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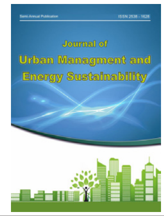

CASE STUDY RESEARCH PAPER

Evaluation of Natural Lighting in the Architecture of Educational Spaces in Temperate and Humid Districts with Emphasis on the Efficiency of Light Shelf

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ABSTRACT

School buildings are the second place students spend most of their time after residential environments. Based on this, using natural light will lead to maintaining and improving health and creating visual comfort and sufficient lighting. The present study aims to evaluate the lighting in the classroom environment and create adequate lighting after installing the light shelf in a moderate and humid climate in a proposed model. In the first step, the importance coefficient of the fields and the factors and variables effective in evaluating the brightness of the light shelf were identified. In the second step, the field information of schools in Mazandaran province, especially Sari City, has been collected. In the third step, six different models of the combined light shelf are proposed based on geometric and dimensional characteristics such as depth, height, and angle of the light frame. The results have shown that the combination of the outer light shelf with the internal light shelf is suitable if the outer light shelf with a depth of 120 cm is placed at a height of 1.80 meters from the floor and with a change in its geometric shape at a depth of 30 cm by -10 degrees failure to occur. Analyzing the spatial adequacy indicators of daylight (sDA) also shows that 72% of the students have received lighting above 300 lux and its sDA is equal to 55.41%, indicating sufficient lighting above 300 lux in the class space.

Running Title: Natural Lighting in the Architecture of Educational Spaces

NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
26	09	08

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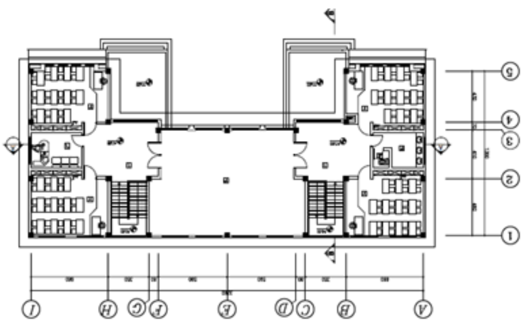
1. INTRODUCTION

Daylight can affect reading, jobs and productivity, sense of health, mood, comfort, perception of space, emotions, experiences, and behaviors of students (Korsavi et al, 2016). Interestingly, visual comfort is an aspect Important for both students and teachers, and it has been reported in the classroom that it is a vital factor for learning (Ricciardi & Buratti, 2018). Lack of environmental comfort can significantly affect the learning capacity of students; this issue increases the use of artificial light in classrooms. The criterion for evaluating daylight in schools is mainly qualitative. Although the recommended light level is different in each country, 300 lux and 2% daylight factor (DF) are suitable for some typical school standards (Meresi, 2016). Since daylighting is dynamic, there is no single solution for all design scenarios. Knowing the sky's conditions is necessary to use daylight (Lim & Ahmad, 2015) effectively. This lighting system distributes the ambient light evenly in the space to improve the quality of the interior space and save lighting energy consumption (Kwon et al., 2014). It is necessary to know precisely what effect each part of the building and its thermal performance has and what costs it will entail. (Alemi & Tafreshi, 2023) By examining the annual number of articles from 1983 to today, it seems that there has been a significant increase in these articles in recent years. It is believed that the reason for this is the increase in efforts to achieve low-cost solutions for profit. It is away from daylight (Kontadakis et al., 2017). Optimal locating of future cities based on effective climate parameters to prevent environmental crises, as well as proper and sustainable use of the facilities of a region, is one of the critical issues facing today's world. (Freidooni et al., 2022) In addition, natural light control systems in buildings such as light shelves, lead to protecting residents from direct sunlight and maximizing daylight penetration into buildings based on preferences. It is their inhabitants that lead to the optimal lighting range in the entire room, the uniformity and transmission of daylight to the depth of the space, and the creation of visual comfort during different seasons of the year and various weather conditions. It also optimizes energy consumption (Mangkuto et al., 2018; Abdulkareem et al., 2018). Sangon Gim et al. (Gim et al, 2014) assumed that the light shelf is an efficient system. which reduces the consumption of electricity by adding natural light in the depth of the building spaces. In his studies, Bayram (Bayram, 2015) sought the optimal amount of daylight to achieve visual comfort conditions and synthetic design parameters to minimize energy consumption for educational buildings. As a result, the efficiency of the light shelf increases and reduces electricity consumption (SOLER & OTEIZ, 1996; GROBE et al., 2018). In another study, by examining the reflection of the flat light shelf, The use of a light frame with diffuse reflection can reduce the lighting energy in the outdoor type by 13.38%-13.3% and 4.4%-1.8% in the case of the indoor kind compared to the flat light shelf (Lee et al., 2014). Using Radiance software, Ochoa and Capeluto (2006) evaluated the risks of lighting and glare. The results showed that the light shelf system improved the distribution of daylight by reducing the contrast between the areas close to the window and the areas far from it. Umberto Berardi and Hamid Khademi Anarki (Berardi & Khademi, 2018) have investigated the benefits of using the light shelf in the annual simulation according to different window-to-wall ratios and different window shapes, orientations, and external restraining elements. Combining the light shelf with other systems leads to challenges in the proper direction of light to increase the brightness and the daily loading time (j.al-khanate & ma bath, 2017). Placing and integrating the light shelf under the canopy can improve the function of the fair stand in reducing energy consumption and creating comfort in the interior space. In an interesting study, a cut hole was made in the cover of the canopy to provide the conditions for natural light to reach the light shelf, this system was able to successfully prevent the passage of sunlight into the interior of the building, improving the uniformity of lighting and reducing energy consumption. (Lee et al, 2018). The current case study evaluates the light shelf in the school space in the spectrum of the high school education group located in the moderate and humid climate of northern Iran with an approach based on a comprehensive assessment of the quality of natural light in the indoor environment.

2. MATERIALS AND METHODS

The current research seeks to develop applied knowledge to apply architectural design solutions in the facade of the building to maintain visual comfort, control glare and create sufficient lighting. It is in the category of user research. At first, among the secondary schools of Mazandaran, different types of plans and dimensional and physical characteristics of each of the research samples were evaluated. The division of forms into primary forms was done to classify the buildings, and the types of school buildings that have been implemented the most in recent years to achieve the most widely used model of the school in the temperate and humid climate was investigated. The current research has tried to select the selected school as the main model for simulation and analysis, which can provide a comprehensive picture of the types of schools in the region. In the next step, research on the typology of the light shelf and its effective parameters was done, then the data analysis was done through simulation in Honey Bee and Ladybug software and the Client Studio plugin, which increases the accuracy of their analysis measurements. According to the purpose and criteria of the study, at this stage, a non-random purposeful sampling method was used. This has been made possible by referring to Mazandaran Province School Renovation Organization and receiving files and information related to the construction and improvement of 100 schools and by creating a detailed classification of map information provided by this organization. The selected samples were categorized and analyzed based on the form of schools and the extent of their construction in the last ten years. As a result, more schools were built in four states: rectangular (concentric), rectangular (stretched), L-shaped, and U-shaped. The results showed that the L-shaped form of the plan had the lowest amount of construction in recent years and accounted for only 14% of the examined samples. The U-shaped structure with 33% of the statistical results obtained was the most constructed in temperate climates, and Mazandaran province is assigned to Humid. Based on this, the plan of Shahid Zamani School in Sari (U-shaped form) has been selected for simulation (Fig. 1). Then, based on the studies conducted in the previous studies and also the climate of the southern front of the building, it has been selected for the pilot test. In the south view, no elements or protrusions affect the lighting control in the interior (Fig. 2). The architectural characteristics of the studied space, including the dimensions of the physical environment and the reflection of the materials, are shown in Tab. 1.

To perform the analysis, the results related to glare



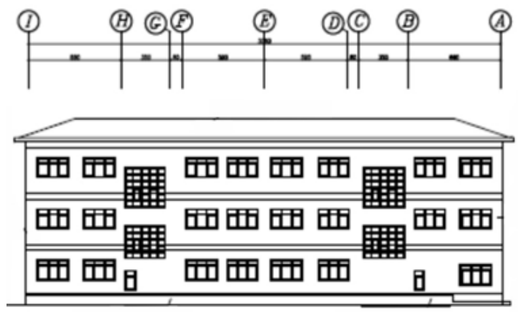


Figure 1- School Renovation Organization, Figure 2- South view of the school

Table 1. 1- Architectural specifications of the studied space of the basic research model (source: School Renovation Organization)

Architectural features (features of components and walls)	*ceiling*	*.White plaster (reflectivity: 0.7)*
	inner wall	*Gypsum cement coating*
	Class floor covering	*Granite mosaic (reflection: 0.6)*
	window	*Glass window (reflection: 0.92)*
Architectural features (general features)	*Class dimensions*	*6.60 * 50.5 Meter*
	The total area of the class	*36.30 square meters*
	Usable area	*30 square meters*
	Height from floor to ceiling	*3/20 Meters*
	The distance between the window and the floor	*110 CM*
	Window dimensions	*140 * 225 CM*
	Desk height	*75 CM*

in the winter solstice and equinoxes at 9, 12, and 3 pm were evaluated (Tab 2). Examining the obtained results has shown that the class with the highest amount of glare is classes No. 4, 6, and 7. By limiting the results and considering the most critical mode in the distribution of brightness and glare, class number 6, located on the second floor (height 7.80 meters), has been selected for simulation. The lighting of the classroom is done with south windows and one-way. The classroom has two windows, each of which has a length of 2.25 meters and a height of 1.40 meters and is placed at an altitude of 1.10 meters compared to the classroom floor.

performance of the light stand in directing lighting to the depth of the classroom by rotating the

Table 2. Table of results of discomfort glare probability index (DGP)

Location of classes	**9 am**			**12 Noon**			**3 pm**		
	21-Mar	*21-Sep*	*21-Dec*	*21-Mar*	*21-Sep*	*21-Dec*	*21-Mar*	*21-Sep*	*21-De*
Class 1	*0/29*	*0/28*	*0/29*	*0/34*	*0/35*	*0/38*	*0/33*	*0/31*	*0/34*
Class 2	*0/29*	*0/29*	*0/30*	*0/34*	*0/35*	*0/38*	*0/33*	*0/31*	*0/34*
Class 3	*0/35*	*0/35*	*0/36*	*0/45*	*0/46*	*0/56*	*0/43*	*0/42*	*0/44*
Class 4	*0/35*	*0/36*	*0/36*	*0/47*	*0/48*	*0/58*	*0/46*	*0/45*	*0/47*
Class 5	*0/35*	*0/36*	*0/37*	*0/47*	*0/48*	*0/59*	*0/44*	*0/43*	*0/45*
Class 6	*0/35*	*0/35*	*0/35*	*0/47*	*0/49*	*0/58*	*0/47*	*0/46*	*0/48*
Class 7	*0/35*	*0/36*	*0/36*	*0/47*	*0/48*	*0/57*	*0/45*	*0/44*	*0/45*

In Fig. 3, the class plan is shown. In this picture, the classroom is divided into three rows, B, A, and C; And the students' seats are numbered. The illuminance above 2000 lux in the summer and winter solstice and equinoxes and the hours of 9 am, 12 noon, and 3 pm (Table No. 3) have been evaluated for the selected class in the simulation of Honey Bee and Lady Bug. Based on that, in the winter solstice compared to other times of the year, due to the sun being at its lowest height, more light has penetrated the depths of the classroom (especially at 9:00 am and 3:00 pm). According to the location of the furniture at 3:00 pm in row A, the desks of students 4, 5, and 6 have received more than 2000 lux lighting. In the middle part of the class (row B), according to the clock and the changing angle of the sun in the sky, the desks Students are affected by different levels of brightness. In such a way, during the winter solstice due to the sun's movement at additional hours, parts of the students' desks have received lighting above 2000 lux, which has reduced the students' performance in reading and writing. This is even though none of the Students in the middle part of the class experience 2000 lux in brightness in all the investigated hours, in the summer solstice, and at 9:00 in the morning. On the summer solstice at noon, only students number 8 and 12, and at 15 o'clock, all the middle row students who are closer to the window (14, 12, 10, 8) also experience the lighting above 2000 lux. Pupils placed on the edge of the window (row C) receive the lightest in all seasons and times.

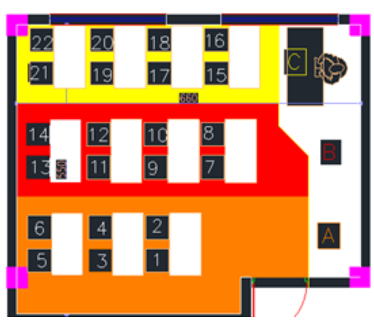
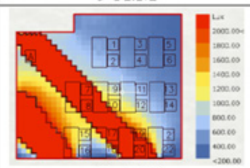
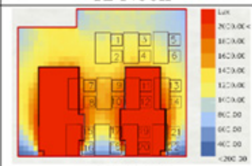
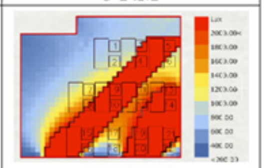
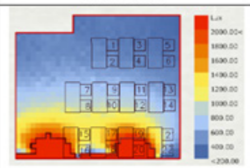
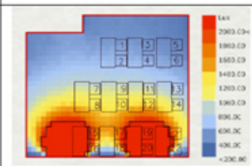
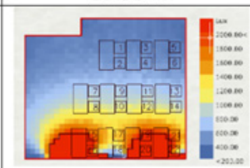
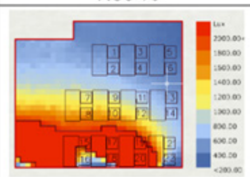
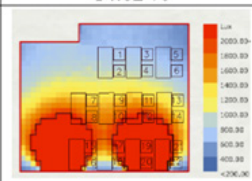
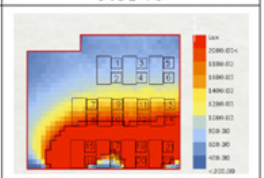


Figure 3: Classroom furniture plan Source: School Renovation Organization

Table 3. Honey Bee and Lady Bug simulation results for the illumination area above 2000 lux in the winter solstice, equinoxes, and

	9 A.M	12 Noon	3 P.M
Winter revolution	 29.66 %	 30.86 %	 33.58 %
moderates	 7.80 %	 14.02 %	 9.61 %
Summer revolution	 20.01 %	 23.74 %	 28.26 %

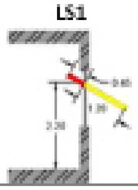
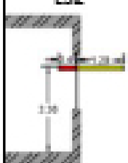
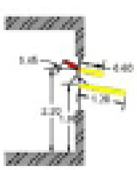
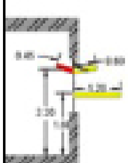
Then the indices of daylight spatial adequacy (sDA), helpful daylight illuminance (UDI), and simplified daylight glare probability (DGPs) were investigated. In the studied classroom, sDA has been obtained more than 93%. Also, the UDI index<100 has shown that it does not exist in a very dark classroom space. UDI100-2000 is equivalent to 85.18%, and UDI>2000 is equal to 14.58%, meaning that 14.58% of the classroom area has received lighting above 2000 lux in 50% of the year's moments. As a result, the class is classified in the category of very bright spaces. Creating visual comfort conditions by controlling glare is a very difficult and important task in such areas. In the following, the DGPs index>0.35 at a height of 1.20 meters from the floor level has been examined. In the selected classroom of DGPs, it is equal to 0.33; As a result, in such a situation where the lighting is more than necessary for reading and writing in the classroom and also there is glare in the classroom, students are forced to draw curtains and block the entry of natural light in such a way that only in a few cases such as the summer solstice and In the winter at 9 am and in the middle of the day at 9 am and 3 pm, the lighting in the classroom has reached 400 to 600 lux. The lack of visual comfort conditions and uneven distribution of lighting in the school is inevitable, and providing a suitable solution to control natural lighting and glare, such as light shelves, seems necessary to create students' well-being and productivity.

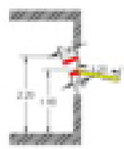
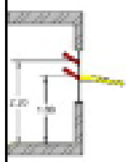
DISCUSSION AND FINDINGS

This research is based on the results of previous research analysis. The optimal parameters for external and internal light shelves are considered, and based on that simulation, six different models of light stands are in order to provide sufficient lighting in the classroom, create more uniformity of illumination between the end of the school and its middle part and glare control has been done, whose dimensional and formal characteristics are given in Table 7. It should be noted that the design of the photo combination shelf has been done step by step. The proposed LS1 and LS2 light shelves are designed as mixed light shelves; Due to the positive effect of increasing the width of the external and internal light shelves, the depth of the inner light shelf is 45 cm, and the depth of the outer light shelf is 120 cm. Due to the shallow light shelf's greater effectiveness than the internal light shelf, a height of 2.20 meters is considered for the mixed light shelf compared to the floor (equal to the optimal size of the outer light shelf). An angle of -30 degrees is considered for the external light shelf because the best results are obtained at a -30-degree angle. It is recommended for the internal light shelf to shade the window's upper part and glare control at an angle of 30+ degrees. In the proposed LS2 model, the light shelf's width and height characteristics are defined as the LS1 model. Still, an attempt has been made to improve the perfor-

In the proposed LS4 model, the external light shelf is placed horizontally (0-degree angle) and 1.60 meters from the floor. External light shelf 2, with a distance of 60 cm from it and at an angle of +10 degrees, is considered so that the combined light shelf can direct more lighting to the middle part and the depth of the class. In the proposed model LS5 and LS6, the combination of the external light shelf and the corresponding internal light shelf is used. In the proposed LS5 model, considering that the optimal internal light shelf is placed at the height of 1.80 meters, the size of the internal light shelf two is considered 1.80 meters. And the internal light shelf 1 is placed at a distance of 40 cm at a height of 2.20 meters from the floor. The external light shelf is also considered at a height of 1.80 meters to complement the internal light shelves. The angle of the external light shelf according to the LS3 proposed model is -10 degrees and the internal light shelf is considered at -20 degrees. To prevent resumption, the finished height of the internal light shelf (1) is equal to 1.90 meters from the floor level and the width of the internal light shelf (2) is 15 cm.The proposed light shelf LS6 is designed according to the results of the proposed light shelf LS3 and LS5. To control the glare, the width of the internal light shelf has been increased to 45 cm, and the angle of both light shelves has been increased to +30 to block the direct sunlight on the edge of the window and create proper shading to positively affect glare. In addition to the results obtained from sDA, it has been shown that the internal light shelf (at an angle of 30+ degrees) can direct the lighting using the reflection principle, which is considered essential in the classroom space. The external light shelf is also designed in a combined way so that a part of it with a length of 30 cm has an angle of 0 degrees, assuming that according to the principle of reflection, it will cause more light reflection to the interior space (according to the results of the software). It will direct more light to the depth of the class. The other part is 90 cm with an angle of -10 degrees to control glare and prevent direct light. In the design of the LS6 model, attention has been paid to the fact that the height of the external light shelf from the floor is higher than 1.50, so it will not block the view of the students while sitting. Also, the internal light shelf's finished height is higher than 1.90.

Table 4. Dimensional characteristics and form of the proposed modelssummer solstice.

Suggested form of light shelves				LS1	LS2
LS1	LS2	Width	Outside	120 CM	120 CM
			Indoor	45 CM	45 CM
		Height	Outside	220 CM	220 CM
			Indoor	220 CM	220 CM
		Angle	Outside	-30 Degree	0 Degree
			Indoor	+30 Degree	0 Degree
LS3	LS4			LS3	LS4
		Width	Outside (1)	120 CM	120 CM
			Outside (2)	60 CM	60 CM
			Indoor	45 CM	45 CM
		Height	Outside (1)	180 CM	180 CM
			Outside (2)	220 CM	220 CM
			Indoor	220 CM	220 CM
		Angle	Outside (1)	-10 Degree	0 Degree
			Outside (2)	-10 Degree	+10 Degree
			Indoor	+30 Degree	+20 Degree
LS5	LS6			LS5	LS6
		Width	Outside	120 CM	120 CM
			Indoor (1)	45 CM	45 CM

			Indoor (2)	15 CM	15 CM
		Height	Outside	180 CM	180 CM
			Indoor (1)	220 CM	220 CM
			Indoor (2)	180 CM	180 CM
		Angle	Outside	-10 Degree	-10 Degree
			Indoor (1)	-30 Degree	+50 Degree
			Indoor (2)	-20 Degree	+30 Degree

According to Figure 2 and Table 8, in general, after installing the combined light shelves, in all cases, the area above 2000 lux has decreased compared to the reference model (without light shelves). It has also been determined that the proposed light shelves in the winter solstice and equinoxes have the greatest effect in reducing the area at 12 noon, 3 pm, and 9 am, respectively. This is despite the fact that the use of combined light shelves in the summer season has been effective first at 3:00 pm and then at 12:00 am and 9:00 am. According to Figure 4, at the winter solstice at 9:00 am, the proposed LS3 and LS1 light shelves have the greatest quantitative effect on the reduction of brightness compared to the reference model, 49% and 53%, respectively. However, the examination of the lighting in the depth of the classroom has shown that after the simulation of the light shelf LS1 and LS3, the amount of illumination in the depth of the classroom has been greatly reduced. Meanwhile, the LS5 and LS6 light shelves have provided better conditions in the depth of the classroom for reading and writing activities and have a 37% and 40% reduction in the brightness above 2000 lux, respectively, compared to the reference model. It has been determined that the furniture arrangement in the classroom has a good performance in terms of the quality of the proposed LS5 models with more shading in the middle part of the classroom and enough lighting to the depth of the classroom. (Fig.4) (Fig. 5)

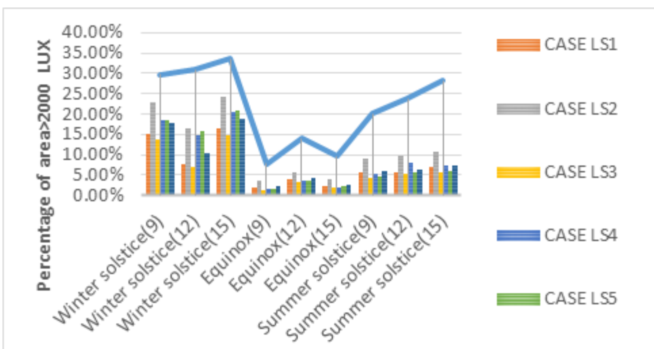
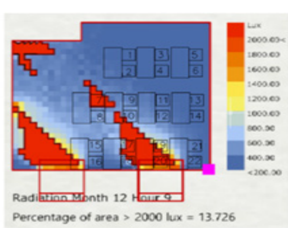
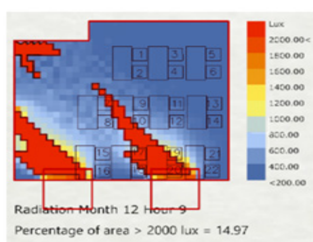


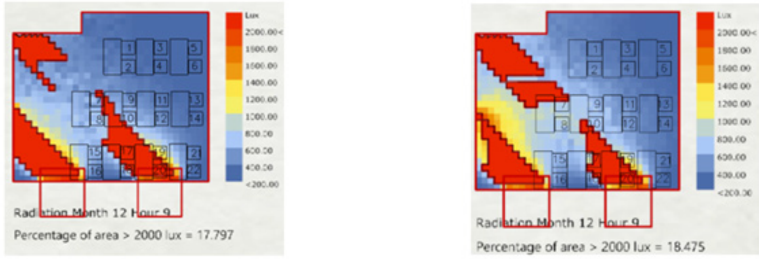
Figure 4. The results of the illumination area above 2000 lux in the proposed models



(b)



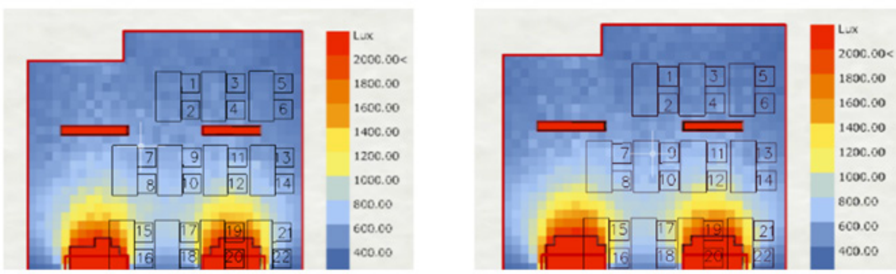
(a)



(d) (c)

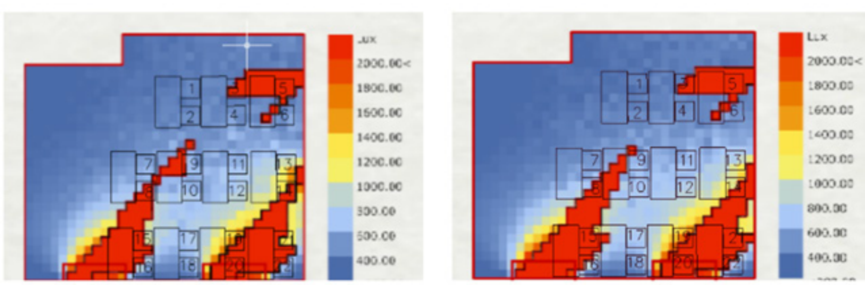
Figure 5. Illumination area above 2000 lux in the winter solstice at 9:00 am (a) LS1 proposed model, (b) LS3 proposed model, (c) LS5 proposed model, (d) LS6 proposed model

On the winter solstice at 12 noon, all the proposed light shelves have reduced the brightness of the window border, especially the middle of the classroom. Among them, the light shelves LS1 and LS3 provided the best performance in more uniform distribution of lighting on the surface of students' desks, and compared to the reference model, it has a reduction of 75% and 77%, respectively (Figure 4). The positive effect of lighting control on the middle part of the classroom by the light above shelves, in the winter solstice at 15:00, has also been confirmed according to the location of the furniture in the interior space, which is 50% and 55% reduction in the brightness above 2000, respectively, compared to the reference model. In addition to these LS1 and LS3 models, by reducing the brightness in the depth of the class on the level of desks 4 and 6 and in the middle part of the class on all desks (so that the desks of students 9 and 10 have higher brightness received from 2000 lux, although its amount is less than the reference model), they have a good performance. Still, the window margin of the light shelves has not reduced the illumination level significantly compared to the reference (without light shelves). (Fig 6 & 7)



(b) (a)

Figure 6. Illumination area above 2000 lux in the winter solstice at 12 o'clock, (a) LS1 proposed model, (b) LS3 proposed model

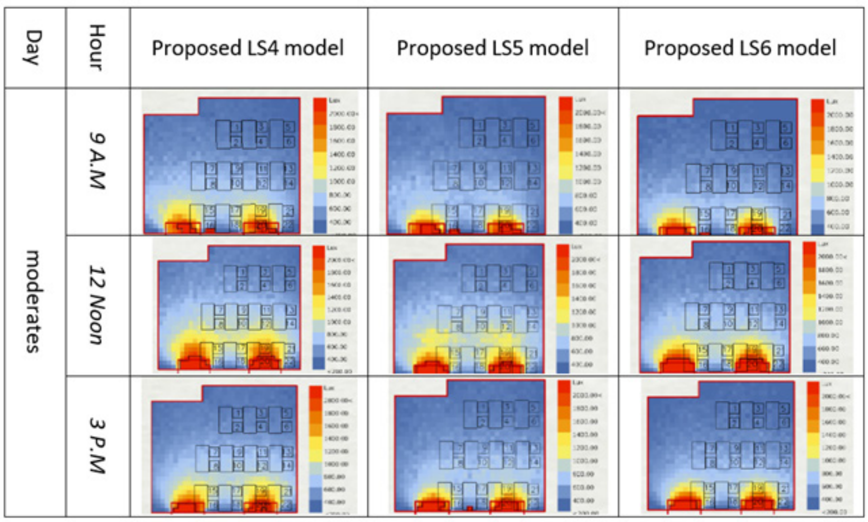


(b) (a)

Figure 7. Illumination area above 2000 lux in the winter solstice at 15:00, (a) LS1 proposed model, (b) LS3 proposed model

According to Table 9, the combined light shelves in Mederani at 9 am have shown that all the proposed light shelves have a good effect on reducing the brightness of the window border. However, the problem of having enough lighting in the depth of the classroom is very colorful. Among the proposed models, LS4, LS5, and LS6 combined shelves have better performance in uniform lighting distribution than other models. At midnight, based on the values mentioned in Table 9, the light shelves LS1, LS3, LS4, and LS5 have a reduction of 72%, 76%, 73%, and 75%, respectively, in the area of illumination above 2000 lux compared to the reference model. However, LS1 and LS3 light shelves have created a very dark space in the depth of the class, and LS4 and LS5 light shelves have an ideal performance. In addition to the mentioned light shelves, the proposed LS6 light shelf has a 70% reduction compared to the reference model. It has been more successful in providing lighting in the depth of the classroom than the proposed LS1 and LS3 models. At 3:00 pm, LS4, LS5, and LS6 models, in addition to controlling the brightness of the window border by increasing the uniformity of the lighting in the classroom space and reducing the contrast between the window border and the depth of the classroom along with providing sufficient lighting, have provided more ideal conditions than the reference model. It has provided 80%, 76%, and 72% brightness reduction above 2000 lux, respectively.

Figure 6. Illumination area above 2000 lux in the winter solstice at 12 o'clock, (a) LS1 proposed model, (b) LS3 proposed model



At the summer solstice and at 9 am, after installing the proposed light shelves on the edge of the window, the area of illumination above 2000 lux is greatly reduced; Among them, the light shelves LS3 and LS5 have had the greatest effect in reducing the brightness level of the window border, so that it has a reduction of 78% and 76%, respectively, compared to the reference state. However, taking into account sufficient lighting on the students' desks, the LS5 light shelf at the end of the classroom has a better performance (Figure 6-a). At noon, light shelves LS1, LS3, LS5, and LS6 have a good performance in reducing the level of illumination above 2000 lux on the edge of the window and in the middle part of the class and compared to the reference state, 75%, 78%, and 76% respectively. And has a 72% reduction. On the summer solstice at 15:00, all the combined light shelves succeeded in reducing the level of illumination above 2000 lux in the window border and the middle part of the classroom. The LS1 and LS3 light shelves have created a dark space at the end of the classroom, while the other light shelves reflect the light deeply. The class has solved the problem of sufficient lighting. However, at 12:00 noon and 3:00 pm, according to the lighting distribution pattern in the classroom, the LS6 light shelf has been more effective in creating visual comfort by reducing contrast than other light shelves (Figure 8-b and c).

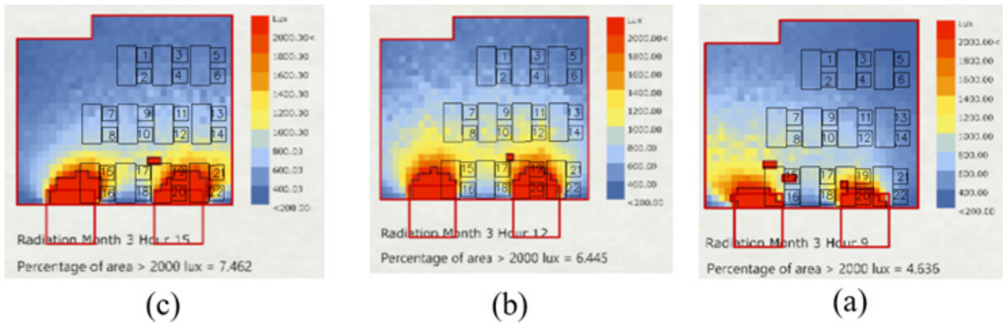


Figure 8. The optimal mode of the light shelf in the summer solstice (a) LS5 proposed model at 9:00 am, (b) LS6 proposed model at 12 noon, (c) LS6 proposed model at 3:00 pm.

Examining UDI<100 in Figure 7 has shown that in the proposed models LS1 and LS3, respectively, UDI<100 is equal to 14% and 6.319%, while in the reference state, the value of UDI<100 is equal to 0%. Reducing the annoying effects of glare has increased the brightness below 100 lux, especially in the depths of the classroom. According to Table 10, in the combined light shelf LS1, according to the location of the furniture and the lighting distribution pattern, UDI<100 is seen in row A on the level of work desks LS1, LS3, and LS5, and in the light shelf LS3 only on the level of work desks 1 and 3. After installing LS2, LS4, LS5, and LS6 combined light shelves, by guiding the light to the depth of the classroom, it solved the risk of creating a very dark space (light less than 100 lux) that was created when LS1 and LS3 light shelves were used. In the mentioned cases, UDI<100 is equivalent to 0%. UDI 100-2000 is acceptable when at least 75% of the classroom area receives average useful daylight (between 100-2000 lux) 50% of the year. According to this issue, all the proposed light shelves can provide sufficient lighting. It is interesting to note here that all the proposed light shelves, except the LS1 model, have increased the UDI100-2000 compared to the reference model. The highest rate of increase has been seen in light shelves LS4 and LS5, and it is equivalent to 96%, which has a variation of 11% compared to the reference state. UDI>2000 indicates an area of the classroom that receives lighting above 2000 lux in 50% of the year. The proposed shelves have been able to reduce the brightness of over 2000 lux compared to the reference state due to the shading feature they bring. The largest decrease compared to the reference model belongs to the proposed LS5 light shelves, approximately equivalent to 11%. According to the arrangement of the furniture, after using the light shelves LS1, LS3, LS4, LS5, and LS6, the students of row C (20, 16, and 22) will receive more than 2000 lux lighting. In the LS2 light

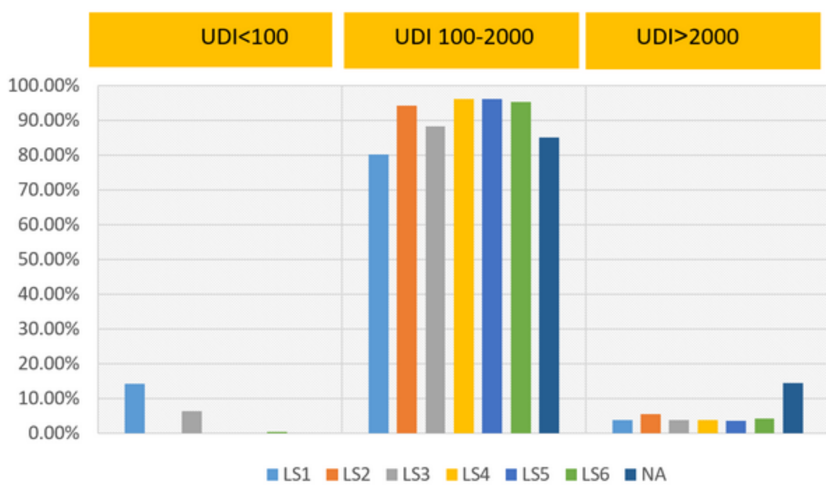
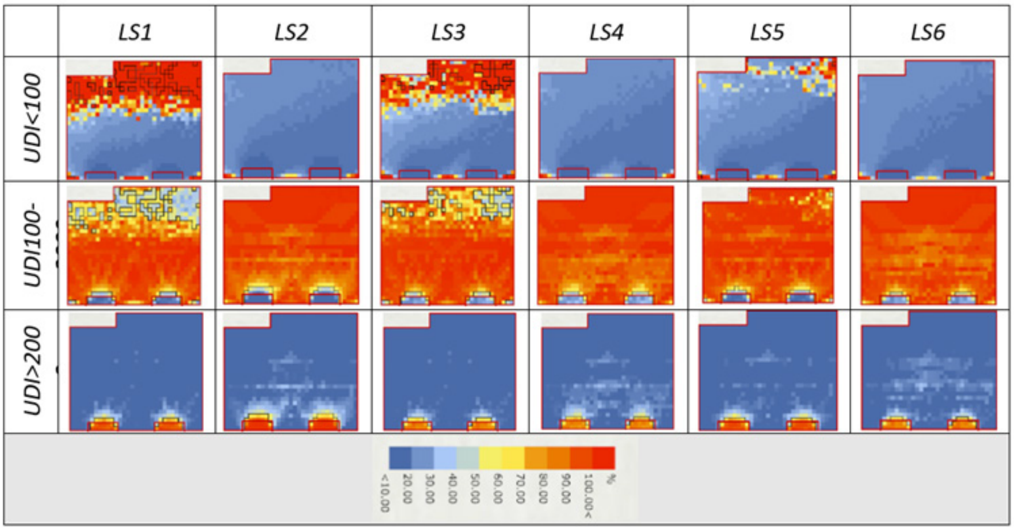


Figure 9. Showing the value of UDI in the proposed combined light racks and its comparison with reference conditions

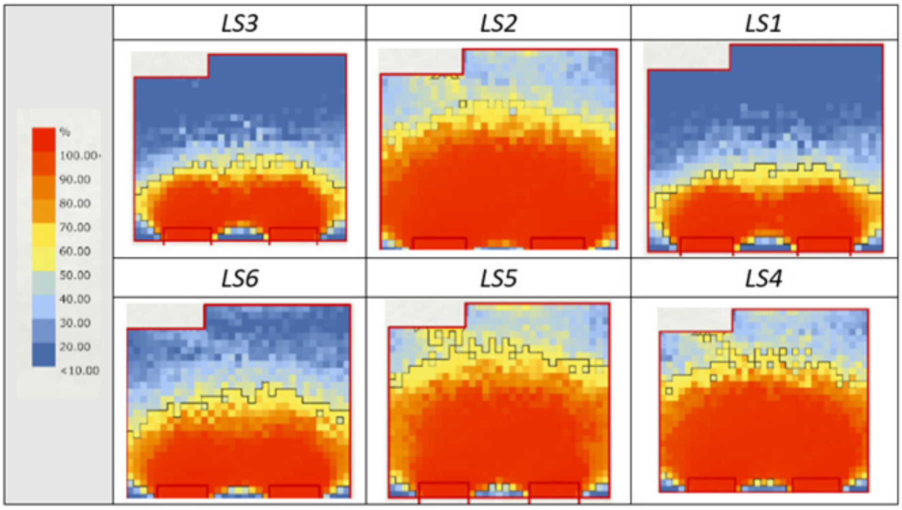
Table 6. Simulation results of useful daylight illuminance (UDI) for the proposed light shelves



According to Figure 8, the sufficiency of illumination (sDA300lx, 50%) in the light shelves LS1 and LS3 is equivalent to 34.4% and 36%, respectively, and is classified in the insufficient category. As a result, the lighting is not enough for students' activities in the classroom. sDA300lx, 50% showed that the LS2, LS4, LS5, and LS6 light shelves could provide sufficient lighting, as 55% or more of the classroom area received lighting above 300 lux 50% of the time. Is. According to Table 11, in the LS1 light shelf, the work desks of row C students and some of the work desks of row B students (especially students 10 and 12) have received lighting above 300 lux. In the proposed LS2 model, all row C and B students and row A (class depth), tables 2, 4, and 6, have received lighting above 300 lux. The simulation of sDA300lx, 50% for the LS3 light shelf, indicates that all the except for the desk of student 18 and in the middle row (B) the desks of students 8, 10, 12, and 14, have illuminance higher than 300 lux in 50 % of the time of the year they receive sDA300lx, 50% in the proposed light shelf LS4 is equivalent to 69.78%. As a result, it has been able to provide sufficient lighting in the classroom for all students except students 3 and 5 in row A. The proposed LS6 model has performed better than the LS1 and LS3 models in such a way that all the students' desks sitting on the edge of the window and in the middle row of the class receive illumination above 300 lux. The index of sDA300lx, 50% in the proposed LS5 model, is equivalent to 74%, which is the highest compared to other models. Based on this, all the students in the class, except for the desk of student No. 5, receive lighting above 300 lux.

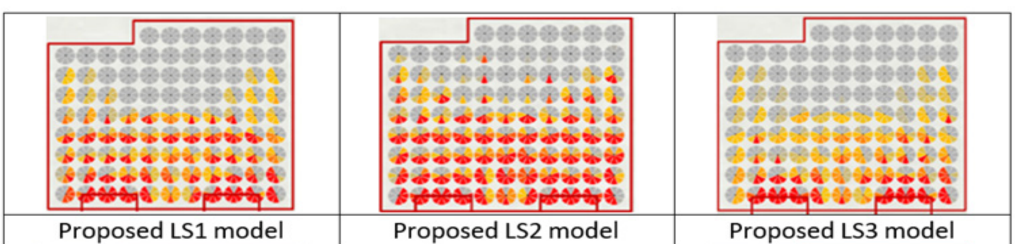
Figure 9. Values of sDA300lx, 50%, and DGPs in the proposed light shelves and their comparison with reference conditions.

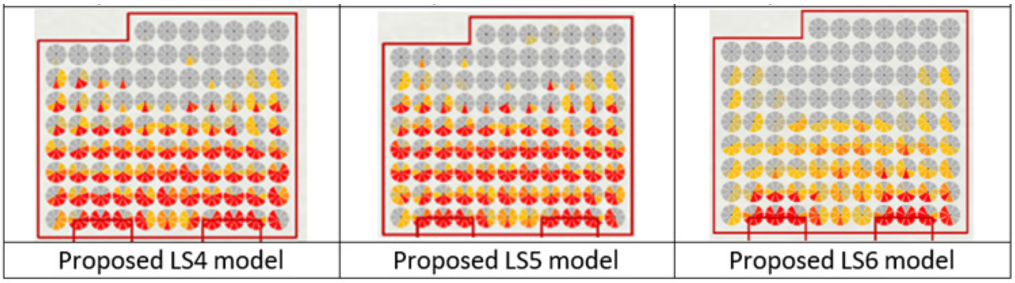
Table 7. The results of daylight quality indicators (DA) of the proposed light shelves



According to the standard, if DGPs>0.35 is higher than 5%, creating visual comfort conditions in the classroom will be difficult. This standard is very strict and challenging to achieve. In general, the use of a combined light shelf in all cases has a significant effect in reducing glare compared to the reference model. According to Figure 8, in the proposed LS2 model, DGPs are equal to 19%; As a result, the glare is well controlled compared to the reference model (equal to the optimal condition in the external light shelf) and has been reduced by 42%. However, most of the students who are sitting in rows C and B at the window border and in the middle of the classroom find the glare at unbearable levels. They feel annoyed. In the proposed LS4 model, DGPS>0.35 is equivalent to 16%. As a result, compared to the reference model, the proposed light shelf has reduced DGPS by 51%. However, it has not controlled the glare according to the standard. In the proposed LS5 model, DGPs are reduced by 54.5% compared to the reference model; And compared to LS2 and LS4 light shelves, it has worked more effectively in controlling glare. However, glare is still perceived as unbearable by students 16, 20, 21, and 22 in row C and by students 10, 12, and 14 in row B (Table 8). Compared to the reference model, the proposed LS1 model has been able to reduce DGPS by 75.7% (DGPS is equal to 8%). As a result, it is effective in controlling glare, but based on the classroom furniture of, students near the window, such as 16, 20, 21, and 22, are affected by glare. They are at an unbearable level. In the LS3 proposed light shelf, DGPs>0.35 equals 6%, a significant reduction of 81% compared to the reference model. DGPs examination has shown that in the proposed LS1 model, the degree of glare on the eye level of students who are sitting on the edge of the window (such as 20 and 22 when they look directly at the board) is at an unbearable level. The problem of glare has not completely disappeared. When using the LS6 combined light rack, DGPS is 5%, and according to the standard set by Wienold, the problem of glare is solved in class. In this case, the level of glare is noticeable and invisible for most students (except student 20).

Table 8. Results of simplified daylight glare probabilities (DGPs) of the proposed light shelves





RESULT AND CONCLUSION

In the present study, based on previous studies, six different models of combined light shelves have been examined for educational space in temperate and humid climates. The results have shown that glare control in the classroom space, especially for students who sit on the edge of the window, and providing sufficient lighting in the depth of the classroom is a challenging matter. The simulation of combined light shelves has shown that the spatial adequacy of lighting (sDA300LX, 50%) in LS1 and LS3 light shelves is equivalent to 34.4% and 36%, respectively, and is classified in the insufficient category. As a result, the lighting is not enough for the student's activities in the depth of the classroom, but the light shelves LS2, LS4, LS5, and LS6 have been able to provide sufficient lighting because 50% of the time of the year, more than 55% of the classroom area, the lighting is higher than 300 has received luxury. In all the proposed light shelves, the results of UDI100-2000 are higher than 75%. As a result, it has succeeded in providing sufficient lighting in the classroom. Also, due to the shading feature of the light shelf, it has managed to control the brightness above 2000 lux. However, in the proposed models LS1 and LS3, UDI<100 has increased by 14.18% and 6.31%, respectively, compared to the reference state. As a result, it is not recommended to use these models due to the creation of a very dark space in the depth of the classroom. This problem can be solved using the combined light shelves LS2, LS4, LS5, and LS6, by directing the lighting to the middle part and the depth of the classroom. Has been the results of DGPs > 0.35 have shown that the use of a combined light shelf in all cases has a significant effect in reducing glare compared to the reference model. However, in LS3 and LS6 light shelves, compared to the reference mode, it is equivalent to 81% and 84%, respectively. It has a reduction. And in the LS6 light rack, the problem of glare in the class has been solved according to the standard. However, it is impossible to eliminate DGPs for all students at all times of the year. In addition, the benefit of combined light shelves in all cases of the area above 2000 lux in summer and winter solstice and equinoxes is reduced compared to the reference model (without light shelf). However, in general, combined light shelves in winter solstice and moderately, it is more possible to create a very dark atmosphere in the depth of the class, especially at 9 am and 3 pm. As a result, it is not recommended to use the combined LS1 and LS3 light rack in these situations. Meanwhile, the mentioned light shelves have performed well in reducing the contrast and providing illumination during the winter solstice at 12:00 and 15:00. Considering the location of the furniture in the classroom during the winter and summer solstice at 9 am and the equinoxes and the proposed LS5 light shelf provides the best conditions in terms of providing lighting in the depth of the classroom and controlling the lighting in the middle part and the edge of the window. In the summer solstice at 12:00 noon and 3:00 pm, the LS6 light rack performed better than other light racks. According to the values mentioned in the indicators, the LS6 light shelf has brought the best conditions in terms of brightness and glare control in such a way that, on average, it has provided 300 lux lighting for 72% of the students, and besides that, It has reduced the lighting of less than 100 lux in the classroom to zero and has performed well in providing sufficient lighting in accordance with the UDI and sDA index. Also, compared to the reference state, it has reduced the lighting of more than 2000 lux by 71% and its use in seasons Different years are recommended as a fixed light shelf. Based on the studies conducted and the cloudy nature of the temperate and humid climate, it is recommended to investigate moving light shelves in future studies. Considering that the brightness and glare in the classroom in the case of studying on the edge of the window and the middle part of the classroom is very high and part of it is due to the side rays, it is recommended to combine other facade elements with the light shelf such as vertical fins and protrusions. Also, considering students' different characteristics and the effects of lighting conditions and glare on them, it is recommended to conduct studies on different factors that affect students' comfort conditions in the classroom.

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