International Journal of Digital Innovation in the Built Environment
Volume 11 • Issue 3

The Role of Light Shelf and Window Size on Daylight Performance of an Architecture Studio

Aybüke Taşer, Izmir University of Economics, Department of Architecture, Balcova, Izmir, Turkey*
https://orcid.org/0000-0002-0335-2904

Tuğçe Kazanasmaz, Izmir Institute of Technology, Department of Architecture, Gulbahce, Urla Izmir, Turkey

ABSTRACT

Daylight affects human beings' health and comfort. Recently, occupants face thermal and visual comfort problems due to the lack of solar control elements and improper design decisions of glazed surfaces. Recent studies show that solar control systems and window-based variables are some of the most significant variables which influence daylight performance. This study aims to test various combinations of window sizes and light shelf scenarios for a uniform distribution of daylight and visual comfort of occupants in two architecture studios in the İzmir Institute of Technology (IZTECH) Campus. In scenarios, window size and location, exterior and interior light shelves' height, incline angle, and materials are tested. It is concluded that variables significantly improved the uniform distribution of daylight of both studios and sun patch areas of the south/east-oriented studio. Also, the artificial light requirement of the south/west-oriented studio is improved by 29.36% and 31.75% for the 21st of June and December respectively.

KEYWORDS

Building Physics, Classroom, Daylight Performance, Daylight Simulation, Izmir Institute of Technology, Light Shelf, Visual Comfort, Window Size

INTRODUCTION

Daylight is a critical factor influencing human health in an environment and uniform distribution (Alhagla, Mansour and Elbassuoni, 2019). It is significant in every building, especially in educational ones, because it is essential for the educational process's physical and psychological aspects in a classroom (Galal 2019). In terms of physical aspects, daylight significantly influences student health because it is associated with the human body's eyesight and biological characteristics (Kralikova, Dzunova, and Rusko, 2020). Additionally, it contributes to students having higher productivity and

DOI: 10.4018/IJDIBE.306253
*Corresponding Author

satisfaction when they have access to daylight (Day, Futrell, Cox, et al., 2019). Daylight-related problems may occur due to lack of daylight, availability of excessive daylight, glare, flicker, and shadows (Liu, Qu, Ren, et al. 2022). Due to glazed surfaces without any solar control strategies, people have started to experience thermal and visual comfort problems related to poor daylight performance (Day, Futrell, Cox, et al., 2019). There may be very dark and very bright surfaces. Human productivity decreases due to the lack of daylight. Excessive illuminance influences human health. Glazed surfaces increase energy consumption due to artificial light usage and excessive heat gain (Skotnicova, Lausova, and Michalcova, 2016). The design phase needs to consider the proper distribution of daylight-related strategies. Studies show that integrating solar control systems with window-based variables significantly influences daylight performance (Cesari, Valdiserri, Coccagna, et al., 2018). Thus, this paper aims to understand how windows and shading elements are crucial for a building's daylight performance. The study intends to respond to: "How is window size effective for daylight performance?" and "What is the influence of light shelves on the proper distribution of daylight and artificial light requirement?"

LITERATURE REVIEW

Light shelves and window sizes are practical components in this sense. A wide range of studies is reviewed based on these. For instance, a study improves the daylight performance of four high education building architecture studios by using illuminance and uniformity metrics (Kazanasmaz & Fırat, 2014). Laser-cut and prismatic panels and light shelves are investigated through the simulation models to achieve an improved daylight performance. Results imply that the design process is significant in testing the effect of architectural decisions on daylight performance. One study purposes to generate daylight redirecting design alternatives and assess their daylight performance for an architectural studio (Grobe, Geçit, Sevinç, et al., 2017). These systems are light shelves, light ducts, and horizontal and 15þangled blinds. The study used both scale models and computational tools for daylight assessment. These systems' optical and geometrical specifications could be determined by several investigations of two types of assessment methods. A study on the proper distribution of daylight in a Greek classroom proves that light shelves, especially if they are combined with semi-transparent external blinds, can improve uniform daylight distribution (Meresi, 2016). The study mentioned that light shelves improved glare risks by providing shading and light redirection. Also, it is noted that a light shelves' width, height, incline angle, and reflectance ratio should be optimized for better daylight performance. As a result, the study presents optimized simulation outputs of a Greek classroom. Another study reveals that optimizing window size directly impacts the uniform distribution of daylight and reduces heating, cooling, and lighting loads (Alhagla, Mansour and Elbassuoni, 2019). The research parameters are glazing types (i.e., single glazing, double glazing, low e), window size, and building geometry. The study aims to define an optimum combination of window-to-wall ratio and glazing type for a south-oriented room in Egypt. An office room is selected as a reference and modeled in Rhino. Similarly, the authors use simulation engines to carry out the research. A Rhino plug-in, DIVA, is used throughout the study. Results of the study reveal that an increased window-to-wall ratio rises illuminance and provides a balanced daylight distribution. Also, different glazing types can reduce glare risks and high illuminance values. As a general evaluation, variables in the study could improve overall daylight performance and energy use in the room.

One study investigates the potential of semi-transparent overhangs on indoor environmental quality and energy performance in Greek schools (Dascalaki & Sermpetzoglou, 2011). Results show that when applied to specific facade orientations, they can retrofit glare risks and overheating problems, resulting in poor visual comfort and high energy consumption.

In such studies, it is proved that shading elements can balance high illuminance differences between near-window zones and the back parts of the room. Window-to-wall ratio (wwr) strongly influences the distribution of daylight more properly by retrofitting light dimming parts of a space.

The effect of window size properties and shading elements on daylight performance needs to be investigated in that sense. Two architecture studios are selected for this study because they have deep plans exceeding 10m, although they are 3m in height, resulting in improperly and insufficient distribution of daylight. Additionally, they are specific types of classrooms and there are not many studies in the literature for architectural studios' daylighting assessment. This study evaluates the combinations of various window sizes and light shelf scenarios on the proper distribution of daylight and visual comfort in an educational building on the İzmir Institute of Technology (IZTECH) Campus. The originality of this work is based on the calculations of artificial lighting requirement ratios of these studios and finding the best solution to decrease this ratio by combinations of light shelves and window sizes. The surface area of windows is enlarged to collect more daylight and transfer it to the studios, while light shelves help to distribute daylight to the back parts of the room and shade the closer areas of the window zones.

MATERIAL AND METHODS

Case Building

The case building is a three-story-high building of 4m in height. In the study, two architecture studios are selected. The first one has over-lit areas near window zones facing south-east and south-west, while the second studio suffers from daylight and faces south-west and north-west. Two studios have dimensions of 11.8x17.8m and 11.9x17.8m, respectively. Figure 1 shows the Relux model and plan of the studios.

Methods

Nine scenarios are tested through simulation models. A daylight performance analysis software Relux is used throughout the study. Relux is one of the most preferred software for daylight studies since it has a user-friendly interface and algorithm. Additionally, according to one study (Uygun & Görgülü, 2016), when compared with other software, it gives more reliable results by using luminance, illuminance, color temperature values, etc. To conduct the simulations, selected studios are modeled, and their surface materials are introduced to the software (Table 1). Daylight performance is calculated and evaluated on a grid with dimensions of 17.7x11.38m for both studios with 0.75m high from the floor. The distance between measurement points is around 1.25m for sensitive calculations. A total number of 126 points are available on the reference plane. All simulations are performed on December 21 and June at 10:00 a.m. under the clear sky with sun conditions. The reason for choosing these dates is to see the worst and most challenging conditions during the year. The calculation model is defined as the average indirect fraction. The variables in the study are window size/location and shading elements' length, height, incline angle, material, and reflectance ratio.

Study Design

In the first three scenarios, window sizes are expanded by 50, 100, and 150 cm, respectively, and overhangs are implemented to windows. Then, the height and incline angle of overhangs are changed in the following two scenarios. Overhang elevation height is decreased by 70 cm, and incline angle is defined as 20þ. Afterward, interior light shelves are implemented in both studios. Lastly, the effect of light shelves' material and the reflectance ratio are investigated. Material is changed from plastic to metal, and the reflectance ratio is increased from 50% to 85%. The research goals, parameters, conditions, and dates for each Scenario are shown below (Table 2) (Figure 2). This study covers a wide range of scenarios to understand the potential of variables under different conditions. The results are compared to the previous scenario and base-case conditions where any shading devices and changes are not implemented in the studios.

Figure 1. (a) The model in Relux Software (b) Plan drawings of studios

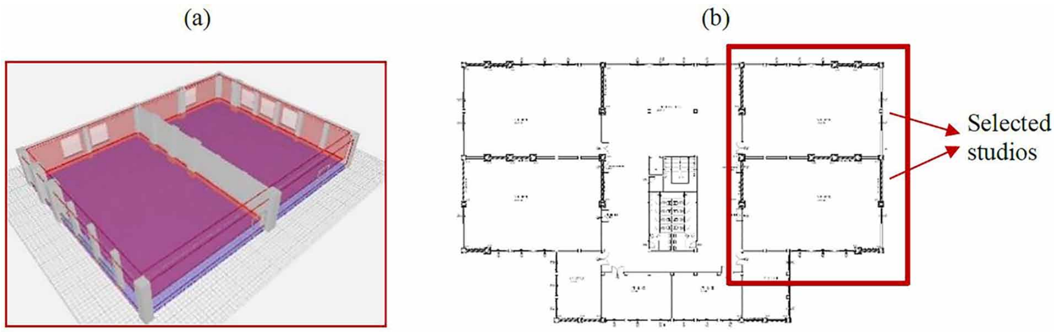


Table 1. Data input details for the daylight simulation model

Building element	Material	Specifications
Floor	White polished marble	Rho 65%
Ceiling	Gypsum board	Rho 80%
Walls	Paint of a light matt color which is close to white	Rho 60%
Windows	Double glazing	Transmittance: 75%

Source: Grobe, Geçit, Sevinç, et al. (2017)

RESULTS AND DISCUSSION

Nine scenarios and one existing situation are analyzed and interpreted in detail (Figure 3). Simulation outputs are evaluated in terms of daylight uniformity ratio (UR), the artificial light requirement (ALR) of studios, and sun patch illuminance values (SPIV). Two types of uniformity ratios are defined. One is the ratio of minimum illuminance value (E_{min}) to average (E_{avg}), while the other one is the ratio of E_{min} to maximum illuminance value (E_{max}). The simulation engine calculates E_{min} and E_{avg} values. E_{max} is defined as the maximum value less than 10.000 lx. If illuminance values are greater than 10.000 lx, it is defined as a sun patch area and considered SPIV. To interpret artificial light requirement (ALR), 126 measuring points are evaluated on the reference plane. Educational buildings require an artificial light if the illuminance value is below 300 lx. (Düzgün & Yağmur, 2019).

Table 2. Research goal, parameters, conditions

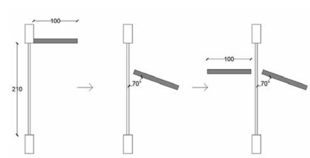
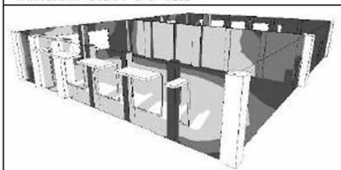
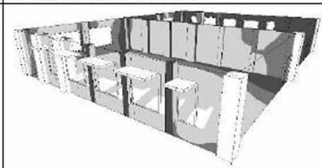
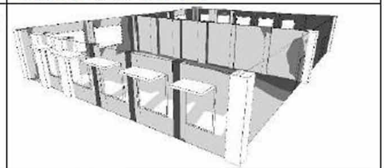
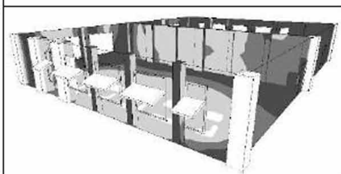
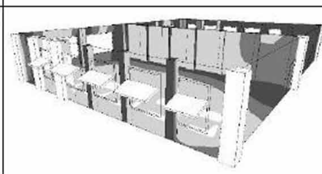
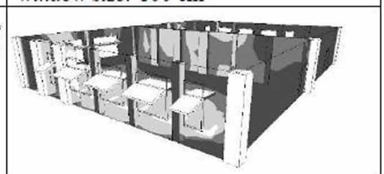
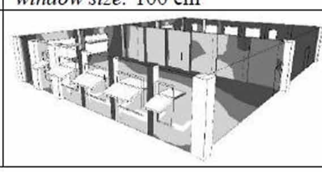
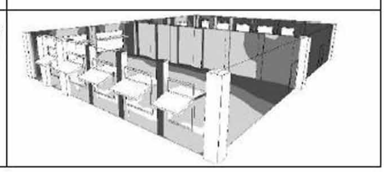
Stage	Research goal	Parameters	Configuration
1,2 and 3	the effects of window size and overhangs due to uniformity and artificial light requirement	Window size and overhang	 S: 1,2,3 S: 4,5 S: 6,7
4,5	the influence of height and incline angle of light shelves on uniformity and artificial light required areas	Light shelves' height and incline angle	
6,7	the impact of interior light shelves on daylight performance	Implementation of light shelves	
8,9	the effect of light shelves' material and reflectance ratio on uniformity	Reflectance ratio and material	

Figure 2. Three-dimensional scenes showing scenario configurations

Scenario 1	Scenario 2	Scenario 3
Overhang: plastic, parallel to the ground *window size:* 50 cm	*Overhang:* plastic, parallel to the ground *window size:* 100 cm	*Overhang:* plastic, parallel to the ground *window size:* 150 cm
		
Scenario 4	**Scenario 5**	**Scenario 6**
Light shelf: exterior, 70 cm below, 20° inclined-plastic *window size:* 100 cm	*Light shelf:* exterior, 70 cm below, 20° inclined-plastic *window size:* 150 cm	*Light shelf:* exterior, 70 cm below, 20° inclined-plastic: interior, 70 cm below, parallel to the ground-plastic *window size:* 100 cm
		
Scenario 7	**Scenario 8**	**Scenario 9**
Light shelf: exterior, 70 cm below, 20° inclined-plastic: interior, 70 cm below, parallel to the ground-plastic *window size:* 150 cm	*Light shelf:* exterior, 70 cm below, 20° inclined, 85% reflectance-metal: interior, 70 cm below, parallel to the ground, 85% reflectance-metal *window size:* 100 cm	*Light shelf:* exterior, 70 cm below, 20° inclined, 85% reflectance-metal: interior, 70 cm below, parallel to the ground, 85% reflectance-metal *window size:* 150 cm
		

Base Case Results

Firstly, the existing situation is analyzed to understand the current problem and insufficiencies. On June 21, it is seen that the first studio (S1) has very bright surfaces and sun patch areas. E_{avg}, E_{min}, and E_{max} values are calculated as 3230, 281, and 6890 lx. Additionally, there were so many measuring points above 10.000 lx and considered sun patch areas. Although the studio does not require artificial light, uniformity ratios are calculated below than needed. On the same date, it is noted that the second studio (S2) does not have enough daylight, and ALR is calculated as 54.76%. It means that 54.76% of the studio lacks natural light.

Contrary to the first studio, illuminance values are estimated to be lower than expected. E_{avg}, E_{min}, and E_{max} are calculated as 332, 42, and 923 lx. Similarly, uniformity ratios are found insufficient. In both studios, uniform distribution of daylight is not achieved. Results are found similar for December 21 (Figure 4). Differently, the first studio does not have sun patch areas. However, E_{avg}, E_{min}, and E_{max} have defined them as 2410, 131, and 8159 lx.

Uniformity ratios are calculated worse than June 21 results. In the second studio, the artificial light requirement is increased from 54.76% to 76.19%. Similarly, uniformity ratios are calculated lower than June 21. Since the sun came with a more inclined angle on December 21, it needed more artificial light and worse uniformity than on June 21.

Figure 3. Daylighting results of June 21, 10:00 a.m. under the clear sky with sun conditions

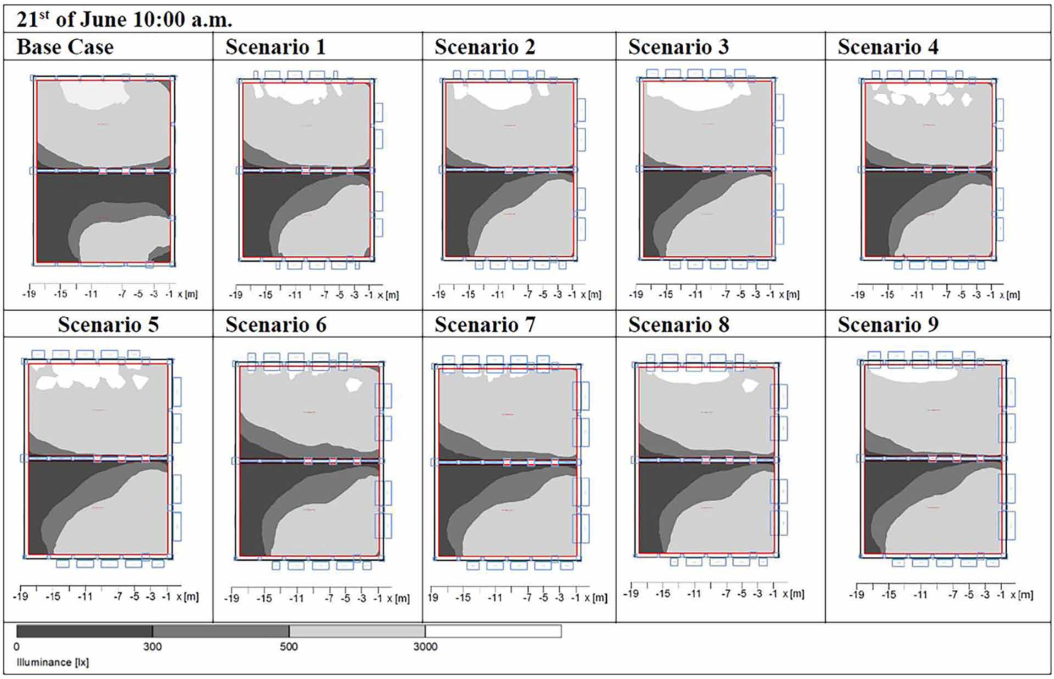
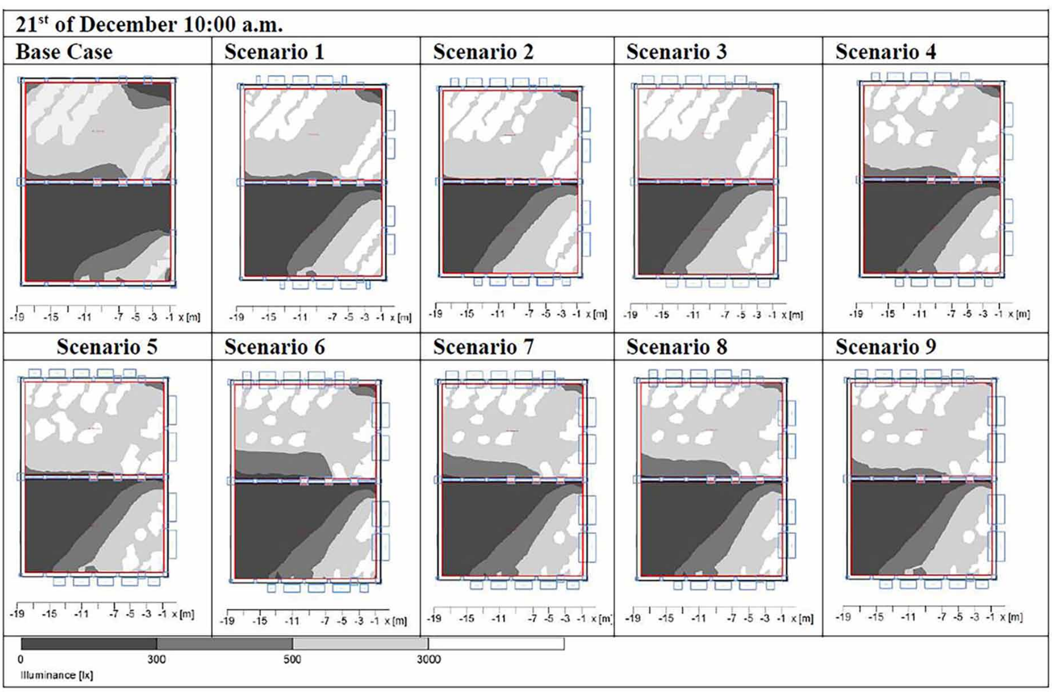


Figure 4. Daylighting results of December 21, 10:00 a.m. under the clear sky with sun conditions



Scenario 1: 50cm Window Expansion and Overhang Implementation

In scenario 1, each window is expanded 50 cm, and overhangs are implemented for all. The width of overhangs is defined as 100 cm, and the height is 3.1 m from the floor, which is the same as window height. They have a thickness of 10 cm, and the material is selected as plastic with a 50% reflectance ratio. For June 21, it is seen in the first studio that, although windows are enlarged, most of the illuminance values are decreased except E_{max}. It is due to the implementation of overhangs since they block some of the sunlight. Thus, there could not achieve significant development in uniformity ratios. However, SPIV and sun patch areas are decreased compared with the base case scenario. In the second studio, all of the illuminance values are increased. There are occurred brighter surfaces near window zones. It has resulted in higher uniformity ratios. The artificial light requirement decreased from 54.76% to 37.30%. On December 21, it was found in the first and second studio that implementations increased all of the illuminance values. Since E_{min} achieved a more significant increase, uniformity ratios are raised for both studios. Additionally, ALR decreased from 76.19% to 55.56%. The second studio has brighter surfaces in the back parts of the room.

Scenario 2: 100cm Window Expansion and Overhang Implementation

In scenario 2, each window is expanded 100 cm, and overhangs are implemented for all. On June 21, the implementation of window expansion for the first studio increased illuminance values. However, the effect of overhangs is not that visible. Since windows are enlarged more, near-window zones become brighter. It resulted in higher E_{max}. Not as expected, but there could achieve development in URs. In the second studio, similarly, enlarged windows resulted in higher illuminations. URs and development in artificial light requirements are calculated above than base case and Scenario 1. On December 21, window expansion resulted in higher illuminance values for each studio. As the illuminated areas increased, uniformity ratios also increased with the effect of overhangs. URs of each studio are calculated above than base case and Scenario 1. Additionally, the ALR of the second studio is decreased to 50%, which is lower than the previous scenarios.

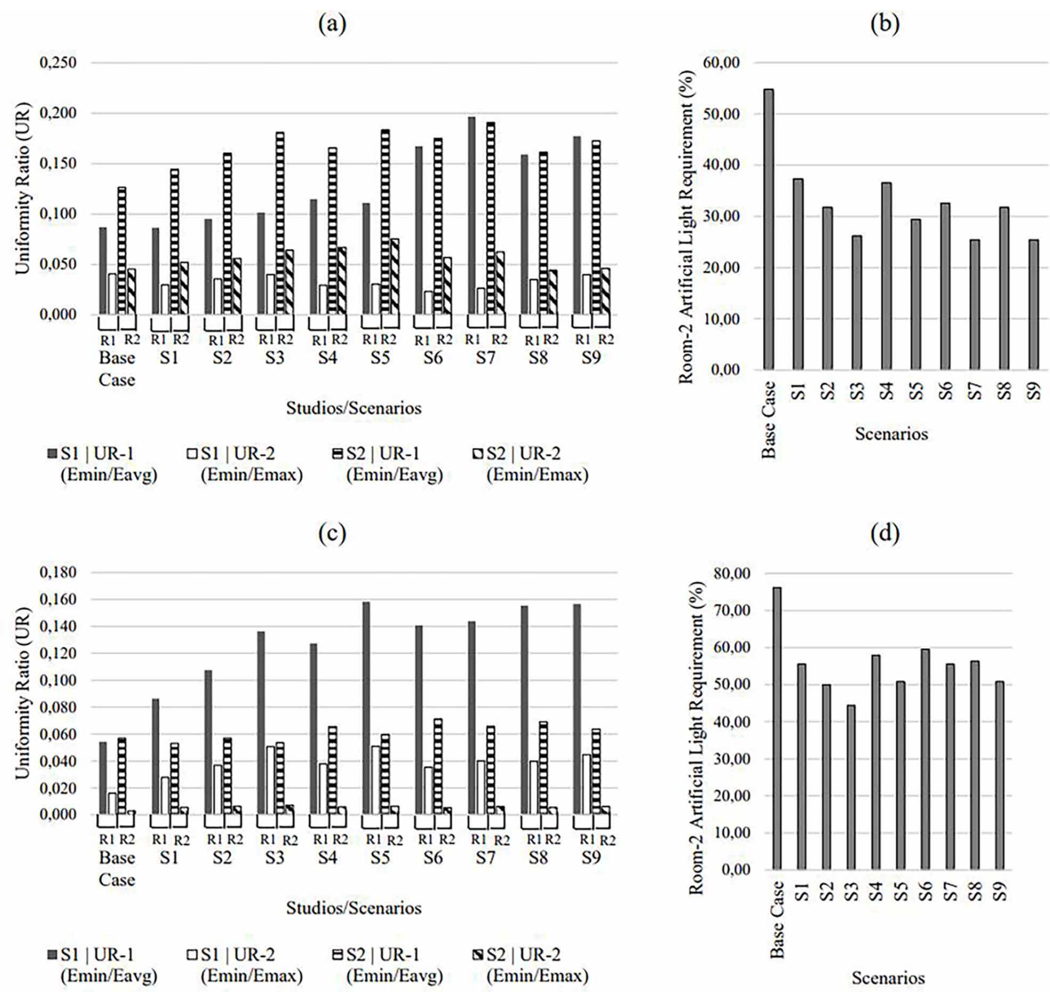
Scenario 3: 150cm Window Expansion and Overhang Implementation

In scenario 3, each window is expanded 150 cm, and overhangs are implemented for all. On June 21, for the first studio, illuminance values are similarly increased as windows are enlarged. Although there could not achieve significant development in UR-2, UR-1 increased the most among the scenarios so far (Figure 5). This is due to the window expansion increasing illumination in near-window zones. Among three scenarios and base case conditions, Scenario 3 performed the best in terms of uniformity ratios and artificial light requirements for each studio and each date. Since windows are expanded the most, ALR is decreased to 26.19% and 44.44% for June and December 21, respectively. Implementations so far primarily increased illuminance values for each studio, resulting less artificial light requirement for the second studio in each Scenario. However, window expansion increases E_{max}. Thus, there could achieve a small development in uniformity ratios. However, it is still possible to see the potential of overhangs. URs are gradually increased in each Scenario. In these scenarios, there could not achieve an essential retrofit in SPIVs. This may be related to the fact that they could not block excessive sunlight due to their height and incline angle. Finally, in the following scenarios, those variables' effects on sun patch areas and the uniform distribution of daylight are evaluated.

Scenario 4: Light Shelf Height and Incline Angle

In scenario 4, the shading elements' elevation height is decreased by 70 cm, and the incline angle is defined as 20þ. Implementations of Scenarios 4 and 5 are applied to Scenario 2 and 3 models, respectively. On June 21, for the first studio, it was seen that elevation height and incline angle of the light shelf significantly reduced illuminance values (Table 3). However, there could not achieve a significant decrease in E_{max} value. Although there is an increase in UR-1, there obtained a reduction

Figure 5. (a) Uniformity ratios of each Scenario and base case for June 21 (b) ALR of the second studio for each Scenario with the base case on June 21 c) Uniformity ratios of each Scenario and base case for December 21 (d) ALR of the second studio for each Scenario with the base case in December 21



in UR-2. Since an inclined light shelf reflects daylight more, there received a decrease in sun patch areas and SPIVs. In the second studio, implementations similarly reduced illuminance values and increased uniformity ratios when compared with the previous Scenario. However, the decrease in illumination caused an increase in ALR. Similar results are obtained for December 21. E_{avg}, E_{min}, and E_{max} decreased considerably in the first and second studios. A lower and inclined light shelf could reduce excessive illumination by increasing uniformity ratios. However, ALR is increased compared with the previous Scenario. Nevertheless, there is still a significant development compared with the base case scenario (Table 4).

Scenario 5: Light Shelf Height and Incline Angle

Scenario 5 similarly focuses on understanding the effects of height and incline angle variables. Results show that there obtained similar results with Scenario 4. Implementations reduced E_{min}, E_{avg}, and SPIV while they increased E_{max}. When compared with the previous Scenario, there could only achieve development in UR-1. Similarly, in the second studio, illumination is decreased and ALR is increased. However, there occurred retrofit in uniformity ratios on both dates. It is seen in Scenarios 4 and 5 that light shelf height and incline angle can reduce sun patch areas and SPIVs. Due to the decrease in illuminance values, they may increase the artificial light requirements of spaces. It is noted that they are not as expected, but they moderately increase some of the uniformity ratios. The potential of these variables is mainly reducing excessive illuminance values by blocking sunlight. Thus, there is still a need to increase the uniformity ratios of both studios.

Scenario 6: Implementation of Interior Light Shelves

Scenarios so far could improve artificial light requirement, uniformity ratios, and SPIVs. However, development in URs and SPIVs are not succeeded at the desired level. In Scenarios 6 and 7, interior light shelves are implemented in both studios to see their effect on the uniform distribution of daylight and sun patch areas. Implementations of Scenarios 6 and 7 are applied to Scenarios 4 and 5 models, respectively. On June 21, interior light shelves sharply decreased illumination values and sun patch areas for the first studio. Both the number of sun patch areas and their illuminance values are diminished. UR-1 is increased significantly. However, there obtained a decrease in UR-2 due to high E_{max}. In the second studio, E_{min}, E_{max}, and E_{avg} are increased considerably.

Similarly, UR-1 increased as UR-2 decreased compared with the previous Scenario. Lastly, ALR is decreased due to higher illumination. On December 21, implementations dropped the illuminance values of each studio. ALR is moderately increased for the second studio. The effect of interior light shelves performed precisely the same for uniformity ratios of both studios.

Scenario 7: Implementation of Interior Light Shelves

The same implementations are applied in the 7th Scenario. Results show that there obtained similar results with Scenario 6. On June 21, implementations similarly decreased excessive illuminance values sharply for the first studio. Differently, there were no sun patch areas and SPIVs. Compared with the previous Scenario, UR-1 increased significantly due to the change in E_{min} and E_{avg}. In the second studio, illuminance values are raised, and ALR is decreased the most among all scenarios. As seen in raytracing images, the light dimming parts of the second studio are improved (Figure 6).

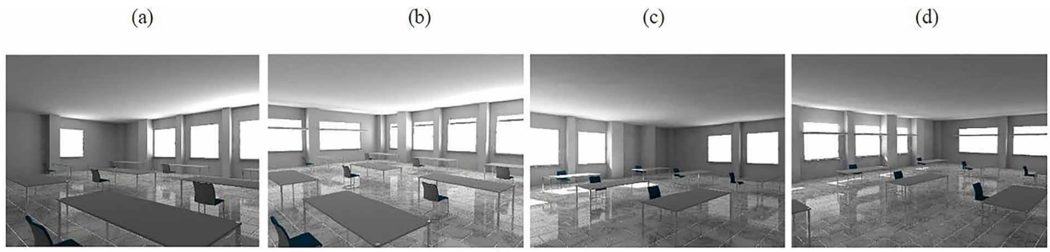
Additionally, UR-1 for both of the studios is calculated as the highest. On December 21, there could achieve no significant development in both of the studios. Results performed worse except for the increase in UR-1 for the second studio. Implementation of interior light shelves significantly reduced excessive illuminance values on near-window zones. Also, they improved sun patch areas and SPIVs for both dates in the first studio. In the second studio, variables helped distribute daylight more appropriately for June 21. There occurred a retrofitting in poorly illuminated parts of the studio. For each studio and date, light shelves' effects performed differently. It may be due to different orientations of studios and sun angle during the year. Nevertheless, compared with base case conditions, results performed better due to applications.

Scenario 8: Implementation of Reflectance Ratio and Material Change of Shading Elements

There could achieve significant developments on SPIVs and ALR of studios in scenarios so far. However, the effect of variables on the uniform distribution of daylight could not be seen clearly. Each shading element's reflectance ratio and material are changed in the last set of scenarios.

Material is changed from plastic to metal, and the reflectance ratio is increased from 50% to 85%. Implementations of Scenarios 8 and 9 are applied to Scenarios 6 and 7 models, respectively. On June 21, for the first studio, material and reflectivity change of shading elements resulted in an increase in E_{min} and E_{avg} and a decrease in E_{max}. This raises UR-2 considerably. Compared to the previous Scenario, SPIVs performed similarly. Higher reflectivity of shading elements resulted in a more appropriately illuminated space in the second studio. ALR is then decreased. However, there

Figure 6. (a) Existing situation of studio 2 on June 21 at 10:00 a.m. (b) Scenario 7 of studio 2 on June 21 at 10:00 a.m. (c) Existing situation of studio 1 on June 21 on 10:00 a.m. (d) Scenario 7 of studio 1 for June 21 on 10:00 a.m.



could obtain no significant development in URs. On December 21, similarly, a higher reflectance ratio increased illumination values, resulting in higher uniformity ratios and lower ALR in general.

Scenario 9: Implementation of Reflectance Ratio and Material Change of Shading Elements

In the last Scenario, similar results are obtained compared to the previous Scenario. In the first studio, material and reflectance change of shading elements significantly increased E_{min} and E_{avg} and decreased excessive illuminance values such as high E_{max} and SPIVs. Similarly, there obtained a development in UR-2 and a decrease in UR-1. In the second studio, there could not achieve development in ALR and uniformity ratios. On December 21, results performed similarly for the second studio. In the first studio, all of the illuminance values and uniformity ratios are increased.

As a general evaluation of reflectivity and material's effect on daylight performance, it is noted for June 21 that in south-east/south-west-oriented studio (i.e., first studio), variables increase average and minimum illuminance values. It is due to the higher reflection of shading elements that illuminate the back parts of the room by distributing daylight more homogenously. Additionally, since the interior and exterior shadings block excessive sunlight, it lowers the E_{max} value. On December 21, for the south-east/south-west-oriented studio, higher reflectivity could not reduce illuminance values since the sun comes with a more inclined angle in that period. They are increased. However, the variables improved uniformity ratios by distributing daylight properly. In the second studio, which faces the north-east and south-west, variables could not improve uniformity ratios. However, they similarly illuminated the back parts of the room due to the high reflection of sunlight inside the space. Thus, there obtained a retrofitting in artificial light requirement.

As a general assessment of each Scenario, on June 21, Scenario 7 is defined as the best case for UR-1 values of studios. Since interior light shelves are implemented in this Scenario, they improve light dimming areas and back parts of the room by properly distributing daylight. Scenario 5 gives more proper results for UR-2 of both rooms for the same date. This is due to the higher reflection of sunlight caused by lower height and increased incline angle of shading devices, which improves minimum illuminance values, increasing the UR-2 value. Similarly, Scenarios 7 and 9 provide the lowest need for artificial light. In terms of sun patch areas, Scenario 7 diminishes those due to the blocking of daylight with interior light shelves.

On December 21, results performed similarly. In terms of UR-1, Scenarios 5,6,7,8, and 9 -in which height and incline angle are changed, interior light shelves are implemented, and reflectance ratio is increased- provide more satisfactory results for both studios. Also, Scenarios 3 and 5 give better results for UR-2 of both rooms. Scenario 3 gives more acceptable results regarding the need for artificial light since windows are enlarged the most in this Scenario, and no interior light shelves are implemented to windows.

Table 3. Detailed results of base case and each Scenario for June 21, 10:00 a.m. under the clear sky with sun conditions

Studio / Scenario		Illuminance (lx)				Artificial Light Requirement (ALR) (%)					Uniformity Ratio (UR)	
		E_{avg}	E_{min}	E_{max}	SPIV	<300 lx	>300 lx	Total	%	RR	U_1 (E_{min}/ E_{avg})	U_2 (E_{min}/ E_{max})
S1	Base Case	3230	281	6890	29.300	1	125	126	0,79	-	0,0869	0,0407
S2		332	42	923	-	69	57	126	54,76	-	0,1265	0,0455
S1	1	3090	267	9004	29.000	1	125	126	0,79	0	0,0864	0,0394
S2		485	70	1340	-	47	79	126	37,30	17,46	0,1443	0,0522
S1	2	3480	331	9296	29.300	0	126	126	0,00	0,79	0,0951	0,0356
S2		543	87	1550	-	40	86	126	31,75	23,02	0,1602	0,0561
S1	3	3720	378	9417	29.400	0	126	126	0,00	0,79	0,1016	0,0401
S2		613	111	1730	-	33	93	126	26,19	28,57	0,1811	0,0642
S1	4	2330	267	9030	25.100	1	125	126	0,79	0,00	0,1146	0,0296
S2		476	79	1180	-	46	80	126	36,51	18,25	0,1660	0,0669
S1	5	2690	299	9751	25.200	1	125	126	0,79	0,00	0,1112	0,0307
S2		534	98	1300	-	37	89	126	29,37	25,40	0,1835	0,0754
S1	6	1160	194	8317	14.900	6	120	126	4,76	-3,97	0,1672	0,0233
S2		503	88	1550	-	41	85	126	32,54	22,22	0,1750	0,0568
S1	7	1150	226	8530	-	4	122	126	3,17	-2,38	0,1965	0,0265
S2		561	107	1710	-	32	94	126	25,40	29,37	0,1907	0,0626
S1	8	1520	242	6901	15.200	2	124	126	1,59	-0,79	0,1592	0,0351
S2		558	90	2030	-	40	86	126	31,75	23,02	0,1613	0,0443
S1	9	1590	282	7100	10.400	1	125	126	0,79	0,00	0,1774	0,0397
S2		643	111	2400	-	32	94	126	25,40	29,37	0,1726	0,0463
SPIV: Sun Patch Illuminance Value (lx)												
ALR: Artificial Light Requirement (%)												
<300 lx: Number of the measurement points below 300 lx												
>300 lx: Number of the measurement points above 300 lx												
Total: Total number of measurement points												
%: Artificial light requirement												
RR: Retrofitting (Difference between base case situation's ALR and Scenario's ALR)												

CONCLUSION

This paper provides a comprehensive analysis of window size properties and light shelves. In the study, different variables (i.e., window size and location, overhang implementation, light shelf height, incline angle, and material change) are tested through simulation models in Relux software. Each variable is tested in different scenarios.

- **The main conclusions of this paper, considering the results, are listed as follows:**
  - Window size expansion and overhang implementation can increase the illuminance values of spaces. As a result, these can decrease the artificial light requirement of investigated rooms.

Table 4. Detailed results of base case and each Scenario for December 21, 10:00 a.m. under the clear sky with sun conditions

Studio / Scenario		Illuminance (lx)				Artificial Light Requirement (ALR) (%)					Uniformity Ratio (UR)	
		Ea_{vg}	E_{min}	E_{max}	SPIV	<300 lx	>300 lx	Total	%	RR	U_1 (E_{min}/ E_{avg})	U_2 (E_{min}/ E_{max})
S1	Base Case	2410	131	8150	-	5	121	126	3,97	-	0,0544	0,0161
S2		369	21	7590	-	96	30	126	76,19	-	0,0569	0,0028
S1	1	2660	230	8290	-	2	124	126	1,59	2,38	0,0865	0,0277
S2		829	44	7900	-	70	56	126	55,56	20,63	0,0531	0,0056
S1	2	3060	329	8950	-	0	126	126	0,00	3,97	0,1075	0,0368
S2		916	52	8180	-	63	63	126	50,00	26,19	0,0568	0,0064
S1	3	3520	480	9500	-	0	126	126	0,00	3,97	0,1364	0,0505
S2		1140	61	8510	-	56	70	126	44,44	31,75	0,0535	0,0072
S1	4	2410	307	8120	-	0	126	126	0,00	3,97	0,1274	0,0378
S2		671	44	7600	-	73	53	126	57,94	18,25	0,0656	0,0058
S1	5	2670	423	8300	-	0	126	126	0,00	3,97	0,1584	0,0510
S2		856	51	7890	-	64	62	126	50,79	25,40	0,0596	0,0065
S1	6	1990	280	7940	-	5	121	126	3,97	0,00	0,1407	0,0353
S2		575	41	7540	-	75	51	126	59,52	16,67	0,0713	0,0054
S1	7	2230	321	8020	-	0	126	126	0,00	3,97	0,1439	0,0400
S2		728	48	7810	-	70	56	126	55,56	20,63	0,0659	0,0061
S1	8	2180	339	8530	-	0	126	126	0,00	3,97	0,1555	0,0397
S2		638	44	7800	-	71	55	126	56,35	19,84	0,0690	0,0056
S1	9	2470	387	8650	-	0	126	126	0,00	3,97	0,1567	0,0447
S2		799	51	8160	-	64	62	126	50,79	25,40	0,0638	0,0063
SPIV: Sun Patch Illuminance Value (lx)												
ALR: Artificial Light Requirement (%)												
<300 lx: Number of the measurement points below 300 lx												
>300 lx: Number of the measurement points above 300 lx												
Total: Total number of measurement points												
%: Artificial light requirement												
RR: Retrofitting (Difference between base case situation's ALR and Scenario's ALR)												

It also increases the illumination of near-window zones as an opposing side of window expansion. It may not significantly improve sun patch areas and UR-2 values. UR-1 values can be retrofitted due to proper distribution of daylight thanks to overhangs.

- Light shelf height and incline angle change can decrease sun patch areas and SPIVs. However, due to the decrease in illuminance values, they may increase the artificial light requirements of spaces. It is noted in the study that not as expected, but they moderately increased some of the uniformity ratios. However, the potential of these variables is to decrease excessive illuminance values by blocking sunlight. Thus, they are beneficial in the south and west-facing rooms while they increase artificial light requirements in north-facing rooms.
- Implementation of interior light shelves can decrease and eliminate SPIVs and sun patch areas in near-window zones. They can improve SPIVs and excessively illuminated zones for

south and west-oriented rooms. In north-oriented rooms, variables can distribute daylight more appropriately during the summer period when the sun comes with a more direct angle. There may occur a development in poorly illuminated parts of spaces. Light shelves' effects may perform differently for different orientations and dates. As is explained before, this is due to different sun angles during the year and varied orientations of spaces.

- In terms of reflectivity and material's effect on daylight performance, it can be said that for the summer period and south and west-oriented spaces, variables increase average and minimum illuminance values. Higher reflection increases illumination of the back parts of a room and distributes daylight homogenously. Also, higher reflectivity prevents excessive sunlight, resulting in lower SPIVs and E_{max} values. However, for south and west-oriented rooms in the winter period, higher reflectivity may not decrease highly illuminated spaces' glare risks. It is due to the high inclined angle of the sun in that period. In north-oriented rooms, this variable increases the illumination of the back parts of a room. Artificial light requirement decreases.

The authors expect this paper to be beneficial for those studying daylight performance in terms of their design principles, performance assessments, and future developments.

ACKNOWLEDGMENT

The authors of this publication declare there is no conflict of interest. This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

REFERENCES

Alhagla, K., Mansour, A., & Elbassuoni, R. (2019). Optimizing windows for enhancing daylighting performance and energy saving. *Alexandria Engineering Journal*, *58*(1), 283–290. doi:10.1016/j.aej.2019.01.004

Bayram, G., & Kazanasmaz, T. (2016). Simulation-based retrofitting of an educational building in terms of optimum shading device and energy efficient artificial lighting criteria. *Light & Engineering*, *24*(2), 45.

Berardi, U., & Anaraki, H. K. (2015). Analysis of the Impacts of Light Shelves on the Useful Daylight Illuminance in Office Buildings in Toronto. *Energy Procedia*, *78*, 1793–1798. doi:10.1016/j.egypro.2015.11.310

Cesari, S., Valdiserri, P., Coccagna, M., & Mazzacane, S. (2018). Energy savings in hospital patient rooms: The role of windows size and glazing properties. *Energy Procedia*, *148*, 1151–1158. doi:10.1016/j.egypro.2018.08.027

Dascalaki, E. G., & Sermpetzoglou, V. G. (2011). Energy performance and indoor environmental quality in Hellenic schools. *Energy and Building*, *43*(2-3), 718–727. doi:10.1016/j.enbuild.2010.11.017

Day, J. K., Futrell, B., Cox, R., Ruiz, S. N., Amirazar, A., Zarrabi, A. H., & Azarbayjani, M. (2019). Blinded by the light: Occupant perceptions and visual comfort assessments of three dynamic daylight control systems and shading strategies. *Building and Environment*, *154*, 107–121. doi:10.1016/j.buildenv.2019.02.037

Düzgün, N., & Yağmur, A. Ş. (2019). Daylight for Qualified Lighting: The Effect of Window Glazing Features on Interior Daylight Illuminance. In *11th National Lighting Congress* (pp. 143-151). İstanbul, Turkey.

Galal, K. S. (2019). The impact of classroom orientation on daylight and heat-gain performance in the Lebanese Coastal zone. *Alexandria Engineering Journal*, *58*(3), 827–839. doi:10.1016/j.aej.2019.07.003

Grobe, O. L., Geçit, B., Sevinç, Z., Altınkaya, G., Aksakarya, G., Ergin, M., Öztürk, Y., & Kazanasmaz, T. (2017). Scale-model and simulation-based assessments for design alternatives of daylight redirecting systems in a side-lighting educational room. *METU Journal of the Faculty of Architecture*, *34*(2), 35–58. doi:10.4305/METU.JFA.2017.2.1

Kralikova, R., Dzunova, L., & Rusko, M. (2019). Impact of Natural Daylight for Human Comfort and Health. *2019 International Council on Technologies of Environmental Protection (ICTEP),* (pp. 160–163).

Liu, G., Qu, G., Ren, L., Zhang, Y., Zang, X., & Dang, R. (2022). The influence mechanism of daylight visual evaluation in college classrooms under visual field physiological characteristics of student group: Case study. *Building and Environment*, *209*, 209. doi:10.1016/j.buildenv.2021.108655

Meresi, A. (2016). Evaluating daylight performance of light shelves combined with external blinds in south-facing classrooms in Athens, Greece. *Energy and Building*, *116*, 190–205. doi:10.1016/j.enbuild.2016.01.009

Skotnicova, I., Lausova, L., & Michalcova, V. (2016). The impact of glazing properties on thermal and daylighting comfort in offices. *Proceedings of the International Multidisciplinary Scientific GeoConference SGEM*, *2*, 325–332.

Uygun, E., & Görgülü, S. (2016). DIALux ve RELUX Aydınlatma Benzetim Programlarının Gün Işığı Benzetimi Karşılaştırması (Comparison of DIALux and RELUX in the Daylight Simulation). *Mehmet Akif Ersoy Üniversitesi Fen Bilimleri Enstitüsü Dergisi, Özel Sayı*, *1*, 1–8.

Aybüke Taşer is a master of science candidate at Izmir Institute of Technology, Department of Architecture. She is also a research assistant at Izmir University of Economics department of Architecture. Taşer is currently developing studies and projects related to building energy, thermal and daylight performance of buildings, building integrated photovoltaics, building performance optimization, and computational intelligence.

Tuğçe Kazanasmaz received her Ph.D. in Building Science from Middle East Technical University (METU) in 2005. She was hired as the Academician in Faculty of Architecture at İzmir Institute of Technology and at present, she is a Professor in the Department of Architecture at İzmir Institute of Technology, Turkey. She has 17 years of academic experience in architectural lighting, building physics, and energy-efficient design.