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## ORIGINAL RESEARCH PAPER

### Explaining the buildings' façade based on meta-heuristic method optimization in the use of daylight, the-state-of-the-art

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#### ABSTRACT

In recent decades, scholars have proposed using daylight in buildings as one of the main aspects of design due to the necessity of energy consumption decrease and also the positive physical and mental influence of natural light on users. Using ordinary glasses in buildings causes energy wastage and thereby increases energy consumption and cost. Consequently, it is necessary to use the appropriate types of glass and windows to reduce energy consumption and not prevent daylight from entering the building. Therefore, comprehensive and extensive attention to the compatibility of the architectural design of façade systems and current advancements in computational tools for understanding specifications of such systems and parametric tools, genetic process (GAs), and building Performance Simulation (BPS) that help designers, are necessary. Hence, In the present study, an attempt has been made to explain recent developments and existing gaps of knowledge with a comprehensive study of research literature.

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## INTRODUCTION

The façade which is the first side of the building encounters the outdoor environment and sunlight and plays a fundamental role in using daylight for providing natural illuminance. In recent decades, scholars have proposed using daylight in buildings as one of the main aspects of design due to the necessity of energy consumption decrease and also the positive physical and mental influence of natural light on users. Also, lots of researches have been done about the influence of daylight on mental and visual comfort, thereby increasing productivity and also decreasing energy consumption indicating the importance of attention to daylight and supplying illuminance needs using natural light. Hence, according to the necessity of common literature in any scientific field for better recognition and understanding of the relation dominant in façade structure of buildings and improving use of light, deep and extended studies have been done in books and researches and theses that according to its importance and history of mentioned subject, some influential resources should be reviewed. To comprehensively review the research conducted on understanding the relationships between building facade forms and optimizing daylight usage. So the main question is what metaheuristic optimization methods are used in defining the facade forms of libraries for maximizing daylight utilization?

## MATERIALS AND METHODS

### *Methodology*

This research is fundamental in nature and descriptive based on data collection. The information has been gathered through library studies utilizing reputable scientific articles to review and examine previous research processes and their results in a specific specialized field. In this research, existing results and data from previous articles have been compiled and systematically presented cohesively and comprehensively. Review studies provide readers with an overview of the collective research conducted in a particular field and its results, and aim to interpret these findings in accessible language for the audience.

### *Theoretical Foundation and Background*

To achieve a precise understanding of the topic, an initial review of studies related to the research subject has been conducted, including aspects such as: (daylight, orientation, geometric impact, optimization, and simulation software).

### *Daylight*

Interest in discussion and use of light after the oil crisis started in 1970 and again declined in the years 1980-1990. Ultimately, today, the endeavor to create buildings that are bright with sunlight has been increased by designers and architects (Boubekri and Boyer, 1974). Based on Robbin's theory (Robbin, 1986), the role of light from two qualitative and quantitative aspects has been attended in Islamic culture and Western culture for a long time. In Western culture, attendance to light in architecture has been very important and in the modern age, effective use of light in illuminance of building internal space for a specific and appropriate goal has replaced random or unwanted presence of light through openings (Philips, 2004). Until the early 19th century, when electricity became available easily, daylight was a common tool in designing buildings (Araji, 2008). Using sunlight to create light in internal spaces of life back to before the cavemen age (Beliveau and Olbina, 2009). Consequently, natural light has been used by architects in the Middle East thousands of years ago, and alternatively, Greeks and Romans embedded yards in buildings to bring natural light into internal spaces. In Islamic architecture, due to beliefs and faith in a supernatural universe, light plays a spiritual role in Islamic architecture works and indeed, was recognized as the expositor of the superior world and incarnation of holiness and spiritual universe. From conventional schools' viewpoints, existence's origin is light; without color or pure light, is the territory and pure presence of God itself that there's no doubt about it. Currently, from the most applicable international criteria for evaluating daylight dynamism, the following cases can be mentioned: Daylight Autonomy (DA), Useful Daylight Illuminance (UDI), Special Useful Daylight Illumi-

nance (sUDI), Special Daylight Autonomy (sDA), Continuous Daylight Autonomy (cDA), Annual Sunlight Exposure (ASE), Glare (Mangkuto et al, 2018; Acosta et al., 2019; Campano et al., 2022; Erlendsson, 2014; Fang, 2017; Hu et al., 2023; IESNA, 2013; Mardaljevic et al., 2012; Pilechiha et al., 2020; Konis and Selkowitz, 2017; Wymelenberg, 2012). Also, two types of criteria determine the favorable size and ratio for receiving daylight that are: window-to-floor ratio (WFR) and window-to-wall ratio (WWR) (Tregenza and Wilson, 2013). Both two factors are used by various regulations of building design (Wang et al., 2009). However, regulations related to WFR have been introduced and set in Iran (Vaisi and Kharvari, 2019). This subject is considered in research (Vaisi and Kharvari, 2019) and obtained results show an optimum scope for WFR that controls glare radiation and also excessive warmth and at the same time considers how shape and size of opening influences daylight factor (DF), average and uniformity (Vaisi and Kharvari, 2019). Nedhal et al. (2016) in their research, considered the relation of WFR and daylight level by percent (DF). In this research, determining the minimal WFR for illuminance goals and its maximum for preventing excessive bright spaces was put on the agenda. According to research results, there is a direct strong relationship between WFR and natural illuminance levels (by percent) (Nedhal et al., 2016). Also, in Iran, some general researches have been done in the field of light mostly in spaces of offices, schools, and urban environments that compared to researches performed in foreign countries are very limited. From these researches, ones performed by Mofidi and PoorNaseri (2006) and Mohammadi et al. (2020) on daylight of schools and daylight useful illuminance, can be mentioned. Also, other researches have been performed by Schregle et al. (2015) and Mcleod et al. (2019) in relation to daylight autonomy and daylight useful illuminance using sensitivity analytical method in classroom space in Tehran. In this paper, daylight indicators' capability for use in evaluating daylight in window-to-wall

area ratio (WWR) in a classroom model of a magnet primary school in Tehran city has been compared by parametric analysis method.

#### *Daylight Directivity*

Directivity is from important factor in designing buildings for the use of daylight and saving energy. A building with appropriate directivity maximizes receipt of light through the building façade and decreases the need for artificial light. This solution is an inactive strategy that should be considered in designing buildings, particularly for office use. This case was considered by Mahdavi et al (2015) as a research subject. In this process, a new indicator (SAZ) has been introduced that evaluates daylight factor (DF) and absolute lux factor. This research shows that the form and size of the same openings on various sides (directivity), causes the consumption of variable energy (decrease or increase) for supplying artificial illuminance and cooling loads (Mahdavi et al, 2015; Shi and Yang, 2013). Kaminska (2020) has considered and studied access to daylight in the internal space of a classroom depending on building directivity and the potential for saving energy (Kaminska, 2020). Heng et al. (2020) in their research has found that economic advantages have caused fluorescence of designing deep open plans followed by daylight non-steady distribution, especially in deep sections, and light tubes are recognized as a solution for delivering daylight to deep sections of building (Heng et al., 2020).

#### *The Impact of Room Geometry on Daylight Reception*

Rubies et al (2018) considered the effect of the geometry of room and window on the receipt of daylight in a classroom and its influence on energy consumption. In this evaluation, considered geometries had an opening-to-floor ratio of 8-12 percent. Daylight analysis that has been done by evaluating daylight factor (DF) and daylight autonomy (DA) shows that the geometry of the room and window has a significant influence on maximizing receipt of daylight (Rubies et al, 2018). Fela et al. (2019) evaluated daylight performance based on climate in an

office. Considered cases in this study have been different opening-to-wall ratios (10 %, 30 %, 50%, 70%), different directivity (east, north, south, and west), and fixed positions of opening in the wall (wall center). In this regard, daylight criteria including daylight factor (DF), spatial daylight autonomy (sDA), spatial useful daylight illuminance (sUDI), daylight glare probability (DGPs), and annual illuminance energy demand have been evaluated as simulation results (Fela et al, 2019). In research by Freewan et al. (2020), the influence of advanced technologies of daylight like a light roof, anidolic systems<sup>1</sup>, light roofs combined with external reflectors, and cases like this on daylight performance and visual environment in university classes have been considered. Aforementioned technologies have been evaluated for studying indicators of illuminance level, uniformity, and saving in energy in an intended environment (Freewan et al., 2020). Considering the influence of the geometry of internal space and opening on daylight performance for university terrace classes has been done by Jia and colleagues. Daylight spatial autonomy (sDA<sub>300</sub>, 50%) and useful daylight illuminance (UDI<sub>100-2000</sub>) have been selected as indicators for evaluating daylight performance. According to the obtained results, the window-to-floor ratio (WFR), height of the terrace classroom (H<sub>tc</sub>), the height of the window (H<sub>w</sub>), window-to-wall ratio (WWR), the width of the terrace classroom (W<sub>tc</sub>), and width of the window (W<sub>w</sub>) have positive effects in improving classroom daylight autonomy and influence degree will decrease respectively (Jia et al, 2023). Farivar and Teimourdash (2023) have studied the effect of opening design on daylight dynamic performance in office buildings in their research, the aforementioned design includes various forms and positions for opening. Accord-

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1. Anidolic systems were developed following the principles of non-imaging optics and take advantage of these properties to achieve outstanding features for daylight collection and re-distribution (Scartezzini & Courret, 2002)

ing to the obtained results, the form and position of the opening have significant influence on daylight dynamic performance for increasing visual comfort (Farivar and Teimourdash, 2023).

Shadings can decrease glare by controlling excessive daylight in buildings and improve residents' visual comfort. However, they may largely decrease the level of illuminance. Shading strategies for shading are very accessible, but it is difficult to select the most appropriate case traditionally. In this regard, Wen et al (2023) have proposed a parametric method for selecting and designing a shading strategy that decreases glare by keeping an effective daylight level by developing a Pareto collection based on a multi-purpose genetic algorithm (Wen et al, 2023). Kilic in 2011, has considered the positive effect of daylight in library spaces on individuals' perception and satisfaction using questionnaire method and also the effect of shading on users' visual comfort through field measurements of illuminance distribution in space (Kilic, 2011). Few years later, in a paper, Yu et al. have expressed that the efficiency of daylight and the use of electrical energy depends on important factors like room geometry, window-to-wall ratio, surfaces reflection, and external barriers. The purpose of this study is a quantitative analysis of daylight annual energy storage capacity in an educational building in Nottingham using Relox software and field measurements (Yu et al., 2014). Yao in 2014, has used multi-purpose optimization processes to consider the effect of use of various shading strategies on thermal and visual comfort using simulation-based analyses (Yau, 2014).

#### *Optimization of Daylight Performance*

In research related to the parametric optimization of daylight, energy, and heat performance of school classrooms performed by Lakhdari et al (2021), different window-to-wall ratios, wall material, types of glass, and shadings were combined to achieve appropriate thermal balance. Results indicate that improvement of daylight-appropriate illuminance, matching

thermal comfort, and energy efficiency can be achieved through reforming building coverage parameters (Lakhdari et al., 2021). Through increasing awareness towards building energy productivity, internal environment quality for human comfort, and work efficiency, endeavors for creating intelligent components of buildings have been intensified (Nasroulah zade, 2021). Sun et al. (2021) have taken the first step in developing a multi-effect intelligent window system. The results of this research can be a guide for the next step in designing and developing materials that tries to balance energy productivity and solar and daylight control by using thermotropic materials (Sun et al, 2021). Using ordinary glasses in buildings causes energy wastage and thereby increases energy consumption and cost. Units of triple-glazed glass, compared to one and double-glazed complexes, attenuate the increase of solar heat transfer, thereby, decrease the cost of air conditioning and greenhouse gas emission. Light, energy, economic, and environmental performance of a unit of glass are intensively dependent on each other. This subject has been considered in research performed by Gorantla et al (2021). This research aims to propose and define an efficient triple-glazed glass unit for decreasing costs related to thermal loads in buildings and experimental test of spectrum performance of reflexive glasses and evaluating thermal loss/profit. In this regard, reflexive glasses with various colors have been studied and evaluated (Gorantla et al, 2021). Alhagla et al (2019) has presented a paper aimed at decreasing energy consumption by creating a balance between useful natural light and excessive solar heat thereby decreasing energy consumption and providing an easy guide for architects in order to help increase building stable design. In this investigation, the focus was on various types of glass so that appropriate performance criteria for transparent systems in buildings could be evaluated (Alhagla et al, 2019). Using optimization processes in the field of engineering back to the 1980s that wasn't prevailed until the first

years of the current century among scholars of architecture and building branch (Barkhume, 2007). Since then, a lot of researchers have done many studies in the field of simulating and optimizing daylight in different parts of the world. Briefly, the following cases can be mentioned as the most important ones: Ochoa in a parametric analysis uses multi-purpose optimization methods in line with optimizing window-to-wall ratio in office building façade in Amsterdam city that this work was done by simulating daylight and energy and with energy plus simulation engine (Ochoa, 2012).

Wortman in 2017 implemented a method for multi-purpose optimization in order to consider maximum productivity of daylight and decrease glare (Wortman, 2017). On the other hand, Yi in 2019, utilized a multi-purpose optimization method in order to implement a way for achieving beauty aspects as qualitative performance and visual comfort as quantitative performance (Yi, 2019). Nadiri et al. have performed a study aimed at providing optimization foundations for office building façade in Tehran relying on the view toward the outside as the only indicator of radiation exposure (Nadiri, 2019). In another research, Kheiri considered the performance structure of two different optimization methods of genetic and cooling simulation process on the façade of an office room for daylight performance that just indicators of exposure to annual radiation and daylight autonomy can be used to evaluate these two different optimization processes (Kheiri, 2019). Nerup Rant performed a project in 2019 in which genetic optimization processes in combination with the parametric design of building façade and optimizing light systems were used to create various atmospheres (Nerup, 2019).

#### *Software Aided Daylight Analyzing*

Some theoreticians have used simulation software like Ladybug, Diva, Revit, Green Building Studio, Ladybug Tools, and ...to evaluate light and the amount of its influence on various factors, decrease energy consumption and daylight

illuminance, identifying illuminance indicators (UDI and DA), improving use of daylight. Koohsari et al. (2016), Toutou et al. (2018), Fang and Cho (2019), Sun et al. (2020), Kharvari (2020), Sandberg (2020), Balint and Tran (2021), Piraei et al. (2022), Xue and Lin (2022), Tong (2023), Ma et al. (2023), Dimara et al. (2023) have used old version of Ladybug software to simulate factors and achieve goals of decreasing energy consumption, daylight illuminance, energy consumption intensity, daylight factor average, illuminance evaluation, glare, thermal comfort. Also, Gonzalez and Fiorito (2015) have used Diva simulation software, Dong et al. (2021) used Revit simulation and Green Building Studio software, Dong et al. (2022) used Ecotect software and pioneers including Fercha et al. (2023), Saleem et al. (2023), Chen et al. (2023), Liu et al. (2023) have utilized Ladybug Tools to simulate factors. According to what can be perceived from researches, it becomes clear that one of the most applicable tools in simulating daylight are Ladybug and HunniBee in old, plus, and new versions that it is more discussed in the form of Table 1. This plugin in the new version just uses radiance engine for analyzing daylight that because of defining sky status at any moment of a year according to climate data can have a dynamic simulation of daylight. Also, Gentile et al (2022) tested a new simulation work process that uses computational fluid dynamics (CFD) for simulating outside temperature and environment comfort (it is appropriate for the initial stages of designing a building) and compared obtained results with real data and data resulted from simulation with ENVI-met software. Results indicate that in predicting temperature with Ladybug tools with error limits of 7, 3-5, 8 percent, there is high accuracy. Kharvari (2020) in his research sought to consider the influence of radiance parameters and components related to mode on the accuracy of simulation results in radiance by comparing simulation results and field measurements. This consideration has utilized a point-to-point illuminance comparison of

simulation results and field measurement under an overcast sky with measured illuminance intensity in HunniBee V.0.04 which uses radiance V 5. Simulation accuracy has been investigated for three different heights by considering an overcast sky. Furthermore, simulation parameters and model settings can influence model accuracy. Results indicate that the settings recommended by software for radiance parameters are accurate enough.

Hessari and Seyf Shojaei (2021) focus on reducing energy consumption in the building sector, particularly in educational spaces in Torbat Heydarieh city, a region with a cold and dry climate. The study evaluates the local climate, comfort conditions, energy reduction criteria, and architectural design standards. Using Ecotect and Radiance software, each space's location is analyzed based on its use and the amount of solar energy it receives. The building's form is modeled in Revit software, and energy consumption is measured in each mode using DesignBuilder software. The lighting in each space is then controlled again using Ecotect and Radiance software. Finally, the plan's accuracy is confirmed based on the National Building Regulations of Iran using Mabna software. The study aims to design buildings that are energy-efficient and climate-compatible (Hessari and Seyf Shojaei, 2021). Elmkhah and Eiraji (2022) examine the impact of dynamic smart shades on the amount of sufficient light supply and the possibility of glare in a classroom. The study 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 (Elmkhah and Eiraji, 2022). Beykaei, Mozaffari Ghadikolaei and Abdollah Ebrahimi (2023) discuss the use of control systems in buildings such as light shelves, which protect residents from direct sunlight and maximize daylight penetration into buildings based on preferences (Beykaei, Mozaffari Ghadikolaei and Abdollah Ebrahimi, 2023). Freidooni, Freidooni

and Gandomkar (2023) discuss the significant impact of climate on urban planning, especially in the context of future cities. The study aims to identify key climatic factors that should be considered to reduce non-renewable energy consumption and ensure climate compatibility. The results indicate that temperature and solar radiation are the most influential factors. Key factors include altitude, latitude, and radiation direction. High-risk factors include radiation duration, time-dependent fluctuations, sky cover and sunshine hours, and precipitation. Dependent factors include atmospheric specifications, relative humidity fluctuations, heat

gain, glacial days, and horizontal pressure gradient. Solar radiation fluctuations were identified as an independent factor (Freidooni, Freidooni and Gandomkar, 2023).

In research by Futrell et al in 2015, using simulation of daylight and its application in architectural spaces by DAYSIM and Energy Plus software, the results indicate that when daylight is utilized as a supplement for artificial illuminance in space, it has the capability of saving energy (Futrell et al., 2015).

A summary of related articles and near topic of this thesis published in recent 10 years are brought in Table 2:

**Table 1:** Considering software and goals of performed researches related to daylight

Author's name	Year	Research variables	Goals	Software
Koohsari, A. M et al.	2015	Window-to-wall ratio, window height	Energy consumption and daylight illuminance	Old version Ladybug
González, J., and Fiorito, F	2015	Shading parameters	Energy consumption and illuminance indicators (UDI and DA)	Diva
Koohsari, A. M et al.	2016	Window size and shading dimension	Energy consumption decreases and improvement of daylight utilization	Old version Ladybug
Toutou, A, et al.	2018	Window-to-wall ratio, materials of transparent and un-transparent walls, shading	Energy consumption and daylight illuminance	Old version Ladybug
Fang, Y., and Cho, S	2019	Building depth, ceiling middle-line position, roof depth and width, and height and light	Energy consumption and daylight useful illuminance (UDI)	Old version Ladybug
Sun, C, et al.	2020	Height and depth of roof light, walls material, type of window, and related characteristics	Energy consumption, UDI and sDA light indicators, and cost of building skin	Old version Ladybug
Kharvari, F	2020	Comparing measured data by simulation	Daylight illuminance	Old version Ladybug and Ladybug Plus
Sandberg, M. H. M	2020	Window-to-wall ratio, glass heat transfer coefficient, solar heat gain coefficient, heat transfer coefficient, and materials of skin	Energy consumption intensity and daylight factor average	Old version Ladybug
Dong, Y, et al.	2021	Model length and width, window dimensions	Light indicators of DA and UDI and energy consumption intensity	Revit and Green Building Studio
Bálint Palmgren, O., and Tran, D. T	2021	Internal reflection of walls and furniture, height above the window, Oucapenci Kingston benchmark (OKB) of window	Energy consumption and considering light indicators (DA, sDA, UDI, and ...)	Ladybug Tools
Piraei, F, et al.	2022	Comparing measured results and real values for considering a model	Light indicators (sDA, DF, ASE)	Climate Studio and the old version of Ladybug

Author's name	Year	Research variables	Goals	Software
Dong, L., et al.	2022	Shape, number, the slope of the ceiling, and amount of light-well percent	Daylight illuminance	Ecotect
Xue, Y., and Liu, W	2022	Atrium glass specification, amount of light-well percent, wall and ceiling reflection	Daylight illuminance (sDA, DGP)	Old version Ladybug
Tong, W	2023	Inactive strategies	Evaluating illuminance, glazing status, thermal comfort, and energy consumption	Old version Ladybug and Ladybug Plus
Fercha, N. et al.	2023	Shading reflection, percent of light pass of window, shading type, light shelf internal depth, distance of shading to window, angles of shadings rotation	Light indicators of sDA and ASE	Ladybug Tools
Saleem, K, et al.	2023	Window-to-wall ratio, number of louvers	Light indicators of UDI, sDA, and ASE	Ladybug Plus
Ma, Q, et al.	2023	Number and angles of louvers	Energy consumption and daylight illuminance	Old version Ladybug
Chen, Z, et al.	2023	Specifications related to atriums	Energy consumption intensity and daylight useful illuminance	Ladybug Tools
Liu, Y, et al.	2023	Shading parameters	Light and thermal comfort	Ladybug Tools

Table 2: A summary of papers related to and near to the subject of thesis in recent 10 years

Theoretician	Paper title	Publication	Goal (question)	Research method	Used tool	Variable	Studied indicators	result
Kaymaz et al.	A Lighting Proposal for A Library Project in Terms of Energy Efficiency	Second Balkan Junior Conference on Lighting (Balkan Light Junior)	Achieving conditions of visual comfort with energy consumption reduction in the university library	Considering quantitative aspects of daylight through simulation of case sample	Computer simulation programs including DIALux 8.0 Design-Builder 6.1	Shading for the southwest façade of the library building	Illuminance, uniformity ratio of illuminance, applicable unified Glare Rating limit	External fixed shading on the southwest façade decreases building consumption energy by as much as 8.5%
Thangaraj and Balaji	A study on the influences of lighting on resource usage in an institution library	IJRET	Evaluating light in the library in order to understand how the library influences using various resources.	Considering both quantitative and qualitative aspects of light through providing questionnaires of users of case sample	Lux meter questionnaire	Place individuals sit to study - duration of presence in the library in different time intervals - the existence of light in the work table in different time intervals - emergence of glare through windows in different time intervals	Illuminance Glare	65% of users agreed on optimized light in the library

Theoretician	Paper title	Publication	Goal (question)	Research method	Used tool	Variable	Studied indicators	result
Buhari and Alibaba	Analysis Of Daylighting Quality In Institutional Libraries	International Journal of Electrical and Electronics Research	Using daylight design to improve visual comfort, energy efficiency, and thermal comfort in the library	Considering quantitative aspects of daylight through simulating case sample	Computer simulation programs RELUX	- just daylight - daylight and artificial light	DF Luminance Glare index	- The daylight quality on the second floor of the library is inappropriate and low. - preference of users for the existence of daylight in the building according to interview results
Keshin et al. (2017)	Daylight And Seating Preference In Open-Plan Library Spaces	International Journal of Sustainable Lighting 34	Considering daylight relation with selection of sitting places in studying saloons of library	Comparison between observation of users' behavior of space and simulation results (quantitative measurement of residents' behavior)	DAYSIM within Autodesk Ecotect Analysis	Different places for sitting of users of library saloon	DF DA UDI	- users more tend to sit near a window - this tendency also exists at night when there's no daylight indicates no relation between daylight and the selection of a place for sitting
Kurniasih et al. (2019)	Daylight Intensity of Reading Room with Shading Device's Opening	Advances in Engineering Research	Finding a solution for designing a shading system that decreases the amount of glare problem for achieving visual comfort	Quantitative research method with an experimental approach	Computer simulation programs DiaLux Evo 8.1	-experimental variables (visual comfort, windows directivity, shading system design) - non-experimental variables (direct light resource, sky conditions, and direct glaring radiation)	Intensity of natural lighting (lx)  DF	Finding the best design of shading system for windows that can decrease light intensity
Saraiva et al. (2019)	Daylight Modelling of a Portuguese Baroque Library	Conference Proceedings of iiSBE Forum of Young Researchers in Sustainable Building	Studying daylight conditions inside the library to prevent continuous destruction of the heritage of historical buildings because of direct radiation of sunlight	Light simulation in a quantitative manner on the case sample of a historical building	Light simulation engine Radiance	Building a three-dimensional model, including surfaces specifications, climate file, and network of sensor points receiving light	illuminance maps (lux)	Results show that natural light is a threat to more heritages and should decrease.

Theoretician	Paper title	Publication	Goal (question)	Research method	Used tool	Variable	Studied indicators	result
Dabaj et al. (2022)	Impact of Different Shading Devices on Daylight Performance and Visual Comfort of A Four Opening Sides' Reading Room In Rasht	Journal of Daylighting	Comparing four types of shading systems on all sides of a saloon with this question which shading can control glare and improve the use of daylight	Library studies, simulation, and optimization	HunniBee plugin Simulation engine of Dynamism/Radiance	Types of shadings on four sides of a building	DA UDI DGP QV	Netted pages on windows aren't efficient in preventing glare, but have efficiency in annual criteria of daylight and vision quality. Types of lowered curtains are effective in eliminating glare
Othman and Mazli (2012)	Influences of Daylighting Satisfaction at Raja Tun Uda Public Library, Shah Alam	Elsevier (AicE-Bs 2012 Cairo)	Considering daylight in the library and finding how daylight in the library influences the satisfaction and comfort of users.	Quantitative research method using a questionnaire of library users	Questionnaire Photometer	A place where individuals sit in a library studying saloon	Visual Comfort Illuminance intensity (lux)	Daylight influences individuals' comfort in a library. There is a strong relationship between daylight and the place that individuals select for sitting
Aram and Alibaba (2018)	Investigation of the effects of daylight in a university library	Journal of Architectural and Planning Research	Considering daylight effect in a university library, including the amount of solar use in internal places for studying and glaring direct radiation exists in these spaces. Also, comparing qualitative results with analysis of simulated model	Quantitative research method using simulation of case sample and quantitative research method using a collection of questionnaires of students who use study space	Simulation software – Ecotect Questionnaire	Place of individuals' position and window and window type	Solar radiation Glare Daylight intensity	More users prefer natural light (65%) to artificial light (45%), mainly because natural light has more positive influence on users.
Wijayanti et al. (2020)	Lighting System Energy Conservation Simulation at Faculty of Engineering Diponegoro University Library Using Ecotect	IOP Conference Series: Earth and Environmental Science	Identifying the amount of light in study saloon and comparing it with standards and decrease of using artificial light with optimized use of day natural light	Quantitative research method including field measurement of case sample light and software simulation	Ecotect simulation software	Use/no use of daylight / artificial illuminance	Illuminance intensity (lux)	- illuminance intensity of artificial light in library room is beyond existing standards - room natural light cannot supply sufficient light needs in a room

Theoretician	Paper title	Publication	Goal (question)	Research method	Used tool	Variable	Studied indicators	result
Omar et al. (2018)	Optimization of daylight utilization in energy-saving application in the library in the faculty of Architecture, Design and Built Environment, Beirut Arab University	Elsevier (Alexandria Engineering Journal)	Determining appropriate method for decreasing dependency on artificial light in hours of day illuminance as an endeavor to decrease energy consumption and increase using daylight	Quantitative research method with simulation of case sample	Ecotect simulation software	Types of various skies and their influence on the amount of illuminance level resulting from daylight	Illuminance intensity (lux)	Appropriate and controlled utilization of daylight with effective illuminance technologies can decrease energy consumption for electrical illuminance by up to 33 percent a day
Wijaya et al. (2019)	Optimization of Natural and Artificial Lighting System Design in the Library of the Faculty of Economics and Business, Universitas Gadjah Mada	6th IEEE International Conference on Engineering Technologies and Applied Sciences (ICETAS)	Finding a scenario of an illumination system with optimized efficiency including daylight and artificial light in a library for achieving optimized visual performance with low energy consumption	Qualitative research method with simulation of case sample model	DIALux Evo 8.1	Simulating space based on two scenarios of day-artificial light and just artificial light	Power (W/m <sup>2</sup> ) Illuminance intensity (lux)	Natural light can brighten 32 percent of the whole area of the library so the library can be classified based on illuminance energy as a green building
Handina et al. (2016)	Prediction of Daylight Availability in a Large Hall with Multiple Facades Using Computer Simulation and Subjective Perception	Elsevier (Engineering Physics International Conference, EPIC)	The purpose of this study is to investigate the daylight of the study saloon in some façade and various directions. For having daylight in that space, daylight is predicted by computer simulation. The purpose is to find criteria of daylight accessibility that have the most correlation with the subjective perception of bright areas in a day.	Simulating daylight by providing a questionnaire of students using a library saloon.	Lux meter Dynamism questionnaire	Information about building model and students' opinions about the extent of daylight in library space	daylight autonomy (DA), daylight factor (DF), useful daylight illuminance (UDI), illuminance(lux)	DA300lx, 50 percent, compared to other criteria of daylight, to predict accessibility of daylight, especially the area of bright half in studied space, is more appropriate. A DF of 2% can be used for predicting minimum daylight area.

Theoretician	Paper title	Publication	Goal (question)	Research method	Used tool	Variable	Studied indicators	result
Dianagri1 et al. (2020)	Simulation of Natural Daylighting Optimization in College Library	ICETIA 2020	Improving daylight-appropriate performance using simulation tools as the main method for analyzing current conditions of case sample and evaluating design proposals for improving conditions of using daylight	Library studies and daylight simulation of studied case sample	DIALuxEvo simulation software	- directivity of windows front - light shelf - external shading	Illuminance (lux)	Among all the proposed options, a recommendation for adding five other windows on the north walls, installing light shelves with a width of 0.8 meters, and decreasing the depth of external shading of a window to 0.25 meters is the most effective way to optimize daylight performance in the library
Zomordian et al. (2016)	The effect of window configuration on daylight performance in classrooms: A field and simulation study	Int. J. Architect. Eng. Urban Plan	Introducing different configurations for daylight in the classroom and useful criteria of daylight through reviewing literature and second, evaluating daylight performance of various configurations of windows using ranking tools of green building	Library studies and considering standards and numerical simulation of daylight of case sample	Design-Builder Radiance simulation	Various configurations of a window like window-to-wall ratio, light shelves, ceiling light	Uniformity ratio (UI), daylight factor (DF), illuminance(lux)	by increasing window to wall ratio to 35, 40, and 50 percent and by installing ceiling light, daylight scores of BREEAM and LEED can be achieved respectively.
Shahraki et al. (2021)	Evaluating quality and quantity of light in study saloons and presenting modifying solutions	Safeh	Evaluating the performance of natural illuminance in libraries of Shahid Beheshti University and comparing them with standards determining weak points and ultimately presenting and prioritizing modifying solutions using field studies and simulation	Field perception and consideration of case samples Simulation and modeling	Taking photo Photometer Brightness assessor Daylight simulation with Rhino Diva Radiance	- using light shelf - changing the reflection coefficient of wall and ceiling - ceiling light - changing glasses' light coefficient - using shading	Possibility of daylight glare (DGP) Daylight autonomy (UDI) Light influence depth Minimum and maximum light	Finding solutions effective in using daylight in 7 various libraries using effective solutions in each one

## **DISCUSSION AND FINDINGS**

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### *Modeling Methods*

#### *Modeling methods for thermal simulation and daylight*

Using computers for predicting thermal behavior, energy and daylight of buildings isn't a new subject. Since the early 1980s, numerous approaches and programs have been developed, improved, and used for simulating building energy by designers and scholars in architectural, engineering, and construction society (Nabil and Mardaljevic, 2006). Predicting the performance of energy of the whole building and daylight depends on several factors including environment climate conditions, sky condition, building physical conditions, performance of building systems like illuminance and heat, ventilation and air conditioning, and conditions of occupation and behavior of residents in building (Mangkuto et al., 2021). Three modeling approaches consider the challenges of simulating thermal performance, energy, and daylight of buildings:

#### *Physical Modeling Methods*

These methods which are also known as white box models, predict the thermal behavior and daylight of buildings by following and modeling physical principles and laws. About simulating building daylight, follow the principle of conservation of energy by balancing light currents from one point to other surfaces. White box models need a description of all specifications of the building. Furthermore, although the phenomena of heat transfer have been known well, their computational implementation in an efficient method is difficult. Therefore, in modeling white box, using some modeling assumptions in order to estimate physical phenomena for computational ease is common (Mardaljevic et al., 2013).

#### *Statistical Modeling Methods*

These models are also called black box models because they don't attend to any physical principle, law, or even information. These models use machine learning (ML) techniques to induce

a prediction performance of measured data samples. The advantage of these methods is that they can predict building physical behavior with low information or no information about building geometry, materials, or physical phenomena. The weak point is that they need a lot of measured data and use of them in cases where collecting data is difficult will be limited. Therefore, the exclusive use of statistical modeling methods in designing new buildings isn't practical. Combining these methods with random optimization meta-heuristic methods like genetic processes (GA) is also possible (Pilechiha et al., 2020).

#### *Combined Modeling Methods*

These models are also called gray box. These approaches combine models of black-and-white box. The purpose of gray box models is overcoming the limitations of both white and black boxes. Gray box models can keep a part of physical meaning, therefore facilitating interpretation, and don't need a complete description of physical and geometrical input parameters (Li et al., 2020).

#### *Illuminance Simulation*

Computer-based computation illuminance simulation aims at predicting illuminance status in a building in specific conditions of daylight. At first, some programs were created to help designers determine light settings for example DIALux and Relux. Other programs have been developed to simulate daylight distribution inside the room and the difference between specular and dispersed reflection - is shown in Figure 1 (Leder et al., 2016). There are four common processes for simulating light: direct calculation, radiosity, ray tracing, and photon mapping.

#### *Daylight Simulation*

A survey performed by Rinhart and Fitter (2009) about the current use of daylight simulation in designing buildings, approved this matter that 69% of professional designers use software to analyze natural light in buildings. However, dynamic daylight simulations (DDS) need a three-dimensional computer-based model that includes

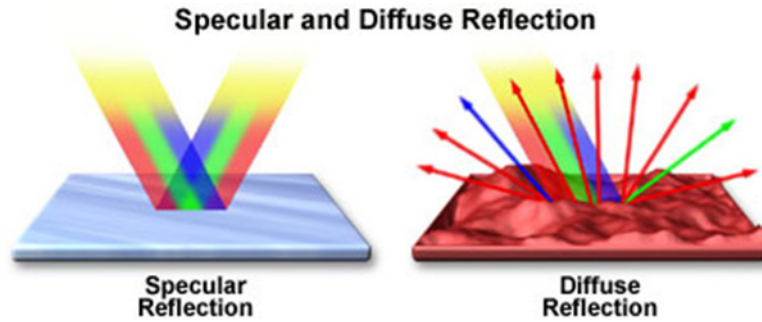


Figure 1: Difference between specular and disturbed reflections (Leder et al., 2016)

data about building geometry, its site, reflection, and transfer specifications of materials surfaces. Building daylight simulation requires a description of a scene that includes three fundamental elements: (1) the three-dimensional geometry of the building and medium for simulation, (2) light specifications of materials for all surfaces in the scene, (3) a sky model that makes share of direct and disturbed components of daylight emitted from sky hemisphere, quantitative (Tur- rin, 2011). Also, radiance which is an advanced simulation program for analyzing the color and brightness of buildings is used. For the first time, radiance was published in Lawrence Berkeley National Laboratory (LBL) in California with the fundamental support of the USA energy ministry and Switzerland Federal government as the first independent tool for analyzing daylight. Radiance is a simulation engine which means it includes a series of command-line programs that perform different stages of simulation. This

method uses a backward tracing method for analyzing mutual reflections between opaque and specular surfaces (Konis and Selkowitz, 2017).

#### Climate-Based Daylight Modelling

One of the most important inputs of simulation for modeling climate-based daylight is data related to climate. To describe the illuminance medium where the building is located correctly, some measurements should be performed on the building site.

The success of climate-based daylight modeling can be attributed to the following cases (Hong et al., 2000):

- 1) Real regeneration of sky brightness distributions based on real data of the outdoor environment of an intended place.
- 2) Increasing calculation efficiency using the daylight coefficient method instead of continuous descriptions of the sky.
- 3) A strong and accurate illuminance engine like Radiance.

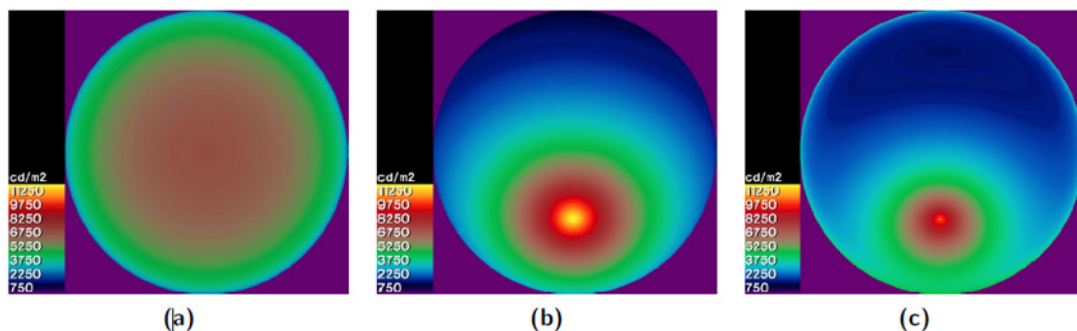


Figure 2: (a) Overcast sky, (b) median sky, (c) clear sky. (Futrell et al., 2015).

### *3.4.1. Sky Models*

First and the simplest sky model, was a model with uniform brightness entitled Lambert that was used to determine the sky coefficient (observable part of the sky from internal space). Also, if the purpose is simulating sky real conditions, but direct measurement of sky brightness isn't possible, sky illuminance distribution models should be used (Hu et al., 2020). Sky models usually are shown as numerical performances of height and solar azimuth (side angle) on the sky hemisphere. Also, using this method is a common practice of planning for ranking energy by the Australia Green Building Council and later, Moon and Spence introduced gradient brightness distribution that currently is used to determine daylight coefficient (DF) that is known as overcast sky. In 1955, their formula has been defined as a standard overcast sky by CIE (Futrell et al., 2015). These three models all have been accepted as CIE standard skies, are shown in Figure 2 has been resulted from the Radiance Gensky program.

#### *Daylight Coefficient*

Introducing the daylight coefficient causes a significant increase in the efficiency of daylight simulation tools. This method has been proposed by Tregenza and Waters (1983) and is based on this concept that the relation between internal and external illuminance is directly proportionate to the built-form factor that is assumed to be constant. The daylight coefficient method (DC) in the early 1990s was used for computational purposes but excessively relied on analytic and geometrical computations. Using illuminance simulation engines was limited to internal calculation reflection and mainly to the radiosity method. However, a combination of raytracing and radioactivity techniques was proposed for complex illuminance systems in which the former could calculate optic reflections and refraction and later could calculate dimensional mutual reflections in space. The role of raytracing engines, especially radiance, became more prominent in the next years (Delgarm et al., 2016).

#### *Complex Fenestration Systems*

To supply the strictest saving requirements in energy consumption, building façade design tended towards matching systems that can respond variable climate conditions and residents' comfort needs (Gherri, 2015). Elements and shadings are an essential part of any façade that provide useful natural light for internal spaces and the possibility of a view towards outside and because of this become more complex and various. These methods include 1) the four-component method (sun direct light, sun indirect light, sky direct light, sly indirect light) and, 2) the DAYSIM method (nearest neighbor, interpolated, shadow test, two-phase method, three-phase method, five-phase method, four-phase, and six-phase methods). Recently, three- and five-phase methods have been added to radiance techniques to be used when there is an external shading system that is not on the same level as the main window. It should be mentioned that although the four-phase method and four-component methods have similar names but they are very different in terms of practice and application.

## **RESULT AND CONCLUSION**

Light phenomenon in general and daylight in particular, is counted as the most fundamental physical and mental need of humans. This factor provides more desirable and enjoyable conditions for individuals due to the creation of connection and familiarity feeling with the natural environment, and hence, can cause the creation of comfort on one hand and an increase of efficiency on the other hand. Lighting with daylight is a process beyond the creation of appropriate conditions for seeing objects. This process has special emotional qualities that can clearly influence individuals' moods. Daylight has a key role in thermal and visual comfort and also in creating a stable environment. Opening size, shape, and dimensions of a related room are three main components that influence the quality and quantity of daylight (Vaisi and Kharvari, 2019). South façade among four main directions, in countries

inside the northern hemisphere like Iran, provide the most desirable daylight for residents (Wang, Gwilliam and Jones, 2009). Throughout history, designers have effectively used solar shading systems and changing light direction for controlling sunlight inside buildings to improve indicators of daylight performance like daylight distribution and influence depth, and also prevent the increase of excessive heat and prevent glaring radiation. The influence of shading systems on energy consumption has been studied extensively. Focusing on the influence of these systems on cooling loads and other studies showed that shadow can decrease the cooling load of buildings effectively. Furthermore, during the last decades, the influence of shadings on daylight has been attended as a tool for decreasing artificial light. All these cases obtained from various studies show that from the past to today, theoreticians have considered window-to-floor ratio (WFR) and window-to-wall ratio (façade) to evaluate the amount of light receipt (Tregenza and Wilson, 2013; Wang et al., 2009; Vaisi and Kharvari, 2019). Also, directivity is from important factors in designing buildings to use daylight and save energy for this, a new indicator named SAZ was introduced to be used for evaluating daylight factor (DF) and absolute lux (Mahdavi et al., 2015; Kaminska, 2020). Rubies et al. (2018) have used the influence of window and room geometry on daylight and its influence on energy consumption. Fela et al. (2019) evaluated climate-based daylight performance. In another research, the focus was on types of glasses to evaluate appropriate performance criteria for transparent systems in buildings and achieve a balance between useful natural light and excessive solar heat by focusing on various types of glass to prevent glare and also decrease received warmth (Alhagla et al., 2019). Heng et al. (2020) considered economic advantages in the direction of designing deep open plans that were followed by non-uniform distribution of daylight especially in deep sections. Freewan and Al Dalala (2020) have considered the influence of advanced technologies like a light roof,

and anidolic systems with external reflectors on daylight performance and visual environment. Lakhrdari et al. (2021) have utilized various window-to-wall ratios, wall materials, types of glasses, and shadings to achieve thermal balance and improve illuminance. Sun et al. (2021) used a multi-effect intelligent window system in the direction of the balance of energy efficiency and solar control and daylight through using thermotropic materials. Jia et al. (2023) investigated the influence of the geometry of internal space and opening on daylight performance. The influence of opening design on dynamic daylight performance in buildings was considered by Farivar and Teimourtash (2023). Considering the influence of shadings through controlling excessive daylight inside buildings can decrease glare and improve residents' comfort (Wen et al., 2023). Multi-purpose optimization processes have been utilized to consider the influence of using various shading strategies on thermal comfort using simulation-based analyses for maximum utilization of daylight, decrease of glare, achieving beauty aspects as qualitative performance, and optimizing daylight system for creating various spatial atmospheres (Mofidi, 2006; Yao, 2014; Mohammadi and Mofidi and Tahbaz, 2020; Wortmann, 2017; Yi, 2019; Ochoa, 2012). Based on studies performed from 2015 to 2023, it can be found that simulation software like Ladybug, Diva, Revit and Green Building Studio, Ladybug Tools, etc. have been used to consider the amount of received light, identify illuminance indicators (UDI and DA) and improve daylight utilization, energy consumption intensity, daylight factor average, illuminance evaluation, glare, thermal comfort (Gonzales and Fiorito, 2015; Oohsari et al, 2016; Toutou et al., 2018; Fang and Cho, 2019; Sun et al., 2020; Kharvari, 2020; Sandberg, 2020; Balint and Tran, 2021; Dong et al., 2021; Piraei et al., 2022; Xue and Liu, 2022; Dong et al., 2022; Lopez and Kabza, 2022; Tong, 2023; Ma et al., 2023; Fercha et al., 2023; Saleem et al., 2023; Chen et al., 2023; Liu et al., 2023). Fonseca (2013) has considered daylight and its application in architectural

spaces using simulation by DAYSIM and Energy Plus software. Based on what past studies show, these tools were valid ones and international simulation engines have been used. Hence, validation of these tools is pre-approved and many papers at national and international levels have been registered by this tool indicates its reliability. Also, all these systems need very low cost and maintenance. However, if they aren't designed correctly and optimally, they cannot respond to variable environmental conditions to keep residents' satisfaction during the year. Therefore, exploration of the progress of computational methods in designing façade systems should be the starting point for any successful design and its dominant role in the initial stages of design, to achieve initial goals for effective day illuminance like supplying sufficient daylight in spaces and monitor glaring radiation and solar radiation for minimizing energy consumption should be studied more than before.

Based on the obtained results, it can be found that in Iran, generally lower researches, compared to researches performed in foreign countries, have been done in the field of daylight most of which are inside spaces of offices, schools, and urban environments. Investigations show that most of those researches are related to the influence of (opening) windows and parameters related to daylight in internal space. But, in particular, for future research, only parameters related to windows aren't investigated, and we can seek to consider parameters related to building façade in line with improving daylight. Therefore, comprehensive and extensive attention to the compatibility of the architectural design of façade systems and current advancements in computational tools for understanding specifications of such systems and parametric tools, genetic process (GAs), and building Performance Simulation (BPS) that help designers, are necessary; and, by awareness about defects of previous models, trying for more complete simulation in order to achieve desirable results in designing buildings' façade for meta-heuristic optimization in using daylight, is important.

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