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Optimization of Windows to Enhance Daylight and Thermal Performance Based on Genetic Algorithm Case Study: a Residential Building With a Common Plan in Tabriz, Iran

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Abstract

In residential buildings, good daylight is critical in maintaining key aspects of our psychological and physiological health, and windows have a key role in daylight performance. However, achieving successful window design in the term of daylight is rather problematic, it can cause thermal discomfort in summer or winter. The balancing of different interrelated window factors is particularly challenging for Tabriz climate. Fortunately, because of advancements in building optimization methods in recent years, genetic algorithms used to explore for design solutions have shown their efficiency in solving complicated architectural problems. This current study aims to determine the applicability of a genetic algorithm for the optimization of windows for a typical residential building in the cold climate of Tabriz considering daylight and thermal performance. Using a parametric algorithm and evolutionary multi-objective optimization via Wallacei X plug-in for Grasshopper, various windows-to-wall ratios and sill height were combined, to find potential solutions that achieve a good performance in terms of thermal comfort and daylight. The survey has shown that in optimal conditions, the increase in useful daylight illuminance towards the base cases for south and north facade is 3.2% - 10.3% and the reduction rate of discomfort hours is 1.1%-23.8% through modification of window-to-wall ratios and still height in a residential building with a common plan in this climate.The results illustrated how an optimization methodology can be applied in the early stages of building design to understand how the windows can be tailored to ensure a good balance between daylight and thermal performance.

Keywords: Window; Residential building; Daylight; Thermal Comfort; Genetic algorithm

1. Introduction

Humans are affected both psychologically and physiologically by daylight (Edwards & Torcellini, 2002). Natural light not only can influence sense of well-being and comfort (Zomorodian, Korsavi, & Tahsildoost, 2016), but also has been associated with higher productivity, improved mood and reduced fatigue (Edwards & Torcellini, 2002). Many other functions, including circadian rhythms, hormonal changes (Tregenza & Wilson, 2013), nervous and endocrine system are also influenced by daylight(Edwards & Torcellini, 2002). Additionally, It can bring tangible energy savings and minimize energy demand for electric lighting (Altomonte, 2008). In the term of decrease in cooling and heating energy consumption, daylight can passively heat a building in the winter and it can be cooler than artificial lighting in the summer (Lechner, 2014). Moreover, thermal comfort as a key measurement in building design, influences how the occupants perceive the indoor environment and their behavior have a major impact on the energy demands (Arntsen & Hrynyszyn, 2021).

Nowadays, the demand for housing has been increased in large cities of Iran due to the growing population and many residential buildings have poor daylight quality (Ahadi, Masoudinejad, & Piriaei, 2016). Moreover, in this underdeveloped country, electricity use is increasing irrationally and there is no effective strategy for decreasing energy consumption (Heydari, 2012). The annual average of electricity consumption is approximately 100 kWh in Iran (Azadeh, Ghaderi, & Sohrabkhani, 2008), and almost 40% of this figure is allocated to the building industry sector (Azadeh et al., 2008). Researches have shown that the most common energy sources are spent on lighting, cooling and heating with 47% of the electricity consumed merely for domestic lighting(Ahadi et al., 2016).

It is noticeable that windows as a transparent envelope component, have a great impact on receiving natural light (Husin & Harith, 2012) and optimum windows' parameters for solving insufficient daylight can bring enormous benefits for contemporary residential buildings. The critical point is that the impacts of window parameters on the building performance interact with each other. For example, large windows will provide more daylight in the space and enhance indoor visual comfort, but they might also lead to excessive heat losses or gains

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which affect energy consumption (Zhai, Wang, Huang, & Meng, 2019). Studies have shown that occupants who have ever sat in direct sunlight on a hot day or near a cold window on a winter day , recognize that openings can cause thermal discomfort (Huizenga et al., 2006). To be exact, Natural light brings heat from solar radiation in winter but the inappropriate opening size can lead to poor indoor thermal comfort environment and more heating energy consumption. However, heat brought by visible solar light into the room may result in indoor overheating and increased cooling energy demand in summer (Zhao & Du, 2020). Therefore, window design is generally a multi-factor and multi-objective optimization problem and it is significant to concurrently optimize the opening parameters in the early stage of design process (Zhai et al., 2019).

According to the all above discussion, considering the living space's quality factors including daylight in metropolitan Iran’s cities such as Tabriz is more vital because of air pollutants, buildings' compactness and cloudy sky in winters that lessen access to adequate daylight. This article proposes the optimal the window-to-wall ratio and still height to achieve a good performance in terms of thermal comfort and daylight in a studied residential building. In this paper, a multi-objective optimization approach combining Radiance, EnergyPlus and genetic algorithm is applied to present optimal window design solutions.

2. Research Background

Extensive research of windows has been carried out for many years. Regarding windows in architecture, the research includes dissertations and articles that are done internationally. The glazing material, window-to-wall ratio, sill height, window transmittance, window size and position and etc. can be studied in the buildings. Most of these studies concentrate on the energy performance for lighting, cooling and heating in buildings. For example, an article proposed an optimization framework for window of office building ,considering the quantifying quality of View in balance with daylighting and energy performance (Pilechiha, Mahdavinejad, Rahimian, Carnemolla, & Seyedzadeh, 2020). A study aimed to optimize the office window in terms of reducing energy consumption and obtaining enough daylight (Moulaii, Pilechiha, & Shadanfar, 2019). An investigation of the effect of different parameters of the double-glazedwindow, such as the type of glass, as well as the filling gas between the double-glazedwindows with four different air distances has been presented the right type of window in reducing energy consumption (Pilechiha, Bayat, & Ghasemi Nasab, 2021). Another paper presented a method based on NSGA-II using an improved Daylight Factor model to optimize building energy demand and the window size (Mebarki, Djakab, Mokhtarii, & Amrane, 2021).A survey on a typical high-rise office building aimed to minimize the energy consumption and discomfort hours with a smart optimization algorithm NSGA-II. In this research, the configuration of windows, building orientation and shading system, including window material, depth of overhangs and installation angle had been taken into consideration (Zhao & Du, 2020). A study investigated the optimal office windows considering the window-to-wall ratio, sill height , window shape and position to provide visual comfort and save energy (Maleki & Dehghan, 2021).

Moreover, the authors in their research article optimized Twenty-one parameters of windows with genetic algorithm to maximize energy savings ,reduce visual discomfort and enhance daylight penetration (S. L. Torres & Sakamoto, 2007).A study aimed to optimize the window parameters and obtained a balance between energy consumption, visual performance and thermal environment based on NSGA-II in combination with EnergyPlus (Zhai et al., 2019).In another article, researchers applied a contour plot to determine the appropriate window by evaluating the effect of window parameters on the natural lighting, heating demand and thermal environment (Vanhoutteghem, Skarning, Hviid, & Svendsen, 2015). A recent study presented the application of simulation–optimization tools to discover the optimal trade-off between minimizing energy consumption for lighting and heating, maximizing Useful Daylight Illuminance and reducing summer discomfort time. The considered parameters in the optimization analysis included orientation, the window-to-wall ratio of different interfaces, room depth and corridor depth, glazing materials and shading types (Zhang et al., 2017). Another article presented a simulation study to investigate the impact of window-to-wall ratio, window orientation and wall reflectance on lighting energy demand and various daylight metrics in the tropical climate (Mangkuto, Rohmah, & Asri, 2016). In another article, researchers used an graphical analysis to determine the appropriateness of combined optimization criteria on window size for high visual comfort and performance with low energy consumption (Ochoa, Aries, van Loenen, & Hensen, 2012).In a recent study, the optimal percentage of the window to the floor, optimal dimensions of a living room and appropriate shading device were proposed to enhance daylight performance in a residential building (Zeinalzadeh, Nikghadam, & Fayaz, 2021). An investigation was carried out for an office building by varying number, shape, position, and type of openings and the thickness of walls through implementation of the NSGA-II algorithm (Echenagucia, Capozzoli, Cascone, & Sassone, 2015). A study aimed to provide a simplified analysis method to evaluate the influence of building geometry, window opening size, and glazing type on Energy savings of artificial lighting use from daylighting for four geographical locations in the United States (Krarti, Erickson, & Hillman, 2005). Five years later, researchers concentrated on the environmental effect of an office to determine optimum WWR for various orientations and window materials (Su & Zhang, 2010). A study aimed to apply genetic algorithms and EnergyPlus to analyze the impact of four types of windows, their size, external wall insulation , building orientation, roof and ground floor and infiltration on the life cycle costs (Ferdyn-Grygierek & Grygierek, 2017). An investigation was carried out for evaluation of building energy saving through the development of venetian blinds optimum orientation and window-to-wall ratio (Kwon, Yeon, Lee, & Lee, 2018), while the effect of window orientation, room width-to-depth ratio and WWR on the energy performance in a commercial office building was an in-depth study with specific recommendations (Susorova, Tabibzadeh, Rahman, Clack, & Elnimeiri, 2013). According to reviewed sources, the data related to the research topic are summarized in the Table 1.

Therefore, most of these studies focus on multi-objective optimization and a large proportion of the target functions in these research focus on the daylight and energy performance. Moreover, the optimization method in the reviewed studies can be grouped into five categories: graphical analysis, intelligent optimization algorithm, regression analysis, deductive analysis, multi-factor combination exploration. Nevertheless, in the present article, a parametric algorithm and a multi-objective genetic algorithm were applied to optimize window parameters to enhance thermal comfort and daylight performance.

Table 1

Summary of articles related to the subject

Study Number	Author(s)	Performance metrics	Design parameters	Optimization method	Character
(1)	Pilechiha (2020)	View, energy performance and daylighting	WWR	Evolutionary algorithm	Multi-objective optimization
(2)	Moulaii (2019)	Energy consumption and Daylight performance	WWR and room depth	Genetic algorithm	Multi-objective optimization
(3)	Pilechiha (2021)	Energy consumption	type of glass, the filling gas ,different air distances	Deductive method+ EnergyPlus	Single-objective optimization
(4)	Mebarki (2021)	Building energy demand, daylight performance	Window size, glazing types and orientations	NSGA-II	Multi-objective optimization
(5)	Zhao (2020)	Energy consumption and Thermal comfort	configuration of windows and shading system, building orientation	NSGA-II	Multi-objective optimization
(6)	Maleki (2021)	visual comfort and save energy	(WWR), window shape and position, sill height	genetic algorithm	Multi-objective optimization
(7)	Torres (2007)	Daylight performance	Twenty-one parameters such as window width, sill height, window height, window transmittance, …	Genetic algorithm	Single-objective optimization
(8)	Zhai (2018)	Energy consumption, thermal environment and visual performance	WWR, orientation and glazing material	NSGA-II + EnergyPlus	Multi-objective optimization
(9)	Vanhoutteghem (2015)	Heating demand, daylighting and thermal	Window size, orientation, and glazing properties of	Graphical analysis	Multi-objective optimization
(10)	Zhang (2017)	Energy use, summer discomfort, Daylight illuminance	Building orientation, building shape, WWR, glazing material, and shading types	Genetic algorithm	Multi-objective optimization
(11)	Mangkuto (2016)	Daylight performance and lighting energy demand	WWR, wall reflectance, and window orientation	Sensitivity analysis + Graphical analysis	Multi-objective optimization
(12)	Ochoa (2012)	Energy consumption and visual performance	Window size	Graphical analysis +EnergyPlus	Multi-objective optimization

3. Research Methodology

This study is a sort of applied research that it is used to meet human needs, improvement of human living standard and optimization for well-being. This study attempts to determine the optimal window-to-wall ratio and sill height of windows in a common residential building in Tabriz for optimal daylight and thermal comfort.

Concerning windows, numerous Latin and Persian articles were collected in information libraries. Then, classifying and summarizing the information collected from the research background, a theoretical framework was formed. In this article, the optimization framework is a parametric process and modeling, simulation and optimization evaluations would be performed on one canvas. This parametric framework is held in Grasshopper software while Honeybee will be responsible for building performance simulation and visualization process. Honeybee connects Grasshopper3D to validated simulation engines, including EnergyPlus/OpenStudio for thermal performance and Radiance for daylighting simulation (Wetter & Wright, 2004). After that, genetic algorithm via Wallacei X plug-in performs multi-objective optimization. Solving the contradictive relationship between daylighting and thermal performance, is the main purpose of this research. The framework begins with creating zones with all parameters based on the technical documentation of the studied apartment. Then, the simulation settings will be set based on Tabriz's conditions and climate ;afterwards, annual illumination analysis was investigated in the present case. Then, Wallacei X optimize window's variables in terms of thermal performance and daylighting. The structure of research method is shown in figure 1.

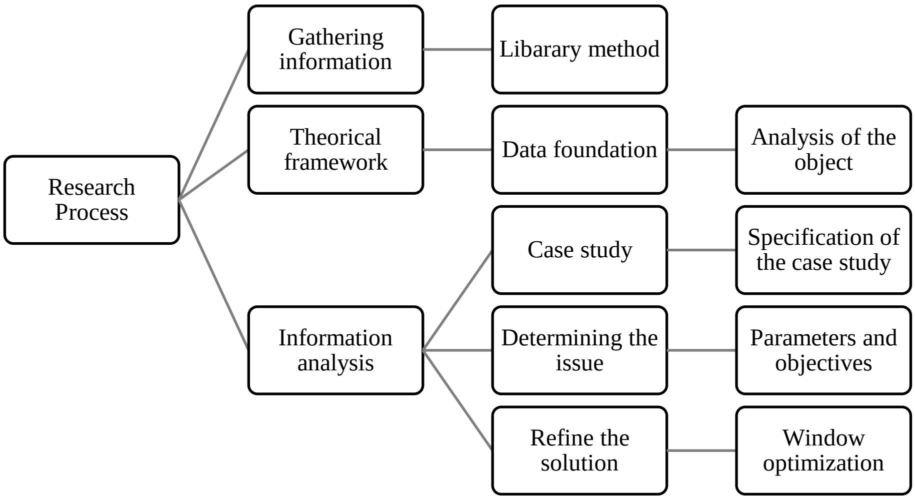


Fig. 2. Flowchart for research method

4. Setting of Simulation

4.1 Geographic location, climate

Ordinary seasons and Semi-arid weather are the most specific features of the climate in Tabriz. The annual precipitation is a combination of both snowfall and rain which is approximately 280 mm. Tabriz City is located at (38_0404800 N, 46_1703000E). The climate data from Tabriz used in the simulation process are shown in Table 2 (Shahbazi, Heydari, & Haghparast, 2019). To run the local climate, the Tabriz 407060 (ITMY) ZIP file was downloaded from Ladybug tools website to gain weather information and then applied in the plug-ins.

Table 2

Climate summery

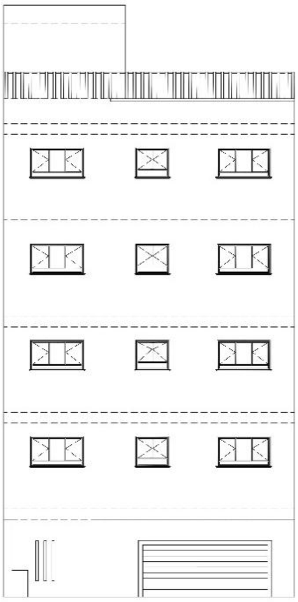
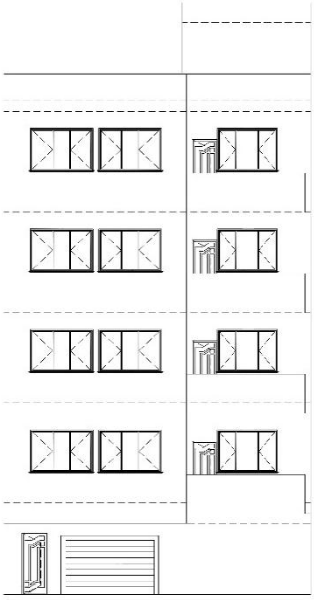
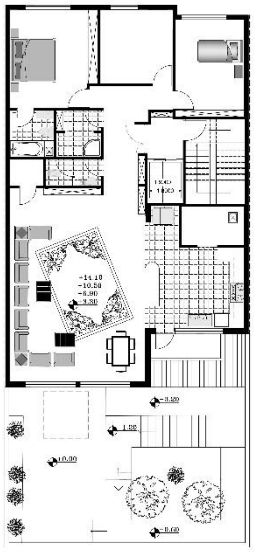
Parameter	Min. temp.(0c)	Max. temp.(0c)	Avg. temp.(0c)	DryBulb temp.(0c)	Relative humidity (%)	Global Horiz. Rad. (Avg.hourly W h/m2)
Value	-2.5	25.4	11.19	11.19	53.5	157.83

(Source: Shahbazi et al., 2019)

4.2 Building geometry and windows

In this paper, a common rectangular plan for Tabriz's residential building was selected to explore the capabilities of the proposed approach. This building is located Area 3, Manzariyeh neighborhood with a north-south orientation. The building consists of four floors in a medium texture with medium height. The specifications of this sample, including space dimension, windows features can be seen in Table 3. The simulation process was performed for first to fourth-floor spaces to determine the optimum fenestration that would lead to a good performance in terms of thermal comfort and daylight. The evaluation of the north and south windows was performed separately for each floor. The parameters for simulating the windows and zones were modelled using Honeybee and Ladybug plug-ins version 1.3.0.

Table 3
Specifications of a 4-story building in Manzariyeh district of Tabriz

	Space dimension			Window					
Zone name	Length	width	height	Direction	Distance from floor	Length and width	Number	Window to wall ratio	Glass type
Living room	8.40m	6.05m	3.20m	South	1.00m	2.25*1.50m^2	2	35%	Double glazed window
Kitchen	5.43m	4.45m	3.20m	South	1.10m	1.75*1.50m^2	1	18.5%	Double glazed window
Bedroom1	4.45m	3.44m	3.20m	North	1.60m	2.00*1.10m^2	1	15%	Double glazed window
Bedroom2	3.35m	3.25m	3.20m	North	1.60m	1.25*1.10m^2	1	13%	Double glazed window
Bedroom3	4.07m	3.10m	3.20m	North	1.60m	2.00*1.10m^2	1	17%	Double glazed window
Case study documents									
North elevation				South elevation			Floors plan		
									

4.3 Obstructions

Surrounding buildings which may block daylight in the spaces have a great impact on daylight access (Muñoz, Esquivias, Moreno, Acosta, & Navarro, 2014) and they determines the daylight potential of the building's facades and daylight availability (Ruck, Aschehoug, & Aydinli, 2000).Hence, the adjacent blocks were modeled with the exact height in the simulation software. Neighbors consist of 4 to six floors in this construction site.

4.4 Daylight analysis

A 20 x 20 cm grid at a height of 70 cm above the pavement is considered to analyze the selected area's annual illumination. The time of the whole year is set for the hours of sunshine in the sky.

The materials for each component of the zones were made using the Honeybee, which also calculated the radiance properties for each surface. The radiance materials used in different space levels such as ceiling, floor, walls, and windows are specified in the case study in Table 4.

Table 4
Specifications of materials used in different levels of space in a four-story building

Space surfaces	Scattered reflection factor	Roughness	Direct reflection factor	Light passing factor	Light refractive index
Ceiling	0.90	0.05	0	-	-
Floor	0.80	0.05	0	-	-
Wall	0.95	0.05	0	-	-
Window	-	-	-	0.8	1.52

4.5 Thermal comfort analysis

Predicted Mean Vote (PMV) is a generally used index to evaluate the thermal comfort of the indoor environment. In this study, PMV model was used to evaluate human thermal comfort in indoor environments, the sitting metabolic rate for users in different spaces was assumed with a clothing level of 0.5. The cooling set point and heating set point was considered at temperatures of 26 ° C and 23 ° C, respectively and a 50 x 50 cm grid at the height of 70 cm above the pavement were performed for thermal analysis.

5. Optimization process

5.1 Optimization

The method (or methods) of making something (such as a design, structure, or decision) as perfectly ideal, functional, or efficient as possible is often referred to as "optimization." Optimization is the procedure of finding the best solution to a problem from various alternatives provided in different scientific fields such as statistics, mathematics and many more. In building performance simulation, depending on the nature of the problem, the phrase "optimization" does not only mean finding the optimal global solution for a problem as this may be impractical (Nguyen, Reiter, & Rigo, 2014) or if the computational time needed to evaluate the function is too long, the simulation program itself may not be usable (Wetter & Wright, 2004). However, it is commonly accepted that the term "optimization" demonstrates an automated procedure that is performed comprehensively based on numerical simulation and mathematical optimization, and this view is most reliably among simulation-based optimization alternatives. In a typical building optimization study, the simulation and optimization process are usually automated when a building simulation program integrates with an optimization "engine", which may consist of one or more algorithms or optimization strategies (Attia, 2012). Optimization as a process of trial and error depends on the computer to do the calculation, and provides an opportunity for designers to be creative as computers and finds the most optimal solutions. For architectural design problem, Grasshopper3D can implement Evolutionary Solvers such as Octopus, Galapagos, Wallacei X to find the design solutions and make effective decisions (WATTS).

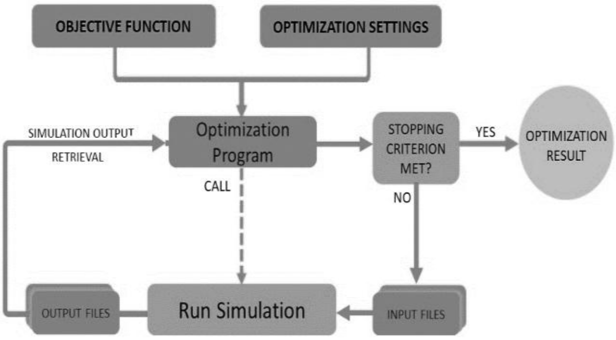


Fig. 2. simulated-based optimization in building performance simulation
(Source: Nguyen et al., 2014)

The summary of the most common process for simulation-based optimization is shown in Figure 2 (Nguyen et al., 2014).

5.2 Optimization engine

The WALLACEI software tool (which includes Wallacei Analytics and Wallacei X) is a scalable multi-objective optimization engine, based on the evolution phenomenon written by C# in 2018 (Aamer, 2021).

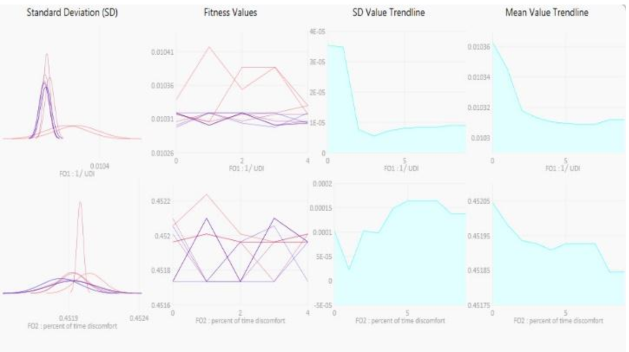


Fig. 3. Using Wallacei engine for optimization of case tudy

Wallacei is a scalable engine that allows users to run scalable simulations in Grasshopper 3D using highly detailed analytical tools combined with various comprehensive selection methods to help users better understand their scalable runs and make more informed decisions at all stages of their evolutionary simulations(Wallacie).Wallacei has specific features that give the user better control over optimization, charts, and graphs to track optimization(A. Torres, Mahmoudi, Darras, Imanpour, & Driver, 2021).This form of computer integration represents an impossible skill for the human mind to calculate, it reduces a task that would normally take a few days for a human to a few hours for the tool. Breaking down a tedious task that would require the basic intuition of trial and error, into a precise alteration process calculated against a series of objectives. MOO (Multi-Objective Optimization) is a mass iteration process that is refined by an algorithm to deliver the optimal result. This process started with the use of Galapagos, a Grasshopper component which was a single target and was not even capable of performing the intense energy data. Therefore, Wallacei, an MOO scalable solver plugin was used as a replacement, providing more controlled and faster optimization with better visualization platforms. Energy results are the fitness goal, which wallacei is able to use as a control standard, where each gene is adjusted to attempt to achieve these fitness objectives(WATTS).

In this study, the performance of Wallacei, a tool based on the NSGAII algorithm, was developed primarily to solve multi-Objective optimization problems. The Non-dominated Sorting Genetic Algorithm II (NSGAII) allows us to solve optimization problems with more than one objective function using fundamental components of the genetic algorithm, which can only be used to solve single-purpose problems(A. Torres et al., 2021).

Table 5
GA parameters

Generation size	Generation count	Population size	Crossover probability	Crossover index	distribution	Mutation distribution index	Random seed
5	10	50	0.9		10	10	1

5.1 Variables

In this study, two parameters of the window to wall ratio and sill height have been considered as the independent variables. Research has shown that the optimal amount of these parameters in energy consumption in Tabriz's climate has been presented between 20% to 50% for the southern facade(Shaeri, Habibi, Yaghoubi, & Chokhachian, 2019). Hence, in this study, WWR was considered between %۲۰ to %۵۰ for south façade with %۵ intervals. According to local building code, window to wall ratio of 45% is allowed for the northern facade.Therefore, WWR was considered between %۲۰ to 45 % for north façade with %۵ intervals. The variable of sill height has been assumed between ۱۶۰ to ۱۸۰cm with ۱۰cm intervals for the northern façade according to local building code, sill height of kitchen between ۷۰ to 110 cm and this parameter was assumed between 0 to 110cm with 10 cm intervals for living room zone.

5.3 Objectives

The main aim of this paper is to evaluate the illuminance of the space considering occupants' comfortability by optimizing the variables (WWR and sill height) of a built project in comparison to the current situation.The illuminance is a measure showing the amount of light reached on a surface and is widely used by designers to determine the illuminance levels . Indices for assessing the quantity of light are divided into two static and dynamic categories(Fazeli, Mahdavinejad, & Bemanian, 2019). To serve this purpose, among dynamic daylight indicators useful daylight illuminance (UDI) was suggested. Mardaljevic and Nabil developed useful daylight illuminance (UDI) indicator in 2005(Nabil & Mardaljevic, 2005). They defined the illuminance between 100 and 2000 as useful for the visual assignments' performance. The UDI calculation method should be based on the percentage of the occupied time in a year which a certain point of a work plane has received an illuminance value between 100-2000 lux. It should also be noted that a level below 100 lux means the possibility of dark space and the necessity of artificial light as an additional light source during the day time and a value above 2000 lux means the possibility of glare. In other words, UDI between 100-2000 lux expresses the comfort conditions of residents in terms of lighting level(Laura Bellia, 2015). In this study, computational simulation was chosen for performing the daylighting simulations using the Honeybee V0.0.65 which is a plugin for the Grasshopper , Rhinoceros and OpenStudio as a simulation engine(Brzezicki, 2021).

The second objective function that was chosen to be easily comprehended is the percentage of hours that the user does not have thermal comfort and includes the total hours that the user feels too hot or cold. To minimize the value of underheating and overheating objectives, the indoor environment of the building is assessed using Fanger's PMV model during the occupied unconditioned period of summer and winter. The period of time that the PMV is less than -0.5 is indicated as under heating and when it is more than 0.5 overheating is represented(Nikolaidou, Wright, & Hopfe, 2017).

DH=Discomfort Hours=Overheated Hours + Underheated Hours
DH=OH+UH
F1: min (DH)
F2: max (UDI 100–2000 lux)

5.4 Optimization settings

The genetic algorithm parameters were set as shown in Table 5. Optimizations were performed for 50 population size at random initial solutions and lasted up to 5 generations Table 5.

6. Result and Discussions

This article’s results present the optimized fenestration patterns for north and south facade based on UDI and total discomfort hours. In Tables 6 and 7, a comparison between the best optimization solutions for each facade with the base cases is presented. After analyzing base cases in south facade, it was found that the first to third floors are almost the same in terms of daylight and thermal performance, while in the fourth floor these values were different. Therefore, the optimization for the first and fourth floors was done separately. Moreover, northern façade has the same condition from the first to the fourth floor relative to the target functions. Hence, the northern façade optimization process was performed just for one of the floors (first floor).

Table 6

A comparative Pareto optimal solutions and base cases for south facade

		WWR (kitchen) %	Sill height (kitchen) (m)	WWR (Living room) %	Sill height (Living room) (m)	UDI %	Discomfort Hours %
First to third floor	Base case	18.5	1.1	35	1.1	64.1	50.0
	Optimized design 1	20	1	45	0.7	68.7	26.9
	Optimized design 2	25	0.9	45	0.6	67.3	26.2
	Optimized design 3	25	1.1	45	0.3	68.7	29.0
	Optimized design 4	25	0.9	45	0.6	67.3	26.2
	Optimized design 5	20	0.9	20	0.8	74.4	47.0
Fourth floor	Base case	18.5	1.1	35	1.1	67.7	50.0
	Optimized design 1	20	0.9	30	1	73.0	42.6
	Optimized design 2	20	0.9	35	1	70.8	36.7
	Optimized design 3	25	0.9	30	1	71.1	44.1

Table 7

A comparative Pareto optimal solutions and base cases for north facade

	`	WWR (Bed room1) %	Sill height (Bed room1) (m)	WWR (Bed room2) %	Sill height (Bed room2) (m)	WWR (Bed room3) %	Sill height (Bed room3) (m)	UDI %	Discomfort Hours %
First to fourth floor	Base case	20	1.6	13	1.6	22	1.6	93.4	46.3
	Optimized design 1	40	1.8	45	1.7	40	1.8	96.9	45.1
	Optimized design 2	40	1.8	30	1.7	35	1.8	97.0	45.1
	Optimized design 3	40	1.6	30	1.7	40	1.8	97.1	45.2

In this study, three optimized designs were presented for northern zones (3 bedrooms). For Southern zones (living room and kitchen), five optimized design was proposed for first to the third floor and three alternatives were presented for fourth floor. Using an evolutionary multi-objective optimization algorithm provides the possibility of achieving the desired target function with multiple alternatives and it facilitates the complexity of the design process.

Window-to-wall ratio and sill height are the main issues that had a significant impact on the final results. In the case of each facade’s optimum outcomes, significant changes in south façade were observed in percent of discomfort hours and obtained values were improved against the base cases. In other words, the fenestration pattern of south façade has a great impact on thermal performance and subsequently the overheated hours in summer and underheated hours in winter.

In the case of each facade’s optimum results, considerable changes were perceived in all the metrics analyzed regarding the base cases. The increase in UDI values towards the base cases is between 3.2% and 10.3% (chart 1). UDI values demonstrates that the north-orientated zones have a higher overall daylight quality than the south-orientated ones; this is because, some spaces go higher levels (UDI> 2000 lux). As the sunlight comes from the south, all spaces oriented in this direction would exceed 2000 lux, hence the overall daylight levels to a point will be lower than in northern zones. Moreover, both façades show relatively uniform optimal results in term of UDI. An interesting point in relation to performing multi-objective optimization was that noticeably different fenestration pattern can even provide better overall outcome for UDI. For instance, optimized design 5 shows the largest increase in the UDI value which is about 10.3% more than the base case.

The optimized design 5 has a window-to-wall ratio of 20% for both kitchen and living room zones,which is the lowest value among the optimal results, but it has been able to perform better in the UDI index (Table 6). Also, in the northern façade, by improving the independent variables, we can see a growth of about 3.5% to 3.7% of the UDI index in the optimal solutions compared to the base case (chart 2).

In terms of the percentage of discomfort hours, the northern façade has a uniform performance compared to the southern façade. The Optimal results show that the southern façade is thermally more sensitive to independent variables, especially the window-to-wall ratio. For instance, in south façade, comparison between optimized design 2 and optimized design 5, each of which shows the best and worst results for the discomfort hours, respectively.The results indicate that the change in the WWR values has led to a large improvement in the discomfort hours while the other parameters are almost the same. This means that qualified configuration of window and the best WWR can reduces the percentage of discomfort hours. For example optimized design 2 have been able to improve thermal comfort conditions by 23.8% while in the northern façade, this value is only approximately 1% (Fig.4 & Fig. 5). Therefore, optimizing the fenestration pattern for southern zones which led to the control of the thermal performance is more critical than for northern zones designers.

Overall conclusions drawn from the evaluations illustrated that there is a direct correlation between fenestration patterns and objectives. Finally, the optimal north and south facade were presented based on having a symmetrical design and receiving maximum daylight which is shown in Figure 6 & 7.

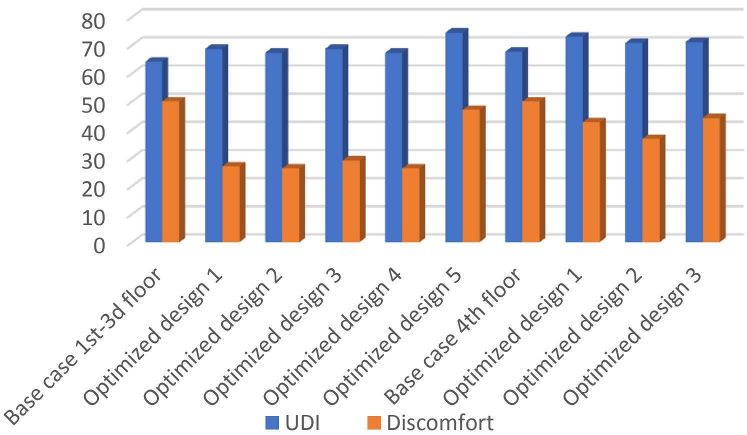


Fig. 4. Comparison of UDI & DH with base case for optimized solutions of south façade

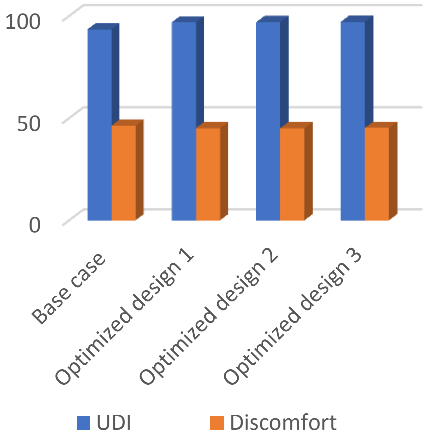


Fig. 5. Comparison of UDI & DH with base case for optimized solutions of north façade

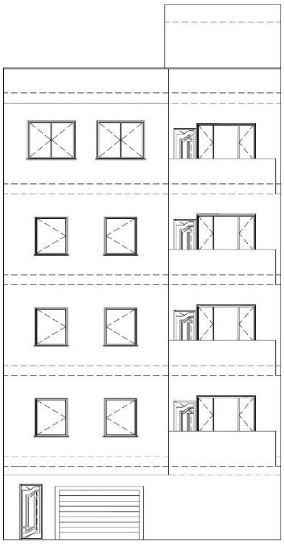


Fig. 6. Optimized design for south façade

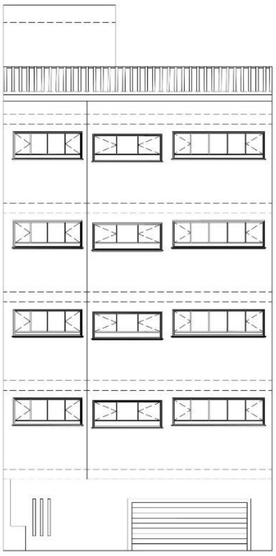


Fig. 7. Optimized design for north façade

7. Conclusion

The principle aim of this research was to develop a workflow to enhance the decision-making process in the early-stage design of a residential building. The most effective decisions for the facade design process are taken by the implementation of simulation tools to develop environmental goals and architects can get worthwhile information during the design process to make more mindful and effective decisions. In this survey, application of simulation-based optimization methods and genetic algorithm not only provided the possibility to propose various design alternatives and select an optimal one, but also a strong relationship between daylight and thermal performance analyzed through various windows-to-wall ratios and sill height to find potential solutions. Study on a typical residential plan in Tabriz were proposed five optimized designs for first to third floor and three alternatives for fourth floor in southern zones. For northern façade, three optimized designs were presented. The results illustrated how an optimization methodology and genetic algorithm can be applied to achieve the optimum fenestration pattern based on the most qualified daylight level and the minimum annual thermal discomfort in the early stages of design. Based on the article's findings, a comparison between the base case scenarios with the best optimization solutions manifests growth on UDI values 3.2%-10.3% and 3.5%-3.7% for south and north façade, respectively. However, decrease in discomfort hours values is 5.9%-23.8% and approximately 1% for south and north façade, respectively. Investigations showed that the UDI values for south façade (64.1%-74.4%) are lower than the north façade (93.4%-97.1%) duo to an 'upper threshold' above (UDI>2000 lux) which daylight is not wanted as the result of glare or overheating. However, the northern facade has a relatively uniform performance for daylight criteria and these values are not significantly different with each other (93.4%-97.1%). Moreover, this research revealed that noticeably different fenestration pattern can even provide better overall outcome for UDI index. As was seen vividly, the optimum percentage of discomfort hours for south and north facade was 26.2%-47.0% and approximately 45%, respectively. These values proved a great impact on thermal performance and subsequently the overheated hours in summer and underheated hours in winter for the south fenestration patterns. Statistical outcomes confirmed that the arrangement of windows have a substantial impact on both thermal and daylight performance.

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