JSER

Journal of Solar Energy Research (JSER)

Journal homepage: www.jser.ut.ac.ir

Analysis of The Impact of Window Properties On the Main Living Space with The Aim of Daylight Efficiency and Energy Saving in The Hot and Dry Climate of Isfahan

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Received: 30-09-2022
Accepted: 30-11-2022

Abstract

Today, considering that the building sector accounts for approximately 30% of the total global energy consumption, the approach of the sustainable architecture model is more emphasized in this area. Windows, as one of the main building elements, play a crucial role in absorbing enough daylight to improve interior space quality and to reduce energy consumption. Therefore, this study aims to design the window optimally considering four window variables, including window-to-floor ratio (WFR), as well as the position and shape of windows in the north and south façades of residential areas in Isfahan City. Finally, the findings indicate the impact of each parameter on daylight and energy consumption by simulating it in the DesignBuilder software. For example, a window with 50% WFR and rectangular shape (ratio of 1:1.5) at the top position of the south façade has optimal conditions in terms of static daylight metrics; however, the same window position at the bottom and middle of the façade will not have acceptable conditions in terms of the metrics. Obviously, other scenarios are not exempt from this rule, and it is complicated to select an optimal model. Consequently, by considering several metrics and evaluating them, it can be claimed that a rectangular window with 40% WFR in the south façade with a ratio of 1:2 at the top position of the façade can provide the optimum model in terms of suitable daylight and energy saving for a residential space in Isfahan and the general requirements of daylighting of the National Building Regulations should be examined considering the proposed glazing to floor ratio and the climate of each region.

Keywords: Window-to-floor ratio (WFR); Shape of a window; Position of a window; Residential building; Daylight savings; Energy consumption; Isfahan

DOI: 10.22059/jser.2022.349312.1258 DOR: 20.1001.1.25883097.2023.8.1.3.9

1. Introduction

According to surveys, the three main and major sectors of energy consumption in the world are residential, industrial, and transportation sectors. Nevertheless, the residential sector is considered the main energy-consuming sector until the end of the 20th century [1], since approximately 30% of the total energy consumed in the world is related to the

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residential sector [2]. According to 7the latest information from the U.S. Energy Information Administration (EIA), the total annual energy consumption by residential and commercial sectors has been 21% and 18% (totally 39%) of the total U.S. energy use in 2021, respectively [3]. Based on the latest information announced by the EIA, the electricity use in the residential sector has augmented from approximately 0.1 quadrillion Btu in 1950 to 5 quadrillion Btu (approximately 50 times) in 2020 [4]. For example, one study conducted on an office building indicates that lighting, cooling, and heating are the main energy-consuming parts in a building; hence, these parts are regarded as the main parts to optimize or save energy in buildings [5]. Indeed, it is worth mentioning that the increasing development of construction industry-related technologies in the last decade and the use of appropriate insulators in buildings have led to decreased energy consumption for heating and cooling loads in buildings. However, the energy use for lighting has increased, so that it is both insignificant and comparable to the energy consumption in the cooling and heating sector [6]. Based on measurements, lighting consumes approximately 25% to 40% of the total electricity in a building [7]. Thus, the planned use of natural daylight in buildings can be a cost-effective strategy to reduce energy consumption. This reduction in consumption is owing to the reduction in the electricity use for lighting. Using more daylight is one of the ways to reduce electricity consumption in the lighting sector. The design of spaces and the opening surface of the spaces should be given special attention to maximize the access and use of daylight in indoor spaces [8]. Therefore, providing the necessary conditions for efficient daylight requires a complete recognition of all types of lighting systems and designs. The compatibility of these technologies with the placement layouts and the types of space syntax in the building should be evaluated and selected the optimum method [9]. For the energy efficiency of the building, the use of a shading system, which is responsive to human and environmental needs, has increased. Generally, external shading system prevent the residents' visual and thermal discomfort by controlling the sunlight. The performance of adaptive facades and their control methods are still under discussion and studies like [10, 11] have evaluated, various approaches and solutions to examine their methods.

The advantages of using natural light can be classified as follows: the first part is associated with the macro and environmental effects of using lighting, while most of the available electricity is obtained from fossil fuels and non-renewable sources. The other part is related to the effect of using natural light on energy consumption in the environment. Therefore, providing lighting using daylight leads to less use of cooling and ventilation equipment in the building and, thereby reducing the energy consumption in the building. Thus, the utilization of daylight instead of lighting can reduce both lighting-related electricity consumption and energy use for the cooling sector [12]. The last category encompasses the effect of using daylight by residents. Thus far, extensive research has been conducted on the effect of exposure to daylight on human health. For example, in one study conducted on the performance of elementary school students, the results imply that students in classrooms with optimal daylight illumination represented 21% better learning compared to those who were in classrooms with minimal daylight illumination [13]. The results of another study with the same aim indicate that adequate lighting improves students' scores and reduces unpleasant behavior. Thus, correct illumination is one of the important factors affecting the residents' performance [14].

Regarding the increasing role of buildings in design, some solutions can be offered to control the environmental effects and preserve fuel resources. Windows are one of the most important components of a building, affecting the residents' health positively. Furthermore, they play a key role in providing daylight illumination, visibility and sight [15], and in responding to the energy needs of buildings [16]. Hence, it is important to consider the lighting sector and equilibrate between using natural light and electricity to achieve a better environment for living, optimize energy consumption in buildings, and improve the residents' performance. Nevertheless, the window-to-floor ratio (WFR), and the shape and position of a window are particularly important. The current study attempts to consider the thermal behavior and performance of daylight in the main living space of a residential building in the hot and dry climate of Isfahan City by assessing the window properties.

2. Background

In the results obtained from energy and daylight, the components are dependent on the design choices in the optimum orientation of buildings and the appropriate size of windows, thus improving the energy efficiency of buildings [17]. Today, some solutions have been applied to reduce energy consumption and cause residents to feel comfortable. For example, glazing facades are used in commercial buildings to receive natural light and better sight; however, shading system are placed in closed mode to prevent sunlight and visual discomfort, and the electricity consumption will increase for heating and cooling if the shading system are open [18]. Applying the potential of daylight to achieve the indoor environmental quality (IEQ) is significantly considered by designers. The dynamic lighting system with the window sill height variables (O.K.B), depth and angle of shading has been proposed on the reference model with the analysis of LEED v4 in improving the lighting of the space. This case represents the effectiveness of light shelf and movable shading with retractable panels equipped with solar tracking sensor in penetrating the natural light into the space [19]. Thus, it is necessary to consider residents' visual comfort when designing the window.

The variable of window dimensions represents its key role in the end part of the room, where the amount of light entering the depth of the space becomes important. Installing the window at the top position than the middle position creates a better light autonomy at the end of the room, and horizontal windows are more effective than other forms in conserving energy [20]. In addition to the performance of daylight, to decrease the use of fossil fuels in the relationship between different parameters of window design, the WFR of more than 30-40% in south-facing windows has limited impact on reducing the heating energy consumption in the space. The application of windows with a thermal conductivity coefficient (U-value) between 0.3 and 0.5 (W/m2K) may lead to reduce the heating energy consumption in a space larger than the appropriate WFR. The windows with a high light transmission coefficient (g-value) are recommended for installation in north rooms to reduce the heating energy consumption in the space [21]. Numerous studies have evaluated the affecting variables of a window, including WWR, SHGC, Tvis, and U-value, and the amount of energy consumption in different orientations, climates and uses each of which has provided favorable results [22, 23].

Proper illumination significantly affects energy conservation in a building and according to the amount of light passing through a glass, finding the best type of window is considered the most important factor in the balance between natural light radiation and solar heat transfer. Most of the energy consumption is devoted to electric lighting, followed by cooling and heating. Double-pane low-E glazing has the greatest effect on energy consumption and encourages the residents' productivity level [5, 24]. In addition, electrochromic smart windows lead to the optimization of the building energy by controlling the sunlight [25].

Different dimensions of space and windows with various geometries affect the amount of light received and finding the best outcome. It can be concluded that room and window geometries have a remarkable impact on maximizing daylight harvesting, so that the space with a rectangular-shape geometry and WFR of 12%, along with using an LED lighting system, can significantly save energy up to 48.5% [26]. It should be noted that wider-than-deeper rooms may use less lighting but may not consume the least amount of energy [27].

More heat is released if lighting is used in the space instead of natural daylight, and the need for cooling energy will be reduced by replacing natural daylight for useful illumination in the space. The largest share of electricity has is from non-renewable causing environmental problems and increased global warming. For example, three units of fossil fuel are needed to supply each unit of electricity. Two out of three fossil fuel units are converted into heat, and these three units of fossil fuels are saved by conserving every unit of electricity, thereby reducing the amount of pollution and the heat released [12].

Moreover, lighting conditions considerably affect human physiology and improve the indoor environment. Glare indices play an effective role in providing visual comfort to respond to the residents' subjective conditions [28]; the impact of environmental conditions on health can be evaluated with the right choice. Therefore, the utilization of daylight in buildings is one of the main design aspects due to the reduction of energy consumption as well as the positive physical and subjective effects of daylight on the residents. Maximizing the use of daylight and providing visual satisfaction result in improving the quality of the environment and increasing the physical and subjective health levels of the users and their efficiency.

Owing to the effective role of residential buildings in the total global energy consumption as well as considering the significant role of the energy consumed by the lighting sector compared to the total energy consumption by the residential sector, it is necessary to design buildings in such a way to meet various needs. The sun is regarded as the main and important source of light, which, if it is adequate, in addition to providing lighting, can offer several health benefits, thereby improving the physical and subjective states of the people using that space. Meanwhile, windows, as the main and most important architectural element to allow daylight to enter the space, play a significant role in achieving this purpose. Thus, it is required to answer this important issue by determining the optimal WFR and other parameters affecting the window as the main factor of daylight distribution in the interior space.

3. Materials and Methods

This is a quantitative study and an applied-research in terms of objectives. Examining the hypotheses and answering them is conducted using computer simulation tools and logical reasoning. The performance of daylight and energy consumption for the main living space of a residential building in Isfahan are investigated based on the analysis of the window features and the relationship between them using the checklists resulting from the quantitative simulation analysis. The steps of this study are as follows: first, after studying valid scientific papers and databases in the field under discussion, the variable of the research and data analysis methods are determined, and then, all available scenarios for the optimal state of the window features in residential buildings are evaluated and analyzed by selecting a reference sample based on the assumed conditions. The research process includes two main steps which are illustrated in figure 1, from collecting inputs to extracting outputs, which will be explained in the following subsections. Eventually, the outputs are analyzed after processing to specify the variables' implications on the energy loads and daylight received by residents, the relationships between the variables and outputs and the main findings. DesignBuilder software with reliable engines, including EnergyPlus for thermal calculations along Radiance and Daysim engines has employed to simulate daylight. This software has been the focus of much attention due to having a wide archive of materials and mechanical systems and a simple graphical user interface. Also, Rhinoceros 3D and ClimateStudio plug in software have been applied to measure the glare index, which is explained in section 4.4.

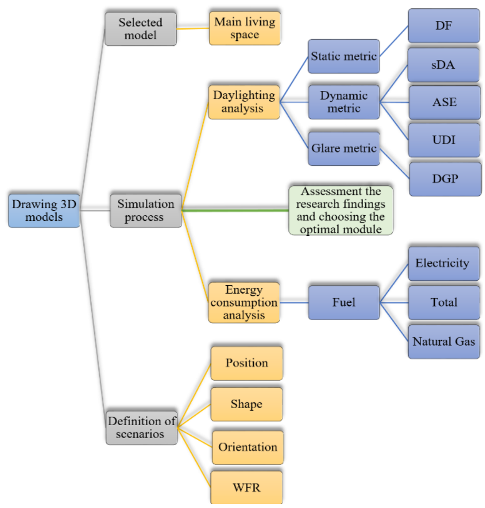


Figure 1. Process of implementing the research

3.1. Information about the model

The most commonly used buildings in most cities like Isfahan are residential. A basic sample should be applied to evaluate the effects of variables and simulate the scenarios due to the various types of residential buildings. The main living space of a dwelling unit is regarded as the reference model that has been used as a basic model to analyze the parameters under evaluation with a minimum surface area of 12 square meters based on the fourth issue of the National Building Regulations of Iran [29]. The common form and typology of residential buildings of 3×4 meters in dimensions and 2.85 meters in optimal height were used to make the results effective.

Other facades, such as the walls, ceiling, and floor of the main model, are adiabatic walls, and only one wall is considered to install windows and have contact with outdoors. The window-to-floor ratio (WFR) ranges from 10% to 90% with an interval of 10% (depending on the proportion and shape of the window). These windows face north and south and three types of window position, including at the bottom, middle, and top of the façade, were considered. Based on the studies, there are five shapes of a window, four shapes in a rectangular form with the ratios (1:2, 1:1.5, 1.5:1, and 2:1) and one shape in a square form with the ratio (1:1). Generally, 182 scenarios were used to evaluate (11 WFR, 5 shapes, 3 positions, 2 orientations). Figure 2 presents the description of the mentioned variables using an example. Double-glazed window with transparent coatings were selected. The residential space building of the unit is considered a thermal zone, where all simulation settings will be equal for each period during the year. Table 1 presents more information regarding the thermal conductivity of the building envelope.

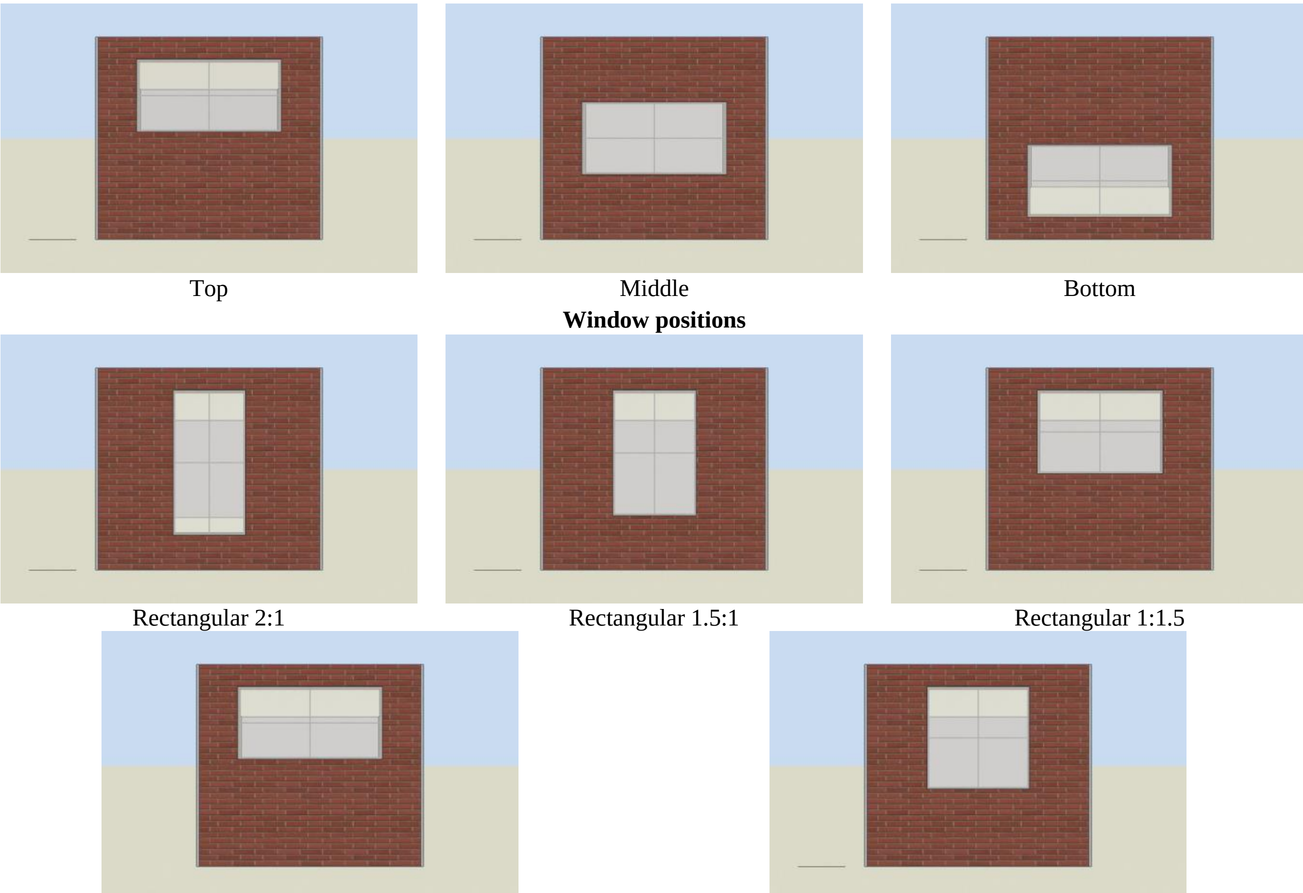


Figure 2. Building geometry with the specifications of the installed window

Table 1. Energy simulation parameters

Parameters	**Value(s)**
Activity	Domestic Lounge
Internal walls	Adiabatic
External wall	U-Value: 1.60 W/m^{2}k
Ground floor/Roof	U-Value: 1.69 W/m^{2}k
Window	U-Value: 2.70 W/m^{2}k, SHGC: 0.48, VT: 0.50
HVAC system	Fan-coil unit
Heating set-point/set-back	21 °C/12 °C
Cooling set-point/set-back	25 °C/28 °C
Occupancy	0.0188 people/m^2
Infiltration	0.7 ac/h
Lighting density	5 W/m^2

4. Findings

After determining the scenarios, two area-based datasets are measured, including thermal behavior in the cooling/heating sector, daylight performance in LEED v2 and LEED v4 sectors, daylight factors (DF), and useful daylight illuminance (UDI).

First, all simulation scenarios are evaluated based on the LEED v2, and the cases that obtained acceptable conditions are compared with the average DF index, and finally the optimum models are provided. All simulation scenarios are once again estimated according to the LEED v4, while models with the domain accepted by this certificate can be selected. Finally, the optimum models have been assessed based on the LEED v2/v4 to save annual energy consumption and the proposed options have been represented considering the ideal range of metrics and their relationships, then the annual glare index of the optimum module has been evaluated by DGP index to provide visual comfort of the residents.

4.1. Evaluation based on LEED v2

The output results are provided considering that settings during daylight simulation calculations are considered the same for all scenarios.

Figure 3 depicts the output data from the DesignBuilder software based on LEED v2 CREDIT 8.1. The standard condition, in this case, is to achieve at least 75% of the area of the occupied spaces, which possess enough daylight, and the illuminance will be more than the minimum threshold. This credit aims to identify designs providing an appropriate level of daylight for the residents.

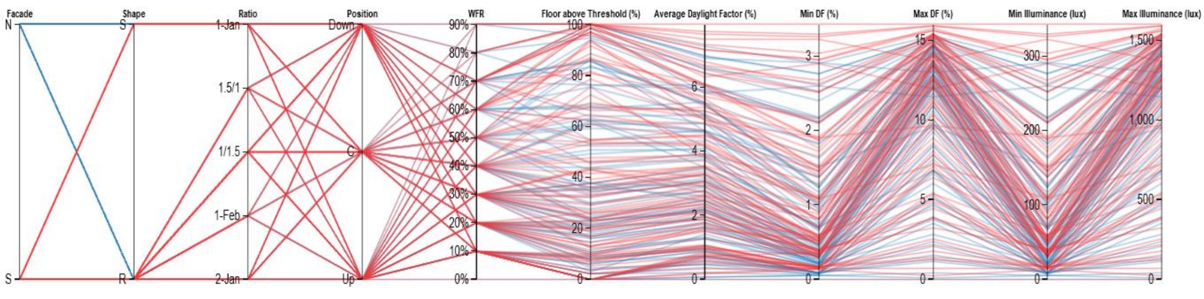


Figure 3. All scenarios based on the LEED NC 2.2.[a] Certification (obtained in Design-Explorer)

By adding this parameter into the outputs, only the scenarios evaluated in Table 2 can receive the adoption conditions.

[a]https://docs.google.com/spreadsheets/d/144fR55bP5kWzZYtSNOz7FNm6qpOSa1cB/edit?usp=sharing&ouid=111556142157952050954&rtpof=true&sd=true

Table 2. Data with LEED v2 CREDIT 8.1 standard

Façade	Shape	Ratio	Position	WFR	Floor Area above Threshold (%)	Average Daylight Factor (%)
S	R	1/2	Top	40%	75.385	3.85
S	R	1/2	Top	50%	93.846	4.952
S	R	1/2	Top	60%	100	6.301
S	R	1/2	Top	70%	100	7.475
S	R	1/2	Middle	60%	86.154	6.07
S	R	1/2	Middle	70%	98.462	6.772
S	R	1/1.5	Top	50%	93.077	5.51
S	R	1/1.5	Top	60%	98.462	6.537
S	R	1/1.5	Top	70%	100	7.151
S	R	1/1.5	Top	80%	100	7.634
S	R	1/1.5	Top	90%	100	7.945
S	R	1/1.5	Middle	60%	88.462	5.813
S	R	1/1.5	Middle	70%	96.923	6.405
S	R	1/1.5	Middle	80%	100	7.149
S	R	1/1.5	Middle	90%	100	7.718
S	R	1/1.5	Bottom	70%	80.769	5.694
S	R	1/1.5	Bottom	80%	99.231	6.661
S	R	1/1.5	Bottom	90%	100	7.312
S	S	1/1	Top	50%	78.462	4.98
S	S	1/1	Top	60%	91.538	5.626
S	S	1/1	Top	70%	96.923	6.072
S	S	1/1	Middle	60%	86.923	5.402
S	S	1/1	Middle	70%	96.923	6.036
S	S	1/1	Bottom	60%	81.538	5.153
S	S	1/1	Bottom	70%	96.154	5.994
N	R	1/2	Top	50%	86.154	4.622
N	R	1/2	Top	60%	98.462	5.802
N	R	1/2	Top	70%	100	6.887
N	R	1/2	Middle	70%	76.154	6.054
N	R	1/1.5	Top	50%	83.846	5.113
N	R	1/1.5	Top	60%	93.846	6.087
N	R	1/1.5	Top	70%	98.462	6.559
N	R	1/1.5	Top	80%	100	6.945
N	R	1/1.5	Top	90%	100	7.253
N	R	1/1.5	Middle	70%	83.077	5.875
N	R	1/1.5	Middle	80%	94.615	6.432
N	R	1/1.5	Middle	90%	100	6.964
N	R	1/1.5	Bottom	80%	76.154	5.919
N	R	1/1.5	Bottom	90%	95.385	6.626
N	S	1/1	Top	60%	75.385	5.071
N	S	1/1	Top	70%	86.154	5.491
N	S	1/1	Middle	70%	85.385	5.468
N	S	1/1	Bottom	70%	85.385	5.448

As observed, the average daylight factor (DF) of all the data is more than the minimum requirement of 2%, and a value higher than 5% of this factor represents the daylight illuminance and no need for lighting in the space, which is considered a potential factor for energy consumption, overheating in the summer, and thermal loss in the winter. Hence, the optimal pattern can be distinguished by adding the average DF parameter range, so that it is classified from green (efficient value) to red (inefficient value).

Accordingly, it can be mentioned that the optimum module based on the useful daylight illuminance is a window with 40% WFR and a south orientation, and its optimum position is at the top of the façade (the upper edge of the window is aligned with under the ceiling), so that the optimum conditions are obtained by being rectangular in shape and the ratio 1:2. Generally, according to Table 2 and based on the LEED v2 standard and the average DF, it can be concluded that 50% WFR is an appropriate value, and a rectangular shape with a 1:2 ratio, the south orientation and the top position are regarded as the optimum state.

4.2. Evaluation based on LEED v4

Dynamic daylight metrics allow users to assess the space illumination conditions and visual comfort during the year due to the consideration of the parameters of design, climate, and changes in the sky, followed by lighting changes based on the meteorological data. Figure 4 depicts the output of scenarios based on the dynamic daylight parameters by applying similar settings for the scenarios.

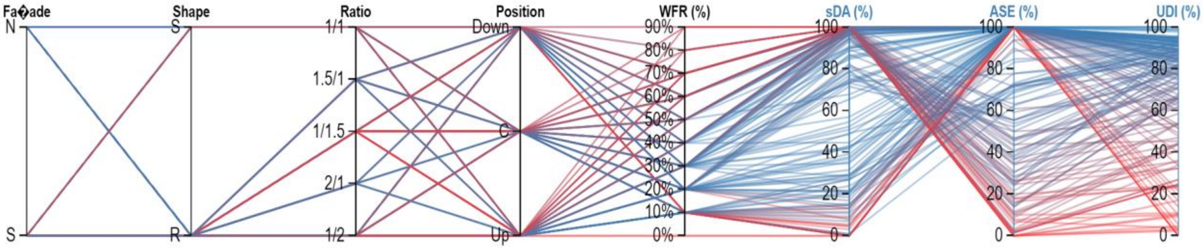


Figure 4. All scenarios based on dynamic daylight parameters[b]

LEED v4 is applied to connect the residents of the building with outdoors and reduce the use of lighting by penetrating daylight into the space. Two metrics of the spatial daylight autonomy (sDA 300lux/50%) of at least 55%, 75%, or 90% from the occupied floor area and annual sunlight exposure (ASE 1000lux,250hour) with the limitation of the occupied floor area above 10% are evaluated to adopt this certification. By selecting the range defined in Figure 5, the window can only be north facing owing to the importance of the ASE index; according to the solar diagram, direct sunlight during occupied hours does not disturb the north-oriented façade. Useful daylight illuminance (UDI) is used to determine the appropriate values with full lighting during the day by changing LEED v4.

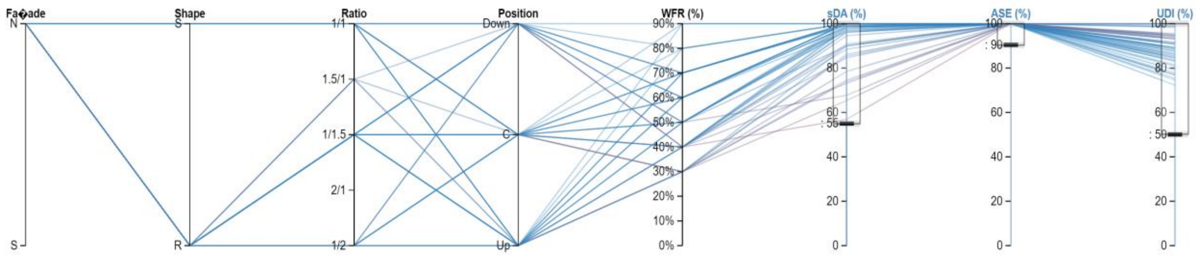


Figure 5. Scenarios selected based on LEED v4 and $UDI_{100\text{-}3000lx}$[c].

[b]https://docs.google.com/spreadsheets/d/1j5nhxcNw16RMnHxsh_NGbG8lAQszDVya/edit?usp=sharing&ouid=111556142157952050954&rtpof=true&sd=true

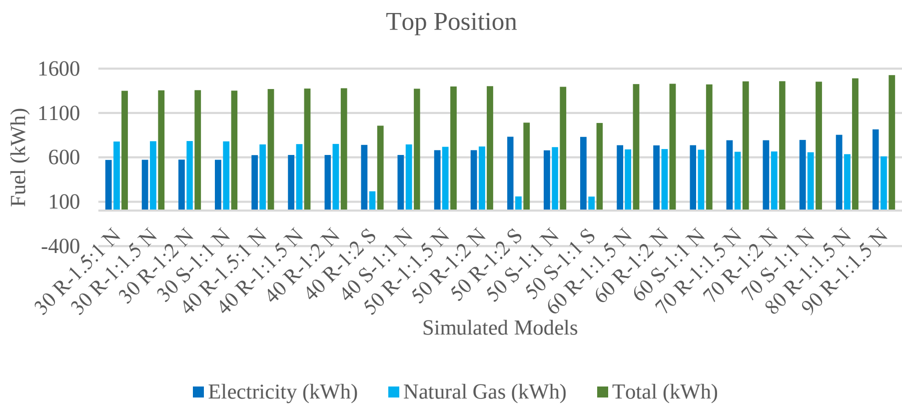
[c]https://docs.google.com/spreadsheets/d/1A6UeRMCcV7aXJKBJs0o3ccr8z51JY8Bt/edit?usp=sharing&ouid=111556142157952050954&rtpof=true&sd=true

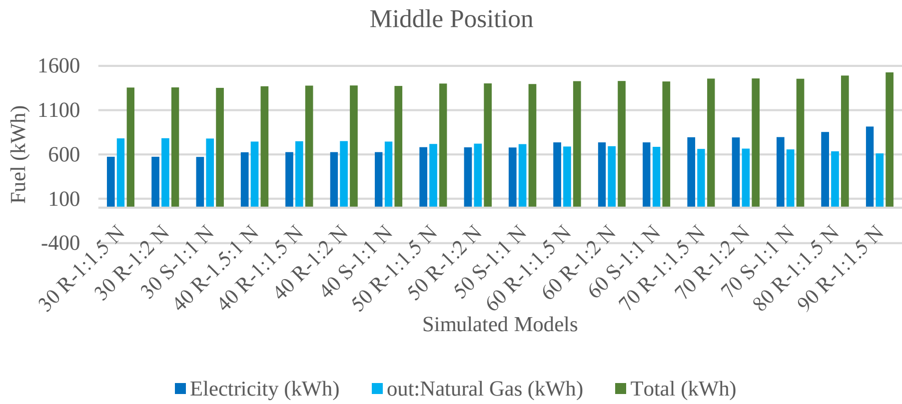
In general, for the parameters of a window due to the frequency of data in each section, it can be concluded that in the north-oriented façade, a rectangular-shape window with a ratio of 1:1.5 and 40% WFR and at the top position is the optimal case due to the LEED v4 domain.

It should be mentioned that owing to the simultaneous consideration of the adopted domain of LEED v2/v4, DF, and UDI, the most favorable design choice is a rectangular window with a ratio of 1:2 and 50% WFR at the top position of the north façade. After identifying the optimum scenarios due to static and dynamic daylight metrics, it is required to measure energy consumption.

4.3. Evaluation based on the annual fuel consumption

The limitation of fossil fuels, an increase in the annual growth of energy consumption in Iran, economic and technical inefficiency of energy consumption and energy loss and increasing environmental problems caused by it, have revealed the necessity of consumption management and the need for increasing the efficiency and productivity of energy more than ever. Figure 6 displays the amount of fossil fuels consumption by the cooling/heating system, artificial lighting, and hot water in four ratios (rectangular shape window with ratios of 1.5:1, 1:2, and 1:1.5, and square shape in a ratio of 1:1) for the optimum models in the daylight section.





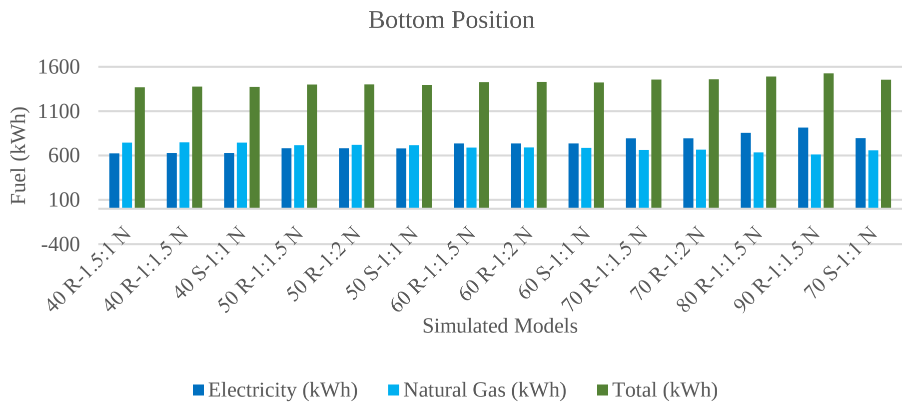


Figure 6. Annual energy consumption in the optimum models according to the daylight (EX: **30**: WFR **R-1.5:1**: Shape-Ratio **N**: Façade)

Overall, the energy consumption in the south façade is much lower than that in the north one, and the difference between the lowest energy consumption in the two cases is 393.5 kWh. Therefore, the lowest amount of consumption (957.29 kWh) is assigned to the 40 R-1:2 S windows at the top position, while the 30 R-1.5:1 N window at the top position is also feasible and suitable in the north orientation. By increasing WFR, electricity consumption has a growing trend and even the north façade responds positively. In other words, the cooling system uses less energy to reach a comfortable temperature. On the contrary, in addition to the south-facing window, which has a good performance for gas consumption, north-facing windows with higher WFR have more flexibility and only consume less natural gas energy. It is worth mentioning that from 60% WFR, there is an increase in electricity consumption and a reduction in gas consumption, respectively; however, the WFR less than this value exhibits the opposite behavior. The lowest amount of electricity is related to 30 R-1.5:1 N at the top position and the lowest amount of gas consumption is associated with 50 S-1:1 S at the top position, which are equal to 572 and 988.2 kWh, respectively. The WFR variable is placed after the window façade (orientation) variable, which has the most impact on the total energy consumption, and window position indicates noticeable changes against energy storage. Table 3 presents the options of the optimal design with the values of daylight metrics and energy consumption. For bold cases, it is necessary to obtain a valid range in the daylight section by providing arrangements.

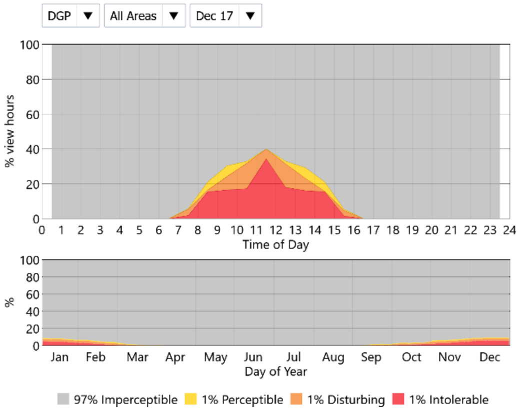
Table 3. Design options based on the evaluation

Model	Position	$DF_{average}$ (%)	Floor Area above Threshold (%)	sDA_{300lx} (%)	ASE_{1000lx} (%)	$UDI_{100-3000lx}$ (%)	E_{Total} (kWh)
40 R-1:2 S	Top	3.85	75.38	100	10	43.8	957.29
50 S-1:1 S	Top	4.98	78.46	100	5.4	44.6	988.2
30 R-1.5:1 N	Top	2.75	30	74.6	100	95.4	1350.78
30 S-1:1 N	Top	2.9	37.69	90	100	98.5	1353.06
50 R-1:2 N	Top	4.62	86.15	99.2	100	100	1403.11

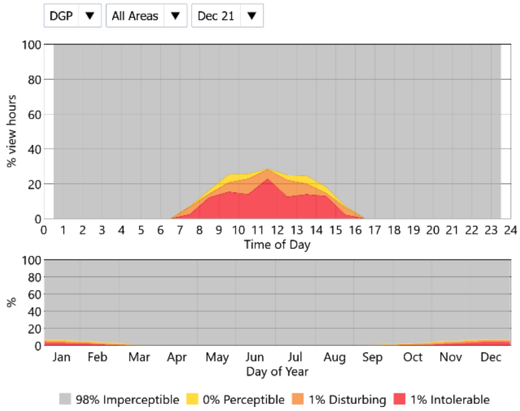
4.4. Assessment of discomfort glare

Calculation of the glare index is required to provide an environment in which users feel comfortable in terms of daylight. The factors affecting the understanding of discomfort glare are classified under source of flare brightness, match level, contrast effect, and size and position of the source of glare

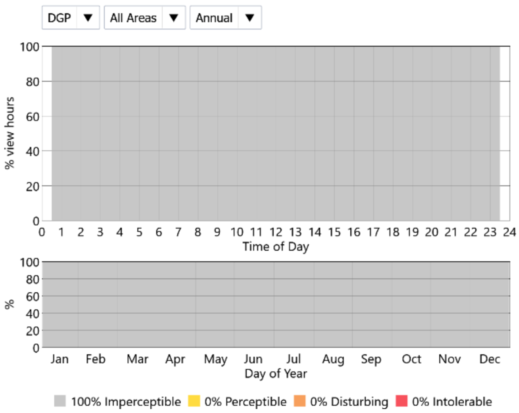
[30]. Thus, annual glare is conducted in Table 3 to examine the visual comfort in the space using the ClimateStudio plugin in the Rhinoceros 3D environment for the optimum models. The glare index is calculated in this plugin based on the daylight glare probability index (DGP) developed by Weinold and Christoffersen [31]. A total of 35 sensors were employed at a distance of 1.2 m from the occupied floor area to simulate the annual glare.



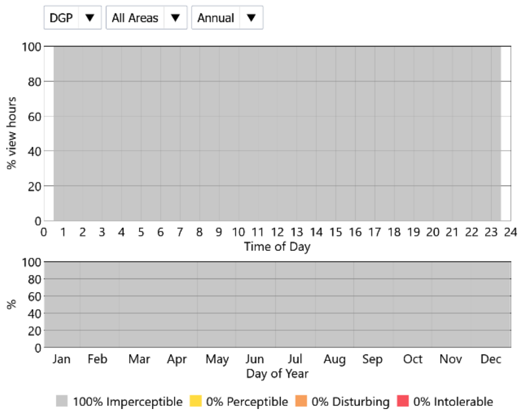
40 R-1:2 S



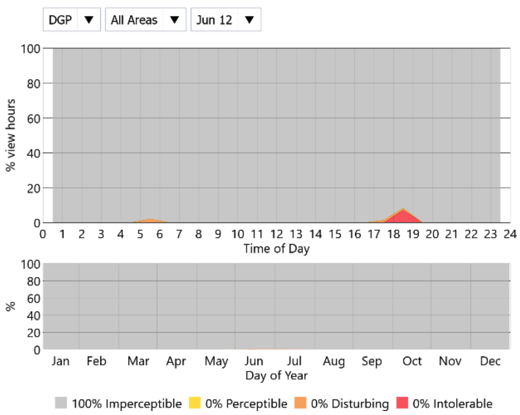
50 S-1:1 S



30 R-1.5:1 N



30 S-1:1 N



50 R-1:2 N

Figure 6. DGP values of the occupied area for the optimum models

Figure 6 shows the annual glare for all five optimum states. According to the data analysis, there is an insignificant discomfort from daylight in the north-oriented façade, and glare is observed only in 50 R-1:2 N models with horizontal window shapes in the early hours of the morning and afternoon, especially at 18:30. This tangible glare occurs in the areas near the window and in June. Two other models behave intangibly in the months of the year. Obviously, the south façade has a glare in the space with sunlight exposure, and the residents feel discomfort. In December, both 40 R-1:2 S and 50 S-1:1 S models make intolerable glare in the space around noon, especially at 11:30, and the hours in which the observer is exposed to the vertical illuminance from the visibility are more in the first model. As Figure 6 shows, there is a glare in the occupied space in both models with south-facing windows from January to March and October to December, and in other months, the glare is imperceptible.

This study has investigated the general requirements of daylighting based on the fourth topic of National Building Regulations for main living space of a residential building. The minimum area of this space and its glazing to floor ratio are 12 m^2 and 1:7, respectively. According to the common form and typology of the main living space mentioned in the topic with 3×4 m of dimensions and 2.85 m in height, these dimensions were considered as a reference model. The WFR, shapes, and position of the window in the south- and north-oriented façades were estimated and the ratio of 1:7 or 14% of the transparent surface of the national regulations must be developed, in addition, the climate issue is also significant.

5. Discussion

Data analysis indicates that considering the parameters affecting the window can lead to the optimal performance of daylight and energy saving. By comparing the current study to studies conducted on the positioning of windows, it can be found that in areas classified as zones 1 and 2 in the ASHRAE classification, installing the window on the north façade has the highest efficiency for saving energy, and then placing a window on the south façade provides more energy saving. However, in areas classified as zones 3 to 5 in the ASHRAE classification, placing the window on the south façade indicates the highest efficiency for energy saving [22]. By reviewing the mentioned article, it can be found that the ratios of 20% to 40% for the window area to the façade area are considered acceptable ratios. However, if the window area to the façade is more than 50%, it has an insignificant impact on reducing the consumption rate in the lighting sector, and it significantly affects the increase in cooling load [6]. Moreover, according to the results of another study evaluating the effect of the position and dimensions of the window on energy consumption, horizontal windows affect more energy saving than other forms, and windows with a position higher than the center create a better spatial daylight autonomy in the intended space [20]. By comparing the results of this study presented in Table 3, it can be stated that placing windows on the north façade with 30% WFR and vertical elongation at the top position and with 40% WFR and horizontal elongation at the top position of the south façade are among the most efficient design options. The reliability and validity of the results are determined by reviewing the previous studies. In terms of daylight metrics and the LEED v2/v4 standard, the 50 R-1:2 N model at the top position achieved acceptable results, so that designers can derive the advantage from this model as an ideal option.

The aim of the current study is to create an innovative approach to the general requirements for daylighting the main living room of the residential space, in which the efficiency of daylight and thermal behavior are calculate by dynamic simulation scenarios. While improving the efficiency of daylight and energy consumption, this approach suggests the optimum models using the conventional window features. Despite the new findings, there are limitations that should be considered. Although the data was collected by creating an unreal residential space, it should be compared with empirical findings in direct use of buildings. In addition, the performance of the optimum model to achieve a low-energy building is limited and other elements should be examined. Therefore, an appropriate platform is provided for research and countless researches can be covered for validating the optimum model using a wider sample of buildings. Research has also been conducted on this study [32, 33] and design models can be provided.

6. Conclusion

Appropriate design of windows and identification of its favorable features can significantly affect daylight efficiency, the residents' health, and utilization of the energy required in the building. In the present study, the impact of daylight on the residents of the space and the consumption of the energy obtained from the fuels generating electricity and natural gas in Isfahan for a dwelling unit were measured by evaluating window variables, including rectangular and square shape, WFR, and position in both north and south-oriented façades. The models were defined using the DesignBuilder software by simulating them, and then the outputs were assessed with each other and respond to the research objectives.

After selecting the reference model and performing the simulation process, the data were analyzed based on the daylight performance, and then the results were discussed. The findings of simulating daylight, along with its related metrics, represent the optimal effect of the window components and the selection of models meeting the conditions of these metrics. Typically, the WFR with higher values receives the LEED v2 certification. Two parameters of window position and ratio significantly affect the selection of optimum modules, and the daylight reaching the floor of a room at a distance of 0.75 meters from the ground floor (the height of the work-plan) is associated with the parameters. The façade of the building in which the window is installed has the most impact on choosing the optimum module with LEED v4 conditions, and all intended models were effective and efficient. Except for the ASE index, which had an effective association with the window orientation, two sDA and UDI indices after the façade of the building were significantly associated with the horizontal rectangular/square shape and the position of the window, respectively. Hence, by considerin the subjects discussed, the selected models entered the simulation process of energy consumption.

The findings of the annual consumption of energy carriers imply that among the window components, the effects of the building façade and WFR are well represented as the first options, and the north-oriented façade, placed in the cold body of the building, will have high energy consumption. In other words, the heating system must consume considerable gas in the winter until the indoor temperature reaches the comfort point and the residents are satisfied. The horizontal and vertical ratios are appropriate in south and north orientations, respectively; therefore, altering the window position appears tangible. As the first finding, 40 R-1:2 S and 30 R-1.5:1 N models at the top position are considered the most efficient and effective options in designing two south and north-oriented facades.

Window geometry is crucial in designing the building façade. Designers can employ window framing ideas to design an appropriate façade. In areas with changing climates, although buildings possess specific strategies and approaches to respond to climatic conditions, the implementation of window framing plans can be employed as an effective factor. Thus, in residential buildings, regarding the occupation of space and the unlimited time that people spend in it than in other buildings, the installation of suitable and practical windows with various geometries will be cost-effective in terms of energy consumption and quality of the natural light entering the space.

Declaration of competing interest

The authors declare no conflict of interest.

Nomenclature

AFs	Adaptive Facades
ASE	Annual Sunlight Exposure (%)
ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
DA	Daylight Autonomy (%)
DF	Daylight Factor (%)
DGP	Daylight Glare Probability (%)

EIA	U.S. Energy Information Administration
g-value	Total Solar Energy Transmittance
IEQ	Indoor Environmental Quality
LEED	leadership in Energy and Environmental Design
Low-E	Low Emissivity Glazing
sDA	Spatial Daylight Autonomy (%)
SHGC	Solar Heat Gain Coefficient
Tvis	Nominal visible transmittance
UDI	Useful Daylight Illuminance (%)
U-Value	Thermal Transmittance (W/m²·K)
WFR	Window-to-Floor Ratio
WWR	Window-to-Wall Ratio

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