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Research Paper

The Effect of Shader's Type, Depth, and Distance on Optimizing Daylight Autonomy in High-Rise Buildings in Cold Climate

Farhad Ahmad Nejad [*], Yaser Shahbazi, Mohsen Mokhtari Kashavar, Misha Zendeh Laleh, Sahar Hossein Pour, Neda Khalili Khou

Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran

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Abstract
For years, research on daylight in work environments with different climates has been important for researchers to distribute light evenly in the indoor space in order to create a healthy work environment and visual comfort. This study, examines the effect of horizontal and vertical shading devices, the depth and distance of louvres on daylight, with the aim of increasing DLA (daylight autonomy), in Abrisham Tower in Tabriz, Iran. As input parameters, the depth of louvres, was considered 5 and 15 cm and their distance was considered 150 and 200 cm. Modeling of the tower was performed in Rhinoceros software and the simulation was done in the Grasshopper plugin, to control the geometric parameters, with the help of Ladybug and Honeybee plugins. The multi-objective simulation tool, the Octopus plugin, was used for optimization. Finally, statistical comparison and quantitative analysis of data was done in SPSS software. T-test, independent and paired mean comparison methods, and ANOVA were used for statistical analysis. The results showed less changes in horizontal and vertical modes. This is due to the cold and mountainous climate of Tabriz, many cloudy weeks at the beginning and end of the year in this city, and the great depth of the building. However, vertical louvers caused more light reduction. Furthermore, the distance between louvers in Tabriz is a more important variable. According to the optimization results, the optimal cases that were obtained for north facade windows are horizontal louvres with a depth of 5 and a distance of 190 cm and vertical louvres with a depth of 15 cm and a distance of 200 cm. In the south facade, are horizontal louvres with a depth of 13 and a distance of 161 cm and vertical louvres with a depth of 14 cm and a distance of 153 cm.

Keywords: *Daylight, Simulation, Optimization, Parametric design, High-rise buildings, Shading device.*

1. INTRODUCTION

Office towers are one of the most important buildings built in the last century, which employ numerous people and actually affect their daily lives, and depending on the size, energy or resources, and sometimes electricity consumption or heating and cooling, some of them are equal to the energy consumption of a small city. For years, the study of daylight in different climates aimed at providing and distribution of light to different climates with the aim of providing and distributing light to the whole interior space and visual comfort to the researchers, and it is necessary to note that studying natural light in working environments is more pivotal than the design of any other environment (Berardi & Anaraki, 2015).

In 2015, a study was conducted on the use of external shading systems to reduce the cooling load and daylight improvement in an office building. Daylight performance was evaluated using daylight factor and useful daylight illuminance (UDI). The results showed that the total cooling load is reduced by 35.1%, and regarding daylight performance, the UDI range is increased. On the other hand, the amount of illumination of more than 2000 lux, which causes visual and thermal discomfort for the residents, was reduced (Kim, Leigh, Kim, & Cho, 2015). In 2017, a study designed a louver system parametrically that

[*] *Corresponding author: f.ahmadnejad@tabriziau.ac.ir*

optimizes the shape of the louver based on its direct solar radiation control performance for each of the two south and west facades of an office building in Seoul, Korea. It also compares the thermal performance of the best louver design with the existing conventional louver design. According to the results, the existing louver designs have lower scores than the best-performing louver designs. The existing louver design for the west facade is worse than the no-louver case. In addition, the louver designs with the best performance compared to the no-louver case and the existing louver designs in both the south and west facades have the highest scores (Choi, Lee, Ahn, & Piao, 2014).

The fully-glass facade in office buildings requires the use of daylight-controlled strategies to minimize the need for excessive light in the interior and to optimize the use of natural light at work hours, because users have a fixed location and are unable to change their position with the objective of achieving a spatial point in order to receive updates. Therefore, due to the dynamics of the nature of daylight, there is a need for optimal lighting design during working hours (Bahdad, Fadzil, & Taib, 2020). Essentially, this issue is not suitable for any climate, on the other hand, the Abrisham Tower of Tabriz is one of the few towers with a glass facade. Therefore, it has been investigated in this research. For designing the glazed facades with shading devices in any building, there are various aspects that have to be considered such as the building type, the natural light prospects, and the latitude (Lim & Kim, 2010).

The performance of the shading elements depends on various parameters, including geometry, dimensions, thickness, and angle to the glass surface and the climate (Kontadakis, Tsangrassoulis, Doulos, & Zerefos, 2018). The two research questions of the study are: 1) How effective can the use of horizontal and vertical louvers in Tabriz office towers be in improving the distribution reception of internal natural light? 2) Which type of horizontal and vertical louvers are more suitable for use in Tabriz?

Answering these questions is followed by assumptions: According to existing literature, the use of shaders can have a significant and meaningful impact in reducing or increasing the productivity of internal natural light, depending on the season. It seems that the horizontal type can have a greater impact on the issue. As mentioned, this is important because of the large number of people working in the office building and sometimes they consume energy as much as a city. On the other hand, with a very low initial cost of construction, it can have a very long-term impact, so it is necessary to address this issue.

2. LITERATURE REVIEW

In this section, a review of previous studies on daylight in office buildings, shading systems, their importance and effective parameters on daylight, and daylight simulation tools has been done.

2.1. Natural Light in Office Buildings

There are many reasons for accepting daylight inside buildings such as saving energy, promoting health, psychological response and believing that daylight is inexhaustible (Commission Internationale de, International Commission on, & Internationale, 1970). However, potential problems such as glare or increased cooling loads caused by increased solar heat can also be due to uncontrolled amounts and quality of daylight (Bellia, Marino, Minichiello, & Pedace, 2014).

More use of large transparent building coatings requires the integration of shading systems. These architectural elements reduce the amount of glare, better light distribution, and also ideally can increase the penetration of daylight indoors (Kischkoweit-Lopin, 2002).

Due to the importance of office spaces, their open-plan, employee comfort and mental issues, access to daylight, and proper visibility in work environments have been important for a long time. This shows that people have a better understanding of the value of the mentioned factors in buildings (Kahn Jr et al., 2008; Leslie, 2003). It is difficult to achieve daylight using windows around the building in most high-rise office buildings. New daylighting strategies are needed to make better use of daylight in office buildings, such as increasing the penetration and uniformity of daylight (Mohapatra, Kumar, & Mandal, 2019). According to studies, 52% of studies in the field of shades and daylight are related to office buildings (Kirimtat, Koyunbaba, Chatzikonstantinou, & Sariyildiz, 2016).

In 2016, a study was conducted by Esquivias et al. on shading and daylight systems in open-plan offices (Esquivias, Munoz, Acosta, Moreno, & Navarro, 2016). Then, in 2018, Mangkuto et al. optimized daylight reception, with a kind of office space shading system (Mangkuto, Feradi, Putra, Atmodipoero, & Favero, 2018). In recent years, new studies are being conducted in this field. A more recent study conducted in 2019 by Mohapatra et al. discusses a type of system for increasing daylight in office rooms (Mohapatra et al., 2019). Recently, in 2020, Bahdad et al. talked about optimizing daylight performance in office spaces (Bahdad et al., 2020). And Burmaka et al. discussed the effective use of daylight in office rooms

(Burmaka, Tarasenko, Kozak, Omeiza, & Sabat, 2020). Odiyur Vathanam et al. in 2021 presented a detailed review of all recent technological advances in daylight harvesting, the impact of architectural design on daylight harvesting, and daylight forecasting technology with an office building in Chennai, India (Odiyur Vathanam et al., 2021). Also, in 2021, Rastegari et al. evaluated the daylight in an office building in Tehran, by changing the structure of the atrium. The atrium is a key component of a sustainable environmental approach in architectural design. Thus, changing the architectural aspect of the atrium had an important impact on lighting (Rastegari, Pournaseri, & Sanaieian, 2021).

2.2. Shading Devices

In recent years, the number of research articles on shading devices and their effect on various factors, especially daylighting in different climates, has increased dramatically. The United States and Italy are the most popular places among the 25 countries selected, for studies on shading devices (Kirimtat et al., 2016).

Bellia, et al. conducted a study on shading systems in 2014 that reported a review of some published scientific articles on solar shading devices for buildings and a critical analysis of some studies that investigated the effects of shading devices on the thermal and lighting performance of buildings. They also pointed out that due to the analysis of buildings with different characteristics, locations and using different indicators, or in other words, the lack of uniformity between studies, it is difficult to compare different results. Therefore, a protocol for conducting these types of studies should be developed to enable comparison between different studies. In addition, he showed that thermal comfort, economic and environmental aspects related to the use of shading devices have rarely been analyzed (Bellia et al., 2014). Similarly, Kirimtat et al. in 2016 reviewed simulation models of shading systems (Kirimtat et al., 2016). In their study, they focused on the types of shading devices used in the building sector, as well as on previous studies conducted to determine the performance aspects of different types of shading devices. Several studies were conducted on various types of buildings located in different climate zones, in order to emphasize the importance of simulating shading devices in buildings. According to the results, regarding the types of shading devices, Venetian blinds are the most common shading devices that have been studied among others. The results regarding the importance of simulation show that the use of simulation programs to solve complex relationships between climate, occupancy requirements, mechanical and electrical systems, energy efficiency issues, and design features is a strong solution to deal with these problems.

Another study conducted in 2016 by Esquivias, et al. discussed shading and daylight systems. In this study, they analyzed the effect of solar protection on the daylighting of an open-plan office. Climate-based daylight modeling (CBDM) was used to predict factors such as daylight factor (DF), daylight autonomy (DA), and useful daylight illuminance (UDI). The obtained results showed that overhangs, horizontal, and vertical louvres behave similarly and sidefins have nothing to do with daylight conditions inside the building. In all cases, it was found that excessive occlusion may excessively reduce the luminance range between 500 and 2000 lux and increase lighting energy consumption (Esquivias et al., 2016).

Thus, studies on shading and daylight systems continued in 2017 by Lee, et al. This study, using the tool of parameter one, investigated different characteristics of different types of facade shading device and considered their effect on daylight criteria and the relative relationships between daylight autonomy (DA) and useful daylight illuminance (UDI), in a normal classroom. Seven different types of facade shading including vertical louver, horizontal louver, eggcrate louver, overhangs, vertical slat, horizontal slat, and light shelf were applied to the building in eight azimuth directions. According to the results, the types of shading devices that cause a significant reduction in DA values are light shelves, horizontal slats, horizontal louvres, and egg louvres. In contrast, the types of shading devices that cause a significant increase in UDI values are light shelves, horizontal slats, horizontal louvers, and egg louvers. In the case of vertical slats and vertical louvres, the improvement of UDI values in the east and west directions is significant. This showed that the application and design of shading devices in facade orientations should be carefully considered to control daylight (Lee, Han, & Lee, 2017). In 2019, Czachura investigated the advantages of passive solar shades by studying the integrated daylighting and energy in a room of a typical office building in the Swedish climate. The overall results showed that, external shaders improve the performance of the building greatly in the Swedish climate. They are better at reducing solar heat gain and can also improve visual comfort. Louvered overhangs are superior to solid overhangs for solar energy systems due to increased daylight. Horizontal louvres block a lot of daylight. Vertical fins added to exterior horizontal shading elements can improve visual comfort and reduce energy consumption (Czachura, 2019). A newer study in 2020 was conducted by Samadi, et al. They improved daylight inside a virtual office building in Tehran by designing a kinetic shading system with independent units that respond parametrically to sunlight through 3D rotation and 2D movement. The results showed that the use of such a shading system in optimal conditions can greatly increase the efficiency of daylight inside the building (Samadi, Noorzai, Beltrán, & Abbasi, 2020). In 2021, Heidari et al. proposed different types of fixed window shading devices for energy consumption in almost extreme summer and winter conditions by conducting energy simulations of residential buildings in the Shiraz region which has a moderate climate. According to the simulation results, shading devices (horizontal, oval, and geometric) reduce solar exploitation in summer and block solar radiation in winter. In all types, it was proven that excessive blocking may cause excessive reduction of the illuminance spectrum between 500 and 2000 lux and increase lighting energy consumption. In addition, horizontal, geometric, and oval devices have the best performance due to energy reduction and having enough daylight in the climate zones of Shiraz (Heidari, Taghipour, & Yarmahmoodi, 2021). In 2022, the daylight and thermal performance of a double-skin facade system without shading devices and with hybrid multi-part shading devices with different control strategies under three climatic conditions of Xiamen, Shanghai, and Beijing were investigated by Hong et al. It was found that, for daylighting performance, the multi-section shading device with an appropriate control strategy eliminates annual sunlight and glare. However, it maintains the availability of daylight at a similar level without shading devices. Meanwhile, this combination can improve the spatial daylight independence (sDA) in Xiamen, Shanghai, and Beijing by 11.9%, 16.7%, and 19.1%, respectively, compared to the individual shading system (Hong, Lin, Yang, Wang, & Shi, 2022).

2.2.1. The Importance of Horizontal and Vertical Shading Devices

There are different types of building shading systems which can be external or internal, fixed, movable, and combined in the building. Many studies have been done in this field. Kirimtat et al. (2016) in the review of simulation modeling for shading devices in buildings focused on determining the functional aspects of different types of shaders and previous studies. He has introduced various types of shading systems fixed shaders, overhangs, oval devices, horizontal shaders, and vertical shaders (Kirimtat et al., 2016). According to studies of various shading systems, there are horizontal and vertical louvers that have been the subject of various articles on their effect on daylight. In the same year, in a study of climate-based daylight analysis of fixed shading devices in an open-plan office in Seville with a hot climate, Esquivias et al. analyzed daylight in an office using overhang, vertical fins, horizontal, and vertical louvers. They used weather-based daylight modeling (CBDM) to predict daylight factor (DF), daylight autonomy (DA), and Useful Daylight Illuminances (UDI). Studies showed that the most effective solar protection to prevent from entering direct sunlight indoors is the horizontal type. The least protection is for vertical elements, and the combination of shading systems in one or both facades increases the linear brightness of the useful area (Esquivias et al., 2016). Another research that examined horizontal and vertical louvers in daylighting was conducted by Lee et al. (2017). They discussed different types of shading devices, including vertical and horizontal louvers, which provide optimal lighting conditions indoors and the correlation between autonomy and useful daylight illuminances in a class. The results showed that horizontal louvers significantly reduce DA values and increase UDI. In addition, the DA average is generally compatible with the vertical louver in all conditions (Lee et al., 2017). Elouadjeri et al. (2021), investigated the effect of the geometry of fixed external shade devices in two horizontal and vertical modes on thermal comfort, daylight and cooling and heating energy demand in a room in a hot and dry climate in the city of Ghardaia (Algeria). Regarding daylight, it was found that fixed external shade devices eliminate all the risks related to glare in the summer by reducing the brightness near the window. However, they do not improve daylight performance in winter due to glare (Magri Elouadjeri, Boussoualim, & Ait Haddou, 2021). Likewise, in 2022, Noorzai et al. proposed a multi-objective approach to optimize the design of vertically fixed integrated PV shading devices to achieve their highest benefits, in relation to the indoor environment and occupants of a classroom. As part of their investigation into daylighting performance, they divided the classroom into adjustable lighting zones to reduce lighting energy requirements and increase users' visual comfort, by providing appropriate lighting levels required for a specific task. The results showed an increase in the thermal and visual comfort of passengers (Noorzai, Bakmohammadi, & Garmaroudi, 2022).

2.2.2. Effective Parameters of Shading Devices in Daylight

Design parameters of shading systems are among the factors affecting indoor daylighting performance. Distance and depth are among these parameters. Chou (2005), in studying the performance of daylighting with the shading device in architecture, tested horizontal, vertical, and eggcrate types of shading devices under the influence of five variables: type of shading device, depth of shading device, material reflection, the ratio of opening, and window pattern. Shading depth was tested at 0,15, 30, 45, 60, 75, and 90 cm. The reflection of the shading material is also tested at six levels. He pointed out that, in addition to the effect of the type of shading system on the performance of daylight, its depth can also be affected. The depth of the devices under test is from 15 cm to 90 cm. Experimental results showed that with increasing depth, low daylight entered the interior of the room and vice versa. However, in the horizontal and vertical types, this effect is not very serious. In order to use daylight, designers must avoid depths of more than 45 cm (Chou, 2005). In 2016, in studying climate-based daylight analysis using fixed shading devices in open-plan offices, Esquivias et al. considered fixed shading devices, overhang, vertical fins, horizontal, and vertical louver to evaluate their impact on indoor daylight. In this study, the shading devices were orthogonal to the facade. Therefore, the angle of their obstruction was determined according to the depth of each element including overhang: 0.36, 0.78, 1.35, and 2.34m, vertical fins: 0.40, 0.87, 1.50, and 2.60m, and the distance between them, vertical and horizontal: 0.06, 0.10, 0.37, and 0.17 cm. Shading devices were applied separately in the south, east, and west facades and in pairs in the north-south and east-west facades. In horizontal and vertical louvers, the depth remains constant and the distance between the louvers is changed to obtain different obstruction angles. Their effect on conditions of daylight showed similar behavior with respect to DF and UDI. By adding overhangs along the horizontal louvers to both facades, the reduction of DA was much more pronounced, so the maximum angle of obstruction should be 45 degrees (Esquivias et al., 2016). Lee et al. (2017), in a typical class in hot weather, evaluated the change of different facade shadows and their effect on daylight standards considering vertical louver, horizontal louver, eggcrate, overhang, vertical fin, horizontal fin, and light shelf. They examined the correlation between daylight autonomy and useful daylight illuminances by changing the shading devices, different parameters, number of louvers, depth, direction and angle, and azimuth orientation. The base value of DA without shading device was considered a common ground for changing each variable such as angle, number, and depth that each type of device has variable values for each parameter. Depth was provided for vertical louver (40, 50, 60, 70, 80cm), horizontal louver (20, 30, 40, 50, 60cm), for eggcrate system (20, 30, 40, 50, 60cm), overhang (20, 30, 40, 50, 60cm), and light shelves (90, 110, 130, 150, 170cm). The results show that DA values decrease and UDI values increase with the installation of the shading system. The DA average is generally compatible with the vertical louver in all conditions. Vertical and horizontal louvers in the south showed better results than the west. In addition, after applying louvers, the DA decreases with decreasing depth and number of louvers, but the UDI increases. The DA average values with the horizontal louver and without the louver are lower than the baseline values. In general, the louvers have a significant effect on environmental light (Lee et al., 2017). In a computational approach for achieving optimum daylight inside buildings through automated kinetic shading systems, conducted by Samadi et al. (2020), daylight in a virtual room was improved by designing a kinetic shading system with independent units. The length, width, and height of the room, the height from the upper window, above the window, and the dimensions of the shading device units were used to compute the results. Then, daylight simulation models were presented. The rotation of the surface of each shading device unit was determined based on two factors: the angle of impact of light and some target points on the ceiling. The distance between neighbor units was then computed to create moderation between light reflection and optimal light. The distance parameter was important, because if the distance was too short, even though the amount of reflected light would decrease, it would completely prevent the penetration of light. On the other hand, if the distance between them was too convenient, there was a risk of direct penetration of light. The results showed that the use of such a shading system in optimal conditions can greatly increase the efficiency of indoor daylight (Samadi et al., 2020).

In 2020, Rocha et al. presented a multi-criteria method for designing shading devices, in buildings. In a part of this study, they considered the use of daylight with DA, UDI, and Uav objectives. The study was conducted in an office room in Rio de Janeiro, Brazil, with a tropical and tropical climate. The design parameters including the depth of the louvers, the distance of the shading device from the building shell, and the height of the louvers were considered between 0.1 and 1.00 m and different solutions were investigated. According to the results, the final solutions do not obtain the best values for each design objective. However, they provide the best trade-off among the objectives according to the preferences of the decision-makers (de Almeida Rocha, Reynoso-Meza, Oliveira, & Mendes, 2020).

2.3. Software Simulation and Optimization

In recent years, ADO architectural design optimization study has increased relevance due to the integration of computing tools such as parametric design. Numerical simulation has also increased. Tools such as parametric design and numerical simulation have increased. The best type of design according to such performance criteria is an optimization issue. Using optimization methods for engineering and architectural problems, it is often difficult to formulate a mathematical optimization problem. This difficulty comes from two sources. Firstly, it is difficult to identify some optimization elements (or decision variables, goals, constraints); secondly, even when these elements are identifiable, they may be expressed in mathematical formulas (Wortmann & Nannicini, 2017).

The most common software used to evaluate daylight is Grasshopper based on 3D Grasshopper as a parametric modeling approach. Grasshopper is connected to several plugins to facilitate communication between different disciplines with a simulation approach. For example, for daylight simulation, Diva, Ladybug, and Honeybee are used as plugins to generate an air simulation and daylight analysis. These plugins connect to Grasshopper and are used as engines for Ecotect, Energy Plus, OpenStudio, Radiance, and Daysim. Therefore, using parametric design in daylight can improve building design performance, daylight, and energy saving in the early stages of design. The connection will be attractive by simulating the thermal performance of the building and visual comfort.

In the reviewed literature, external shading devices and their relationship with daylight in office buildings, the impact of different types of shading devices, especially vertical and horizontal, as well as the effect of shading device parameters on daylight, are presented. In general, the literature related to shading devices goes towards the evaluation of daylight performance in different climates, among which, most of the articles, analyze the effects of shading devices on natural light in a hot climate. In addition, the analysis of the effect of different shading devices on daylight, in office buildings in cold climates, has not been done so far. According to studies, it has been proven that daylight and visual comfort in cold weather is also very important for the well-being of building residents. Therefore, this study examines the effect of shading devices and their effective parameters on daylight with the aim of increasing DLA in an office environment in a cold climate. DLA is used for daylight annual measurement.

3. METHODOLOGY

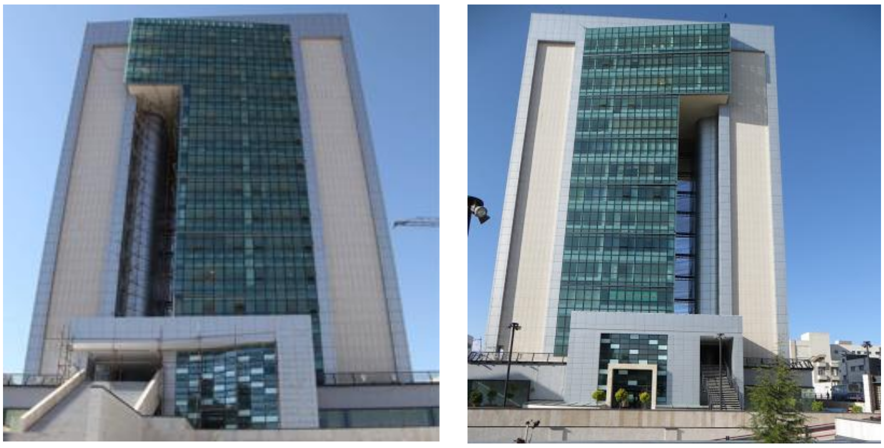
In this study, daylight autonomy simulation has been performed on the two northern and southern facades of Tabriz Abrisham Tower. The western and eastern facades can also be chosen for study, but according to the studies, the use of large building transparent facades requires the integration of shading systems for better light distribution. Therefore, because in this building, the north and south facades are transparent, only these two facades were studied.
A shading device, in both horizontal and vertical positions, is provided for the windows of these two facades. By considering the two variables of depth and distance for the shading device's units, the DLA inside the tower is examined. This study consists of three steps. The first step is parametric modeling in the Rhinoceros and Grasshopper environment. The second step is the daylight simulation that was done using the Honeybee and Hadybug plugins in Grasshopper, and finally, the third step is multi-objective optimization with the Octopus tool in Grasshopper to determine the optimal conditions.

3.1. Data Collection

3.1.1. Model

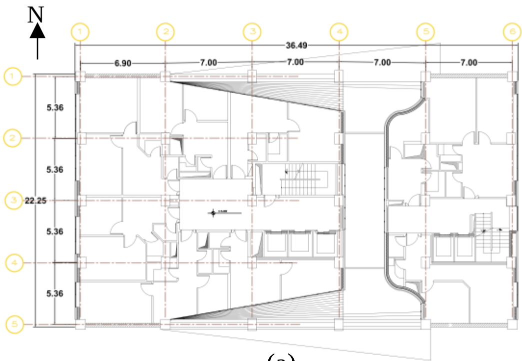
In this study, the Abrisham Tower, located in the city of Tabriz, Iran, with a geographical location of 38.0703°N and 46.3043°E, and with a cold and mountainous climate is considered. This building has a rectangular plan, with a length of 36.49 meters along the northeast-southwest direction and a width of 22.25 meters along the east-west. The images of this tower are shown in Figure 1. To simulate the north and south windows of the tower, each with a length of 3.84 m and a width of 13.87 m, is considered. In order to investigate the effects of external canopies, the present study used computer modeling techniques that have been widely promoted as a reliable tool for optimizing the building design process. However, for successful computer simulation of buildings, accurate and reasonable input data for buildings and weather is essential.

Tower plans on 18 floors were prepared and used for modeling. The tower was modeled in Rhinoceros software and Grasshopper plugin. Then, two floors with office use were considered for simulation as zones with a length of 36.49 m, a width of 22.25 m, and a height of 4.00 m, as is shown in Table 1. The plans of selected zones are shown in Figure 2 and the zones are shown in Figure 3.

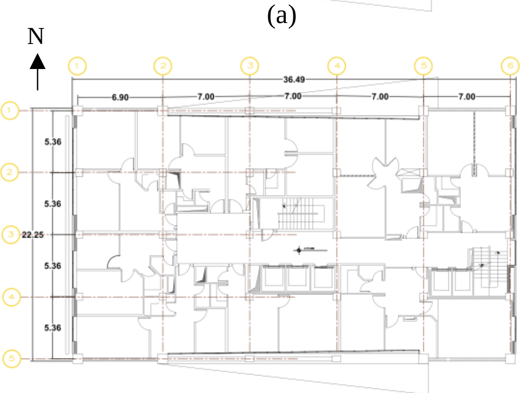


(a) (b)

Fig 1. North façade (a) South façade (b)



(a)



(b)

Fig 2. Plan of Zone 1 (a). Plan of Zone 2 (b)

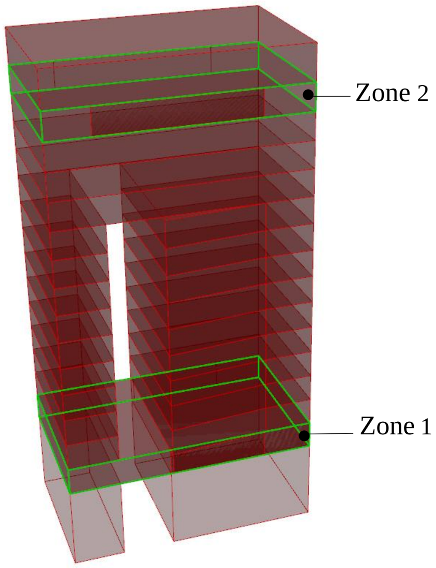


Fig 3. Base Model and Selected Zones

Table 1. Dimensions of the Selected Zones

Dimensions (m)	Zone 1	Zone 2
Length	36.49	36.49
Width	22.25	22.25
High	4.00	4.00

3.2. Simulation

Nowadays, a large number of simulation tools are available that have user-friendly environments. Using them, and after determining the parameters and goals involved, design teams can come up with new solutions that were not previously possible through the design of conventional models. A significant approach that can be used to increase building performance is known as “Parametric simulation model design”. Parametric tools have the potential to solve complex design formulas and are adapted to the specific needs of the user through algorithmic modeling (Shahbazi, Heydari, & Haghparast, 2019). In this research, Rhinoceros 3D graphics software and its Grasshopper plugin and the Honeybee and Ladybug tools were used to simulate daylight and control geometric parameters. The simulation process has been shown in Figure 4.

For simulation, zones 1 and 2 were considered input zones. Each zone was divided into 27 points and finally, 9 points were selected in the northern, middle, and southern positions of the region, as shown in Figure 5. Then, the daylight inside the tower in its existing state was tested through the north and south windows. Input data are shown in Table 2.

In the next step, the shading device with mirror glass material and RGB = 0.5 was implemented on the north and south windows. Louvers were considered in two horizontal and vertical positions with a depth of 5 and 15 cm and a distance of 1.5 and 2 cm from each other. The climate file of Tabriz (EPW) was extracted through the site www.energyplus.net/weather and connected to the daylight simulator. This file contains weather data used to run energy usage simulations. You can enter a specific location by entering the standard weather file downloaded online at: https://energyplus.net/weather. In this way, the simulation was done by the Radiance simulator engine. The simulation algorithm can be seen in Figure 6.

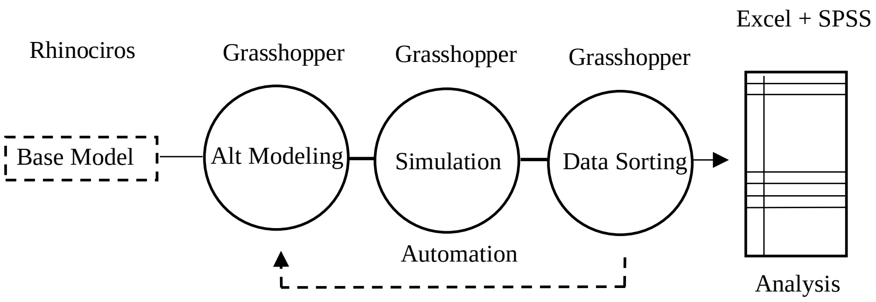


Fig 4. Simulation Process (Lee et al., 2017)

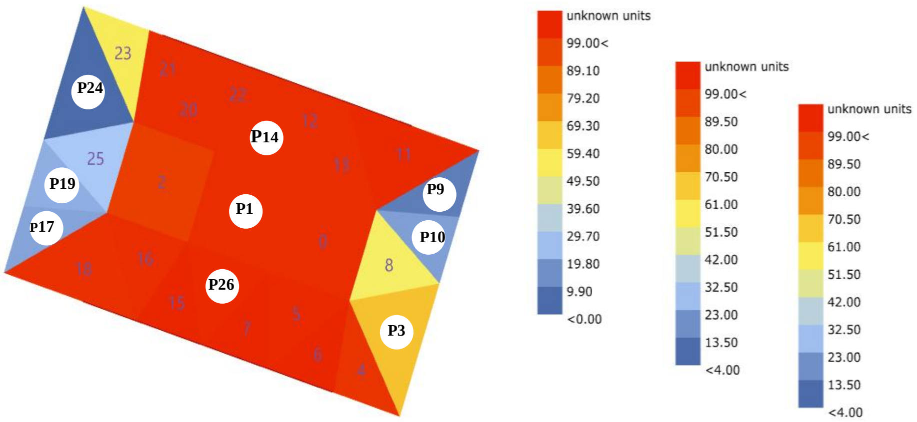


Fig 5. Simulation gride analysis and test points (including 27 general points and 9 selected points)

Table 2. Input Information

Location	Orientation	Area of each floor	Selected floors	Selected facades	Test points	Selected test point
Tabriz, Iran	Northeast-Northwest	811.9025m^2	2 Floors	North, South	0-26	3,10,9,26,1,14,17,19,24

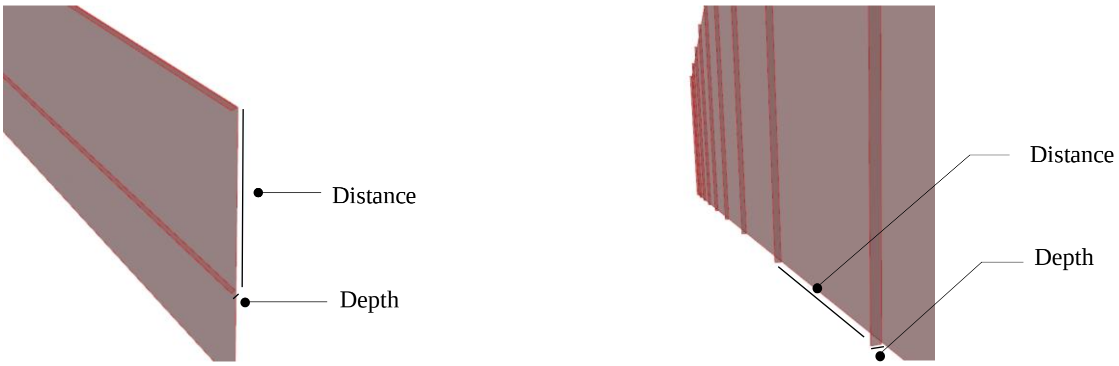
Natural light inside the space was tested in different modes including horizontal louvres with depth 5, distance 150 cm, horizontal louvres with depth 15, distance 150 cm, horizontal louvres with depth 5, distance 200 cm, horizontal louvres with depth 15, distance 200 cm, vertical louvers with depth 5, distance 150 cm, vertical louvers with depth 15, distance 150 cm, vertical louvers with depth 5, distance 200 cm and vertical louvres with depth 15, distance 200 cm. Table 3 shows examined modes.

3.3. Optimization

The Octopus plugin is a multi-objective simulation analysis tool. Octopus is available as a plugin for Grasshopper and users can apply evolutionary principles to optimize various functions through the graphical user interface (Octopus plugin; Available: http://www.foOptimized Design 4 Rhino. com/ app/ Octopus 2012). This plugin allows searching for many targets simultaneously and generating a wide range of optimized solutions (Octopus plugin; Available: https://www.food4rhino.com/en/app/octopus). In this study, the octopus was used to find the optimal values of the depth and distance of the louvers in the shade device. As shown in Figure 7, the DLA values are the target function for the octopus, and the depth and distance of the louvres on both the north and south sides are considered as variables.

Table 3. The Type, Depth, and Distance of the Tested Shading Devices

1. Horizontal louvers				2. Vertical louvers			
Mode1 (cm)	Mode2(cm)	Mode3(cm)	Mode4(cm)	Mode1(cm)	Mode2(cm)	Mode3(cm)	Mode4(cm)
Depth 5 Dis 200	Depth 15 Dis 200	Depth 5 Dis 150	Depth 15 Dis 200	Depth 5 Dis 200	Depth15 Dis200	Depth 5 Dis 150	Depth 15 Dis 200



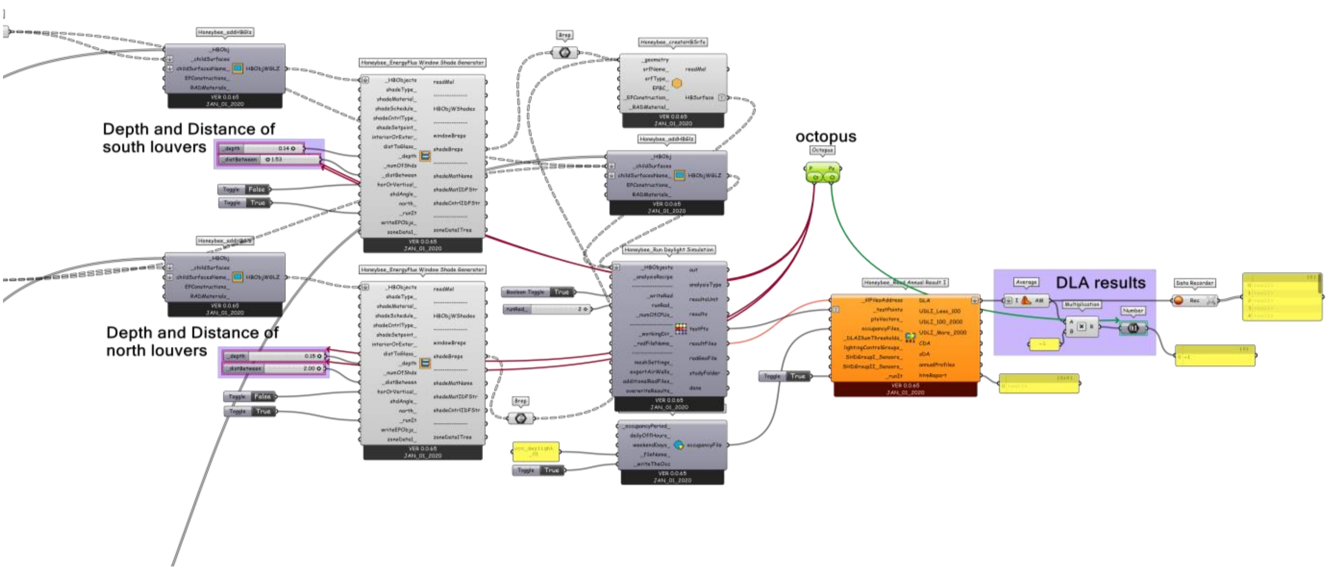


Fig 7. Optimization Algorithm

4. RESULTS

4.1. Descriptive Statistics

Daylight simulation results have been obtained first in the existing state of the building without a shader, then with horizontal and vertical shaders along with the defined parameters. Finally, the results and optimal values are presented. Table 4 shows the DLA values of the test points. According to this table, in the south view of zone 1, the maximum DLA value is 98% and the minimum DLA value is 18%. In the north view of the same zone, the maximum DLA value is 79% and the minimum DLA value is 3%. Similarly, in the south view of zone 2, the maximum DLA value is 98% and the minimum DLA value is 20%. In the north view of the same zone, the maximum DLA value is 79% and the minimum DLA value is 3%.

The simulation results after adding the shading device with horizontal louvres showed that, according to Table 5, in the first case (louvres with a depth of 5cm and a distance of 200cm), in the south facade of zone1, the maximum value of DLA is 98% and the minimum value is 0. In the north facade of the same zone, the maximum value of DLA is 96% and the minimum value is 0. In the south facade of zone 2, the maximum value of DLA is 98% and the minimum value is 18%. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is 4%. In the second case (louvres with a depth of 15cm and a distance of 200cm), in the south facade of zone 1, the maximum DLA value is 98% and the minimum value equal to 0 has been obtained. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is 0. In the south facade of zone 2, the maximum value of DLA is 98% and the minimum value is equal to 21%. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 3%. In the third case (louvres with a depth of 5cm and a distance of 150 cm), in the south facade of zone 1, the maximum value of DLA is 98% and the minimum value is equal to 0. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 0. In the south facade of zone 2, the maximum value of DLA is 98% and the minimum value is equal to 21%. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 3%. In the fourth case (louvres with a depth of 15cm and a distance of 150 cm), in the south facade of zone 1, the maximum value of DLA is 98% and the minimum value is equal to 0. In the north facade of the same zone, the maximum value of DLA is 96% and the minimum value is equal to 0. In the south facade of zone 2, the maximum value of DLA is 98% and the minimum value is equal to 21%. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 2%. The DLA values of each point after adding the shading device with vertical louvres can be seen in Table 6. According to this table, in the first case (louvres with a depth of 5cm and a distance of 200cm), in the south facade of zone 1, the maximum value of DLA is equal to 98% and its minimum value is 0. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 0. In the south facade of zone 2, the maximum value of DLA is equal to 98% and the minimum value is 91%. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 4%. In the second case (louvres with a depth of 15cm and a distance of 200 cm), the maximum DLA value of 98% and the minimum value equal to 0 have been obtained in the south facade of zone 1. In the north facade of the same zone, the maximum value of DLA is 96% and the minimum value is equal to 0. In the south facade of zone 2, the maximum value of DLA is 98% and the minimum value is equal to 20%. In the north facade of the same zone, the maximum value of DLA is 98% and the minimum value is equal to 4%. In the third case (louvres with a depth of 5 and a distance of 150 cm), in the south facade of zone 1, the maximum value of DLA is 98% and the minimum value is equal to 0. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 0. In the south facade of zone 2, the maximum value of DLA is 98% and the minimum value is 21%, and in the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 3%. In the fourth case (louvres with a depth of 15 and a distance of 150 cm), in the south facade of zone 1, the maximum value of DLA is 98% and the minimum value is equal to 0. In the north facade of the same zone, the maximum value of DLA is 96% and the minimum value is equal to 0. In the south facade of zone 2, the maximum value of DLA is 98% and the minimum value is 21%. In the north facade of the same zone, the maximum value of DLA is 97% and the minimum value is equal to 2%.

The results of optimization showed that, according to Table 7, the optimal cases of using the shading device in connection with daylight according to the location of the studied building and the climate of Tabriz city with the aim of increasing DLA are as follows:

In the north façade, there are horizontal louvres with a depth of 5 and a distance of 190 cm and vertical louvres with a depth of 15 cm and a distance of 200 cm. In the south façade, there are horizontal louvres with a depth of 13 and a distance of 161 cm and vertical louvres with a depth of 14 cm and a distance of 153 cm.

Table 4. DLA Results for Model without Shading Device

Examined case	Zone 1 Selected test points									Zone 2 Selected test points								
without shading device	P3	P10	P9	P26	P1	P14	P17	P19	P24	P3	P10	P9	P26	P1	P14	P17	P19	P24
DLA (%)	0	0	0	98	86	97	18	14	3	59	17	23	98	97	97	20	16	3

Table 5. DLA Results for Horizontal Louvers

Examined cases		Zone 1 Selected test points									Zone 2 Selected test points								
DLA (%)	Parameters &Values (cm)	P3	P10	P9	P26	P1	P14	P17	P19	P24	P3	P10	P9	P26	P1	P14	P17	P19	P24
	Depth: 5 Dis: 200	0	0	0	98	88	96	22	15	0	62	17	9	98	97	97	18	20	4
	Depth: 15 Dis: 200	0	0	0	98	86	97	18	18	3	56	17	16	98	97	97	21	27	3
	Depth: 5 Dis: 150	0	0	0	98	91	97	18	18	0	56	14	14	98	97	97	21	27	3
	Depth: 15 Dis: 150	0	0	0	98	88	96	18	14	0	62	19	7	98	97	97	21	18	2

Table 6. DLA Results for Vertical Louvers

Examined cases		Zone 1 Selected test points									Zone 2 Selected test points								
DLA (%)	Parameters & Values (cm)	P3	P10	P9	P26	P1	P14	P17	P19	P24	P3	P10	P9	P26	P1	P14	P17	P19	P24
	Depth: 5 Dis: 200	0	0	0	98	89	97	23	14	3	53	10	17	98	97	97	19	19	4
	Depth: 15 Dis: 200	0	0	0	98	88	96	20	16	2	57	10	9	98	97	97	20	23	4
	Depth: 5 Dis: 150	0	0	0	98	91	97	18	18	0	56	14	14	98	97	97	21	27	3
	Depth: 15 Dis: 150	0	0	0	98	88	96	18	14	0	62	19	7	98	97	97	21	18	2

Tables 7. DLA Results for Horizontal and Vertical Louvers with Optimal Depth and Distance

Examined cases			Zone 1 Selected test points									Zone 2 Selected test points								
DLA (%)	Type	Parameters &Values (cm)	P3	P10	P9	P26	P1	P14	P17	P19	P24	P3	P10	P9	P26	P1	P14	P17	P19	P24
	H North	Depth: 5 Dis: 190	0	0	0	98	91	97	20	15	0	0	0	1	99	73	97	24	22	5
	H South	Depth: 13 Dis: 190																		
	V North	Depth: 15 Dis: 200	53	18	11	98	97	97	20	23	5	50	17	9	100	94	98	31	23	6
	V South	Depth: 14 Dis: 153																		

4.3.2. Analytical Statistics

The results obtained from SPSS analysis are simple analysis through ANOVA by filtering the points between the floors and removing the shader-free mode as follows:

The climatic analysis compared to the averages show that there is a significant difference between the amount of light received in the northern and southern parts of the modeled building. So, the average income is 35 in the northern part and 49 in the southern part.

In this regard, we have Sig= 0.009, F = 6.90, DF = 238. The corresponding diagram is shown in Figure 8.

According to the analysis, it can be concluded that there is a significant difference between the amount of light received in Zone 1 and Zone 2. So, the total periodic average absorbed in Zone 1 in all its parts is 36, and in Zone 2 is equal to 48. Therefore, Sig=0.026, F=5.03. The corresponding diagram is shown in Figure 9.

In the relevant analysis, it could be found that the distance between the louvers does not have a significant effect on the amount of DLA light in general. That is sig> 0.05. In such a building, it seems that to increase the efficiency of natural light and to reduce the amount of light, at least according to the DLA criterion, applying the louvers, whether horizontally, vertically, and even with the depths and distances studied in this study, does not have a significant effect.

The results of the following file, called the repeated measure model, were obtained by filtering only the north and south louvers.

In t.test analysis, the difference between the north and south façades with horizontal and vertical louvers is significant when Grasshopper software and Octopus optimizer control depth and distance. In this case, the vertical louvers showed more light reduction, so in this case, the DLA in horizontal louvers is 41.73 and in vertical louvers is 43.43. The result of this analysis is as follows: Sig= 0.034, t= -2.24, DF = 23.

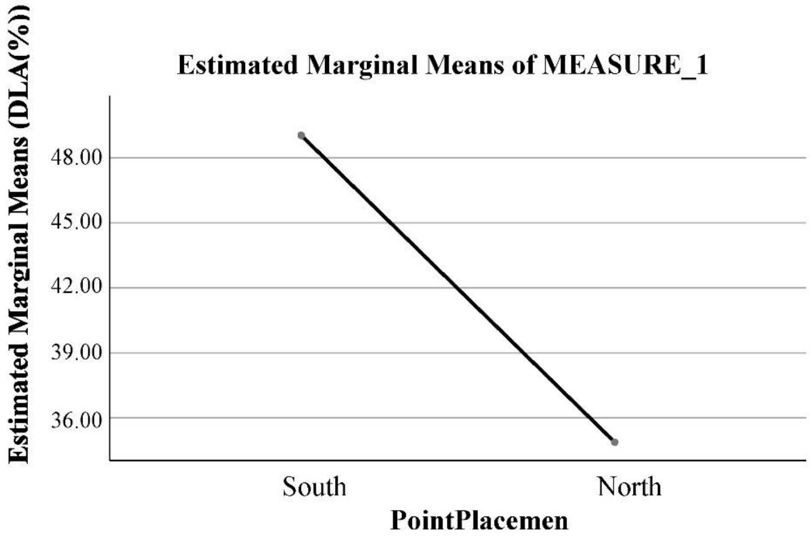


Fig 8. Diagram of Light Received in the Northern and Southern Parts

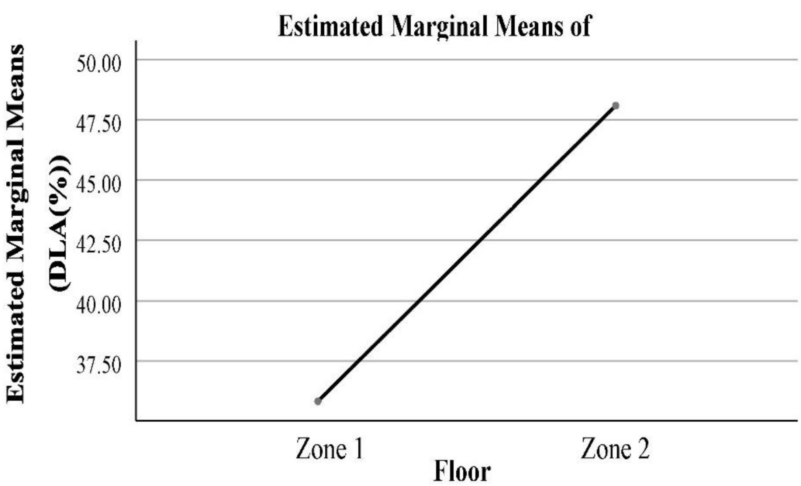


Fig 9. Diagram of the Analysis of the Amount of Light Received in Zones 1 and 2

The results of repeated measures of the previously mentioned filters were obtained in the following order: The effect of horizontal and vertical louvers was not significant, Sig.0.05. But the interactive effect of horizontal or vertical louvers on the floors, as well as in the north and south, was significant. Thus, in zone 1, horizontal louvers have a greater effect on reducing the amount of DLA, and in zone 2, vertical louvers have a greater decreasing effect and the entire interior space (Sig=0.007, F=9.73). The corresponding diagram is shown in Figure 10.

Examining the interactive effect of horizontal and vertical louvers on the north and south fronts of the software shows that the effect of reducing the amount of DLA in vertical canopies on the north side is more significant. However, the decreasing effect of horizontal louvers on the south side is more significant (sig=0.017/F=9.73). The corresponding diagram is shown in Figure 11.

The interactive effect of horizontal and vertical louvers on the interaction with depth shows an interesting, but meaningless result, statistically. Thus, according to the diagram in Figure 12, louvers with a depth of fewer than five centimeters, when used horizontally, have a greater effect on decreasing DLA. While louvers with a greater depth, as used in this study 15 cm, when used vertically, have a greater effect on decreasing DLA. In these conditions, due to the general trend and the number of samples, still no significant result was obtained.

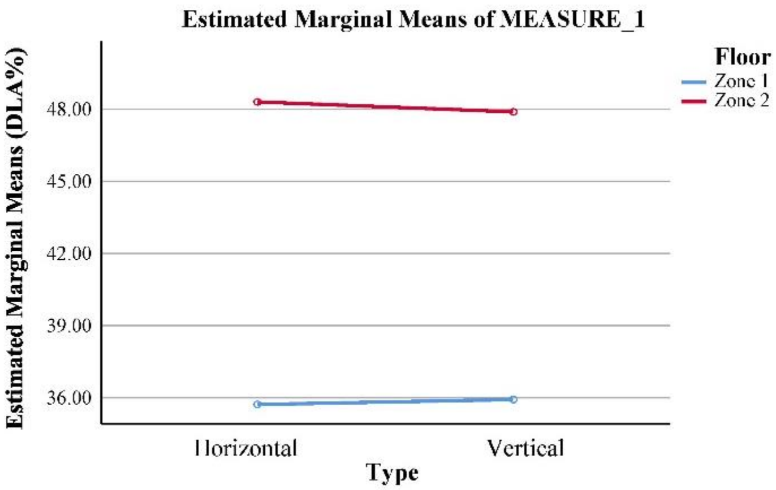


Fig 10. Diagram of the Interactive Effect of Horizontal or Vertical Louvers on the Interaction with Floors

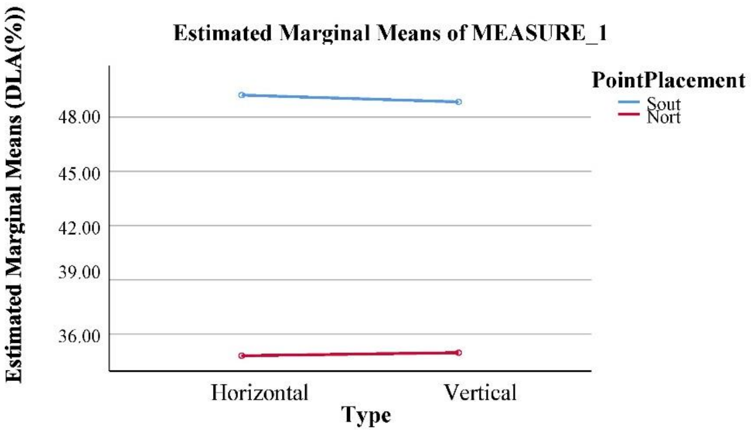


Fig 11. Diagram of the Interactive Effect of Horizontal or Vertical Louvers on the Interaction with North and South Facades

If only applying louver conditions is considered by filtering and the analyzed midpoints are removed from the test, it can be seen that the effect of distance alone is significant, so the amount of DLA in the interior space in the case of the distance between louvers is 200 cm, which is less than when the distance between the canopies is 150 cm. The corresponding diagram is shown in Figure 13.

But in this case, the analysis of the effect of depth alone did not show significance (Sig> 0.05).

The interactive effect of louvers depth and side in the north and south was significant. Applying this on the north side decreases with increasing depth in the interior space, while on the south side where the depth of the louver is 15 cm compared to the case where depth is 5 cm, the amount of internal DLA is higher. The corresponding diagram is shown in Figure 14.

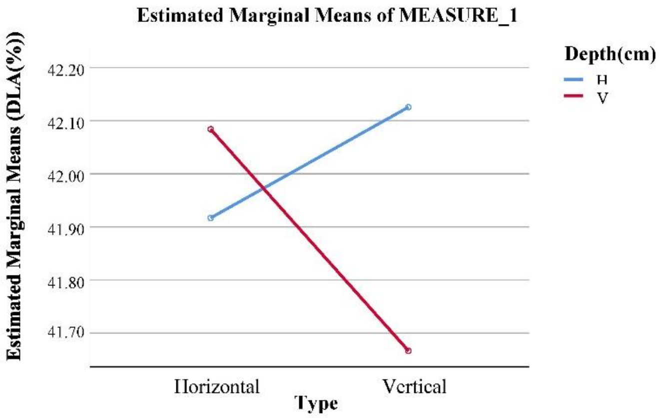


Fig 12. Diagram of the Interactive Effect of Horizontal or Vertical Louvers on the Interaction with Depth

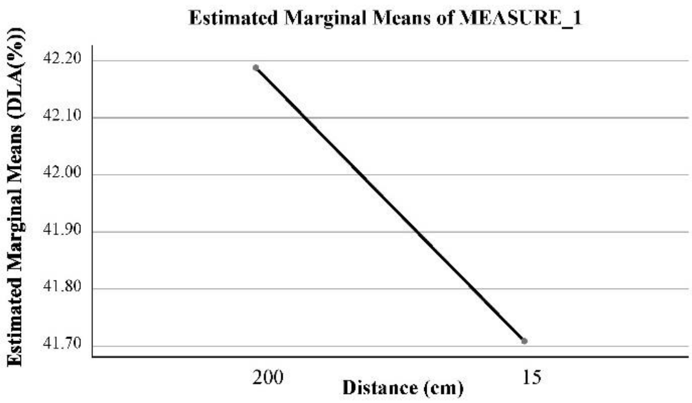


Fig 13. Diagram of the Effect of Distance on DLA

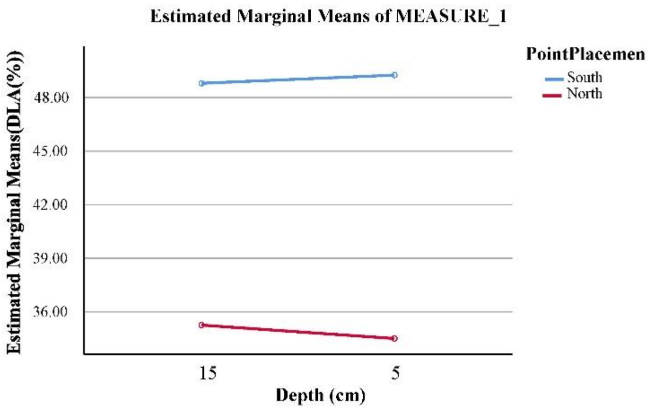


Fig 14. Diagram of the Interactive Effect of Depth on the Interaction with North and Facades

5. DISCUSSION AND CONCLUSION

According to studies, in a work environment, the least amount of light occurred in the horizontal position. Some also show that the most effective protection against direct sunlight entering indoors occurs horizontally, while the least protection is vertical. On the other hand, studies show that, with increasing depth, low light enters the interior space and vice versa. However, in horizontal and vertical louvers, this effect is not very serious. In the case of the distance parameter between the louvers units, the shorter the distance, the less light penetrates. On the other hand, if the distance is longer, there is a risk of direct light penetration. In this study, the effect of horizontal and vertical shading devices, the depth and distance of louvres on daylight with the aim of increasing DLA (daylight autonomy) were examined in Abrisham Tower in Tabriz, Iran. The type of shading devices, the depth of the louvres, and their distance from each other were considered as the investigated parameters. The depth of louvres was considered 5 and 15 cm and their distance was considered 150 and 200 cm. Modeling and simulation were performed in Rhinoceros and Grasshopper plugins. The Ladybug and HoneyBee plugins were used to simulate daylight. Eventually, the Octopus plugin was used for optimization. The results of this study show that, unlike other studies, vertical louvers caused more light reduction, while the DLA value of vertical louvers was 43.43 and this value was recorded for horizontal louvers at 41.73. The results also show that in zone 1, the DLA of horizontal louvers is reduced and in zone 2, the DLA of vertical louvers is reduced. Similarly, on the north side, DLA decreases in vertical louvers, and on the south side in horizontal louvers. Louvers with less depth are more effective in reducing DLA when used horizontally, while deeper louvers are more effective in reducing DLA when used vertically. In addition, the amount of DLA is less if the distance between the units is greater than when the distance between the louvers is less. The optimal modes of shade devices with the aim of increasing DLA, according to the checked climate are as follows:

- In the north facade are horizontal louvres with a depth of 5 and a distance of 190 cm and vertical louvres with a depth of 15 cm and a distance of 200 cm.
- In the south facade are horizontal louvres with a depth of 13 and a distance of 161 cm and vertical louvres with a depth of 14 cm and a distance of 153 cm.

Generally, it can be concluded that making decisions about louvers in the climate of Tabriz city, according to its characteristics, would not be modified and is not easy to comment on.

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AUTHOR (S) BIOSKETCHES

F. Ahmad Nejad., *Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran*
Email: *f.ahmadnejad@tabriziau.ac.ir*

Y. Shahbazi., *Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran*
Email: *y.shahbazi@tabriziau.ac.ir*

M. Mokhtari Kashavar., *Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran*
Email: *mo.mokhtari@tabriziau.ac.ir*

M. Zendeh Laleh., *Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran*
Email: *ma.zendeh@tabriziau.ac.ir*

S. Hossein Pour., *Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran*
Email: *sa.hosseinpour@tabriziau.ac.ir*

N. Khalili Khou., *Faculty of Architecture and Urbanism, Tabriz Islamic Art University, Tabriz, Iran*
Email: *neda.khalilikhoo@gmail.com*

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