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Determining the Proportions of the Living Room to Optimize the Daylight Case Study: A Building with a Common Plan in Tehran

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Abstract

Space geometry design is the first stage of proper daylight design. The basic ideas of form and space design should provide the best conditions for daylight. This article investigates the effect of living room proportions on the amount of interior lighting received in Tehran's residential buildings. In the first step, the information from literature related to daylight was studied. In the second step, a checklist has been compiled to examine the space based on daylight from the classification and summarization of the information obtained from the research background. Based on this theoretical framework, one of the houses in Tehran with a common plan was selected as a case study according to daylight design indexes to achieve the goal. In the third step, the problem was determined, and then the solution was provided by simulating using applied models and software. The modeling process and changing the geometric variables were performed parametrically with Grasshopper software, and daylight simulation was performed by Radiance and Daysim software. Thus, the intensity of annual illumination is examined in the current situation to optimize the illumination conditions; the window of this space is optimized by maintaining the optimum ratio of this window, the optimum space proportions obtained. The survey has shown that in optimal condition, the ratio of length to depth in the living room is 1.54 to 1.91, and the WFR ratio is 9% to 22%. Thus with the values obtained, the living room will have the best thermal and lighting performance during the year. In addition, with the optimal percentage of the window to the floor, appropriate shading device, and optimal dimensions of the room, this space can provide suitable light for various daily activities in a multi-purpose living space.

Keywords: Proportions, Living room, Residential, Daylight, Tehran

1. Introduction

Iran is located in a region with one of the highest levels of solar energy in the world. The amount of solar radiation in Iran is estimated to be between 1800 and 2200 kWh, above the global average (Safaii, 2005: 27-44). Observation of contemporary Iranian architectural works has shown that engineers' interest in energy saving in the lighting sector has decreased. Electricity is one of the most critical and expensive types of energy, but, unfortunately in underdeveloped countries, its consumption is increasing unbelievably and irrationally. In most of these countries, there is no clear strategy for reducing consumption. The annual average of Iran's electricity consumption is about 100 kWh, and about 40% of this figure is allocated to the construction sector (Heydari, 2012: 15-18). Studies have shown that most of the building's energy sources are spent on lighting, heating, and cooling, with 47% of the electricity consumed only for home lighting (Ahadi, 2016: 41-50). Demand for housing has increased today with the growing population in metropolitan areas such as Tehran. Many apartment residential projects are affected by many factors, have low quality. One of these qualitative factors is paying attention to daylight. Considering the living environment's quality factors including daylight in cities such as Tehran is more critical due to buildings' compactness and air pollutants that reduce access to adequate daylight (Ahadi, 2016: 41-50). Research shows that the amount, intensity, type of source, direction, and distribution of light in different human activities and environments can significantly affect people's behaviors and productivity (Shahparnia, 2019: 65-80).

Therefore, according to the above discussion, while considering lighting in architectural design to reduce energy consumption, accessing optimal daylight in space based on its performance at different times of the day and in different seasons is desirable. In addition to accessing the daylight in a multi-purpose living space in residential buildings, the amount of light is provided, and access to it is commensurate with the activities performed in this space during the day. This research aims to explain the optimal proportions of this multifunctional space to achieve the desired amount of light for conventional activities in this space after optimizing the windows' dimensions and area.

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2. Research & Theoretical Fondation

Extensive studies of daylight and its optimum utilization have been conducted for many years. Regarding lighting in architecture, the research includes books, articles, and dissertations that are done domestically. The light types, quality, and quantity, natural and synthetic light computing can compile in light physics. In addition, daylight control and transmission technology, architectural and lighting special considerations, and daylighting have been investigated in researches such as Heidari, 2012; Tahbaz, 2013; Ghiabakloo, 2013; Namdari, 2016, Alborzi 2017, Inanlou 2017, Fazeli 2019 Articles related to an analysis by daylight simulation software include the effect of architectural design on the naturalistic play, correct window design, optimal window surface, and proper orientation by Tahbaz 2015, Ahadi 2013, Fayaz 2013 Miri 2013, Esmailian, 2014 are presented. Research that has been carried out overseas so that older articles are concerned with the window design in size, direction, and area for administrative and educational use. In recent research, the relationship between window and space has become apparent as it relates to window-to-floor ratio, window-to-wall ratio, reduced energy consumption, and visual comfort by Matusiak 2006, Ihm and Krati 2012, Lee 2013, Syed Fadzil 2013, Huang 2014, Acosta 2016, Nedhal 2016 investigated. Related dissertations such as Poornaseri, 2011 and Maleki, 2017 were done to optimize daylight, which is done to the geometry of the space, window position, and time of use. Also, the existing standards in relation to windows, the nineteenth chapter of the national building regulations states the amount of external light into the wall surface to receive sunlight, and the fourth chapter of the national building regulations states the required glass surface.

According to reviewed sources, Table 1 summarizes the data related to the subject under study in recent years. The studied parameters are mentioned in these sources (Existence with a symbol ✓ and non-existence with a symbol ×).

Table 1
Summary of resources related to the subject under review in recent years

Resources		Optimal window level	Considered parameters						
			city Climate	Building Neighborhood	Building Function	Levels	Material	Function	
								Thermal	Lighting
Articles	Ahadi, 2013	84.2% of the total surfaces, 20% of the window	✓	✓	✓	✓	×	×	✓
	Fayaz, 2013	Double glazed window 15% single glazed 20%	✓	✓	✓	✓	✓	×	✓
	Acosta, 2016	Geometry and position of the window	✓	✓	✓	×	×	✓	✓
	Nedhal, 2016	Window level to floor level less than 10%	✓	✓	✓	✓	✓	×	✓
	Syed Fazil 2013	25% -50% of the window surface to the wall 17% -35% window level to floor level	✓	✓	✓	×	✓	×	✓
dissertation	Poornaseri, 2011	The physical variable of windows in Tehran schools	✓	✓	✓	×	✓	×	✓
	Maleki, 2017	Tehran office plan patterns, space geometry, window position, time of use	✓	×	✓	×	✓	×	✓
Books	Heidari, 2012	Properties of windows, shadings	×	×	✓	×	✓	×	✓
	Tahbaz 2015	Window size Illumination amount	×	×	×	×	✓	✓	✓
	Ghiabakloo 2013	Proper distribution of daylight to form, direction	✓	✓	✓	×	×	×	✓
Standard	Chapter Four National Building Regulations	One-eighth floor level	×	×	×	×	×	×	×
	Chapter Nineteen National Building Regulations	1.9 of floor, 25% wall surface	×	×	×	×	×	×	×

Therefore, according to the subject under study, some parameters have not been considered in the mentioned sources. Nevertheless, in the present article, the climate parameters of the city, neighborhood, function, levels, and building materials of the same building for the whole year in terms of both heat and lighting are considered the percentage of each window to the floor level for each floor of the proposed building.

3. Research Methodology

The present study is a kind of applied research in the sense that it is used to meet human needs, improvement and optimization for development, welfare, comfort, and improvement of human living standards and is a type of developmental research in a variety of applied research. This is done to develop and improve existing systems that are quantitative and have numerical data. This study seeks to determine the optimal proportions of the living space for optimal use of daylight; in other words, the intensity of light required by the space based on the type of use in a percentage of times used by the building per year. Thus, the values of space proportions and light intensity are both quantitative variables.

Concerning natural light and residential space, numerous Persian and Latin books, publications and articles, and standards were collected in information libraries. Then, summarizing and classifying the information collected from the research background, the data theory theorizing method was used to find the design indicators, the study area, and the case study specifications based on the theoretical components of the research, and a theoretical framework was formed. In the next step, quantitatively and using the computer simulation method, the case study was analyzed. First, the current situation through software modeling and brightness was analyzed for determining the problem. Then, software modeling, optimization, and lighting analysis have been done to refine the solution (Figure 1). Thus, the process of modeling and changing the geometrical variables parametrically was performed by the Grasshopper software 0076, 9, 0. Using this software, all possible modes for creating the geometric form are defined. Then, daylight simulates by the Radiance software 0, 1, 5 and Daysim 08,1. To evaluate the dynamic daylight, such as; daylight autonomy computation, spatial daylight autonomy, and proper annual illumination), the parametric model (output geometry of the generating algorithm) and Daysim software materials were defined. This research considers Tehran's conditions and climates to determine the dynamic daylighting needs of multi-purpose space and optimum daylight utilization. First identifies deficiencies and problems with providing daylighting in one of the most common residential buildings in Tehran; afterwards, annual illumination analysis in the present case was investigated, and due to the low lighting of the space, the window of this space was first optimized in terms of thermal performance and lighting. Then, by keeping the window ratio constant, the room's proportions are examined, and finally, the optimal state of these proportions is obtained. To make the best and most of the daylight in this space, we have created shading devices to prevent glazing. Different functions of the space characterize this desirable space. Finally, a multifunctional gathering space is proposed with a particular focus on maximizing daylight.

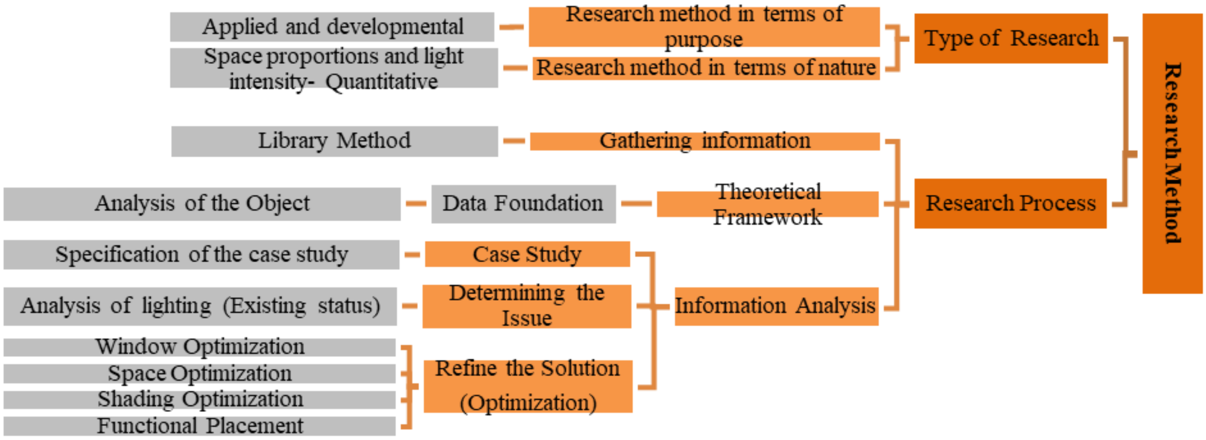


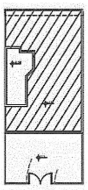
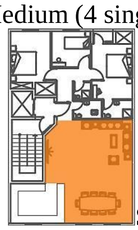
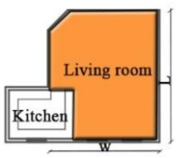
Fig. 1. Research method process

3.1 Theoretical aspects of the research

In the metropolis of Tehran, the compactness of the buildings has reduced access to daylight. For this purpose, in a previous study by the authors of this article, the 22 areas of Tehran based on daylight design criteria outside the building (urban context, building height, and direction of passages) are divided into several species by the grounded theory method. Data is collected through libraries, a study of documents, and maps of each region. Finally, according to the design criteria of daylight outside the building of Area 4, District 5, the Tehran Pars neighborhood has a higher frequency in these indicators than other areas. The example studied in the present article is a 4-story building in Tehran, located in District 5 in the Tehran Pars neighborhood.

This case study's specification based on daylight design indices outdoors and indoors is given in Table 2. In terms of daylight design features outside the building, this building is in a medium texture (The age of the building), medium height, and east and west side passages. The facilities located near it had similar conditions to the building under review. The passage pattern of these buildings is east west, and the height of buildings in this neighborhood is moderate. It often has 4, 5, and 6 story buildings. The simulation process was performed for the living room on the first to fourth floors of this residential building. The south side of the building has a window. The specifications of this sample, including dimensions and proportions and the room's direction, and the window position, sizes and balances, the type of glass, and its surface, can be seen in Table 2. In addition, the ceiling, floor, wall, and window specifications are listed in Table 4. Optimization for optimal lighting intended for residential use and its functions. The kitchen next to this space is not considered. However, because the kitchen has no walls and is openly designed, it has affected the living room lighting. That is why the effect of the kitchen window on the living room has been seen.

Table 2
Specifications of a 4-story building in West Tehran Pars district

<table>
<tr><td rowspan="7">The Case Study</td><td colspan="18">Outdoor light design features</td></tr>
<tr><td>Context</td><td colspan="5">Passage pattern</td><td colspan="12">Height</td></tr>
<tr><td>Middle</td><td colspan="5">East and West side alley

Sc:1/800</td><td colspan="12">Medium (4 single unit story building)

Sc:1/500</td></tr>
<tr><td colspan="18">Indoor light design features</td></tr>
<tr><td rowspan="3">The pattern of leaving room plan</td><td colspan="5">Space</td><td colspan="12">Window</td></tr>
<tr><td>Pla n</td><td colspan="3">Dimensions</td><td rowspan="2">Direction</td><td colspan="4">Location</td><td colspan="6">Dimensions</td><td colspan="2">glass</td></tr>
<tr><td>Layer position</td><td>length and width</td><td>height</td><td>Length to width ratio</td><td>Light type</td><td>Direction of light</td><td>Distance from floor</td><td>Distance from ceiling</td><td>length and width</td><td>Length to width ratio</td><td colspan="4">Window alignment</td><td>Type</td><td>Area</td></tr>
<tr><td>West Tehran Pars district 4-story building</td><td></td><td>First and middle</td><td>L:5.25m w:8.07m</td><td>2.76m</td><td>0.6</td><td>South</td><td>grade 1</td><td>South</td><td>0.36m</td><td>0.40m</td><td>1.20m*2.00m</td><td>0.6</td><td>First Level: 3.06m</td><td>Second Level: 6.12m</td><td>Third Level: 9.18m</td><td>Fourth Level: 12.24m</td><td>Double glazed window</td><td>2.06m^2</td></tr>
</table>

3.1.2 Simulation and lighting conditions

Analysis of annual lighting by dynamic daylight indices, such as daylight autonomy[1], spatial daylight autonomy[2], and annual proper illumination,[3] is shown in table 3.

[1] The percentage of time during the active occupancy hours that the test point receives more daylight than 300 lux

[2] The percentage of analysis points across the analysis area that meets or exceeds daylight illumination thresholds value (set to 300 lux for LEED) for at least 50% of the analysis period

[3] The percentage of time during the active occupancy hours that the test point receives between 300 to 900 lux

Table 3
Assess the intensity of natural light according to human visual needs in various activities

Intensity of light	Lighting status	Conditions requiring auxiliary artificial lighting
Less than 100 lux	Insufficient lighting	Requires electric lighting
100 to 300 lux	Relatively insufficient lighting	Need extra lighting in some situations
300 to 900 lux	sufficient lighting	No need for extra lighting
900 to 2000 lux	Excellent lighting	No need for extra lighting
More than 2000 lux	possibility of glare	Need to control glare in some situations

(Nabil, 2005: 41-59)

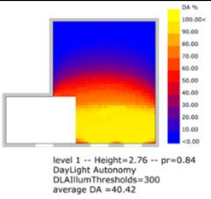
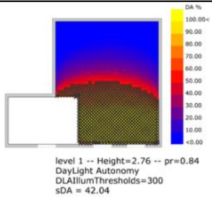
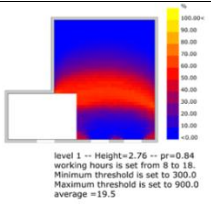
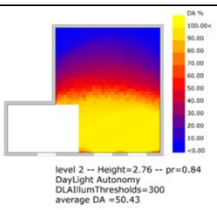
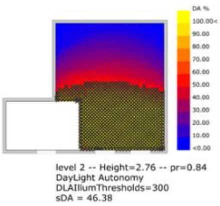
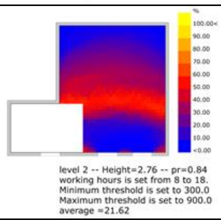
A 20 x 20 cm grid at the height of 70 cm above the pavement is considered to analyze the selected area's annual illumination. The time of the whole year is set for the hours of sunshine in the sky. The materials used in different space levels such as ceiling, floor, walls, and windows are specified in the case study in Table 4. Neighbors are also considered according to the similar characteristics of the case study.

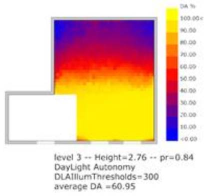
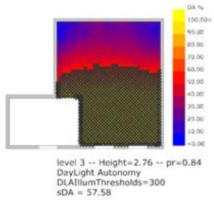
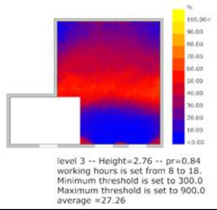
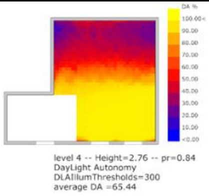
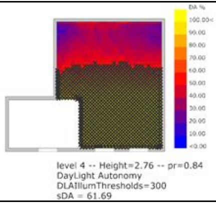
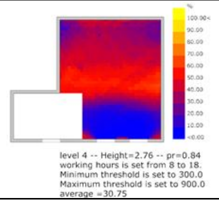
Table 4
Specifications of materials used in different levels of space in a four-story building

Space surfaces	Scattered reflection factor	roughness factor	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

3.2 Findings of the research
3.2.1 Analysis of the annual lighting conditions of the gathering space in the current status:
Dynamic daylight indices calculated the annual illumination analysis; daylight autonomy, spatial daylight autonomy, and proper daylight illumination in the gathering space in 1 to 4 levels. The results of this analysis can be seen in Table 5.

Table 5
Analysis of the annual lighting of the living room for a 4-story building in the existing status

Case study	Analysis of the annual lighting in the existing status			
	Floors	Daylight autonomy(DA_{300})	Spatial daylight autonomy(sDA_{300})	Useful daylight illumination($UDI_{300-900}$)
West Tehran Pars district 4-story building	First Floor	 	 	
	Second Floor	 	 	

	Third Floor			
	Fourth Floor			

In the annual analysis in the autonomous part of daylight, each floor's illuminance analysis grid is specified by the color spectrum. It represents a percentage of the year where space's illuminance is at least 300 lux. It was observed that the first floor is 36.15%, the second floor is 45.06%, the third floor is 54.49%, and the fourth floor is 58.60%. Therefore, the higher the levels, the higher the index. The spatial autonomy daylight is likewise specified in the second column and represents the percentage of points in space that most of the year has an illuminance of more than 300 lux. The higher this percentage, the greater the percentage of area with an illuminance of more than 300 lux, and it is more desirable in terms of lighting. Space points have been identified in the analysis grid and observed in the floors with different values, with the upper floors having more of these points. Finally, the UDI index value, representing the percentage of the year where space's illuminance is between 300-900 lux in the lighting range, is acceptable. Proper annual lighting is defined here. According to Table 5, daylight indices have low amounts on the 1st to fourth floors. Due to these values in the third and fourth floors, the building's lighting and proportions compared with the first and second floors in this form of plan and ratios were generally not desirable. According to Table 6, the values of daylight design indicators are increasing from the first floor to the fourth floor, so as the height increases, the space's brightness increases. On the fourth floor (last floor), the indicators' values are higher than the other floors. It is concluded from the values of sDA index that at least %42.04 and at most %61.69 of the points of the living room in this building have to daylight. Therefore, on none of the floors, the whole space was illuminated. UDI index values have also shown that the proper light intensity (300 to 900 lux) in floors one to four is at least %19.50 and at most %30.75.

Table 6
Comparison of the annual lighting in the living room for a 4-story building in the existing status

	Floors	Daylight indices			
		DA_{300}	sDA_{300}	$UDI_{300-900}$	
Analysis of the annual lighting in the existing status	First	40.42%	42.04%	19.50%	⇨ The higher the floor, the brighter the space
	Second	50.43%	46.38%	21.62%	
	Third	60.95%	57.58%	27.26%	
	Fourth	65.44%	61.69%	30.75%	

As a result, space is not in a good position in terms of lighting. In the present case, in general, the total brightness in each of the spaces includes sufficient light (900 lux> brightness> 300 lux), insufficient light (300 lux> brightness), and glare (brightness> 300 lux) (Figure 2). Therefore, to solve this problem and improve the lighting situation, optimization is done. Therefore, the window is optimized first, and then space is optimized.

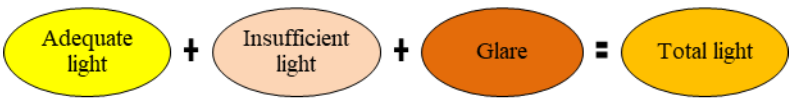


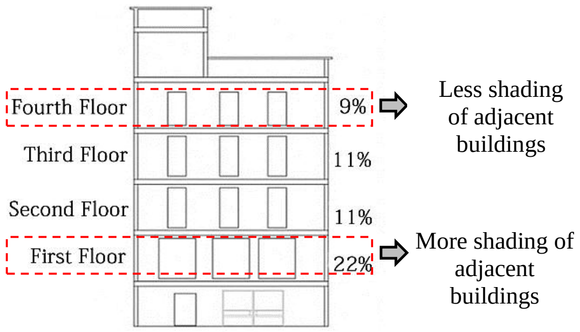
Fig. 2. The amount of light in the living room for a 4-story building in the existing status

3.2 Optimization of the sample window studied

Building window modeling process based on light and heat energy consumption with three Main sections: 1-Lighting calculation and definition of input parameters; 2-Thermal calculation and description of input parameters; 3-Optimization process and definition of the objective function and its variable parameters. The optimization procedure for all available modes has been calculated and optimized to minimize the thermal target function and maximize the lighting target function for different states of window dimensions on the room's south face. In the window dimension optimization section, the variables are the window length and height. The objective function of the window dimension optimization is considered in both lighting and thermal groups. In window optimization, assuming the window's center is held constant, the window starts to reduce and increase from the four sides (top, bottom, right, and left). Furthermore, in this process, the window length is at least 24cm (from 0.2 available sizes) to a maximum length of 4.08m (full size that does not interfere with the next window) by 24cm in each interval, and the window height is at least 40 cm (from a percentage of available size) to 2.40 m (maximum of 0.9 floors to ceiling) changed by 40 cm per interval in each window.

Due to the public space's unfavorable lighting in the existing building, the window of this space on the first to fourth floors has been optimized. Table 7 shows that the ratio of window level to floor level (WFR) on the first floor is 22%, the second floor 11%, the third floor 11%, and the fourth floor 9%. Therefore, the percentage of window area to floor level on the first floor has the highest value (due to shading of adjacent buildings) and the lowest value on the fourth floor (due to less shading).

Table 7
Functional placement based on the intensity of illumination required for various indoor activities

	Floors	Condition	Window to Floor Ratio (WFR)	
Window Optimization	First	Existing	11.4%	
		Optimum	22%	
	Second	Existing	11.4%	
		Optimum	11%	
	Third	Existing	11.4%	
		Optimum	11%	
	Fourth	Existing	11.4%	
		Optimum	9%	

According to Table 8, the window length was increased on the first floor. It has increased from 1.20 meters to 1.9 meters on the first floor, and on the second, third, and fourth floors decreased from 1.20 to 0.96. As a result, the total size of the three windows has been reduced. Nevertheless, the height of the first, second, and third-floor windows is longer than the existing one, and it has reached 2.40 meters from the height of 2.00 meters. Finally, the fourth-floor window height is equal to the existing state's height because it can obtain the desired illuminance with the same size.

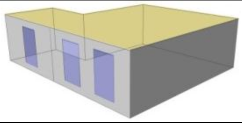
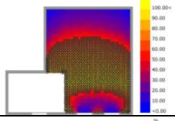
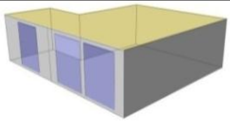
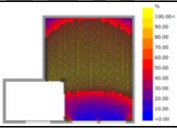
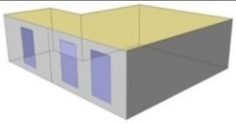
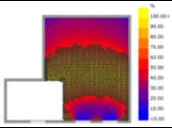
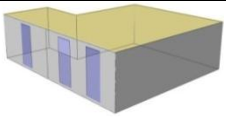
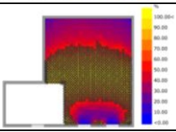
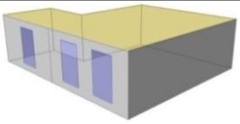
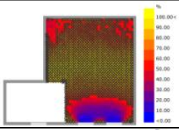
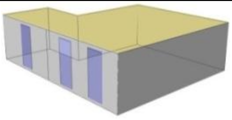
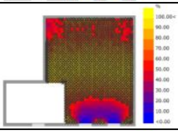
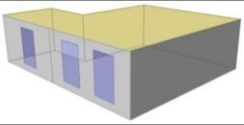
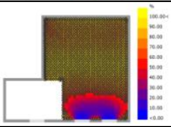
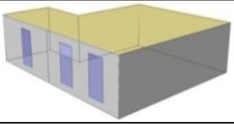
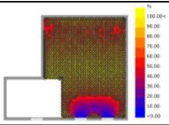
Table 8
Available and optimal state lighting and thermal values

Level	Condition	Window length	Window height	Total window length	Window to floor ratio	Thermal Target Function	Lighting Target Function	Target function
First Floor	Existing	1.20m	2.00m	3.60m	11.4%	69.91	-73.59	-3.67
	optimum	1.90m	2.40m	5.76m	22%	64.70	-93.64	-8.94

Second Floor	Existing	1.20m	2.00m	3.60m	11.4%	64.34	-76.71	-12.37
	optimum	0.96m	2.40m	2.88m	11%	63.69	-82.10	-18.40
Third Floor	Existing	1.20m	2.00m	3.60m	11.4%	61.17	-96.52	-35.35
	optimum	0.96m	2.40m	2.88m	11%	60.30	-99.34	-39.04
Fourth Floor	Existing	1.20m	2.00m	3.60m	11.4%	60	-96.90	-36.90
	optimum	0.96m	2.00m	2.88m	9%	56.62	-100	-43.38

As a result, increasing the height and decreasing the window's length in the optimum state, the light distribution, and the depth of light penetration in each building floor increased. The window is optimized in thermal and lighting performance by reducing the window length and decreasing the thermal load.

Table 9
Distribution of window illumination in the available and optimal state on the floors of the building

Levels	Window status		Lighting distribution		
	Condition	Perspective of Space	sDA		WFR
First Floor	Existing			53%	11/4%
	Optimum			68.32%	22%
Second Floor	Existing			52%	11/4%
	Optimum			56%	11%
Third Floor	Existing			78%	11/4%
	Optimum			80.35%	11%
Fourth Floor	Existing			83.17%	11/4%
	Optimum			85.83%	9%

The depth of light penetration and light distribution is increased using the optimum window dimensions on each floor relative to the existing one. Thus, as the height of the window increased, the light load increased, and the depth of light penetration and brightness distribution increased, as shown in Table 7; on the first floor, from 53% to 68.32%, on the second floor from 52% to 56%, the third floor was from 78% to 80.35%, and on the fourth floor from 83.17% to 85.83%. As a result, the optimal state of each level was favorable to the existing one. According to Tables 8 and 9, the amount of thermal load is reduced at each level, and the light load increases. Finally, the value of the objective function of the total heat and light is decreased.

3.2.2 Optimization of space

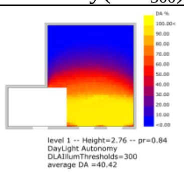
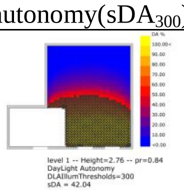
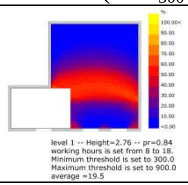
A numerical solution is used, and all situations are considered to optimize this step. Thus, all possible permutations for the two parameters, the ratio of length to width (a/b) and height, were supposed to determine the sample space's optimum case: (a) is the length of the space, and (b) is the width of the room. First, the minimum and maximum length variations were determined, ranging from 3.00 meters to 9.45 meters. In 10 states, each state is 0.5 meters to 0.5 meters. The width is also obtained by dividing the initial place by the chosen length value to keep the area constant due to the length value specified. Height was also investigated in four modes: 2.60m, 2.80m, 3.00m, and 3.50m. The purpose of optimization in this study is to find the highest intensity of illumination. Finding the most dynamic daylight values for DA, sDA, and UDI to determine which ratio of length to width and height works best.

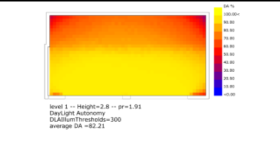
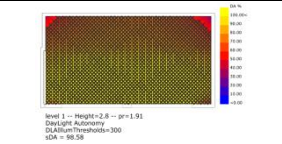
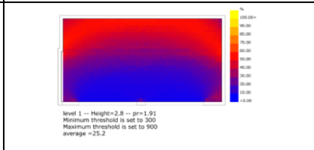
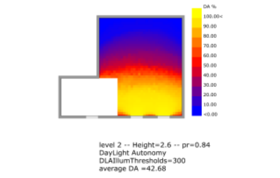
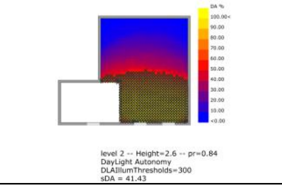
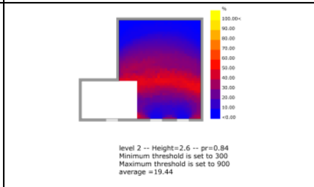
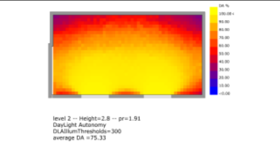
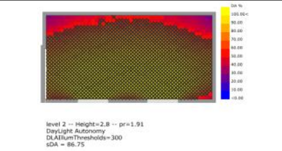
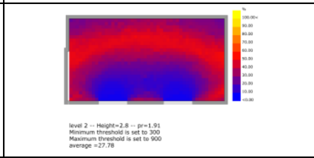
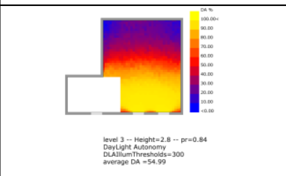
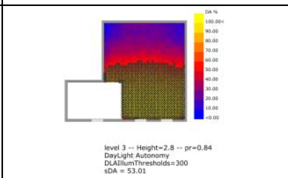
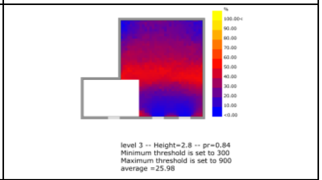
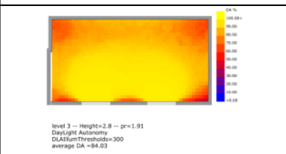
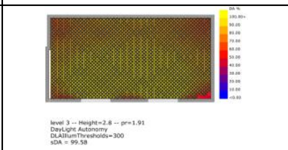
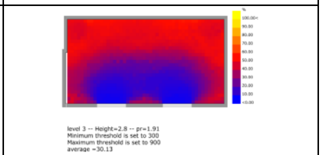
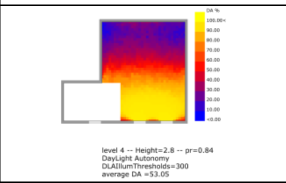
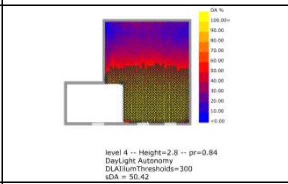
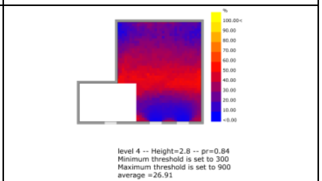
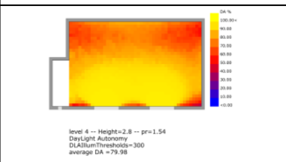
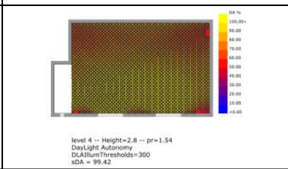
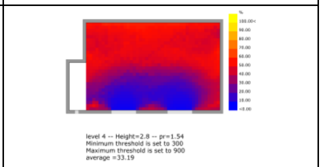
Table 10
The optimal height and length to width ratio is 1 to 4 levels of buildings

level		Common construction		Uncommon construction	
First Floor	Dynamic Daylight Indicators	Height 2.60m	Height 2.80m	Height 3.00m	Height 3.50m
		length to width ratio1.91	length to width ratio1.91	length to width ratio1.91	length to width ratio1.91
	DA	79.09%	82.21%	84.43%	Max $_{DA}$=88.64%
	sDA	96.33%	98.58%	99.58%	Max $_{sDA}$=100%
	UDI	26.26%	25.20%	23.45%	19.00%
Second Floor	Dynamic Daylight Indicators	Height 2.60m	Height 2.80m	Height 3.00m	Height 3.50m
		length to width ratio1.91	length to width ratio1.91	length to width ratio1.91	length to width ratio1.91
	DA	70.88%	75.33%	79.46%	Max $_{DA}$=86.04%
	sDA	78.00%	86.75%	94.67%	Max $_{sDA}$=99.83%
	UDI	27.11%	27.78%	Max $_{UDI}$=28.29%	26.89%
Third Floor	Dynamic Daylight Indicators	Height 2.60m	Height 2.80m	Height 3.00m	Height 3.50m
		length to width ratio1.91	length to width ratio1.91	length to width ratio1.91	length to width ratio1.91
	DA	81.07%	84.03%	83.86%	88.16%
	sDA	99.33%	99.58%	99.83%	99.92%
	UDI	Max $_{UDI}$=30.94%	30.13%	30.05%	26.75%
Fourth Floor	Dynamic Daylight Indicators	Height 2.60m	Height 2.80m	Height 3.00m	Height 3.50m
		length to width ratio1.91	length to width ratio1.54	length to width ratio1.54	length to width ratio1.21
	DA	79.75%	79.98%	82.70%	83.99%
	sDA	98.92%	99.42%	99.75%	Max $_{sDA}$=99.84%
	UDI	Max $_{UDI}$=33.36%	33.19%	32.44%	31.92%

From the findings in table 10, it is clear that as the height increases, the values of dynamic luminance indices increase. According to the research's purpose, typical construction in Tehran, between 2.60m to 2.80m, is considered. Moreover, in this interval, it has been observed that at 2.80m height, the values of DA, sDA, and UDI dynamic daylight indices in the first, second, and third level in the ratio of 1.91 and the fourth level in the proportion of 1.54 had the most value. It is therefore considered as the most optimal for the floors in typical buildings. In addition, in constructions that are not common at the height of 3.00m and 3.50m, where the height is 3.50m and the ratio of length to width in the first, second and third level is 1.91 and on the fourth floor is 1.54 as the optimal case is considered for uncommon buildings.

Table 11
Annual lighting analysis of the existing and optimal state of the four-story building

<table>
<tr><td rowspan="2">Level</td><td colspan="4">Analysis of the annual lighting in the existing status</td></tr>
<tr><td>Condition</td><td>Daylight autonomy(DA_{300})</td><td>Spatial daylight autonomy(sDA_{300})</td><td>Useful daylight illumination($UDI_{300-900}$)</td></tr>
<tr><td></td><td>Existing</td><td>
</td><td>
</td><td>
</td></tr>
</table>

First Floor		40.42%	42.04%	19.50%
	optimum			
		82.21%	98.58%	25.20%
Second Floor	Existing			
		42.68%	41.43%	19.44%
	Optimum			
		75.33%	86.75%	27.78%
Third Floor	Existing			
		54.99%	53.01%	25.98%
	Optimum			
		84.03%	99.58%	30.13%
Fourth Floor	Existing			
		53.05%	50.42%	26.91%
	Optimum			
		79.98%	99.42%	33.19%

4. Analysis

As shown in Table 12, the values of DA, sDA, and UDI dynamic daylight indices increased in the optimum state relative to the present government. It is also concluded from comparing the available space with the optimal window mode and the optimal space mode that space optimization is more significant than the window optimization on the lighting intensity.

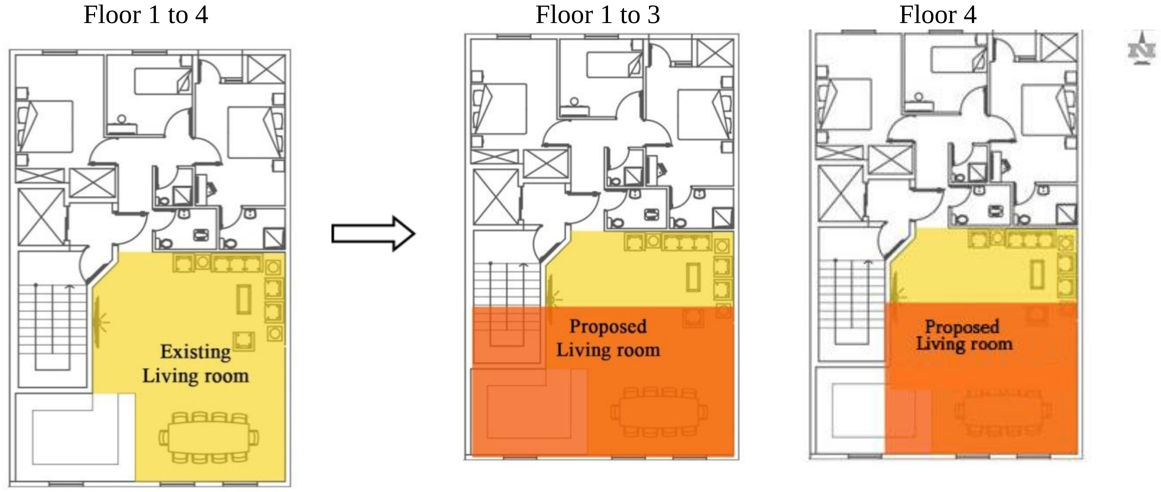
The values of dynamic daylight indicators have reached their maximum. The value of the sDA index has changed from a minimum of 86.75% to a maximum of 99.58%, which means that almost the entire desired space has brightness, and the value of UDI has reached a minimum of 25.20% to a maximum of 33.19%. However, the amount of proper light (300 to 900 lux) of the space is still not desirable because the amount of glare (brightness greater than 900 lux) has increased in the optimal state (Table 12).

Table 12
Comparison of the annual lighting in the living room for a 4-story building in the optimum status

	Floors	Daylight indices		
		DA_{300}	sDA_{300}	$UDI_{300-900}$
Analysis of the annual lighting in the optimum status	First	82.21%	98.58%	25.20%
	Second	75.33%	86.75%	28.78%
	Third	84.03%	99.58%	30.13%
	Fourth	79.98%	99.42%	33.19%

The space proportions are investigated, and the optimum state of these proportions is obtained. By comparing the current form with the optimum condition, it is found that the longer the length of the window wall, the shorter the depth, and the greater the height of the room, the greater and more desirable the annual illuminance is (Figure 3).

Existing — Floor 1 to 4 | optimum — Floor 1 to 3, Floor 4



a/b=0.75 h=2.60 m | a/b=1.91 h=2.80 m | a/b=1.54 h=2.80 m

Fig. 3. Existing living room plan and proposed space in the 4-story building (scale: 1/200)

Also, on the fourth floor of this building, the living room's form has been transformed into a rectangular form in the optimal state, but its length to width ratio is different from floors one to three. Thus, the fourth floor of the mentioned building, with a length to width ratio of 1.54 and a height of 2.80, has favorable lighting (Figure 3).
According to Figure 4, by comparing the existing state with the optimal state, it has been determined that in the existing state, the form of the collective space is L-shaped with a great depth relative to its length and light source (south window), Available 0.84 and its height was 2.76 meters. The values of sDA (percentage of points in space that has a light) are at least 42.04% and 61.69%.
.
However, the mentioned collective space's depth has decreased concerning the length and light source in the optimal case. The length-to-width ratio in the first to third floors has reached 1.91 and in the fourth floor has reached 1.54, and the height of the space has increased as well. The fourth floor, because it is located at a higher height than the other floors, has less elongation (Figure 4). In addition, sDA values have increased to at least 67.99% and 99.04% and have created favorable conditions in terms of brightness. Therefore, the more the desired space is longer than the wall with a window, the more length and depth, and the higher space's height, the more desirable the amount of light

Existing Condition		Optimum Condition	
Floor 1 to 4	Optimization Window and room	Floor 1 to 3	Floor 4
a/b=0.84		a/b=1.91	a/b=1.54
h= 2.60 m		h= 2.80 m	h= 2.80 m
sDA		sDA	sDA
42.04%		98.58%	98.92%
46.38%		86.75%	99.42%
57.58%		99.58%	99.75%
61.69%		99.42%	99.84%

Fig. 4. Comparison of length to width, height, and light intensity ratios in the existing and optimal condition in a four-story building

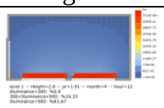
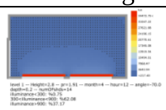
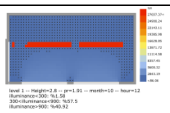
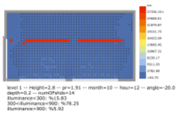
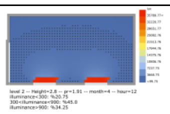
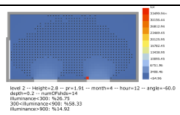
In the optimal mode, the useful UDI brightness (brightness of 300 to 900 lux) has increased slightly from the existing model but has not reached the desired value. Therefore, to take full advantage of natural light in this space, shadings have been created to prevent glare (Figure 5).

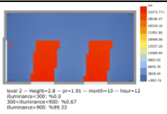
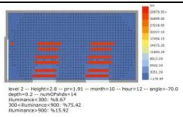
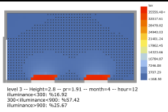
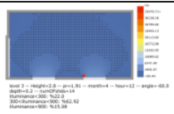
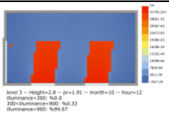
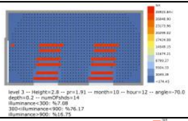
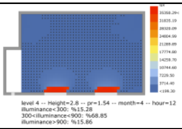
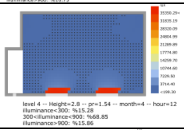
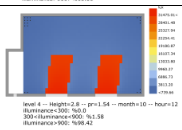
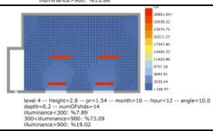
Fig. 5. The amount of light in the living room for a 4-story building in the optimum status

4.1 Optimized shading

Momentum lighting analysis is optimized for the time of year when maximum glare is performed. Instantaneous shading optimization is performed for the angle of -80 to +80. The shadings are considered the Louvre type and have 14 pieces (to cover the entire window in closed mode) with a depth of 0.2 meters (common depth of shading in buildings).

Table 13
Momentum luminance analysis of solstices in optimized space to create optimal moving shadings in floors 1 to 4 of the investigated building

Level	Maximum glare in the solstices				Optimized movable shadings		
	Date	Hour	Lighting analysis for maximum glare	UDI	Lighting analysis with optimal shading	UDI	Angle
First Floor	Summer solstice	12		16.33%		62.08%	-70
	Winter solstice	12		57.50%		78.25%	-20
Secon d	Summer solstice	12		45%		58.33%	-60

Floor	Winter solstice	12		0.67%		75.42%	-70
Third Floor	Summer Solstice	12		57.42%		62.92%	-60
	Winter solstice	12		0.33%		76.17%	-70
Fourth Floor	Summer Solstice	12		68.85%		68.85%	-
	Winter solstice	12		1.58%		73.09%	10

According to Table 13, maximum glare occurred at noon in the solstices. Thus with the shading optimized shortly and at optimum angles in the space floors, it has sufficient illumination of 300 to 900 lux. It has been concluded that removable shadings for this space are needed to obtain optimal lighting. The shadings' angles on the second and third floors are similar to each other in the summer and winter solstice. They differ from the shading angles on the first and fourth floors.

4.2 Placing functions in an optimum state on floors 1 to 4 of the investigated building

Most parts of this space are in the range of sufficient brightness (300 to 900 lux); now, the amount of light intensity in each part can be compared to the intensity of light required for residential building activities and placed in the desired functions areas.

According to the comprehensive standard of interior architecture, the minimum lighting intensity required for lux various indoor activities in Table 14 can be determined by the multifunctional space's interior design and each function's location.

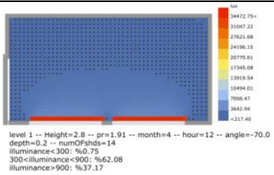
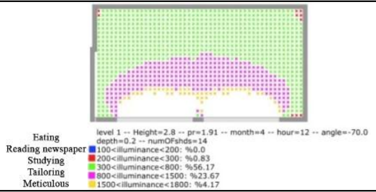
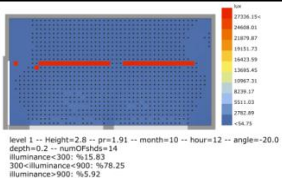
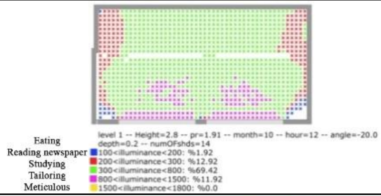
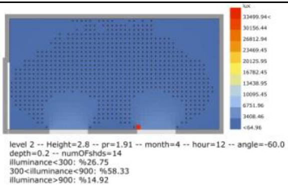
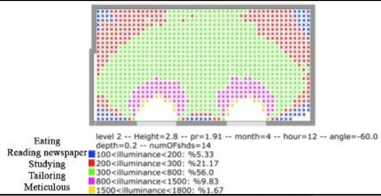
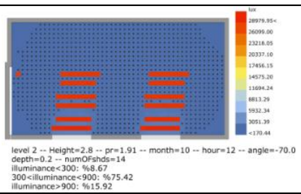
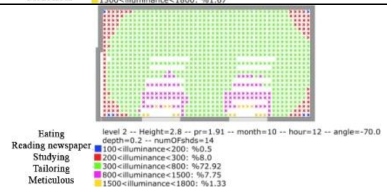
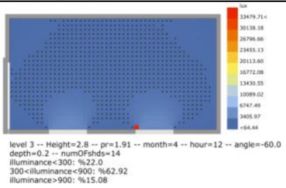
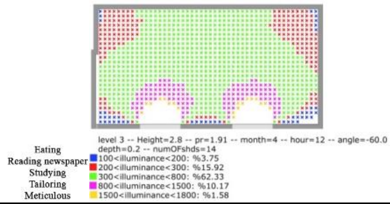
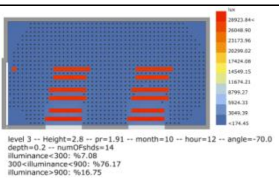
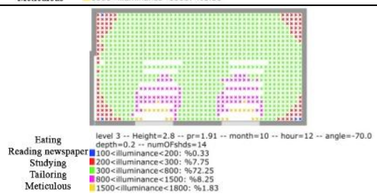
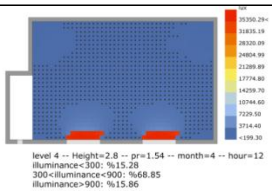
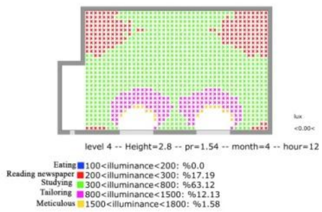
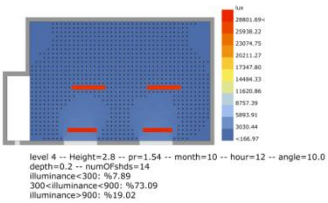
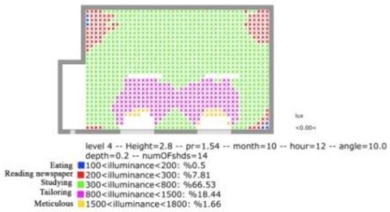
Table 14

Minimum lighting intensity required for various indoor activities in terms of luxury (Dechara, 2010)

Row	Function Type	Light intensity (lux)
1	Items that need a daylight	777
2	Items that require close vision	1777
3	Items that need a powerful vision to do that	1577
4	Studying	777
5	Eating	157
6	Ironing clothes	577
7	Reading newspapers and magazines	277
8	Sewing of bright fabrics	577
9	Sewing ordinary colored fabrics	1777

Therefore, using existing standards, the range of activities for 1 to 4- floor space is suggested: eating 100-200 lux, reading newspaper and magazine 200-300 lux, studying 500-800 lux, tailoring 500-1800 lux, and meticulous work 1500-1800 lux are considered as shown in Table 14.

Table 15
Functional placement based on the intensity of illumination required for various indoor activities

<table>
<tr><th rowspan="2">Level</th><th rowspan="2">Time</th><th colspan="2">Placing functions in an optimum living room of 1 to 4 floors of the investigated building</th></tr>
<tr><th>Optimized gathering space with shading intended for maximum glare</th><th>Placing functions in an optimized gathering space</th></tr>
<tr><td rowspan="2">First Floor</td><td>12 Noon</td><td></td><td></td></tr>
<tr><td>12 Noon Winter</td><td></td><td></td></tr>
<tr><td rowspan="2">Second Floor</td><td>12 Noon</td><td></td><td></td></tr>
<tr><td>12 Noon Winter</td><td></td><td></td></tr>
<tr><td rowspan="2">Third Floor</td><td>Noon Summer</td><td></td><td></td></tr>
<tr><td>Noon Winter</td><td></td><td></td></tr>
<tr><td rowspan="2">Fourth Floor</td><td>Noon Summer</td><td></td><td></td></tr>
<tr><td>Noon Winter</td><td></td><td></td></tr>
</table>

Generally, in the two mentioned times, the southern part of the spaces on floors 1 to 4 is specified for detailed activities and sewing marked in yellow and purple. The southeast and western portions of the area marked in blue for the eating, east and west area to read newspapers and magazines with red color and the rest of the space is green with enough lighting in the range of 300 to 900 lux and is suitable for study and activities in the area. According to Table 15, most of the living rooms on floors 1 to 4 have sufficient lighting in the range of 300 to 900 lux.

5. Conclusion

In the present study, considering Tehran's conditions and its climates, to determine the dynamic conditions and optimum utilization of daylighting in multi-purpose space (living room), first deficiencies and problems related to the provision of daylighting in one of the typical residential buildings have been identified. The annual illumination analysis is examined in the present case study. Due to the space's low lighting, this space's window is firstly optimized in terms of thermal and lighting performance.

In window optimization: a) the amount of thermal load decreased with decreasing window length compared to each level's existing state. With increasing height, the light load value, depth of light penetration, and light distribution increased. Ultimately, the thermal and lighting aggregate objective function value is reduced, and energy saving has been achieved. b) The WFR ratio is optimally shown on the first floor to be 22%, the second floor 11%, the third floor 11%, and finally 9% for the fourth floor. According to the findings, the windows on the upper floors have lower percentages and higher illumination. The difference in levels should be evident in the façade; there should be a fundamental difference between the ground floor, other floors, and the end floor. The overall composition of the facade is, in fact, the order in these differences. Geometric proportions play a crucial role in synchronizing the appearance of the façade. The composition of the windows and the texture and material of the facade and its composition is different in each era, and at the same time, it changes in an urban continuity. The designer can bring the facade to the highest level of architectural composition. By using factors in facade design such as geometry, material, color, a suitable proportion can be achieved. For example, the use of one-size-fits-all frames with specific shapes and geometric proportions around each of the windows on the floors of the building facade can be considered a harmonious and suitable combination for the facade

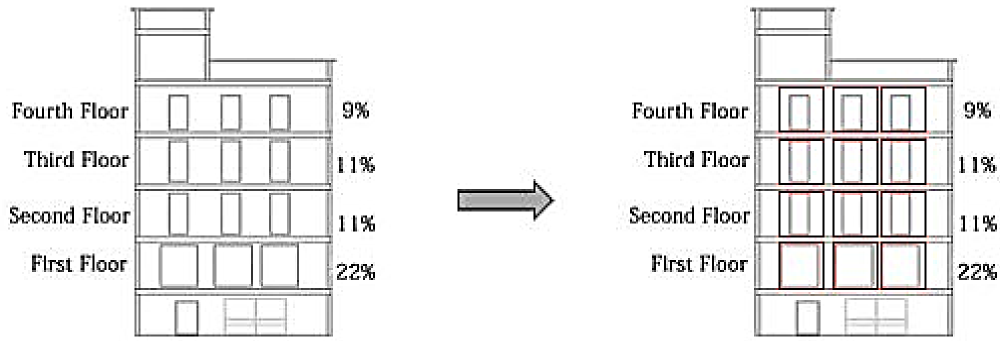


Fig. 6. The use of the same frames for windows to design a suitable facade in the optimum status

The shading effect on the window has been lessened on the upper floors. The smaller dimensions have also created the desired illumination. Then the space proportions are investigated, and the optimum state of these proportions is obtained. By comparing the current form with the optimum condition, it is found that the longer the length of the window wall, the shorter the depth, and the greater the height of the room, the greater and more desirable the annual illuminance. In addition, shades are created to prevent glaring to make the most of the daylight in this space. In addition, to minimize the glare created in optimum mode, the shading optimization is performed shortly for the angle of -80 to +80. The shading depth of 20cm and a Louvre of 14 were taken to cover the window surface completely. In the optimization process, it is observed that the angle of the shading devices (louvers) on the first floor is -70 degrees in summer solstice and -20 degrees in the winter solstice, in the second and third floors in summer solstice -60 and the winter solstice -70 and the fourth floor in summer solstice is good without shading. Nevertheless, in the winter solstice, the angle is 10 degrees. The shading angles on the second and third floors of the building are similar to each other and different from the first and last floor angles.

Finally, for the optimized living room with appropriate shaders, the different functions of this space have been accommodated concerning daylight's optimal use. Most of the activities with an illuminance ranging from 300 to 900 lux are located in the central part of the space and make up most of the area. The illuminance moves less or more significant than this range has been identified and accommodated according to each function's needs. Thus, multifunctional space with appropriate lighting is provided for each of the parts of this space.

The present research has provided suggestions for designers of similar buildings for windows, space, and shading of the building and tips for users and users of this space for interior space layout with the optimum utilization of daylight.

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