

Daylight optimization and energy retrofit by using proportionate automated louvers in home-based offices (case study: a house in Tehran, Iran)

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ABSTRACT

Many businesses ceased working physically during the current pandemic and started working remotely. Therefore, launching home-based offices has now become popular among people ever before. One type of place where people are currently working is home-based offices. However, these residential places are not as standard as they are supposed to be. While working at their homes, workers consume more artificial lighting than natural lighting compared to normal conditions (their workplace). Thus, his research aims to study daylight and energy optimization used in home-based offices to achieve maximum natural light during working hours. This optimization works based on auto-extract-window-to-wall and automatic louvers for windows. The suggested research method for this study is the "Genetic Algorithm" to optimize the proportion, which can be achieved by using a special parametric algorithm in Grasshopper. The paper concludes that optimization can be conceived as a creative modeling method for increasing natural light and reducing energy consumption in home-based offices. The results of this study validate that with the use of optimization used for louvers, shelves, and other mentioned elements, spatial daylight autonomy have the potential to be increased up to 25%. The annual sunlight exposure can also be reduced up to 10%. This will lead to a reduction in artificial lighting consumption. This type of optimization

develops the agenda of optimizing "daylight and energy retrofit."

Keywords: Daylight, Retrofit, Genetic Algorithm, Home-based Office, Automated Louvers, Optimization.

NOMENCLATURE

Abbreviations	
sDA ¹	Spatial Daylight Autonomy
ASE ²	Annual Sunlight Exposure
MOGA	Multi-Objective Genetic Algorithm

1. INTRODUCTION

Having a plethora of energy-saving advantages, paying attention to natural lighting (in architecture) can bring economic benefits related to temperature control. In order to find energy-efficient approaches for minimizing the effects of climate change, different assessment tools have been developed (Papargyropoulou et al., 2012). Daylight is a significant issue in designing a green building. The benefits of incorporating appropriate natural lighting for visual comfort and energy efficiency are undeniable (Ihm et al., 2009). Avoiding shading or misusing it over windows can cause overheating, which increases the load exerted on the cooling system and additional glares, especially in

¹ The percentage of a space gained enough daylight annually, for at least half of its operating hours.

² The percentage of a space gained direct sunlight with a level of illuminance causing visual discomfort. This level is considered 1000 lux for at least 250 hours of yearly operating hours.

warm climates. Nevertheless, incorporating daylighting systems in designing a building's windows utilizes the sun as a renewable source of energy, lessens energy consumption, and facilitates the development of green, sustainable, and productive buildings (Kischkoweit-Lopin, 2002).

Incorporating daylight in residential and administrative spaces requires different lighting intensity and capacity. In that regard, maximizing daylight in administrative spaces is of much interest. After the Coronavirus outbreak, many businesses closed their offices and started working remotely. Thus, home-based offices were further developed. These spaces had been designed based on the amount of lighting required for residential purposes. And consequently, they needed to be remodeled based on factors such as window to the wall surface ratio, the proportion of shelves, an angle, and the number of louvers. This research recommends a collection of integrated lighting systems for open plan home offices located in Tehran to achieve optimal energy performance and visual aesthetics in administrative buildings.

The purpose of this research is the retrofit of residential buildings, which, due to the recent changes caused by the Coronavirus outbreak, converted into home-based offices. This retrofit is confined to the addition of shelves and louvers targeting utilizing maximum available daylight. The attachment of these elements neither requires the change in the physical structure of the space nor necessitates renovation while it provides users with the most optimal daylight possible. Thus, the innovation of this research is the application of some changes in the shading and adding flexible structures to the building's façade. Offering accurate calculations and not requiring any major reconstruction, this innovative approach increases the amount of penetrated natural light by some alterations.

2. PAPER STRUCTURE

2.1 Daylight in a home-based office

Many studies have been conducted in the scope of energy-consumption optimization, and residential spaces retrofit with daylighting orientation, one of which is Reinhart's studies. Reinhart takes daylighting as part of the process of designing a building aiming to provide optimal natural light without the glare while maintaining high levels of visual comfort and the least amount of energy requirement for temperature control. Renovated administrative offices with open plans typically have the capacity to gain natural light (Reinhart & Wienold, 2011).

In other studies carried out by Goia and Partners, the optimization of three residential buildings was analyzed with respect to the correlation between daylighting and energy consumption. In Gioia's research, these three buildings' facades were the core of their study. The outcomes of the general consideration in this Goia's research demonstrate the necessity of 34% to 45% more transparency for their façades for gaining enough daylight (Goia et al., 2013). In other research cases conducted by Qingsong, windows' optimization in an administrative space was examined to optimize natural light and minimize energy consumption by adjusting the ratio of windows' surfaces to walls (Qingsong & Fukuda, 2016). In another model, also created by Mahdavejad, with the intention of lighting's optimization done for a day in the year, the Regression model indicates the influence of structural transformation on the reception of natural light (Mahdavejad et al., 2012). The literature review suggests that despite abundant research regarding natural lighting and its optimization, especially in home-based offices, the spread of which is relatively a new phenomenon, there are still some aspects not considered. In reference to identified problems, the question of this research can be defined as "how can the efficiency of choosing natural lighting systems in home-based offices be improved?"

2.2 Multi-Objective Optimization

Computational simulation is used extensively in daylighting selection and design. The accurate measurement of criteria (especially ones related to daylighting) requires time-consuming calculations, which preclude designers from using the latest techniques (Dogan et al., 2012). Researchers have invented innovative approaches to strike the right balance between calculation time length and simulation accuracy. Some advanced techniques like Neural Networks are suggested to predict natural light in order to solve this problem (Hu & Olbina, 2011). From the second half of the 2000s, optimization procedures have been widely applied in the field of sustainable design (Vermeulen et al., 2018). Results of building optimization programs are used as fitness functions (Shi et al., 2017). The purpose of optimization in multi-objective issues is minimizing or maximizing fitness. The main drawback of this method is that fitness weight is not easily assessable.

Furthermore, depending on the configuration of an optimization issue, the Pareto optimization system might have several optimal solutions which are easily found.

This system can have tens of solutions. In order to simplify the group of optimal solutions, Pareto is usually studied in 2D spaces(Suga et al., 2010). Therefore, we use Optimization Genetic Algorithm Pareto-front to find correct economical solutions in every project.

2.3 Material and methods

Studies have shown that residents prefer spaces with windows. (Veitch & Canada, 2014) Residents also express more positive feelings while working closer to windows(Yildirim et al., 2007). Daylight is more desirable for residents in comparison to artificial light(Galasiu & Reinhart, 2008). Modern administrative buildings seek to utilize natural lighting in order to improve the quality of lighting and decrease energy consumption(Kim et al., 2016). The proportionate use of glass surfaces in administrative buildings is highly debated among the facility management industry, real estate, and construction sectors(Cai & Marmot, 2013). This research aims to achieve a special ASE and SDA optimization model in home-based offices free from complex calculations. Thus, with this model, designers will be able to reach an optimal decision in the first steps of the design process and maximize users' visual comfort in home-based offices by incorporating details, dimensions, and the project site in the proposed daylight system available for the building. Figure 1 illustrates a daylight optimization model of a north-facing wall of a home-based office which is analyzed using factors such as louvers, shelves, and the window to wall surface ratio.

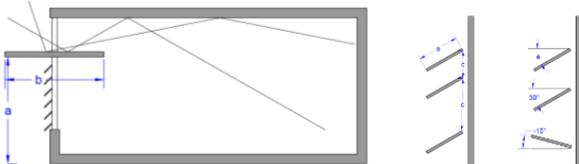


Fig. 1. Combined optical shelf system with Louvre

In this research, a 7*7 home-based office located in Tehran is chosen. Tehran was selected for the study because many large corporations have been shut down ever since the COVID-19 pandemic, and consequently, employees started working remotely. This change of workplaces caused lighting-related problems. There is no compatibility between required lighting and the initial lighting of the primary function of these places. Thus, in order to create compatibility in a home-based office and adjust the amount of natural light, we applied minimal changes to the northern window. Furthermore, due to the purpose of optimization, the research variables used

in the analysis benefited from MOGA optimization algorithms.

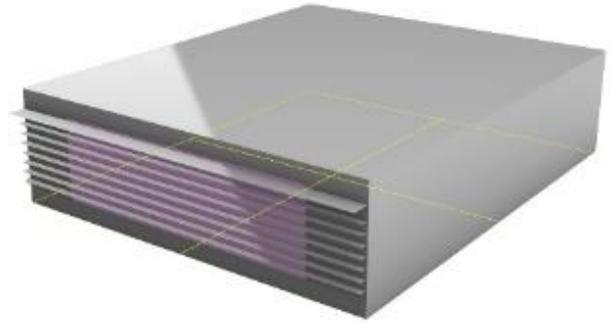


Fig. 2. Schematic form of the studied administrative space (simulated model based variables)

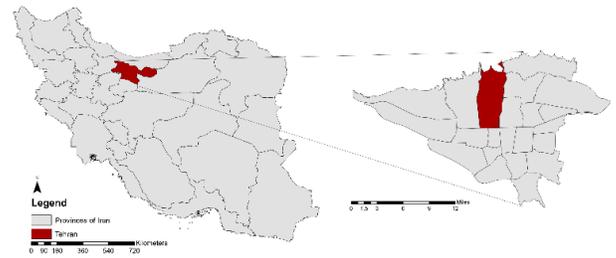


Fig. 3. Location site in Tehran, Iran,

Thus, to create compatibility in a home-based office and regulate the amount of natural light, we applied the least possible adjustments to the northern window. Furthermore, due to the purpose of optimization, the research variables used in the analysis benefited from MOGA optimization algorithms. Specifically, as shown in Table 1, the Pareto method of MOGA has been deployed in optimizing variables. At the same time, assigned coefficients for window/wall surfaces ratio and glass refraction ranged between 0.4 to 1 and 0.5 to 1, respectively. Specifically, as shown in chart 1, the Pareto method was deployed to optimize variables while the window to wall ratio and refractive index for the glass were restricted between 0.4 to 1 and 0.5 to 1, respectively.

Table 1. Variables in the compound system of Light shelves and louvers

categories parameters	Variable parameters	Range of changes	Variable distribution type
horizontal	number	4-8	Discrete
louvers	width	0.1-0.4	Continuous
external	angle	0°- 90°	Discrete with a single-degree pace
	Refraction coefficient	0.4-1	
Light shelves	Distance from floor	0-2	Discrete with a 10 centimeter pace

length	0.8 - 2	Discrete with a 10 centimeter pace
Reflective index	0.1 - 0.9	

2.4 Theory/calculation

There is no reliable computation for analyzing the sunshine quality and its effect on human vision in current conventional design methodologies(Galiasu & Reinhart, 2008). However, empirical data indicate that high levels of natural light penetration and glare created by buildings enveloped with glass surfaces cause visual discomfort(Nabil & Mardaljevic, 2005), and solar radiation affects urban morphology(Shakibamanesh & Veisi, 2021). One of the determining factors in designing a building is users' comfort, either visual, thermal, or acoustic, which are measured to evaluate their sustainability other than a label as a "green building"(Arbab et al., 2021). Projects seeking the "green building" title should receive related certificates measuring sustainability parameters. Qualification systems and standards such as LEED, BREEM, and WELL are established to standardize efforts and meaningful measures towards sustainability. The rating systems of sustainable buildings determine criteria to assess the amount of utilized natural lighting.

Table 2. Leed4 rate

source	rate	sDA	ASE
(Yoon, 2017)	3	75%	10<%
	2	55%	

Nevertheless, a thorough examination is required to achieve a daylight index in sustainable design (Brute Force Algorithm) in various possibilities. This detailed examination requires testing a large amount of data and consuming a great deal of time and energy. Therefore, algorithms save time, while finding optimal alternatives consumes less energy. In the examination performed in this research, MOGA (Pareto method) is used to pursue a continuous space. The optimization process used in this study is illustrated in figure 4.

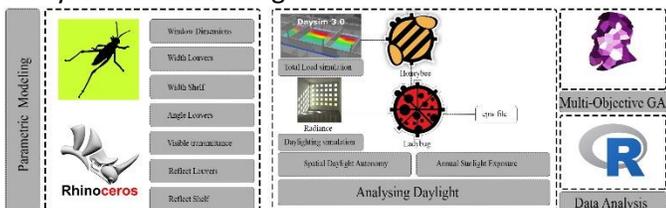
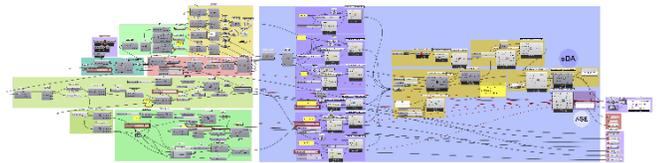


Fig. 4. Research Framework

In this research, parametric patterns have first been deployed to model the intended architectural space; subsequently, open-source plugins such as Ladybug and Honeybee have conducted natural lighting analyses. The variables involved in this analysis were sDA and ASE. Owing to its superior convenience, speed, and compatibility with Python codes in Grasshopper space, Walleci Plugin was deployed to find optimal data. The process of this parametric modeling can be seen in the following figure.

Fig. 5. Parametric Modeling in Grasshopper



2.5 Results

Analyzing the research data indicates that to maximize sDA and minimize ASE, the glass used in the window requires the highest transparency and reflection, while the materials used in louvers only need maximum reflection. Although 0 to 90 was the study's designated limit of possible rotation in attached louvers, their inclination showed a range of angles from 0 to 73°, and mostly angle 24°. The specified range of window surface/wall ratio was 0.4 to 1.

However, the perceived amount in the optimized face of the Pareto Front reached 0.9, which indicates the need for large windows with a specific number of louvers. In this study, allocating seven louvers was a smart choice made by advanced settings of parametric design. According to Table3, louvers' widths varied between 0 to 0.5, with an average difference of 0.3, which in the fifth generation of Pareto (the final face of Pareto), this amount remained at 0.3. For shelves, this amount was 0 to 2, which had an average of 0.7. In the final optimization of the Pareto Front face, this amount was a different number between 0.4 to 0.7.

Table3. A summary of parameters and variables in the optimization process

	sDA	ASE	T_glass	R_L	R_Sh
Min.	0	0	0.5	0.1	0.5
1st Qu.	97.2	0	1	0.8	0.8
Median	98.6	0	1	0.8	0.9
Mean	92.6	2	0.9	0.7	0.8
3rd Qu.	99.3	2.7	1	0.9	0.9
Max.	100	19.5	1	0.9	0.9
	Window	W_Sh	W_L	Angle	-
Min.	0.4	0.4	0.1	0	-

1st Qu.	0.9	0.6	0.3	20	-
Median	0.9	0.6	0.3	24	-
Mean	0.8	0.7	0.28	22.6	-
3rd Qu.	0.9	0.7	0.3	24	-
Max.	1	2	0.4	73	-

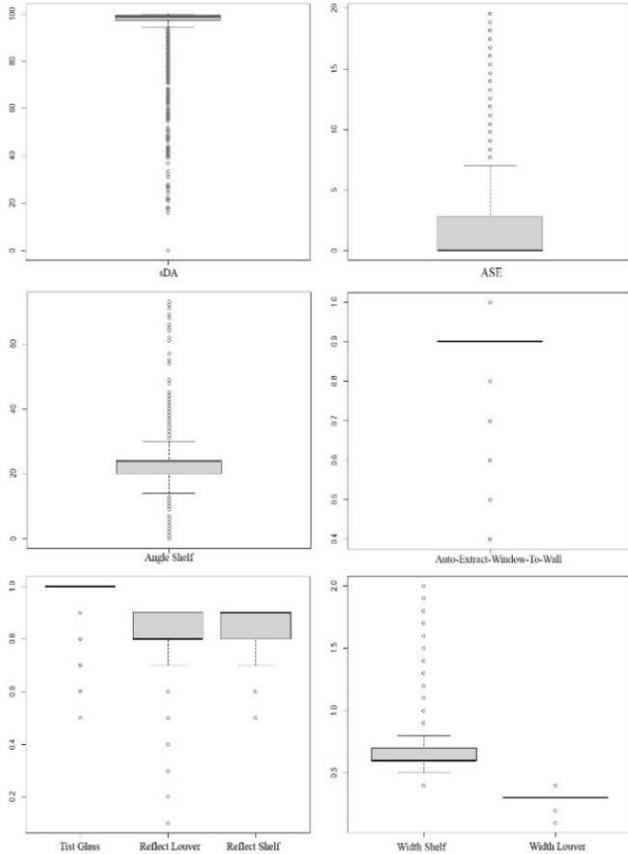


Fig. 6. Box Plot Graph Optimization Data

The data analysis process used in this research is depicted in figure 6. This graph indicates that values for sDA and ASE can fluctuate between maximums and minimums with regular spans. Furthermore, the additional elements which are attached to windows have the capabilities to absorb sunlight. P-value in Table 4 shows meaningful correlations between all variables with fitness functions, and in all of them, figures are all almost zero. This inclination of figures to zero proves a strong link between the research's data and SDA and ASE. However, the R-squared of the research's data displays a minuscule amount. This amount only for defining the reflect-shelf reflection of shelves is a significant number (R-squared =85.4) that implies the complexity of this data's prediction. Due to its complex nature and different variables, energy-related matters can neither be addressed fully nor be predicted accurately.

Table4. Analysis regression for a significant relationship between variable effective on Daylights.

Dim		sDA	ASE
Window	p-value	2.2e-16	1.001e-15
	R-squared	0.06956	0.02508
W_louver	p-value	2.2e-16	2.2e-16
	R-squared	0.09538	0.1281
W_shelf	p-value	2.2e-16	2.2e-16
	R-squared	0.06485	0.1139
Angle	p-value	2.2e-16	2.2e-16
	R-squared	0.06386	0.4077
tist_glass	p-value	2.2e-16	2.2e-16
	R-squared	0.308	0.06831
Reflect_louver	p-value	2.2e-16	2.2e-16
	R-squared	0.1305	0.1157
Reflect_shelf	p-value	2.2e-16	2.2e-16
	R-squared	0.1185	85.4

Table5. The assessment of the current status and optimized condition

	Exist	Optimum
sDA	74.12587	98.6014
ASE	9.79021	0
Window	0.7	0.9
W_shelf	1	0.6
W_louver	0.2	0.3
Angle	0°	24°
tist_glass	0.9	1
reflect_louver	0.7	0.8
reflect_shelf	0.7	0.9

According to Table 5, the value for sDA function has risen from 74% to 98%. In contrast, this amount for the ASE function decreased from approximately 10% to 0. This improvement was achieved while the variations of variables are not remarkable. In contrast, Auto-extract-window-to-wall had the most notable shift, 0.7 to 0.9. The angle of louvers was expanded from 0 to 24, the width of the shelves had a 0.4 decrease, from 1 to 0.6. A subtle increase in the louvers' width explains a 0.1 boost, from 0.2 to 0.3. The level of reflection elevated with a 0.1 increase in louvers and a 0.2 increase in shelves; and finally, reached 0.8 and 0.9, respectively.

2.6 Discussion

The discussed field of this research is examining the possible association between variables and spatial daylight autonomy, and annual sunlight exposure was conducted using sDA and ASE. Studies are exhibited in chart4. This summary indicates a meaningful correlation between change, intensity, and daylight illuminance based on their functions. The research's

results validate that utilizing Genetic Algorithm optimization elevates the level of sDA light gains up to 25%, influencing the users' efficiency. In this procedure, the ASE amount can be reduced up to 10%, and glare of any kind can be eliminated.

2.7 Conclusions

The review of this research's components substantiates that elements attached to the façade are highly influential in daylight gains; and, consequently, reduce energy consumption. Since this research's data was directed to improve the quality of received daylight in home-based offices and customize it for administrative purposes, this paper has successfully raised the amount of received daylight to 25% for these spaces' new function.

2.8 References

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