interior wall surfaces are determined due to the intervals recommended in the standard TS EN 12464-1 "Light and lighting - Illumination of workplaces - Part 1: Indoor working areas". The list of scenarios is in Table 5.

Table 3. Material properties of reference condition.

Parameter	Material Properties		
Wall	Beige wall Reflectance Specular Diffuse		 %52,14 %0,72 %51,41
Ceiling	White Painted Room Ceiling Reflectance Specular Diffuse		 %82,2 %0,44 %81,76
Furniture	Wood Laminate Reflectance Specular Diffuse		 %50,92 %1,41 %49,52

Table 4. Features that remain the same for both reference condition and scenarios

Parameter	**Material Properties**	
Exterior Floor	Red Exterior Floor Tiles Reflectance Specular Diffuse	 %28,62 %0,12 %28,50
Vegetation	Green Leaf Tree Reflectance	 %11,32

	Specular Diffuse	%0,21 %11,11
Interior Floor	Dark Grey Reflectance Specular Diffuse	 %20,06 %1,25 %18,81
Window	Clear - Solarban U- Value [W/(m2K)] SHGC TVIS Layers	60 1.66 0.46 0.696 Clear Float Glass Clear 5.8 (mm) Air: EN673 12.7 (mm) Solarban 60 on Clear 6 mm-Flipped 5.7 (mm)

Table 5. Simulation scenarios.

Scenario	**Wall**	**Ceiling**	**Furniture**	**Operable Blind**
S1	White painted walls Reflectance %79,8 Specular: %0,39 Diffuse : %79,41	White plaster wall Reflectance: % 89,9 Specular: %0,13 Diffuse: %89,76	Light Brown Laminate Reflectance: %62,77 Specular: %1,37 Diffuse: 61,40	P13 oyster beige Permeability: %4,4 Tvis: %15,4
S2	Beige wall Reflectance:%52,14 Specular: %0,72 Diffuse: %51,41	Plastic Ceiling Vent E14 Reflectance:%72,33 Specular: %1,10 Diffuse:%71,24	Wood Laminate Reflectance: %50,92 Specular: %1,41 Diffuse: %49,52	P13 oyster beige Permeability: %4,4 Tvis: %15,4
S3	Beige wall Reflectance:%52,14 Specular: %0,72 Diffuse: %51,41	Plastic Ceiling Vent E14 Reflectance:%72,33 Specular: %1,10 Diffuse:%71,24	Light Brown Laminate Reflectance: %62,77 Specular: %1,37 Diffuse: 61,40	P13 oyster beige Permeability: %4,4 Tvis: %15,4
S4	White painted walls Reflectance:%79,8 Specular: %0,39 Diffuse : %79,41	White plaster wall Reflectance: % 89,9 Specular: %0,13 Diffuse: %89,76	Wood Laminate Reflectance: %50,92 Specular: %1,41 Diffuse:	P13 oyster beige Permeability: %4,4 Tvis: %15,4

			%49,52	
S5	White painted walls Reflectance:%79,8 Specular: %0,39 Diffuse : %79,41	White plaster wall Reflectance: % 89,89 Specular: %0,13 Diffuse: %89,76	Light Brown Laminate Reflectance: %62,77 Specular: %1,37 Diffuse: 61,40	V22 Charcoal Gray Permeability: %3,7 Tvis: %4,1
S6	Beige wall Reflectance:%52,14 Specular: %0,72 Diffuse: %51,41	Plastic Ceiling Vent E14 Reflectance: %72,33 Specular: %1,10 Diffuse:%71,24	Light Brown Laminate Reflectance: %62,77 Specular: %1,37 Diffuse: 61,40	V22 Charcoal Gray Permeability: %3,7 Tvis: %4,1
S7	White painted walls Reflectance : %79,8 Specular: %0,39 Diffuse : %79,41	White plaster wall Reflectance: % 89,89 Specular: %0,13 Diffuse: %89,76	Wood Laminate Reflectance: %50,92 Specular: %1,41 Diffuse: %49,52	V22 Charcoal Gray Permeability: %3,7 Tvis: %4,1
S8	Beige wall Reflectance: %52,14 Specular: %0,72 Diffuse: %51,41	Plastic Ceiling Vent E14 Reflectance: %72,33 Specular: %1,10 Diffuse:%71,24	Wood Laminate Reflectance: %50,92 Specular: %1,41 Diffuse: %49,52	V22 Charcoal Gray Permeability: %3,7 Tvis: %4,1

3. Results and Discussion

3.1. Visual Comfort Analysis of the Classrooms

Classes A, B, C, and D with different orientations, and the locations are evaluated by comparing their current situations with derived scenarios. Classes A and B face south, and C and D face north. Classes A and B are under the shadow effects of trees. Furthermore, the annex building shades the west direction of the A and C classes. The evaluation of daylighting performance is based on Leed V4.1. sDA, ASE, and point-in-time metrics were used. Simulations of the current state of the classrooms revealed that spatially adequate lighting levels occur in the classrooms according to the sDA metric. However, glare problems from direct sunlight can evolve in south-facing classrooms.

Classroom A
The ASE value is 20% for this class. Figure 6 presents the distribution of daylight according to the current situation and the reference months for S1. The results show that the luminance distribution is generally homogeneous, but towards the windows facing south, illuminance

levels above 3000 lux occur. Therefore, these locations require appropriate precautions, especially for glare problems. Although the existing situation shows similar performance for S1, S4, S5, and S7 sDA, the most effective scenarios can be selected as S1 and S4 when the average lux values and sDA are examined together (Figure 2). Considering that the S1 and S4 are the two scenarios with the highest material reflectivity values, it can be concluded that the distribution of daylight in the space is supported by these two. The excessive difference between the average lux values between the scenarios and the current situation shows that the interior shading element reduces the glare problem. However, this situation also causes a decrease in the illuminance level at non-glare points. According to the program data, 95.7% of the interior shading elements remain open throughout the year.

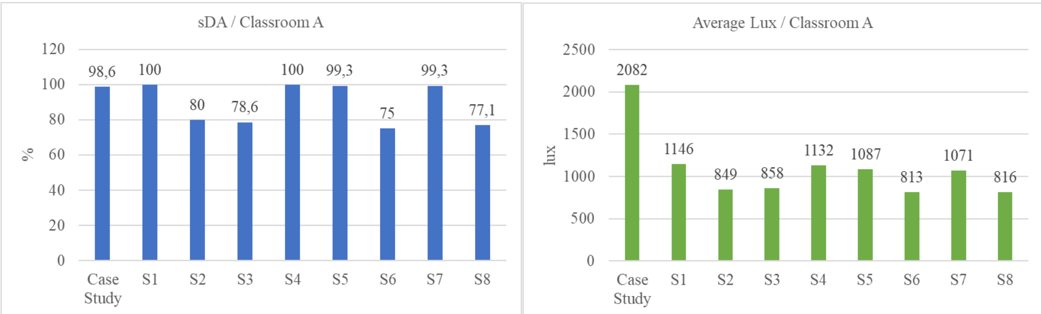

Figure 2. sDA and average lux values of scenarios for classroom A.

<u>Classroom B</u>

The ASE value is 31.4% for this class. Considering the sDA values, although the existing condition seems to be the most optimal solution for this class, with the altogether examination of the sDA, average lux, and ASE values, the S1, S4, S5, and S7 scenarios seem to perform well (Figure 3). However, the distribution is not uniform in the existing condition, but S1 performs better (Figure 6). The selection of curtains with higher daylight transmittance (Tvis) has a better effect on sDA and average lux values due to the observations. According to the program data, the interior shading elements remain open throughout the year with a rate of 95.4%.

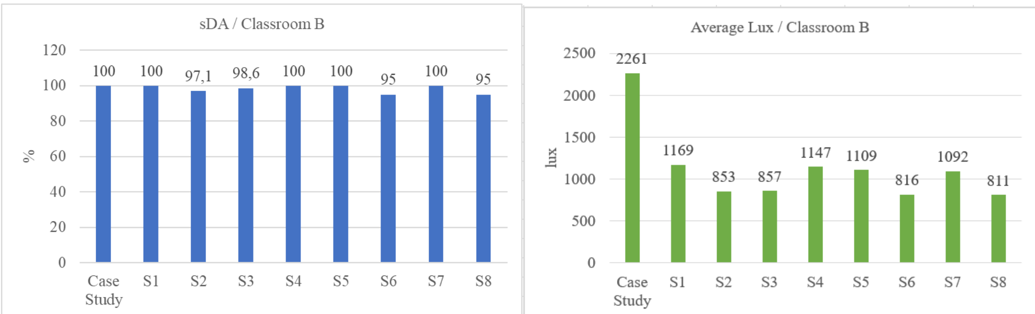

Figure 3. SDA and average lux values of scenarios for classroom B.

<u>Classroom C</u>

ASE value is 0% for this class. The sDA values for S1, S5, and S7 are approximately the same (Fig. 4) . However, S1 has the best average lux value. It is seen that the luminance distribution is uniform (Figure 7). Since there is no glare in this class, the position of the curtains is always open throughout the year.

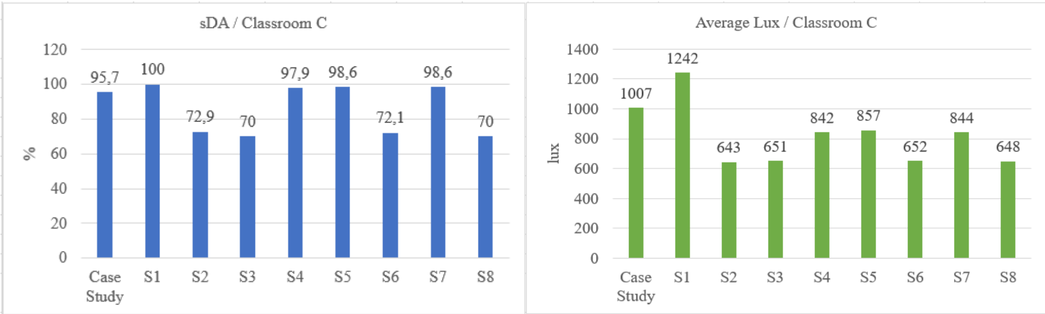

Figure 4. sDA and average lux values of scenarios for classroom C

Classroom D

The ASE value is 3.9% for this class. Since the ASE value is below 10%, the glare level that may occur due to Leed V4.1 is tolerable. The sDA values are at the same level for all scenarios (Figure 5). However, S1 provides a higher average lux value with a slight difference compared to other options. The results of the examination point-in-time of the existing condition and S1 show that S1 has much more illuminance uniformity. According to the program data, 98.5% of interior shading elements remain open throughout the year.

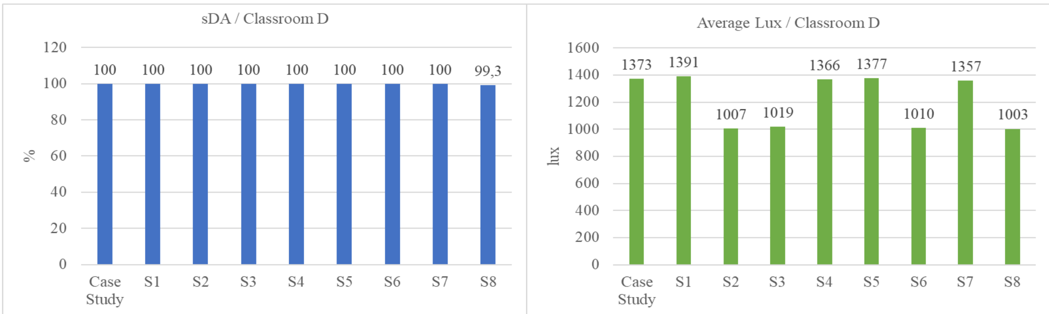

Figure 5. sDA and average lux values of scenarios for classroom D.

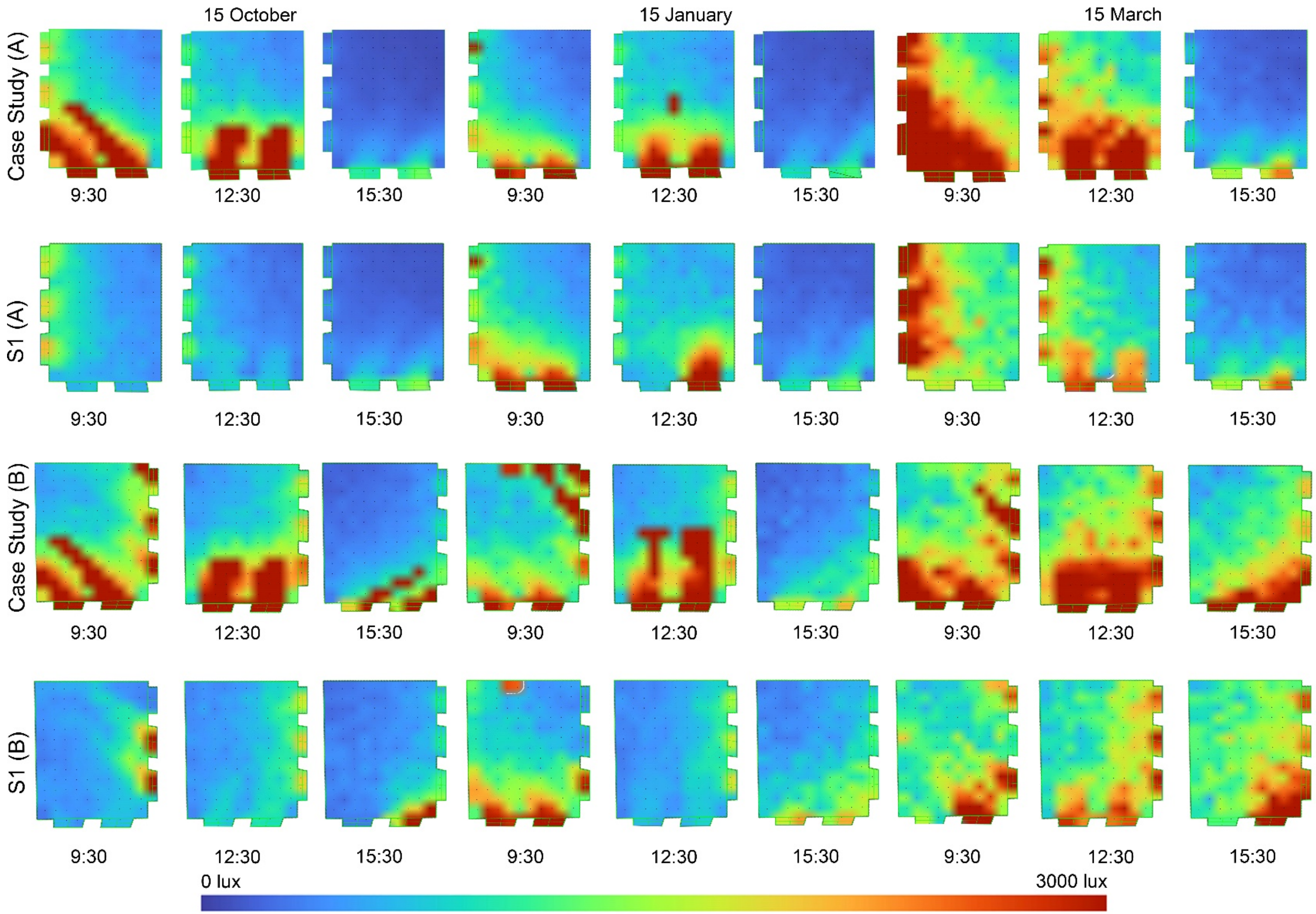
15 October
15 January
15 March
Case Study (A)
S1 (A)
Case Study (B)
S1 (B)
9:30
12:30
15:30
0 lux
3000 lux

Figure 6. Daylight distribution for existing condition and S1 in classrooms A and B.

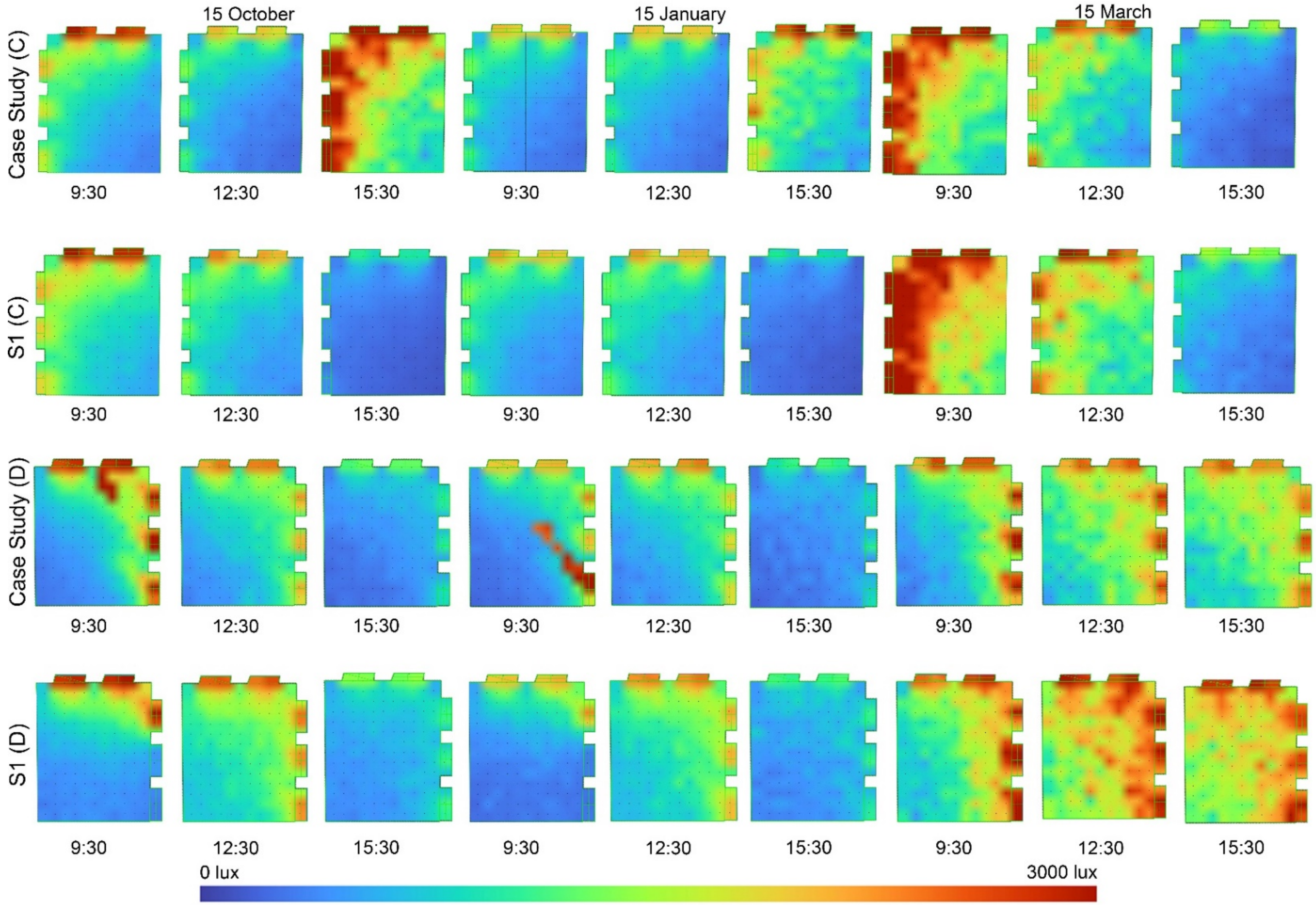

Figure 7. Daylight distribution for existing condition and S1 in classrooms C and D

4. Conclusion

One of the essential criteria affecting the quality of the indoor environment in educational buildings is the design of natural lighting. Effective daylight design in classrooms and common areas of school buildings allows both stable and sufficient natural light indoors. The time students spend at school is more than the hours they spend at home or outside. Therefore, the visual comfort of the students in the classrooms is a priority to be addressed. Sufficient natural lighting in educational buildings supports the healthy development of students. Daylight design requires a comprehensive study involving many factors. It is crucial to consider daylight design and environmental parameters in new buildings and to shape the spaces accordingly. However, the solution to daylight-related problems in existing and historical buildings may be limited. While creating natural lighting strategies, the protection limits of historical buildings should be considered.

This study examined the natural lighting performance of the classes facing different orientations in the historical Ulugazi Primary School. When the current situation and the scenarios are compared, it is seen that even the finishing materials used in the space can change the natural lighting performance. When the current situation is examined, it is seen that different natural lighting performances are provided for the classrooms facing south and north. The ASE values of the classes facing south are quite high, which increases the glare problem. The priority for classes facing this direction should be to eliminate this negativity. S1 was the most optimal choice for all the classrooms. When looking at the point-in-time situations, it is seen that the values above 3000 lux are reduced compared to the current situation. However, the study reveals that illuminance levels at the back locations of all classrooms are insufficient. Therefore these areas should be supported by artificial lighting.

Supporting natural lighting with artificial lighting when necessary is a comprehensive issue that requires a holistic design approach. Correctly selecting luminaires, spectra, colour codes, and positions is essential in constructing artificial lighting. A future study can be conducted on the support of artificial lighting control and luminaire selection strategies on natural lighting in these classrooms.

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