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ORIGINAL RESEARCH PAPER

The Effect of Using Smart Dynamic Skins on Increasing Visual Comfort and Use of Daylight in Schools

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ABSTRACT

Creating suitable lighting conditions in educational environments is one of the most important factors in the design of such spaces. If daylight is used to provide it, it will have significant effects on the mental and physical conditions of students, as well as reducing energy consumption. But for the design of space lighting, attention should be paid to not creating too much or too little light and glare in the space. One of the modern solutions to provide these conditions is the use of dynamic and smart skins that react based on the amount of light received from the sun and its position in the sky. In this research, with the help of computer analysis and by keeping all the conditions constant, the impact of the presence of dynamic smart shade and its absence on the amount of sufficient light supply and the possibility of glare in a classroom is examined. These analyses were done at 12 pm on the 21st of March, June, September and December in a classroom located in the southern part of an educational building in Tehran, which has a hot and dry climate. The purpose of this research is to prove the better performance of the designed dynamic and smart facade, in providing proper light and no glare in the climate. Based on the obtained results, it was found that the design with the help of Iranian-Islamic architectural patterns in smart shade systems, especially on the southern side of the buildings, leads to the creation of visual comfort in the environment. Furthermor, according to the results obtained from the comparison of the two facade systems, in all the analyses, the intelligent facade, unlike the case without the shade, has been able to provide enough light for more than 50% of the class area at all times, without causing glare. This result shows the good performance of dynamic smart shade in providing daylight.

Running Title: The Effect of Using Smart Dynamic Skins...

NUMBER OF REFERENCES
31

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1. Introduction

Learning environment, along with other influential components in education, such as curriculum, teachers, etc., has an important impact on education. Although the physical environment of the school is just one of the influential factors in learning; but it can be said that it is the most important component in an active learning environment (Gregory, 2007). Providing suitable lighting condition in the classrooms is the most important factor of the all-effective physical factors in the learning environment, because the eyesight plays a very important role in the education and students' learning, so that more than 83% of learning comes from that (Shehbazi et al., 2015). In most classrooms in Iran, artificial light is used in all classroom hours regardless of the presence of daylight. While, if an intelligent lighting control system is used and a classroom is designed properly, daylight can be used to provide lighting for the classroom during many hours of the class. In addition to reducing energy consumption, this issue will also increase the level of visual comfort of students (Ghanbaran and Hosseinpour, 2015). Window is the main artery of daylight and at the same time the weakest point of the building in terms of heat loss, and its fundamental effect on the amount of energy consumption, as well as the internal comfort conditions, has made this type of study more extensive and necessary. Although, large windows with no shadings in educational buildings provide a lot of daylight, they also cause glare and excessive heating of the space (Zamardian and Pour Dehimi, 2017). Therefore, due to the essential role and great importance of providing daylight in educational environments, the question is, how can the visual comfort conditions be provided at the same time as receiving only sunlight? The answer to this question can be examined from various aspects. One of the solutions is to design and use intelligent and responsive dynamic facades. Then we should optimize it in terms of receiving light and filtering it for use in the interior space to provide sufficient and appropriate light without creating glare in the space. Therefore, the main topic of the research is to prove the performance of smart dynamic facades in providing visual comfort for students in classrooms, especially the classrooms located on the south side of the buildings. This work is done by computer simulation of visual comfort factors in classrooms and optimizing the performance of dynamic skins in response to the light received during the day in order to achieve the goals have set in providing the mentioned factors.

2. Literature review

Considering the above information and the importance of daylight in human life, it seems that there are limited studies in the field of investigating the provision of suitable daylight in educational spaces with the help of shades and using computer simulations and it is necessary to conduct more extensive studies in this field. Among those, we can refer to the research of Javani, who in her research dealt with the relationship between the shape and location of the window or skylight and the way of light distribution and she also provided a detailed description of how to combine all kinds of artificial lights with natural lights for the best light condition in the space (Javani, 2011). Moreover, in the research of Fadaei Ardestani et al., various types of visual comfort factors have been investigated and several factors have been proposed in the field of daylight and glare evaluation: static factors and dynamic ones (Fadaei Ardestani et al., 2018). Or Shafavi Moghadam et al. have researched the accuracy of the factors in the field of daylight sufficiency and the amount of annoying glare in a space with fixed shades, with the help of environmental studies and computer simulations (Shafavi Moghadam et al., 2019).

Pour Ahmadi et al. has studied the effect of changing the window-to-wall ratio[1], and from the point of view of their research, this issue has the greatest effect on changes in the probability of glare caused by daylight (98%) (Poor ahmadi et al., 2019). Shea et al., in their research, tested the effect of the type of movement mechanism (rotation and folding) in dynamic facades on the amount of energy and daylight performance and they found that the rotary motion performs better in terms of daylight quality, while the folding motion leads to greater energy savings (Shia et al., 2020). And finally, Ahmed Mahmoud

1. WWR

and Elghazi also showed that the performance of kinetic facades with rotary movement is much more suitable from the climate perspective than other systems with other types of movement (Ahmed Mahmoud and Elghazi, 2016).

Before entering the computer simulation′s part, it is necessary to know a little about the light and its function, its effect in the educational spaces, the visual comfort factors that are used as a mediator in the theoretical discussions and learn more about how to estimate daylight:

a) light

Light in the city, as one of the non-physical elements of the urban landscape, has a great impact on the quality of the space, feeling, perception, mental image of the environment, behavior and even the physical and mental health of people (Mohammadi et al., 2018). In the ancient times, building lighting was mostly done with the help of natural light, and usually, for a limited time at night, some indoor spaces as well as some outdoor spaces and urban spaces were illuminated with the help of artificial light using various lanterns and torches. The limitations and difficulties of using night light make human societies understand the value of natural light and take maximum advantage of it (Soltanzadeh, 2009).

Using natural light has many advantages and benefits:

1) Reducing energy consumption
2) Reduction of microbial agents and fungi inside the building
3) Health caused by absorption of vitamin D
4) Improving efficiency due to changes in the work environment
5) Increasing visual beauty in interior design
6) Regulating the natural rhythm in the body's biological systems
7) Increasing the quality of other standard space factors; such as temperature and humidity
8) More communication with nature
9) Health of the visual system
10) Reducing anxiety (Arabi and Ghorbani Param, 2016).

Recognizing environmental potentials plays an important role in environmental planning. Climate is one of the interesting topics in studies related to the role of weather factors on human life (Tavoosi and Abdollahi, 2010). The climate in architecture has two main goals, which are: 1) in the winter season, preventing heat from being wasted or leaving the building and absorbing as much solar heat as possible, such as the sun rays that shine through the south windows and 2) in the summer season when cooling is needed, these goals are reversed, i.e. resistance to the heat of solar radiation by creating a shadow and exiting the building's heat (Rezai et al., 2018). Considering the increasing importance of the global warming crisis and its tangible consequences, and on the other hand, the expensive and limited fossil fuels, paying attention to climate design and adjusting the amount of energy consumed in buildings and using as much natural resources as possible is very important. (Esmaili et al., 2010). Despite current calls for energy conservation, daylighting is rarely used as a significant strategy to reduce energy consumption. Electric lighting in many buildings remains "on", even when they are empty at night, and during the day, when additional light is not needed, electric lighting in many offices and stores is still on. As a result, as long as we do not step on environmental concerns such as gas emissions and global warming and until we show its negative impact on the health and well-being of the residents of the buildings, architectural and engineering approaches in the design of buildings will support very little engagement with natural resources (Bubekri, 2008).

Light is the amount of light irradiated on the surfaces of objects that makes them visible and recognizable (Ghazi Noori, 2002). Research results show that lighting affects people in two direct and indirect ways: its direct effect is caused by changes in the quality of vision due to lighting and by changing the stimuli of the visual system or changing the functioning of the visual system while its indirect effect is the result of light's ability to attract attention, change motivation, state, behavior and correct the hormonal balance of the human body (Poor deihimi and Haji Seyed Javadi, 2008). One of the most important factors in designing an optimal lighting system is daylight. Daylight is a combination of diffused light of clear or cloudy sky, surrounding reflections, building condition and geographical location, season, different hours of the day, etc. which the designer should use according to the variety of these conditions (Ghazi Nouri, 2002).

b) Light and its application in educational buildings

Light is one of the principles of architecture in providing visual comfort.

The educational environment should have proper lighting and the most suitable light is to use natural sunlight through windows (Divandi and Bozorg Ghomi, 2018). The history of expressing the issue of natural lighting in the design of educational environments reaches from 1592 to 1562 in California. According to research conducted in America as well as other researches in educational spaces, it was found that classes with sufficient and suitable daylight had a positive effect on the mental health and academic process of students (Nasiri and Mahmoudi Zarandi, 2020). Natural lighting is one of the important factors in the design of educational spaces with good quality and has a significant effect on students' memory. Teachers want to teach in a classroom that gets the most natural light from its windows and skylights. On the other hand, research shows that student′s study better in classrooms filled with natural light than those filled with fluorescent lamps. And even their academic progress is much better (Azemati et al., 2017). Hypotheses related to the impact of the physical environment on people's attitude and behavior are the products of different cultures throughout history, which have drawn the attention of researchers to school architecture. For example, Ann Taylor, from the University of New Mexico, has pioneered studies on the educational importance of the school environment. In an article published by her in 1988 entitled "Ecology of Learning Environment for Children"[2], it is quoted: "The learning process and the physical environment are an inseparable part of each other" (Gregory, 2007). Ecological psychologist Barker believes that there is a special relationship between physical, architectural and behavioral aspects, even classroom benches, their arrangement and material affect people's behavior and learning. Gump calculated that each person spends an average of 14,000 hours in school from elementary school to graduation, therefore, the educational environment should be attractive and liked by the users in order to enable the necessary traction for their useful and effective attendance (Shahbazi et al., 2015). Teachers and students spend most of their time in classes and very different visual works are done in them, such as the act of reading on the surface of the table and blackboard, visual communication between the teacher and students, watching the map on the walls, etc. In addition, in classrooms there are always several working positions (at least one position for each student), for this reason, careful measures must be taken to design artificial lighting and daylighting systems with good performance (Belia et al., 2011).

Considering the importance of lighting for educational environments, in order to benefit as much as possible from lighting in educational spaces, there are some points that are recommended to be followed:

1. The light source should not be in the field of vision of the students, because it causes glare.
2. The direction of the classrooms should be towards the north and south, as well as towards the east and west, in order to prevent direct sunlight from entering the space.
3. Use large windows, because these windows bring more light into the classroom and illuminate the classroom.
4. The intensity of received light depends on the design and size of the window. For classrooms, windows with an area of 30-60% or about 15-30% of the classroom area are usually more suitable.
5. The minimum amount of lighting required in the classroom is 200 lux and the maximum is 500 lux (Hafezi, 2017).

c) Visual comfort

Comfort is a complex perception that reflects the interaction between objective and subjective stimuli, and accordingly, the feeling of general comfort is the result of the evaluation of human senses. Visual comfort in the environment depends on the vision, perception, shape of the space and its compatibility with the different activities of the residents, and it improves when visual messages are clearly received from the visual environment.

2. The ecology of learning environments for children

Visual comfort is achieved with the following conditions:

A- Absence of strong contrast and uniform distribution of light

B - Avoiding disturbing reflections and glare

C - Appropriate color temperature

D - Providing sufficient lighting

E - Establishing a proper vision from the inside to the outside (Ghiabakloo, 2020).

In order to evaluate the two most important factors affecting visual comfort, which include the sufficient amount of received light and the absence of annoying glare, factors representing several homogeneous variables with different values are used, and after combining, they are finally expressed in the form of a range or value and determine the quality of ambient lighting. The photometric factors are divided into two groups, static and dynamic, in terms of the evaluated time range and considering the sky conditions. The evaluation done by static factors is only for a short period of time and the calculations are done for a steady state. But dynamic factors evaluate all design parameters, climate, changes in sky conditions based on meteorological data, light conditions of space and visual comfort of users during a year, and provide more comprehensive results. Dynamic factors can be calculated with the help of daylight modeling based on climate and simulation; by specifying the geometry and form of the space, materials and light sources (sun and sky) as input data for the software, a network of sensors is determined at a certain height (generally at the height of the work surface), and by the lighting data obtained at the location of each of these sensors, the desired factors are calculated. In order to predict the level of user satisfaction with the lighting conditions, it is necessary to determine values for the mentioned indicators as a basis, therefore, it is possible to judge whether the light is insufficient, suitable or excessive in different parts of the space (Shafavi Moghadam et al., 2019).

Among the various static and dynamic factors, the factors that have been more popular in research and daylight standards have been selected and summarized in the Table 1.

d) Daylight estimating

Daylight performance in buildings can be assessed using a variety of methods, from simple diagrammatic manual design tools to more complex computer-based design tools. There are four ways to do this: small-scale models, mathematical or analytical models, full-scale models, and the use of computer simulation software. Building energy simulation programs are a valuable tool in the design phase of new buildings and in order to evaluate the possible savings in the optimal use of daylight by conducting parametric studies of different windows and shading devices, it is used to optimize the energy performance of the building. Simulations allow detailed comparisons, provides practical and computationally efficient solutions for evaluating energy performance in daylighting applications and enables researchers to focus on the performance of building designs to achieve the best results (Wong, 2017). In recent decades, many softwares have been designed to simulate natural light, each of which has various capabilities. Some of these softwares are widely accepted and are reviewed and modified annually, one of these powerful softwares is Radiance. Radiance is a free lighting simulation software that was designed in 1985 at the Lawrence Berkeley Laboratory in California. This software has solved the problems related to multiple reflections, mirror surfaces, and large light sources with modified simulations based on the backward ray trace method (Ghiabakloo, 2020).

To perform some calculations and check the results of daylight and energy simulations, which are defined based on various parameters such as variable dimensions of design components, time, etc., we need to use a method to control these variables and changes Apply them in our calculations and research results.

This is a parametric design method. In this method, forms are created by combining basic parameters that are entered into the model after defining a basic form (Monedero, 2000). In parametric design, the use of special software programs such as Grasshopper is useful for designs with constantly changing factors. One of these cases is dynamic and smart sunshades (Samadi

Table 1. Static and dynamic factors (Fadaei Ardestani et al., 2018)

Type	Factor	Description	Accepted Range	Lighting Condition
	Mean Daylight factor(MDF)	The average ratio of daylight brightness at any point in space to brightness on the horizon is in CIE sky conditions.	2> 5< >2 >5	Inappropriate Daylight Appropriate Daylight Intense daylight
Static	spatial Daylight factor(sDF)	Percentage of area where the amount of daylight factor received is more than 2%	>75% <75%	Inappropriate Daylight Appropriate Daylight
	Daylight Glare Probability (DGP)	The glare of daylight is calculated based on the brightness of the source and background, the amount of light applied to the eye (Ev), and the viewing angle of the light source. This rate is acceptable from 0.35 to 0.40	< 0.35 0.35– 0.40 0.40 – 0.45 > 0.45	Invisible Comprehensible Annoying Unbearable
	spatial Daylight Autonomy	It is the percentage of space (floor) that receives a certain amount of daylight (300 lux) in a certain period of hours of annual space occupation. For example, sDA (300, 50%) represents the percentage of space where the brightness level is more than 300 lux in more than 50% of the hours of annual space occupation.	<55% >55%	Inappropriate Daylight Appropriate Daylight
Dynamic	Useful Daylight Illuminance	This index shows the annual natural light distribution in a space within predetermined ranges (in more than 50% of the occupation time) in terms of luxury.	0 – 150 lx 150 – 300 lx 300 – 3000 lx 3000 lx<	Insignificant Low Appropriate Intense
	Spatial visual Discomfort (SVD)	Lack of visual space comfort (DGPs is acceptable in at least 20% of space occupancy above 0.45)	< 10% > 10%	Comfort Discomfort
	Annual Sunlight Exposure(ASE)	Percentage of space where the amount of direct daylight is 1000 lux, for a certain period of hours of annual space occupation (250 hours)	> 12% < 12%	Unacceptable Acceptable

et al., 2020). The simulations of this research were done by Honeybee and Ladybug plugins. Honeybee is one of the most comprehensive plugins available for environmental design that implements and visualizes the results of daylight simulation using the Readiness engine and Ladybug provides various 2D and 3D interactive weather graphics by Energy Plus standard weather files. It also supports the evaluation of initial design options based on site studies. These functions link simulation engines to CAD and Grasshopper and Dynamo plugins, which act as an object-oriented API for these engines and because of the capability of these plugins, they are used in parametric design (Ladybug Tools website).

3. Materials and methods

3.1. Selection of indices

In order to provide the conditions of visual comfort in this research, the most used factors in this field in many studies and especially more recent researches are UDI and DGP. The reason for choosing each one is as follows:

1) Useful Daylight Illuminance: UDI is a dynamic index. Due to the consideration of design parameters, climate and changes in the condition of the sky, it provides comprehensive and suitable results for evaluating the light sufficiency in the environment. Also, this index provides annual evaluations, but by creating a space occupation schedule, it can also provide the results in the desired time intervals.

Based on the type of facade, which is an intelligent dynamic one and is constantly changing its form during the time of occupying the space, the evaluation can be done hourly too. And it can also be measured based on a certain interval, which amount of space receives the right amount and which area receives more or less than the expected amount of light.

2) Daylight Glare Probability: This indice is actually the best indice in the field of glare evaluation and the reason is that the formula for calculating this indice, which can be seen below, is based on vertical illuminanace at eye level[3]. It also includes the distribution of contrast in the environment, so it can evaluate both the effect of direct illumination at the eye level and the ratio of darkness and brightness of the environment in determining the final glaring condition. The vertical illuminance of the eye is sometimes considered as the most important factor in some studies.

It makes this indice sometimes perform better than the most complex indices.

In this indice, the viewer's location in the desired space and his viewing angle plays a fundamental role in evaluating the glare of the scene.

$$\mathrm{DGP} = 5.87 \times 10^{-5}\, E_v + 9.18 \times 10^{-2} \log_{10}\left(1+\sum_{i=1}^{n}\frac{L_{s,i}^2\,\omega_{s,i}}{E_v^{1.87}\,p_i^2}\right) + 0.16$$

In this formula, E_v is the vertical total brightness, and L_s, ω_s and p are the brightness, net angle and position indice for each glare source (Konstantzos and Tzempelikos, 2017).

In the Table 2, the final goals of visual comfort are briefly stated.

3.2. Simulation process

In order to prove the better performance of dynamic smart shades in maintaining visual comfort conditions, these simulations were done in two situations: without any shades and in the presence of smart shades. The image related to each class can be seen below. The simulation of the desired indices and the examination of its results have been done in three stages:

First stage: Parametric modeling of classroom space, dynamic facade, attraction point algorithm and space occupation schedule

Second stage: UDI indice and DGP indice simulation process

Third level: Comparing the results of the simulation of two facades with each other

Before modeling, it is necessary to check the climatic information of the project location:

The location is in Tehran. The city of Tehran is placed in the BSK category in terms of Kopen's climate classification, which are usually found in the inner spaces of the continents, far from the seas. A semi-arid climate usually has hot to very hot summers and cold winters. Tehran is located near the desert, which means that the sun's radiation is very intense most of the year. The use

3. E_v

Table 2. Criteria for research to compare the shading strategies (Author)

	Factor	Accepted Range
1	UDI	More than 50% of the space occupied should receive 300 to 3000 lux of lighting
2	DGP	Only values less than 0.35 are acceptable

of sunlight to provide daylight in building spaces and to provide solar electricity in Tehran has high capabilities. The amount of radiation in the month of June and the three months of summer (when the sun reaches its highest radiation angle at this latitude) is on average nearly 800 watts per square meter per hour and its lowest amount has been recorded in the months of December to February with a value of slightly more than 600 watts per square meter per hour.

In the psychrometric chart, we can see the comfortable temperature conditions of Tehran city throughout the year. According to the diagram, in general, this city spends 10% of the annual period in comfortable conditions without the need for any additional activities. But in order to establish comfortable conditions in the rest of the year, active and passive measures should be used. One of these measures is the use of a suitable shade, with the help of that, at least 20% of the time period or in other words about 1750 hours of the year can be spent in comfortable conditions.

3.3. Research Design

To design a modular facade, it is necessary to make the same division on the surface of the facade. So that the surface can be easily filled and covered with complete and specific units of the designed modules. The square unit is considered a suitable base in the field of dynamic and modular facade design and a suitable surface for the volumes of functional buildings that generally have a cubic form. The units of the same shape in the facade provide the possibility of modularization and, as a result, easy handling and replacement of each unit. These features are listed in “Gereh” which is one of the decorations of Iranian architecture and it is caused by the use of geometry in the creation of abstract motifs,

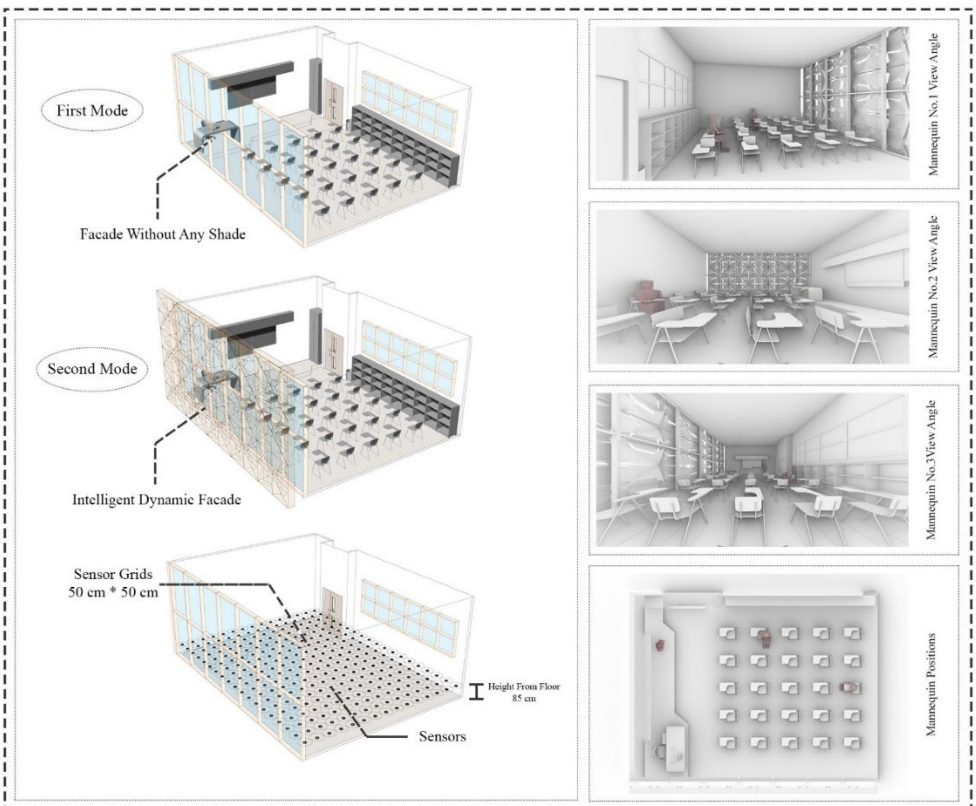


Fig. 1: Class modes for simulations, sensor positions and mannequins view angle

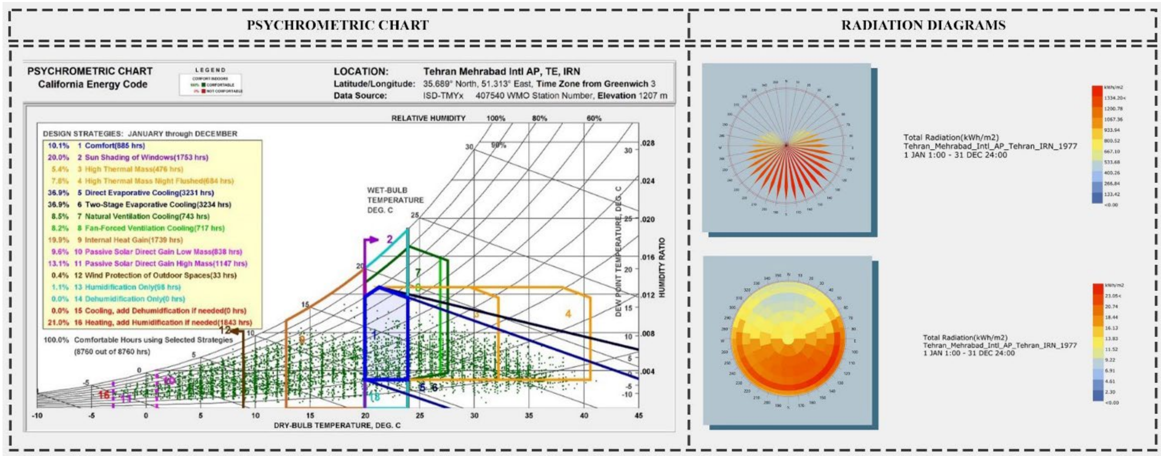


Fig. 2: Tehran Psychometric diagram of Tehran (Climate Consultant software) (Left) Tehran Radiation diagrams (Ladybug Plugin) (Right)

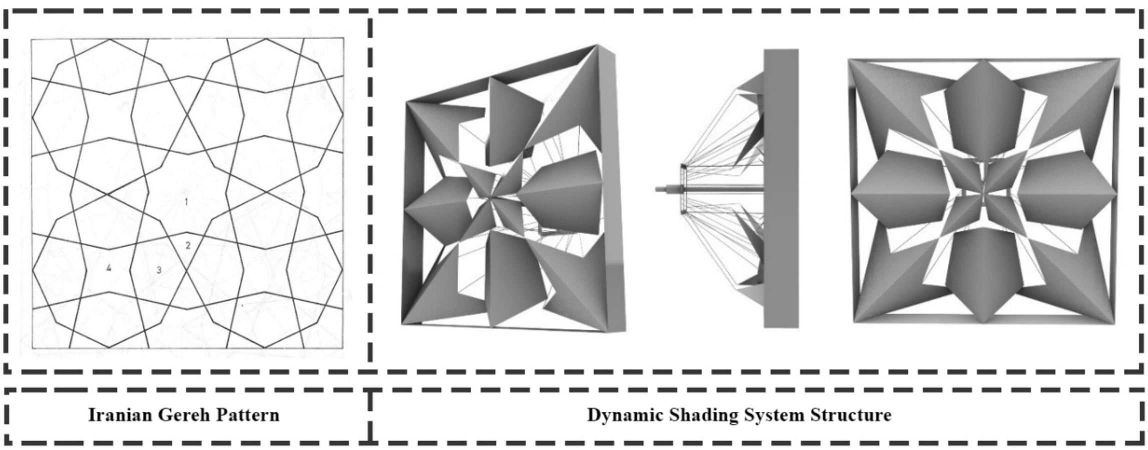


Fig. 3: Gereh pattern (Helli, 1986) (left), Shading unit structure (right) (author)

which is obtained from paying attention to the form.

The dynamic facade modules in this research are a combination of movable units in the Gereh shape and fixed horizontal and vertical louvres that the movable unit controls the direct light and its entry into the space and fixed louvres also monitor how light is distributed in the space. The reason for adding louvres is that in the simulation and initial analysis, the system was not able to distribute the light proportionally. Therefore, by placing the louvres in the area around the movable shade system, in addition to creating a strong frame for each shade unit, we see the proper distribution of light in the interior while reducing the possibility of glare. The dynamic facade system in this project is placed at a distance of 1 meter from the surface of the main facade of the building so that the movements of the movable units can be done easily. And the process of control and repairs can be easily accessible from the floors.

In the next step, first, the designed skin was placed on the south facade of a school building located in Tehran. Then, because the responsiveness of the smart facade is proven during the critical hours of the year when glare is at its peak, it can be extended to all other times of the year as well. For this research, four time points were considered as time parameters, as follows: at 12 p.m. on the 21st of April (spring equinox), at 12 p.m. on the 21st of July (summer revolution), at 12 p.m. on the 21st day of September (autumn equinox) and at 12 p.m. on the 21st day of December (winter solstice), when the sun is at the highest point of its path in those seasons, it has the highest amount of radiation and also the possibility of glare is at its highest level during these times.

Then, the model mannequins and dynamic modules of the facade were placed, and the attraction point algorithm was implemented, which is actually the position of the sun (obtained by the sun path simulation component from the Ladybug plugin) in the sky. The date and time of the simulation and subsequently the space occupation schedule based on that date and time were determined parametrically. Then, with the help of the sensor generation component in the Honeybee plugin, the points related to the sensors were generated based on the plane that forms the floor of the classroom. In this research, the points were placed at the height of the students' desks or at a distance of 85 cm from the classroom floor and at a distance of 50 cm from each other.

And finally, the parameters of Table 3, assigned to the sections and the process of producing the algorithm and running the computer simulation began.

Simulation parameters and intended properties for surfaces.

According to what was mentioned in the selection of visual comfort factors, the simulation process has been implemented in two categories:

1) Useful Daylight Illuminance: With the help of the network analysis component, we connect the generated sensors to the annual daylight analysis component of Honey Bee. We also connect the Energy Plus climate standard file to this component. Then we connect this component to the radiance simulation engine and start the analysis by running the process start command. By extracting annual daylight indices, we select the desired index (useful daylight) and enter it into the graphical visualization components of Lady Bug, and by calculating the area of the sections that receive enough light, which are marked with red color and the sections outside the range that are displayed in blue, we can determine the percentage of the space that receives light properly and sufficiently.

2) Daylight Glare probability: In the process of simulating the probability of glare, because the investigations are based on image analysis, it is necessary to place mannequins as samples in the space to extract images from their viewing angles. Therefore, we can determine the possibility of glare. In the next step, it is necessary to determine the radiance parameters based on image analysis, which, due to access to home computers, it is only possible to use average level parameters, so we consider the number "one". In the last part, with the help of the standard weather file of Energy Plus, related to the city of Tehran, the standard sky of Honey Bee is selected by choosing the second type, which includes a sky with an average amount of clouds (the most similar to the sky of

Table 3. Extra surface qualities in simulations

Parameter Type	Surface Type	Surface Feature	Color
Fixed	windows	VLT = 65%	No color
Fixed	walls	Reflectance = 50%	white
Fixed	floor	Reflectance = 20%	light colored tiles
Fixed	ceiling	Reflectance = 80%	white
Fixed	exterior floor surface	Reflectance = 20%	-
Changeable	dynamic skin	Reflectance = 25%	light colored wood
Changeable	dynamic skin frame	Reflectance = 25%	-

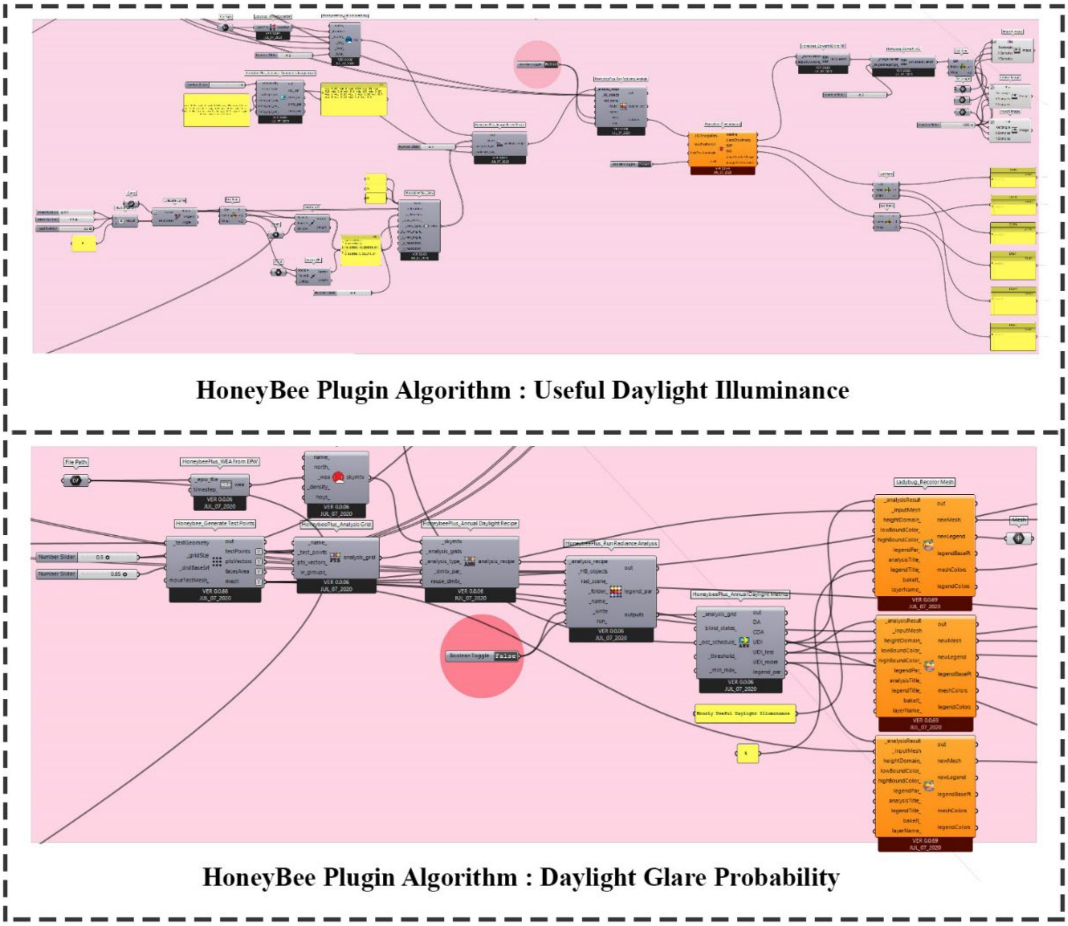


Fig. 4: Simulating algorithm of UDI (up) and DGP (down) by the HoneyBee plugin

Tehran city). We connect these components to the space analysis component based on the produced images, finally, we connect this component to the radiance simulation engine and start the analysis process. After performing the calculations, to get the results of the daylight glare analysis, we connect the Honey Bee glare analysis component to the output of the radiance engine.

Based on the obtained values, we find out whether the desired viewing angle has the possibility of glare or not. Grasshopper's algorithm for these processes can be seen in the image below.

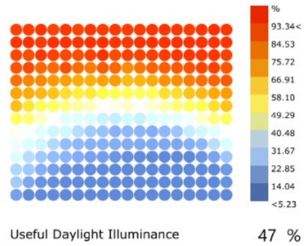
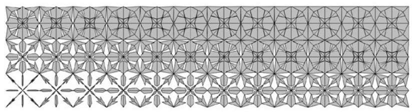
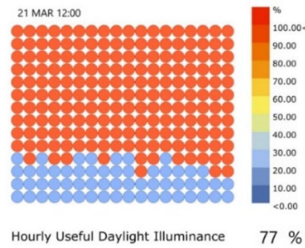
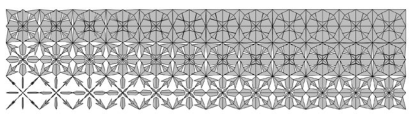
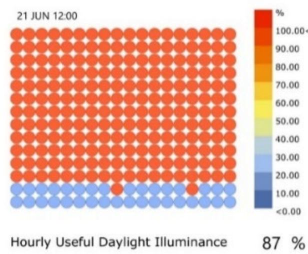
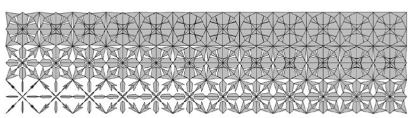
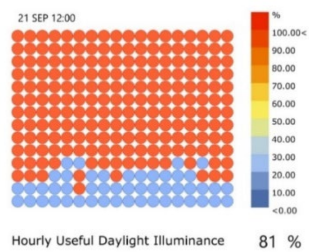
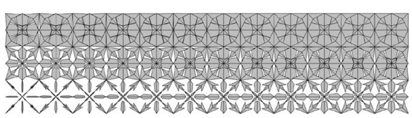
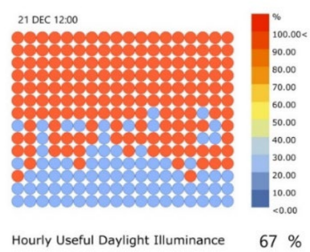
4. Result and Discussion

4.1. Checking the results of simulations

4.1.1.) Useful Daylight Illuminance on Facade without any shade: According to the chart number Flan, which represents the result of the annual simulation of useful daylight illuminance, only 47% of the environment receives the right amount of illumination during the occupancy schedule, which is actually in the range of 300 to 3000 lux. And these sections often include middle to end class sensors, and in the section in front of the window, intense light with a brightness of more than 3000 lux is received, which definitely has problems such as severe glare for people who are placed in that section.

4.1.2.) Useful Daylight Illuminance in the Presence of Dynamic Smart Shade: Regarding the performance of smart shades, it should be noted that due to the constant reactions of this type of shade to the path of the sun and the amount of light received by the sensors and the constant changes that they apply to the degree of

Table 4. Results from the openness of the facade modules (left) and UDI diagrams at specific times (right) for classroom with dynamic shading

Time	Dynamic Façade Openness	UDI Diagram
One Year	No Shading	 (Diagram 1)
March 21st, 12 p.m.	 (Fig. 5)	 (Diagram 2)
June 21st, 12 p.m.	 (Fig. 6)	 (Diagram 3)
September 21st, 12 p.m.	 (Fig. 7)	 (Diagram 4)
December 21st, 12 p.m.	 (Fig. 8)	 (Diagram 5)

opening of the modules, performing simulations in the time frame of one year for this strategy is practically impossible. And the desired factors are checked hourly and the results received from them are also in the critical hours of the day. If the minimum required for each factor is obtained in these times, their proper performance can be extended to all times of the year. Of course, it should be explained that due to the position of the sun exactly in the middle of the sun's path diagram every month and at 12:00 PM, the movements of the facade and the changes in the opening of the modules in standard times are very imperceptible and small. According to the final diagrams, we find that in all of them, the amount of area that covers the light in the range of 300 to 3000 lux includes more than 50% of the work surface and this shows the success of dynamic smart display performance in the field of UDI factor.

4.1.3.) Simulation Results of Daylight Glare Probability on Facade without any Shade: As we can see in the images Table 5, in the three positions considered for the sample mannequins in the class, the mannequin that has a direct view of the window has the highest probability of glare

Table 5. Results of the DGP for classroom with no shading

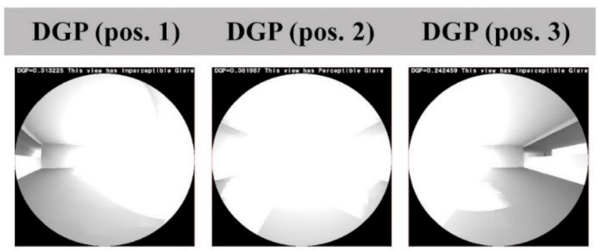
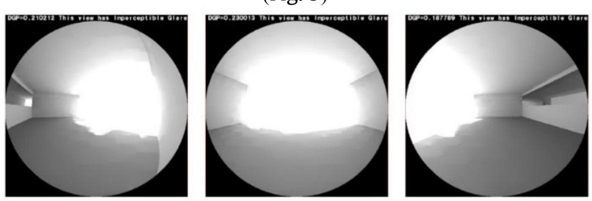
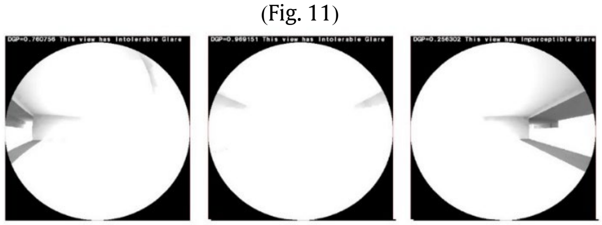
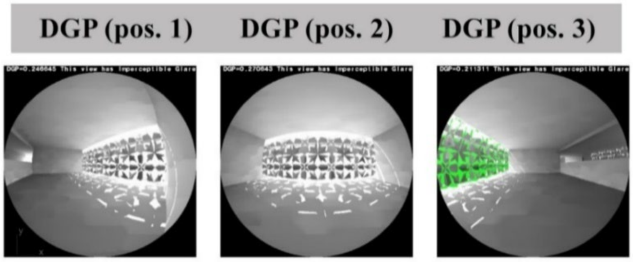
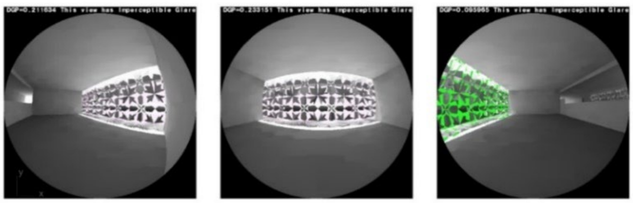
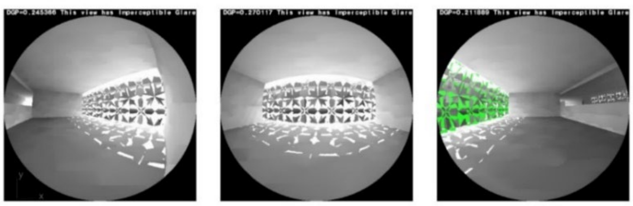
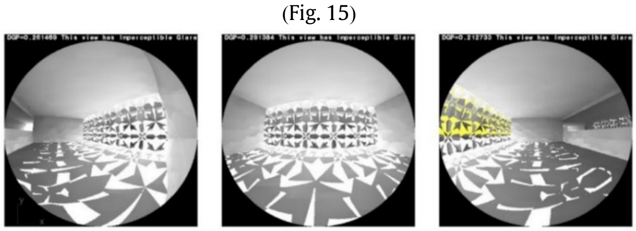
Time	Glare Analysis Result	DGP (pos. 1)	DGP (pos. 2)	DGP (pos. 3)
March 21st, 12 p.m.	 (Fig. 9)	0.31	0.38	0.24
June 21st, 12 p.m.	 (Fig. 10)	0.21	0.23	0.18
September 21st, 12 p.m.	 (Fig. 11)	0.30	0.36	0.24
December 21st, 12 p.m.	 (Fig. 12)	0.76	0.97	0.25

Table 6. Results of the DGP for classroom with dynamic shading

Time	Glare Analysis Result	DGP (pos. 1)	DGP (pos. 2)	DGP (pos. 3)
March 21st, 12 p.m.	 (Fig. 13)	0.24	0.27	0.21
June 21st, 12 p.m.	 (Fig. 14)	0.21	0.23	0.09
September 21st, 12 p.m.	 (Fig. 15)	0.24	0.27	0.21
December 21st, 12 p.m.	 (Fig. 16)	0.26	0.29	0.21

in each simulation. Besides, in the simulations, except for December, when the glare conditions are at their worst level, in the rest of the months, the glare factor is in a good condition, according to the criteria that have been determined.

4.1.4.) The Results of Glare Simulation in the Presence of Dynamic Smart Shade: According to the table, the images produced from the viewing position of the three mannequins located in the classroom and the results of the analysis, glare did not occur and the visual comfort conditions in the classrooms during critical hours are suitable. In other words, in all situations, the amount of glare probability factor caused by daylight is less than 0.35, which is the ultimate limit in providing light without glare in the visual scene, and according to the results, it shows the best performance in all situations and hours.

According to the comparison of the results, the strategy of intelligent dynamic modules has gained sufficient superiority in the results compared to the other mode. Undoubtedly, this strategy has achieved the best performance in

Table 7. Hourly simulation results (It should be noted that due to the placement of most of the students in the classes in the third position, which is facing the board and parallel to the window, we used this position and viewing angle to compare the results)

Occupation Hours	No	Shading	Dynamic	Shading
Indices	DGP (pos. 3)	UDI UDI (overlit)	DGP (pos. 3)	UDI UDI (overlit)
March 21st, 12 p.m.	0.24	33 67	0.21	77 23
June 21st, 12 p.m.	0.18	50 50	0.09	87 13
September 21st, 12 p.m.	0.24	38 62	0.21	83 17
December 21st, 12 p.m.	0.25	23 77	0.21	68 32

all cases and by obtaining values exceeding the considered criteria, it has performed completely successfully in all of the cases.

5. Conclusion

In this research, we sought to answer two questions, one is whether applying sun shade on the facade of the building is effective on the amount of internal light and the probability of glare or not, and next question, how much is the effect of the sun shade on the sufficiency of light in the environment and the probability of glare?

At first, we studied numbers of researches that had been done in this field, then we discussed the fundamental topics related to daylight, visual comfort and the indices that are effective in it, and the amount of each indice to create visual comfort in the environment. In the next part, we discussed how to estimate the daylight, and then designed dynamic shading system, whose design is taken from Iranian-Islamic architecture. The design project in this research is located in Tehran. According to the geographical location and the type of climate of Tehran, the buildings have the ability to receive a lot of light, especially in their southern façade, so that you can receive direct sunlight in more than seventy percent of the days of the year. This issue causes the lighting of the south face of the building to reach such levels that the lack of use of light controllers, especially when there are large windows, causes problems such as glare or receiving too much light in the space. One of the advanced daylight control systems is the use of smart dynamic shades that can automatically and intelligently adapt to sunlight conditions. This system helps a lot in the effective use of daylight in educational spaces and in reducing its negative effects, such as the creation of light spots caused by direct sunlight, which causes disturbances in the vision and perception of people present in such spaces. Finally, we started the simulation process by selecting the desired indices. The variables presented in these simulations are the pattern of the openness rate of the smart dynamic facade and the date and time of the day. Daylight simulations were done by Honey Bee plugin in the designed space and the graphic diagrams were obtained from the investigation of the desired factors in the field of glare and the level of light sufficiency at the location of the sensors placed in the environment.

Based on the simulations and results obtained, due to the decrease in the height of the sun's path in the sky and the direct entry of light into the interior spaces, there is a high probability of glare in late autumn, winter and early spring. Therefore, the desired sun shade should be designed in such a way that, in addition to reducing the glare, it also directs enough light deep into the classroom space.

The simulations of the classroom in the

absence of shades show that in addition to the lack of light at the standard level in the annual analysis, severe glare has also been created in the classroom, which will definitely be a problem for the students and the teacher. The diagram of the annual analysis of useful daylight in the first row of Table 4 shows the number 47%. This number and the diagram show that in addition to the inappropriate distribution of light in the classroom throughout the year, the light receiving conditions have not even reached the minimum required level, which is to maintain the light in the range of 300 to 3000 lux in 50% of the time the space is occupied. As well, in Table 5, which shows the images from the simulation of the daylight glare probability in the considered dates, all year round except for summer (in Iran during this season, all schools are closed, so there is no use of this conditions do not occur) glare is unacceptable and annoying. Therefore, the results of simulations and analyzes prove the necessity of using shades to create suitable lighting conditions in the classroom.

After designing and applying the intelligent dynamic shade on the facade of the building, the simulations and analyzes were repeated. According to the results of the diagrams obtained from the investigation of the useful daylight illuminance at critical times in facade mode with the presence of shades (rows 2 to 5 of Tab. 4), we find that the distribution and quality of light have improved between 34 and 74 percent more than the minimum required amount. These results indicate that the presence of a suitable shade with all the parameters applied to it, between 67 and 87 percent of all times of occupying the space, has maintained the classroom light in the range of 300 to 3000 lux.

The results of the simulation of the probability of daylight glare in the presence of a shade on the facade can be seen in Table 6. Based on the analysis, there is no probability of glare in the viewing angle of any of the three considered positions, and all of them are in the range of 0.21 to 0.29, and they show less than the final considered limit, which is 0.35. The obtained numbers indicate that the incoming light does not cause any sensitivity in the range of vision of the observers located in the classroom and completely maintains the conditions of visual comfort.

Finally, by analyzing and comparing the results obtained from the window simulations in the presence and absence of the shade on the facade and as described numerically in the previous paragraphs, we found that the presence of the shade has a significant effect on the amount of incoming light. So that it improves the conditions of light distribution in the appropriate range by approximately 30 to 70% at different times of the year and is definitely effective at all times in preventing glare caused by direct sunlight, which in this research project is maintaining the visual comfort of the classroom without any glare.

Based on the general result of this research, it is emphasized that the use of dynamic smart shade has many benefits in terms of maintaining the physical health of the students and reducing energy consumption and thus reducing environmental pollution. In addition, the different patterns that are created by the opening and closing of each unit of the skin on the surface of the facade, create visual diversity and, in addition to matching the changeability of the skin in different conditions, add remarkable beauty to the facade of the building. It should be said that computer simulation provides a reliable, effective and time-saving optimization tool. Although some influential parameters such as the way mechanical items are used, their performance over the duration of use is not clearly highlighted in the simulations. But due to the high costs of installation and maintenance and relying on electric energy, it is possible to save energy in these buildings by combining dynamic systems and passive designs.

And finally, it is suggested for future research, that comprehensive researches should be done to check that creating and maintaining visual comfort conditions do not cause problems in other cases. These problems can lead to people's thermal discomfort, followed by an increase in energy consumption and environmental complaints.

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