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Improve Attached Residential Buildings Daylight Access Through Atrium Optimization in Hot Climate

Mahsa Nikoukar[a], Mohsen Taban[a*]

[a] *Department of Architecture, Faculty of Architecture and Urban Planning, Jundi-Shapur University of Technology, Dezful, Iran*

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ABSTRACT

The construction industry tries to optimize energy consumption and reduce environmental damage. Lighting is an important parameter which is effective in energy consumption of buildings. The amount of light which is received on different floors of high-rise residential buildings is not the same. Therefore, it is necessary to determine the best optimal physical parameters of the atrium that can provide sufficient lighting to all building floors. This study analyses this issue in the humid subtropical climate of the Dezful city. A model was simulated by Grasshopper, then Honeybee and Ladybug plugins were used to evaluate each space lighting. Daylight autonomy and Useful daylight illuminance indices were considered to compare the proposed models. This research aimed to achieve the best position and elongation of the atrium and to optimize the dimensions as well as the setbacks of the atrium on the floors to receive the minimum light is required for residential spaces. Based on the results, the position of atriums can be selected according to occupancy hours, and east-west elongation illustrated the best performance. Using the obtained patterns can lead to introducing models that can increase the DLA value of the first floor in multi-story buildings by 3% to 8%.

1. Introduction

Energy has become a global concern in developed countries. The International Energy Agency (IEA) showed that 81% of the world's energy comes from fossil fuels, which are known to be poor resources [1]. The buildings sector consumes more than 40% of the worldwide Primary Energy Consumption which has been increasing exponentially over the last few years around the world [2]. There is no universal definition of energy efficiency [3], and the appropriate definition depends on the problem being considered as well as the context (light, heat, etc...). Based on the problem at

*Corresponding Author Email Address: mntaban@jsu.ac.ir

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hand, thermodynamic, physical, or economic measures may be used in the energy efficiency process [4]. Natural daylight can be used as a cost-effective strategy to reduce energy consumption in buildings by reducing electricity use for lighting The use of natural daylight can help reduce energy consumption in the lighting sector by up to 40% . This can be achieved by using more daylight in buildings [5]. Therefore daylighting is one of the most important indexes of the environment that should be considered in order to provide a convnient indoor environmentand also to help achieve energy efficiency and other sustainability results [6]. Before the 1940s, daylight was the primary source of lighting in buildings. Artificial lights were complementary to natural light. Over time, the use of artificial lights increased and they became an important part of annual energy consumption [7]. Artificial light sources not only cause carbon emissions but can also have an adverse psychological impact mental states of the residents [8]. As a result, people tend to use more natural light to compensate for these damages and realize the necessity of reducing the energy consumption. The use of natural daylight can increase people's ability to concentrate by increasing consciousness and reducing their depression levels [9]. In some buildings, daylight cannot penetrate the spaces effectively, especially in the deeper parts of the building. Also the central space in an open-plan building site and buildings that receive light only from one face, can have limited accsess to natural lighing [10]. An atrium (pl. atria) is usually a large, multi-story room with a glass roof used to bring daylight into large buildings. The atrium can be a source of natural ventilation as well. Provide thermal comfort, reduce energy loss and consumption, and bring daylight into the core of the building [11]. The atrium is one of the most effective elements to use daylight and absorb passive solar energy. Implementing atrium in buildings means using renewable solar energy for lighting during days [12].

The benefits of daylighting have been confirmed to be improved health [12], increased mood and energy levels on non-cloudy days. In addition, enhancing natural light is an effective strategy in sustainable building design [13]. Atrium buildings first emerged in the 19th century in order for the light to reach the deep parts of the building [14]. Atriums are spaces with large, multi-story glass roofs that allow daylight to penetrate, linking spaces from transparent openings, Improving natural ventilation and thermal comfort [15]. These features make the atrium a basic architectural component [16], used in various building types, especially residential buildings surrounded on three sides. [17].

Atriums can be categorized into four general forms: The centralized atrium has a centralized glass courtyard, which is located in the center of the building and is covered by a glass roof. The semi-enclosed atrium, in which the glass space is within the building one side of the atrium is visible on the exterior facade of the building. In this type of atrium, the roof can either be uncovered or the cover could be made of glass. The attached atrium is constructed outside the exterior walls of the building and in contact with the outside space from three sides. The last type is the linear atrium, which is located in an area between two separated blocks with glass walls on two sides [18]. That is the fundamental problem in receiving natural light from atriums [19].

Rastegari et al. [20] conducted a study on daylight optimization through architectural aspects of the atrium in Tehran's office buildings. The study aimed to obtain the optimum illuminance by validation and simulation of the illuminance data using such outputs as Daylight Autonomy (DA) or Useful Daylight Illuminance (UDI) at different ratios of atrium height (H), width (W), and Length (L). The table of ideal atrium is suggested for optimizing the daylight in an atrium building. The atrium design process can follow the recommended details for the architectural aspects. It could be developed as a framework for other future buildings.

Xiang & Ding [21] conducted a study on the effect of atrium geometric parameters on the energy consumption of office buildings in China's hot summer climate. The study investigated 6 parameters of the atrium position in the plan, atrium dimension in different directions, the ratio of the atrium ceiling, the height from the ground, the geometry of the atrium section, and the ratio of the windows to the wall surface of each floor based on 27 models which simulated in Design builder software. The results show that floor height, skylight-to-ceiling ratio, cross-section geometry, atrium position, atrium dimension ratio and window- to- wall surface ratio had the greatest to least effect on the cooling load of the environment, respectively. While the ratio of skylight to ceiling and geometry of section had the greatest effect on lighting.

Frivar & Agharabi [18] tried to investigate the impact of the most common methods of using solar energy in passive ways, which are sunspaces (glazed balconies and atrium) on reducing the energy consumption of two residential buildings. This paper analyzed annual energy consumption in case A (with balcony and without balcony) and in case B (with atrium and without atrium). Results indicated that glazed balconies and atrium in two buildings could reduce energy consumption by 41.33% in case A and by 26.28% in case B with concerning reference buildings, respectively. Overall, using sunspaces can have a significant effect on the city scale, by repetition in cold semi-arid climates.

Mohsenin & Hue [2] focused on daylight assessment in office buildings with different atrium types, proportions, and roof aperture designs. The goal was to assess and optimize atrium type and proportions to improve the energy efficiency of atrium buildings. Their research applies both scale-model and computer simulation methods to assess daylight and energy performance in atrium buildings based on Well Index. The results demonstrate that Well Index is a reliable indicator to characterize atrium proportion and confirm that Well Index works with (CBDM). Therefore, based on previous studies, lighting and atrium research method, variable parameters and results which were obtained in recent researches are presented in Table 1.

Table1. Overview of previous research (Own elaboration)

Autor	variables	Research method
Mokhtari et al. [5] (2023)	window-to-floor ratio, position of window, shape of windows in the north and south facades	Design Builder
Zabi & Bina [22] (2021)	floor height, Window area or window-to-wall ratio (WWR), the dimensions of the reference office room	Grasshopper (Ladybug, Honeybee and Honeybee-plus)
Farivar & Agharabi [18] (2021)	With glazed balcony and atrium and without glazed balcony and atrium	Revit (insight 360)
Rastegari et al. [20] (2021)	Number of floors, well index (WI), Plane aspect ratio, Roof fenestration	Grasshopper (Honeybee, ladybug)
Susa & Beatriz [23] (2020)	Floor Area, Atrium ratio, Clerestory height, Adjoining spaces, height	Grasshopper (Diva)
Cheshmehnoor et al. [24] (2020)	Balcony depth (well index distance)	Design builder & Ansys workbench
Li et al. [25] (2019)	Atrium shapes, Roof-glazing area, building height	Grasshopper (Diva)
Samir Mahmoud et al. [26] (2019)	Comparison of natural ventilation and lighting in existing hospitals	Questionnaire
Alah Ahadi et al. [27] (2017)	Height of light-wells, The slope of wall, Atrium shapes	Daysim
Mohsenin & hu [2] (2017)	Skylight aperture types (Monitor roof glazing height)	Grasshopper (Diva)
Ghasemi et al. [15] (2015)	Skylight aperture types, Atrium width	Radiance

According to previous studies, static and dynamic daylight metrics have been developed to evaluate daylighting performance which are shown in Figure1. Evaluation by static metrics is only for a short period while dynamic indicators evaluate the lighting conditions of the space during a year and take into account, climate, and changes in the sky [28]. Using these indicators and comparing them can be effective in choosing the best conditions that bring the most daylight into space [20].

Daylight factor (DF) is the most known and oldest static index to evaluate the amount of light in space [22]. DF is defined as the ratio of horizontal indoor to outdoor illumination by daylight under continuously overcast sky conditions, expressed as a percentage. The advantage of daylight factors in building regulations is that they provide minimum daylighting standards [29]. However, DF disadvantages such as being insensitive to climate, and building orientation make it unfavourable. Therefore, a more complete index is used instead in recent studies [30]. Daylight autonomy (DA) evaluates the daylight on an annual basis that depends on the weather conditions. [11]. DA is defined as a Percentage of the time, that the test point receives more daylight than the illuminance threshold during the active occupancy hours [24]. The common threshold for residential buildings is an illumination level of 300 lux. A minimum percentage of DA that enters the appropriate daylight into the space is considered to be 50% [22]. Useful Daylight Illuminance (UDI) is defined as the fraction of the time in a year when indoor horizontal daylight illuminance at a given point falls in a given range. it is divided into three ranges from 100 to 2000 lux. The range below 100, which receives less light than usual, (underlit), the range greater than 2000 lux, where the received light is so much that it causes discomfort and annoyance (overlit), and the middle range, which ranges from 100 to 2000 lux. It includes balanced light and shows a suitable level of brightness (useful). UDI is also known as the modified and invalid autonomous version of daylight [24].

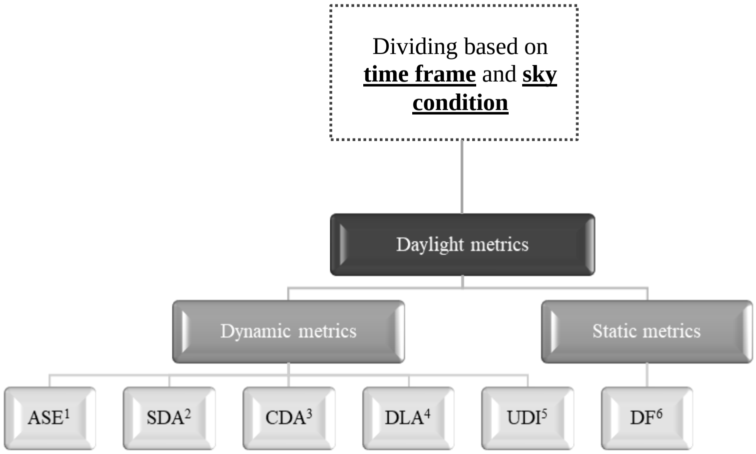


Figure1. Daylight metrics (own elaboration)

2. Materials and Methods

This paper is assessing the impact of physical parameters of atriums in high-rise attached residential buildings to increase the daylight quality in indoor spaces. Due to the previous research software study method was chosen to measure the amount of atrium light.

The most common indicators which were used in previous research are Daylight Autonomy (DLA) and Useful Daylight Illuminance (UDI) [23]. Due to that, this research focuses on optimizing atriums in Dezful city by comparing the amount of DLA and UDI value of the floors.

Previous studies on daylighting in atrium buildings define atrium by parameters such as atrium geometry (e.g., shape, height, width, floor ratio, roof ratio, plane orientation, interface angle, volume) and fenestration system (e.g., shape, type, glazing size, interface window-to-wall ratio (WWR) and transmittance). Some of them were considered Fix and the others were examined as variable parameters as shown in Figure2 [21]. Optimizing the physical parameters and discovering their connection leads to achieving a state of the atrium that solves the existing problem [25] In this research the models were defined with fixed specifications such as the initial dimensions of the models, the percentage of the area of the openings, the number of model floors, and neighborhoods.

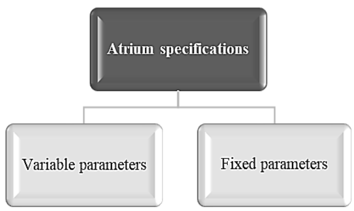


Figure2. Atrium specification (own elaboration)

The review of past studies shows that the research method in similar subjects has mostly been by software simulation and computer analysis. Therefore, Rhino and Grasshopper softwares were chosen for simulating the models, and Honeybee (ver 0.065) and Ladybug (ver 0.069) plugins for lighting analysis.

In a sample, Bina & Zabi [22] conducted a study to investigate and explain an optimal dynamic lighting system for equipping office building windows to deepen, balance and control the received light. For this purpose, physical variables including the floor height, the ratio of the occupied surface by the window to the total surrounding surface (Window area or window-to-wall ratio (WWR)) and the dimensions of the reference office room were modeled in the Rhino software. The lighting of the reference room in the climate of Ahvaz was simulated by Grasshopper, Ladybug, Honeybee and Honeybee-plus plugins in the Rhino software. The models were defined and the annual dynamic simulation was conducted using the Honeybee plugin for Rhino. Honeybee plugin is an environmental program that is a highly advanced annual daylighting modeling plugin [11]. As Figure3, honeybee links Grasshopper to Energy Plus open studio and Radiance and Days.

Illuminance calculation is based on RADIANCE backward ray tracing techniques, which have been widely validated by previous studies [20].

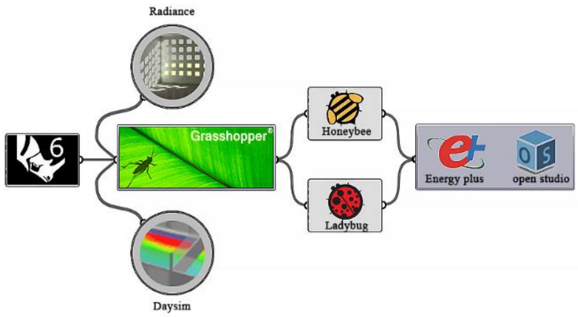


Figure3. Software cycle (own elaboration)

Hence, DLA and UDI indicators (all three ranges) were examined for the models and their results were compared step by step with Honeybee and Ladybug in the early stages. Figure 4 shows the methodology of this research.

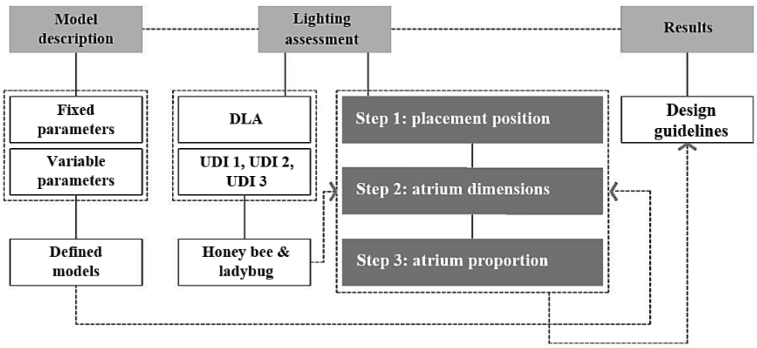


Figure4. Research methodology flow chart (own elaboration)

3. Results & Discussion

The courtyard form is one of the vernacular and ancient elements of building structure in Iran and has been in place in Iranian dwellings for ages. The central courtyard is an element to meet the need for ventilation and light in the surrounding spaces and affects the thermal conditions of the building Specifically in Dezful city. This effect can lead to the control of energy consumption. [31]. The atrium in modern construction in multi-story buildings can have the same impression as the central courtyard in traditional buildings. The chosen case study is located in Dezful (32.16°N, 48.25°E) and has a hot semi-arid climate with extremely hot summers and mild winters. [32]. Dezful climate information is shown in

Figures 5, 6, and 7. Most of the lands have atriums with a dimension ratio of 1:33:1 or 1:1/33 length to Width. Therefore, a plot with a north-south extension was considered as the basis of the study.

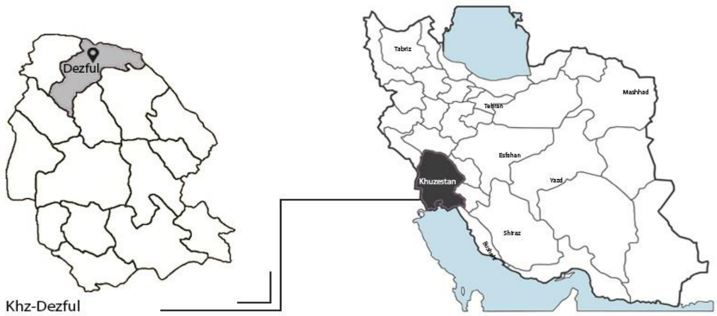


Figure 5. location of Dezful- Khuzestan

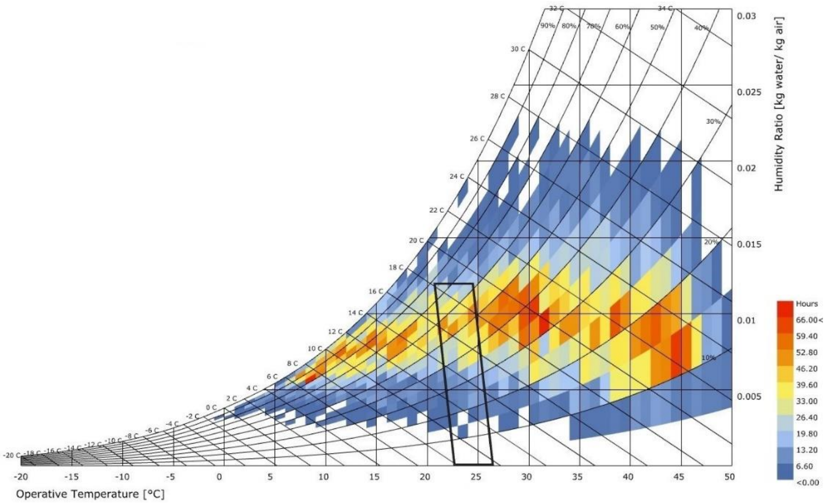


Figure 6. Psychrometric chart (grasshopper-ladybug).

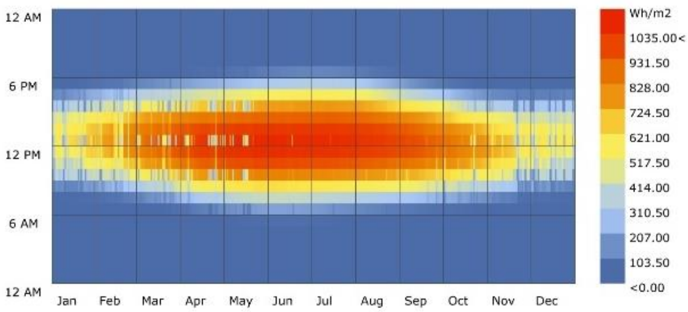


Figure7. Global horizontal radiation chart (grasshopper-ladybug)

Based on Figure 8, consistently a plot which was measuring 23x10 m with 60% occupancy level, main yard 5x10 m, and back yard 3x10 m with one unit per floor was considered for all models. The neighborhoods surround the model only from the east and the west.

Figure 8. Selected site template

The amount of DLA depends on the number of occupied hours in the spaces. Therefore, it is necessary to define a fixed schedule for residential buildings during the analyses. occupation of spaces is defined based on a number between 0 and 1. Number 1 means the presence of all residents in the space and number 0 means the absence of residents. In Figure9, all the people are at home from 12:00 PM to 7:00 AM. After 7:00 AM, they start to leave the house and a smaller percentage of people stay at home. From about 9:50 or 10:00 onwards, the attendance of people reaches its lowest level. From 5 pm, the residents return home again. at 9 pm, all residents are present at home. Based on this, it is understood that fewer people are present at home when the light from the east is received, and instead the occupied hours of people are more when it is received from the west.

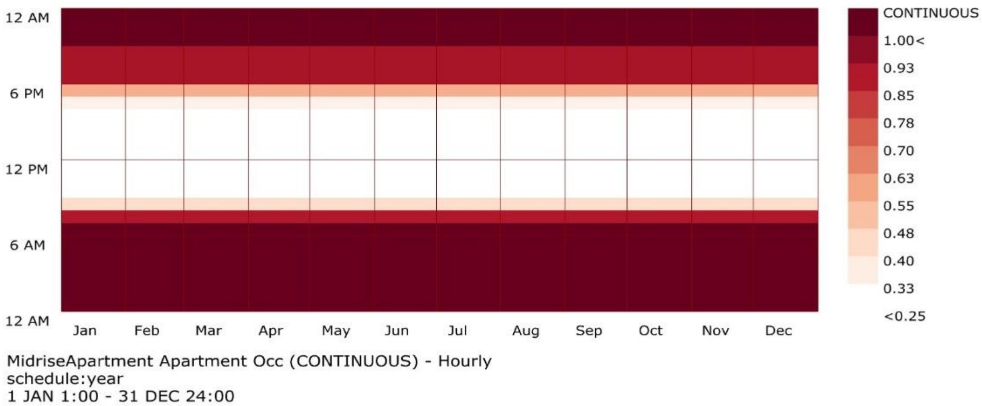


Figure9. The occupied hours (grasshopper-honeybee & ladybug)

Figure 10 shows the step-by-step flow of the proposed algorithm. First, the position of the atrium was examined. Then, in the best position, different dimension ratios were analyzed. In the next steps, the function of atriums and lighting in multi-story buildings were discussed.

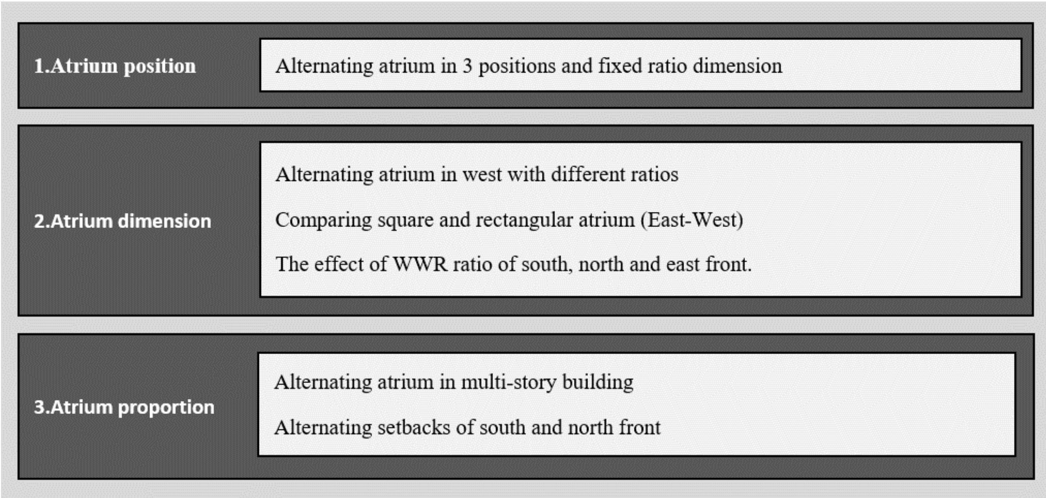


Figure10. Research framework (own elaboration)

3-1- Atrium position

Based on Figure 11, the ratio of windows that can receive direct light was fixed at 60%, and the ratio of southern windows that receive northern light was defined as 80% in all models. The models were simulated in Rhino software and linked to Grasshopper for lighting analysis by considering the dimensions of the atrium (4 x 3 m), which is the usual length-to-width ratio of 1/33:1 that is recommended and used in most buildings. The floor plane of the spaces was graded to check the received light and this plane. The test points were defined with a graded plate (0.5 x 0.5 m distances) and at a height of 0.5 m from the floor of the model. The analysis of light at different heights has different results, so the height of the grid plane is considered to be fixed at 0.5 m in all analyses. The grid plane is shown in Figure 12.

The annual daylight factors (DLA) and UDI (UDI1, UDI2, UDI3) were examined for each model and are shown in Tables 2 & 3. Twelve results were simulated and analyzed with three positions of the center, east, and west, and two annual factors.

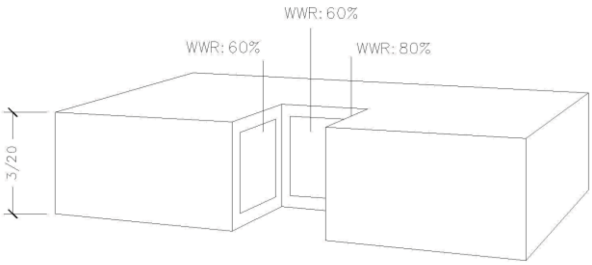


Figure 11. Model description

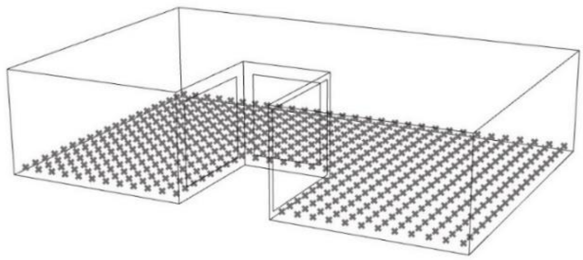


Figure 12. Test points in 0.5 height

Table2. Atrium positions in plans

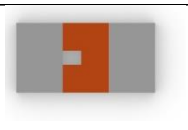
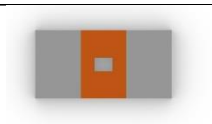
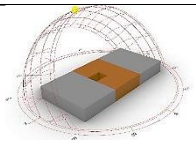
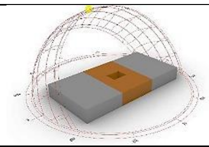
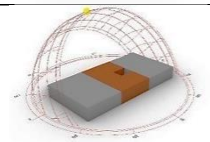
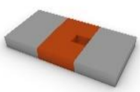
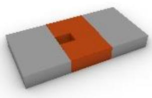
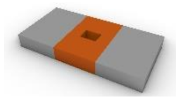
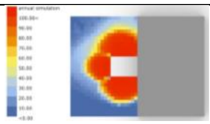
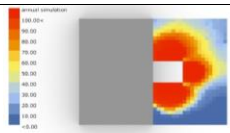
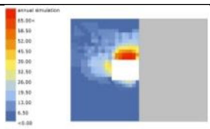
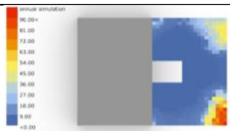
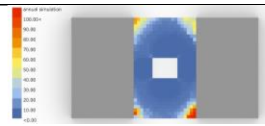
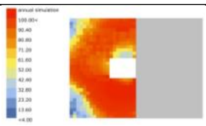
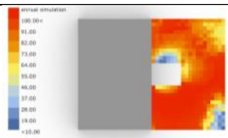
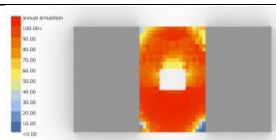
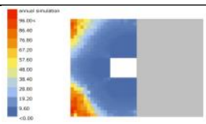
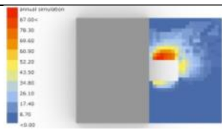
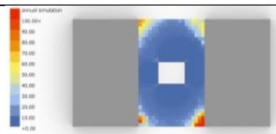
Neighbourhoods Case study		
west	Centre	East
		
		

Table3. DLA and UDI (UDI1, UDI2, UDI3) results in 3positions. Model 01: atrium in East. Model 02: atrium in west. Model 03 atrium in center. Percentage of atrium openings: north 60%, south: 80%, east & west: 60%. Atrium location: east, west, center

Model		Model 01		Model 02		Model 03
DLA%		42/12%		41/87%		50/90 %
UDI%		14/90%		16/58%		8/85%
UDI2%		79/05%		77/02%		82/72 %
UDI3%		6/01%		6/37%		8/39%
		99/98%		99/99%		99/95%

The results show that the central atrium receives more than 300 lux of light in 50.9% of the occupied hours of the day. The eastern atrium receives 42.42%, and the western atrium receives 41.87%. Therefore, by placing atriums in the center, the atrium has the best performance in receiving light. However, in plots with limited dimensions, placing the atrium in the center causes problems in the design of spaces. By using the eastern and western atriums according to the defined schedule, for approximately 42% of hours the required light is provided by natural lighting. Also, a higher UDI2 value in the central atrium indicates a higher percentage of occupied hours of the day when each defined test point receives light between 100 and 2000 lux. To ensure the obtained results, analyses with dimensions of 2x3 m and 3x3 m were also examined. The comparison of their DLA values is shown in Figure 13.

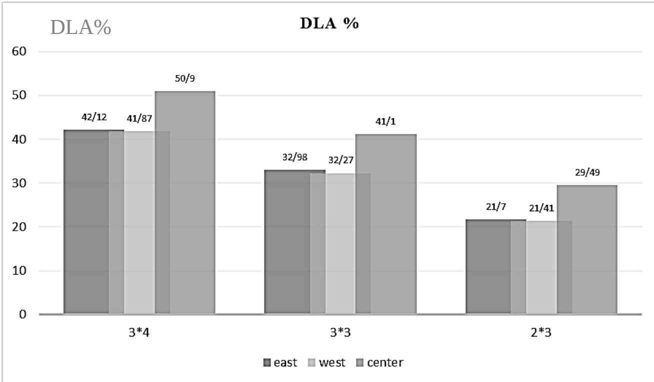


Figure13. Comparing DLA amount in 3 positions with ratio L/W: 1/33:1, 1:1, 1/5:1.

3-2-Atrium dimension

The ratio of length to width, the comparison between the different elongations of the atrium, and the ratio of the window-to-wall were analyzed. The goals are shown in Figure14.

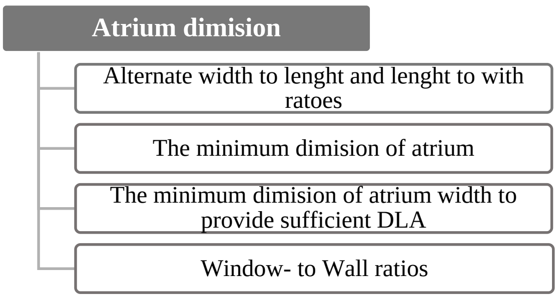


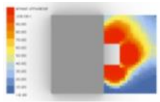
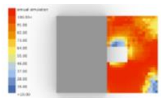
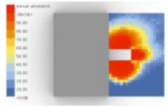
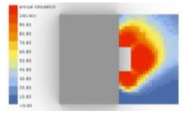
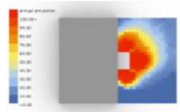
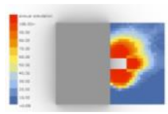
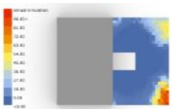
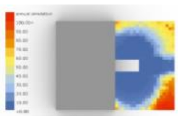
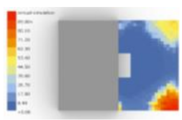
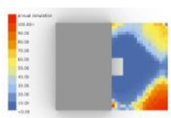
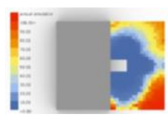
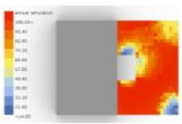
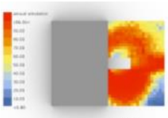
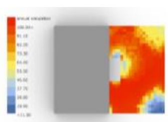
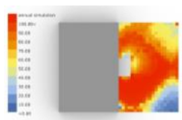
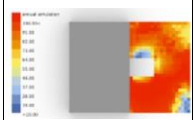
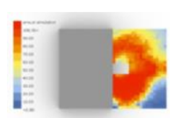
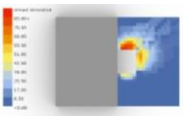
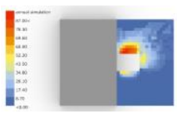
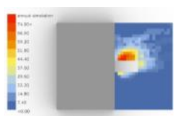
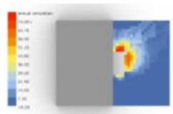
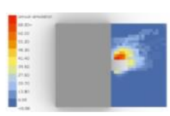
Figure14. Atrium dimension framework (own elaboration)

3-2-1 Alternate width-to-length and length-to-width ratios

Placing the atrium in the center has the best performance, and the eastern and western atriums have a close result. Using the central atrium is not suitable for the plan design of limited lands; due to this, the central atrium was omitted in future analyses.

Assuming that the purpose of placing the atrium is to provide light for spaces that receive western light when they are used, the western atrium model was chosen for further analysis. L/W ratios of 1:1, 1:1/33, 1:2, and 1:1 were defined for the dimensions of the atrium and were investigated in both east-west and north-south elongations. The results show that in the ratio of 1:1:33, most of the test points receive 300 lux and more in most of the occupied hours. In addition, the east-west orientation will have a better result than the north-south elongation in all ratios. In the east-west elongation, larger glazing faces receive south radiation; therefore, despite the smaller distance between the two sides of the north and south, it brings more amount of light into the space. The comparison of the ratios defined in both elongations is shown in Table 4 & Figure 15.

Table4. DLA and UDI (UDI1, UDI2, UDI3) results in different ratios. All the ratios are analyzed in 2 elongations: East-west and North-South

	1:1/33	1:1/33	1:2	1:2	1:1/5	1:1/5
	3*4 (N-S)	3*4 (E-W)	4*2 (E-W)	4*2 (N-S)	2*3 (N-S)	2*3 (E-W)
DLA%	40/22% 	41/87% 	30/82% 	27/56% 	21/41% 	22/86% 
UDI1%	18/81% 	16/58% 	31/22% 	35/18% 	47/29% 	45/74% 
UDI2%	75/25% 	77/02% 	64/45% 	60/86% 	49/70% 	51/18% 
UDI3%	5/90% 	6/37% 	4/30% 	3/95% 	2/96% 	3/06% 

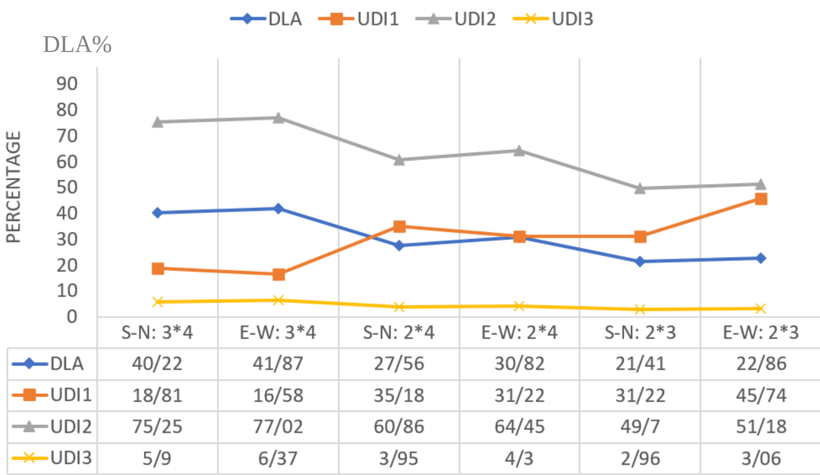


Figure15. Comparing DLA and UDI amount in different ratios and 2 elongations

3-2-2- Square and rectangular models with the same area

The east-west elongation has the best performance in atriums. Comparing rectangular and square atriums with the same area can have an important result in lighting. The square and rectangular atrium was tested with the same area of 9 meters. Figure 16 shows that in this case, stretching in the east-west direction is better than a square atrium with the same area.

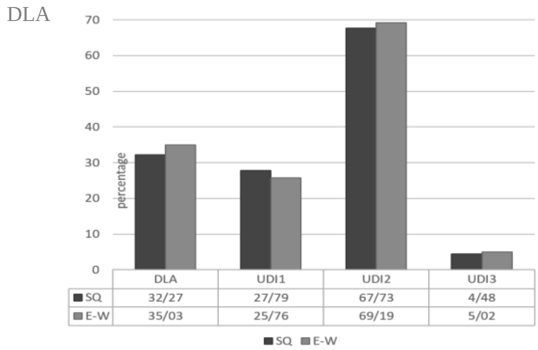


Figure16. Comparing DLA and UDI amount in square and rectangular (E-W) models

3-2-3- The minimum dimension of atrium width to provide sufficient DLA

According to previous analysis, if a constant area is considered, an atrium with an east-west elongation has the best performance. So, Considering L/W of 1:1.33, the distance between the north and south walls of the atrium was tested to determine the minimum size that can provide enough light.
Figure 17 shows that by adding every half meter to the length of the atrium wall, DLA increases almost 10%. But there is a difference of about 14% between 3m and 3.5m width, which is the best range of nearly 50% DLA. Therefore, the minimum dimension of the atrium width is 3 m to provide sufficient DLA. (According to Figure 18, if the minimum dimension is 3.5 m, the DLA value will be 55%, which is more than the minimum DLA required for the space. With the dimension of 3 m, the value of DLA will be close to 42%, which is acceptable, and close to 50% that is required.)

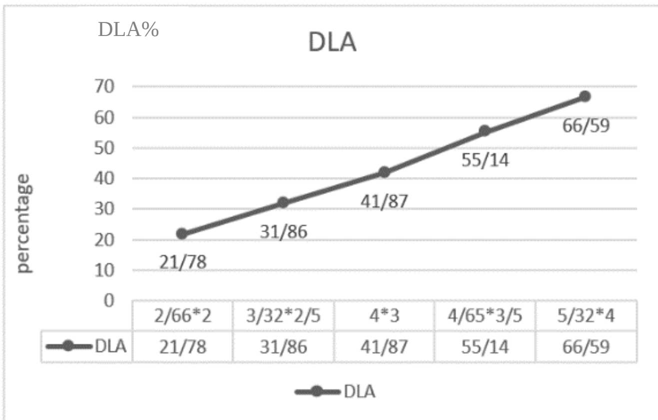


Figure17. Finding the minimum dimension for atrium Width

3-2-4- WWR Ratio

In optimizing the dimensions of the atrium used in the building, the window percentage and the window-to-wall ratio are particularly important in light received and the DLA amount. In a model with the previous dimensions, the window-to-wall ratio was analyzed and examined in three stages (48 models) to determine the minimum dimensions of the window that can receive minimum light. (The goal is to find dimensions in which the DLA value will significantly decrease.)
Based on Figure 18, in the first sample, there is no glazing on the southern and eastern walls of the atrium while glazing on the north facing wall alternates between 10% to 80%. The window-to-wall ratio for the south side of the atrium was fixed at 0%.

(To check the effect of the dimensions of the north window, the ratio of the window to the east wall is 0%). Similarly, in 16 models, the ratio of window to wall for the eastern and northern front of the atrium was analyzed and changes were examined in a diagram.
According to Figure 19, the eastern window has a greater effect on the received light and performs better than the northern window with a fixed percentage. However, the slope of both graphs shows that for every 10% added to the window-to-wall ratio, an almost constant amount is added to the DLA on both the north and east sides (about 2% on the northern front and about 3% on the eastern front). window-to-wall ratio, an almost constant amount is added to the DLA on both the north and east sides (about 2% on the northern front and about 3% on the eastern front).

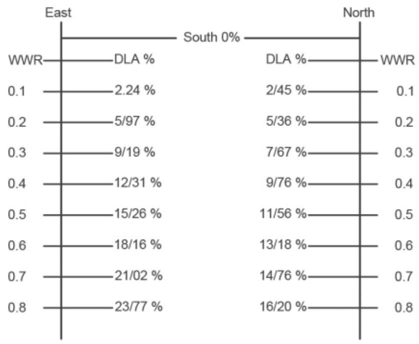


Figure18. DLA amount for each WWR in both eastern and northern front of first sample

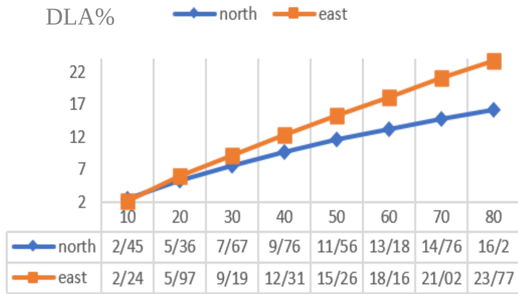


Figure19. Comparing the chart for eastern and northern front effect of first sample

In the second sample, there is 40% glazing on the south while glazing on the north-facing wall alternates between 10% to 80% in 16 models. The window-to-wall ratio for the East side of the atrium was fixed at 0%. To check the effect of the dimensions of the northern window, the ratio of the window to the eastern wall is also 0%. Figures 20 and 21 show the results of the second sample.

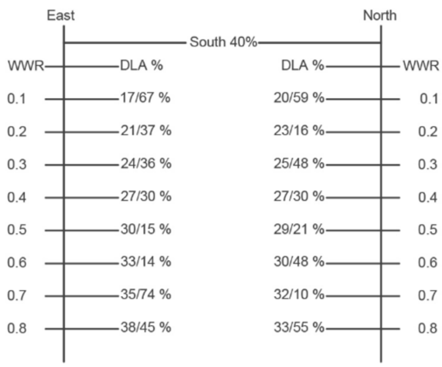


Figure20. DLA amount for each WWR in both eastern and northern front of second sample

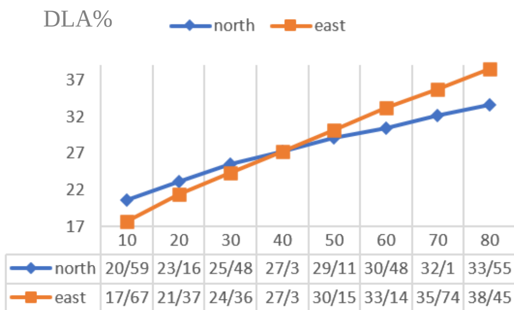


Figure21. Comparing the chart for eastern and northern front effect of second sample

Based on Figures 22 and 23, in the third sample, there is 80% glazing in the south while glazing on the north-facing wall alternates between 10% to 80%. The window-to-wall ratio for the East side of the

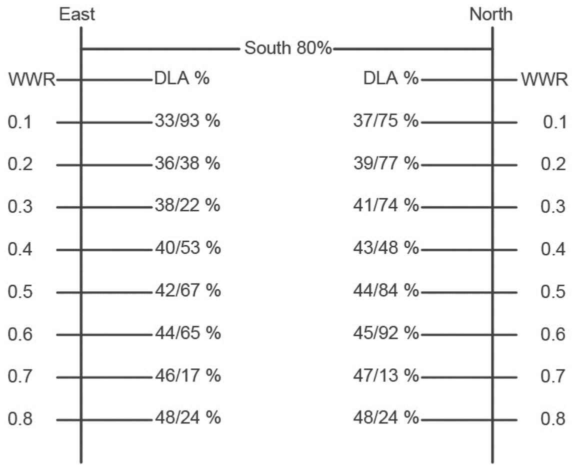


Figure22. DLA amount for each WWR in both eastern and northern front of third sample

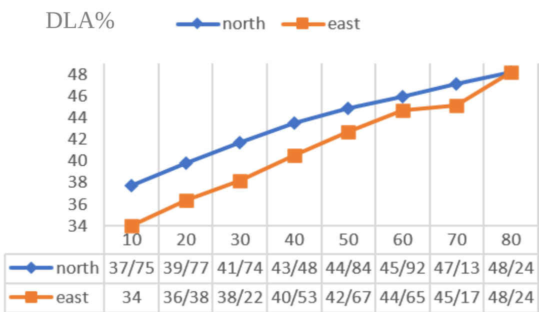


Figure 23. Comparing chart for eastern and northern front effect of third sample

Previous studies have found that extending glazing proportion has a prominent effectiveness in enhancing daylighting [25]. Therefore, in this research, an attempt was made to determine the minimum ratio of WWR that is effective in improving light reception on the northern and eastern fronts. The results show that when the window-to-wall ratio of the northern and eastern walls is less than that of the south wall (until 40% in the second model), the effect of the northern window is greater than that of the eastern one. When WWR is more than that of the southern front, east glazing has a greater impact on the DLA amount. So, in the case that the window-to-wall ratio of the studied facade is greater than that of the southern wall, the percentage effect of the east window will be better than that of the northern wall. The graphs of the second and third stages also show that for every 10% increase, a fixed amount is added to DLA.

Therefore, it is not possible to find the minimum percentage of WWR for atrium walls and the window-to-wall ratio is chosen according to the dimensions of the atrium and the existing conditions, and with analysis models. To facilitate this process and to find the pattern of the relationship between the ratio of windows to the eastern and northern walls, it was done as follows: assuming the percentage of the southern opening is 80% and intending to add 20% to the eastern and northern openings, in the first model 20% added to the north, in the second model added 20% to the east and the third model added 10% to the north and 10% to the east. The results of the analysis show that 20% increasing on north WWR is equal to a 10% increasing on the east and both have almost the same DLA. As a result, assuming the highest opening percentage for the south front, first adding to the east front and then the north front can be effective in increasing the light entering the space. The results are shown in Figure24.

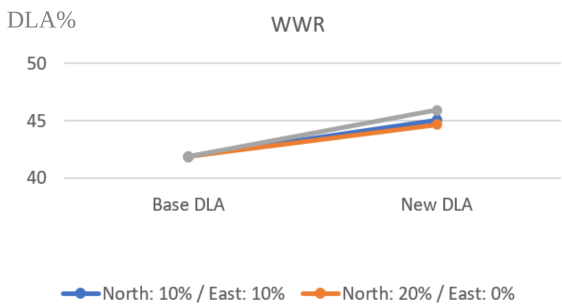


Figure24. Comparing east and north effect in adding WWR

3-3- Atrium proportion in multi-story buildings

In multi-story buildings, setbacks should be created on higher floors to provide light to the lower floors by reducing the amount of shadow that falls on them. The goals of this are shown in Figure 25.

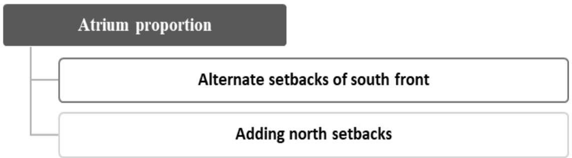


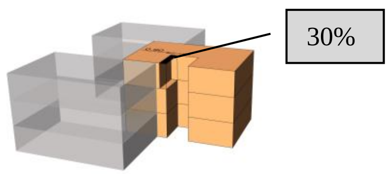
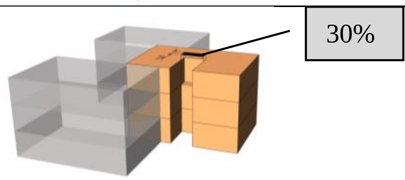
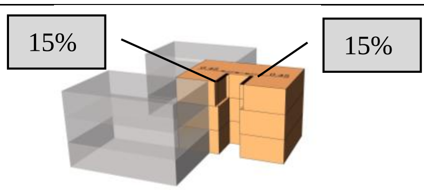
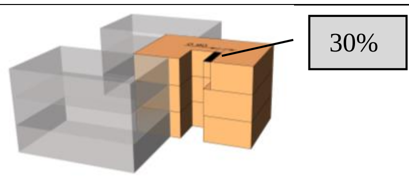
Figure25. Atrium proportion framework (own elaboration)

3-3-1- Alternate setbacks of the south front

All the previous models were analyzed for a one-story building with neighbors of the same height. In multi-story buildings, adding more floors to the building means that the sun's radiation entrance to spaces from the atrium is facing more obstacles. Shadows of upper floors on lower ones prevent sufficient light access for lower floors. Therefore, there is an obvious difference between the amount of light received by the upper floors and the lower floors. The same physical conditions cannot be considered for atriums and their openings on all floors. So, what changes should be made in the atrium proportion on a different floor?

The ground floor was considered in all analyses for parking and the amount of DLA analysis for the first floor. The size of the atrium must be larger on the upper floors than that on the lower ones to achieve more daylight. Based on Table 5, to identify the front where adding area has a greater effect on the received light, 30% of the atrium area was considered fixed and added to the east, north, and south directions.

Table5. Adding 30% of below Atrium to 3 fronts. North, south, east

	Base DLA: 18/53 DLA: 6/74	30% * 12 = 3/6 Dim: 4*3/9
	Base DLA: 18/53 DLA: 20/40	30% * 12 = 3/6 Dim: 3*5/2
	Base DLA: 18/53 DLA: 21/72	90% * 12 = 4/8 Dim: 4*3/9
	Base DLA: 18/53 DLA: 22/98	30% * 12 = 6 Dim: 4*3/9

According to Figure 26, first, the additional percentage of the atrium should be added to the south direction of the upper floor atrium. If a later change is needed, it can be added to the area of the atrium to provide more light from the north side. In general, with defined occupation hours, receiving light from the south side has a greater effect on the light amount. Therefore, increasing the distance between the north and south walls of the atrium (first from the south side to reduce the barrier in front of the radiation) can be helpful. As can be seen in other studies, building height has a negative impact on the daylight performance of an atrium [25]. The daylight amount received by each floor of a building significantly varies [33]. So that spaces on the lower floors cannot receive sufficient daylight whereas upper floors are usually overlit [34]. With an increase in building height, a larger atrium space is needed on upper floors to have better natural light on lower floors. Skylight-to-ceiling ratio has the greatest impact on access to natural lighting [21]. Different percentages were added in ten-percent intervals towards the south. The results show that adding at least 30% of the area of the base atrium to the upper floor atrium is needed to improve the light conditions of the space. Less than this amount will change the chart slope in Figure 27. Therefore, subsequent analyses were continued based on adding 30% to the south, and higher floors were examined too.

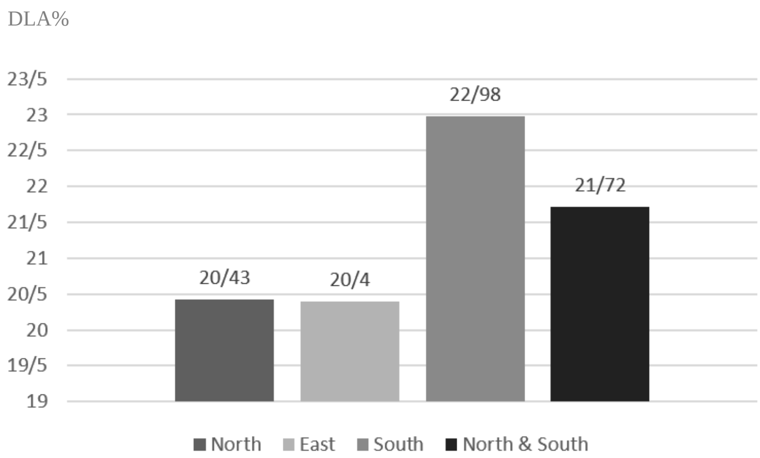


Figure26. Comparing east, south and north effect in increasing DLA amount

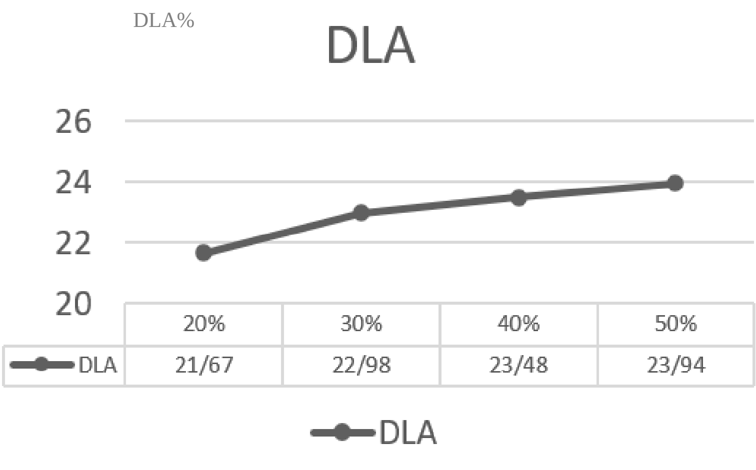
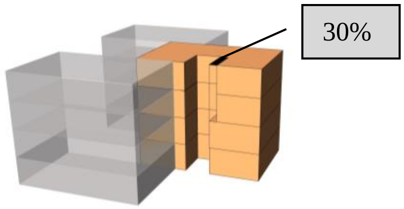
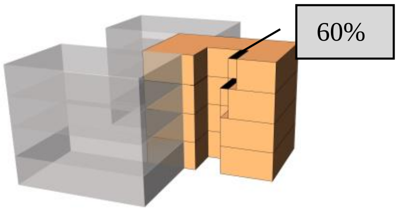
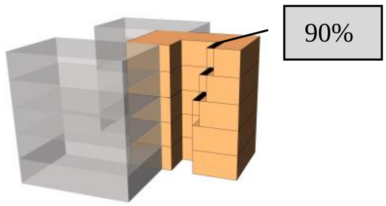
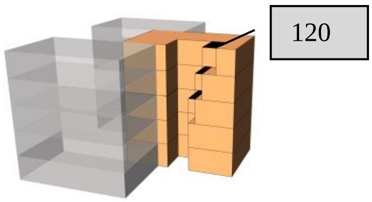


Figure27. Adding different ratios of atrium area to the southern front

For each floor, 30% was added to the area of the atrium. But for the fourth floor, the amount of DLA was below 5%. Therefore, for the last setback, 120% was added instead of 90%. Although the percentage of DLA reached nearly 5%, the difference with a 90% addition in the size of the atrium is inconsiderable. To keep the usable area and avoid narrow space, expanding the atrium from the north side was tested. The results are shown in Table 6.

Table6.Adding 30% of the below Atrium to southern front on third and fourth floor

	Base DLA: 4/19 DLA: 6/74
	30% * 12 = 2/4 Dim: 4*3/9
	Base DLA: 4/19 DLA: 9/07
	60% * 12 = 7/2 Dim: 4*4/8
	Base DLA: 0/81 DLA: 3/64
	90% * 12 = 10/8 Dim: 4*5/7
	Base DLA: 0/81 DLA: 4/47
	120% * 12 = 14/4 Dim: 4*6/6

3-3-2- Adding north setbacks

The DLA value of the first floor in a 4-floor building is 0.8% without any changes. By adding 0.9 m (30%) per floor to the atrium, the DLA value of the first-floor increases to 3.64%. The optimum dimensions of the atrium on the last floor must be 5.7 x 4 m. If the north wall has a 30% setback at once in all levels, the DLA will increase to 6.58%. If the northern front also has a setback similar to the southern front (each upper floor is 30 % larger than the lower floor), its DLA will improve to 8.18%. Likewise, with a base of 30%, various changes were applied in the setbacks. As a result, DLA values are 9.01%, 9.48%, and 9.92%, and finally, 11.20%. Based on Figures 28 & 29, the best result was obtained from the model in which setbacks are as follows: The setback of the first and second floors from the south front is 30%, the third floor is 60%, and the fourth floor is 90% larger than the atrium size on the ground floor. The setback of the northern front is 60% (1.80 meters) in a unified way. In this case, the DLA value is 11.20 (model E). This model is used as the basis of the model in the next stages for the number of higher floors.

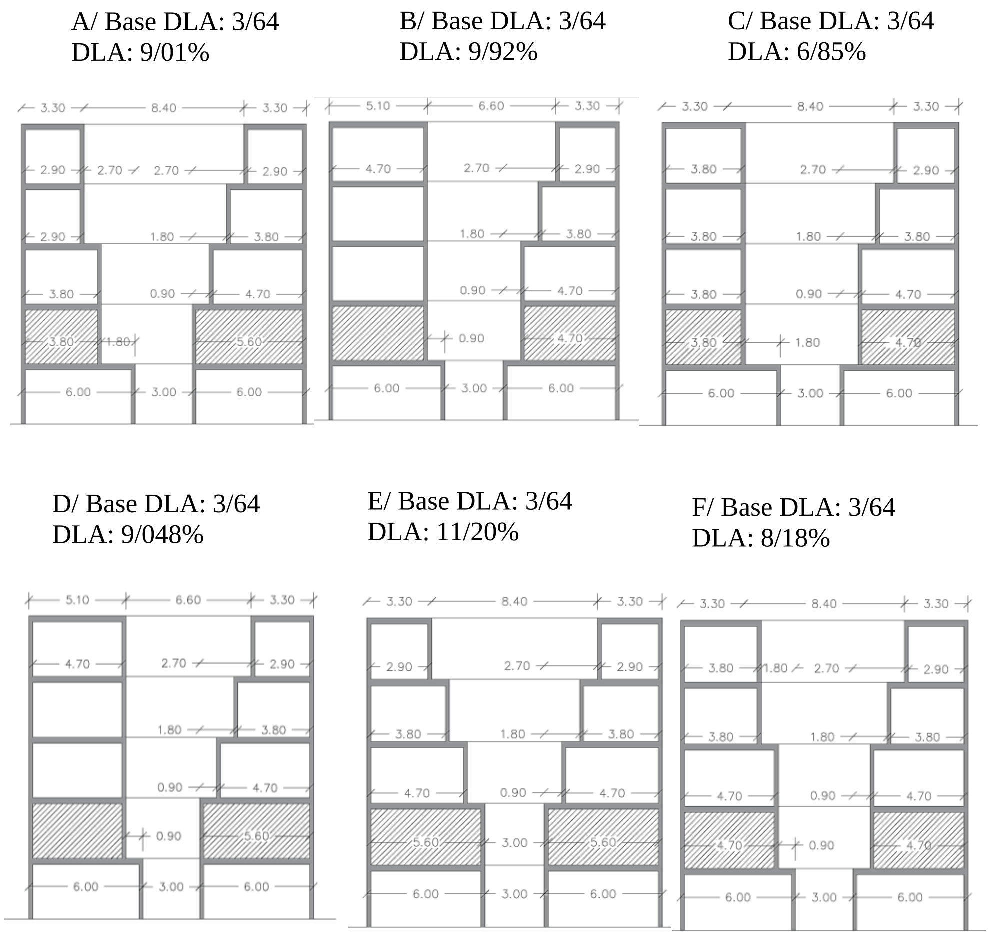


Figure 28. A-F. Adding different setbacks to south and north front in 4-floor building.

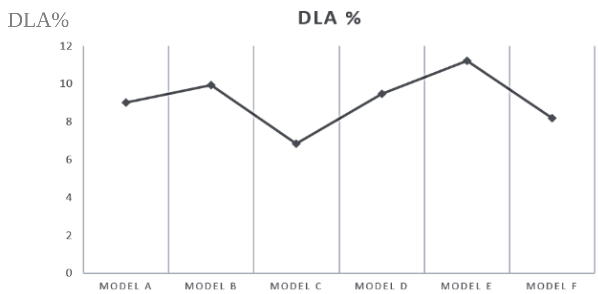


Figure29. Comparing DLA amount of model, a- model f

In the 5-floor building, different setbacks were tested for the northern and southern sides, and their effects were examined. The results showed that in the model where the setbacks of the south facade are 30% on the first and second floor, 60% on the third floor, and 90% on the fourth and fifth floor, and the setbacks of the north facade are 60% in the first, second and third floor and 90% in the fourth and fifth floor, the DLA value for the lowest floor is 5.13%. A floor with a similar setback to the fifth floor was added to the model and was tested. The results showed that only 2.46% of the occupied hours of the day, the space receives 300 lux or more light. To improve it, more fractures are required, which is not possible given the remaining width of 2.90, and a larger plot is needed for this alternative. Figures 30 & 31 show the result.

G/ Base DLA: 2/12
DLA: 5/03%

H/ Base DLA: 2/12
DLA: 4/12%

I/ Base DLA: 2/12
DLA: 5/13%

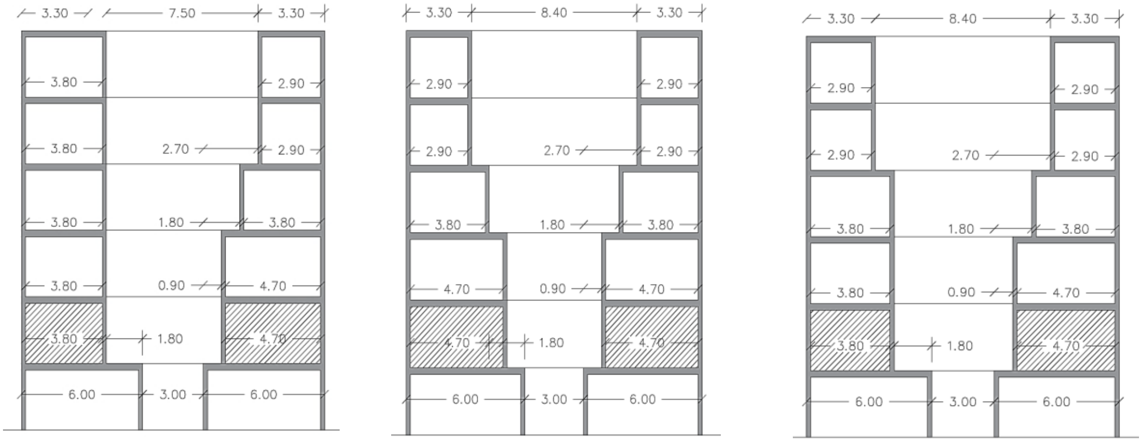


Figure30. G-H. Adding different setbacks to southern and northern front in 5-floors building

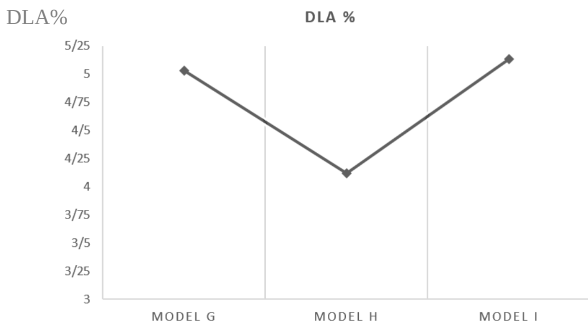


Figure31. Comparing DLA amount of model G- model I

4. Conclusions

The limitation of energy resources and the increasing energy consumption, in addition to the environmental crises and wasting national funds, have put the future life of humans at risk. The strongest step to reduce energy consumption is to reduce the demand for lighting, ventilation, cooling, and heating. Therefore, the most reliable way to optimize energy consumption is to control and discover the needs of residents through natural passive design methods.
The use of natural energy such as sunlight, and its potential is an important issue. Residential buildings which are used every day and for long hours, play a major role in the country's annual energy consumption. Each user-spaces needs lighting based on the occupied hours. Therefore, by knowing the probable pattern of occupied hours of the residential buildings and with using the annual light measurement indices that are defined based on the occupied hours, it is possible to make suggestions that providing enough light with a natural light source, while reducing the energy consumption is required for artificial light sources in the required hours.

One of the limitations of using natural light is providing natural light to the lower floors of high-rise buildings. The results of this study show that with a fixed schedule, the amount of DLA in the central atrium shows the best result. Eastern and western atriums have almost the same results. Therefore, different areas of the building and their occupancy hours are important in choosing the best position. The length-to-width ratio of 1:33:1 is the best result achieved. In general, atriums with east-west elongation have better performance than square and north-south ones. The results of the analysis show that in high-rise buildings, for each floor, at least 30% of the atrium area of the lower floor should be added to the atrium area of the desired floor. Adding area to the atrium section on the south side has the greatest effect on improving the DLA value of the lower floors.

Therefore, by choosing the best placement position and the best proportion of each side of the atrium and its connection with the number of floors, the light that is entering the building can be increased. By studying the reflectors and the type and color of their materials, it is also possible to increase the incoming light more than the obtained result.

Nomenclature

ASE	Annual Sunlight Exposure, %
SDA	Spatial Daylight Autonomy, %
CDA	Continuous Daylight Autonomy, %
DA / DLA	Daylight autonomy, %
UDI	Useful daylight illuminance, %
DF	Daylight factor%
WWR	Window-to-wall
IEA	International Energy Agency

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