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Harvesting Daylight in High-rise Office Buildings Using Phyllotaxis Model

[1*]Amirhossein Zekri, [2]Rima Fayaz, [3]Mahmood Golabchi
[1]Ph.D. Candidate, School of Architecture and Environmental Design, Iran University of Science and Technology, Tehran, Iran.*
[2]Associate Professor, Faculty of Architecture and Urbanism, University of Art, Tehran, Iran.
[3]Professor, Faculty of Fine Arts, University of Tehran, Tehran, Iran.

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ABSTRACT: Various researches have introduced methods to use daylight in office buildings in the Middle East zone, but none of them have ever considered the use of plant leaf arrangement, called phyllotaxis, as a comprehensive solution for harvesting daylight. The idea of the Phyllotaxis Tower has been raised for several years but the main question of this research is whether using the phyllotaxis model is capable of exploiting daylight in high-rise buildings or not. So, in response to this question, the main aim of the research was set to evaluate daylight efficiency in high-rise office buildings by presenting an exemplary and phyllotaxis-inspired design. The research method is encompassed several steps including, studying the literature on the subject firstly, then modeling a prototype building based on the Biomimicry Problem-Based approach, and eventually computer simulation to evaluate the performance of the proposed building. The results show that office units can get daylight illuminance of 500 lux at 50% of operating time per year in addition to proper performance on four single days of different seasons of the year. Furthermore, the sample building obtained label B of energy consumption from Standard No. 14254 presented by the Institute of Standards and Industrial Research of Iran, which has been compared with the energy label of 45 office buildings in the same location and same climate conditions, based on the figures are defined on the aforementioned standard and has the best performance among them.

Keywords: *Daylight, Energy Efficiency, Visual Comfort, High-rise Building, Phyllotaxis, Biomimicry.*

INTRODUCTION

In recent years, rapid population growth, urbanization, and business development have led to a dramatic increase in energy consumption worldwide (Mostafaeipour et al., 2016; Madlener & Sunak, 2011; Urpelainen & Yang, 2019; Zarei, 2012). However, according to statistics of the World Bank and the research done by Taheri, more than 75% of the world's energy consumption is associated with non-renewable energy resources (Taheri, 2012; The World Bank, 2015). Besides, the fossil-fuel supply will terminate and there would be an energy crisis if this trend continues. Energy consumption in buildings plays a crucial role in creating and exacerbating the crisis. In Iran, the building sector accounts for more than 40 percent of the country's total energy consumption, according to the figures presented in article 19 of the National Building Regulations of Iran. (2017) (Valinejab Shoubi et al., 2014). Particularly in high-rise buildings, the amount of energy demand is so high due to several reasons such as multi-functionality and the multiplicity of users (Shafiei et al., 2014). Also, electricity consumption per square meter in Iran, is on average 98 kWh per year, with office buildings having the highest consumption share equivalent to 132 kWh in this arena (Heidari, 2016). Iran, on the other hand, as the 16th most polluting country, has committed to the Paris Climate Change Agreement to reduce its greenhouse gas emissions by 4 to 12 percent by 2030 (depending on conditions). It is noteworthy that 47.6% of the country's pollution contribution is in the field of architecture and construction. The primary energy consumption index in office buildings in Iran is on average 350 kWh/m^2 annually, taking into account 8 to 10 working hours, which is very

*Corresponding Author Email: *a_zekri@arch.iust.ac.ir*

significant, according to the energy balance sheet of the Ministry of Energy of Iran and the hydrocarbon balance of the Ministry of Petroleum (Bagheri et al., 2013). The energy consumption index is a reliable criterion to evaluate building energy consumption status and may be calculated by Standard No. 14254 (2016) presented by the Institute of Standards and Industrial Research of Iran. The purpose of this standard is to determine the criteria of energy consumption and provide instructions for energy labels for non-residential buildings. Factors which are involved in devoting energy label to buildings are climate conditions and building's type. Based on the specific table of this standard, Iran's climate is categorized into 8 different types while each city is devoted to a specific type of climate and the type of the buildings is office.

To preserve the future generations' share of the environment and natural resources, which is the philosophy of sustainable development (Spijkers, 2018; Mensah & Casadevall, 2019; Ghiabaklou 2017); reducing dependence on fossil fuels is a necessity. Basic action will not be possible except with the proper utilization of climatic potentials. In this regard, this study tries to implement a design perspective to correctly utilize sunlight in a high-rise building and evaluate its efficiency. Tehran, a vast metropolitan area, has been selected as the study site. This study is the first to investigate the efficacy of plant leaf benchmarking for optimal use of sunlight in a high-rise office building.

MATERIALS AND METHODS

In the present study, first, the parameters on phyllotaxis design are introduced through studying the literature on the subject. A tower is then designed mimicking nature and is simulated using Rhino V (5), Grasshopper V (0.9.0076), Ladybug V (0.0.66), and Honeybee V (0.0.63). Radiance V (5.1.0) and Daysim V (4.0.0.0) software to evaluate the interior illuminance and after that, open Studio V (2.5.0) and Energy plus V (9-0-1) software were used to evaluate its energy consumption. Figure1 illustrates the energy simulation steps in the present study.

Climate

Iran is located between 25 to 40 degrees north latitude and in a region that ranks among the highest in the world in terms of solar energy. The solar radiation in Iran is estimated to be between 1800 and 2200 kWh per year, which is above the global average (Shafiei et al., 2014). Iran experiences an average of 300 sunny days per year approximately, which is quite significant (Bashiri & Alizadeh, 2018). Tehran, as the study area, has a dry and cold semi-desert climate (BSk), according to the Köppen-Geiger climatic division (Akaf et al., 2019; Raziei, 2017). The solar radiation that is received in Tehran is between 4.5 and 5.2 kWh/day (Figure 2) (Bashiri & Alizadeh, 2018). According to the Tehran Meteorological Organization, the average annual sunny hours at the Mehrabad station in Tehran have been 3025 hours (Shafiei et al., 2014).

Visual Comfort

Visual comfort is a pleasant state of mind for perception arising from the visual environment (British Standards Institution, 2011). Visual comfort depends on the physiological state of the human eye, physical quantities including the amount of light and its diffusion in space, and the spectrum of radiation from the light source (Micheal & Heracleous, 2017). Article 13 of the National Building Regulations of Iran has proposed

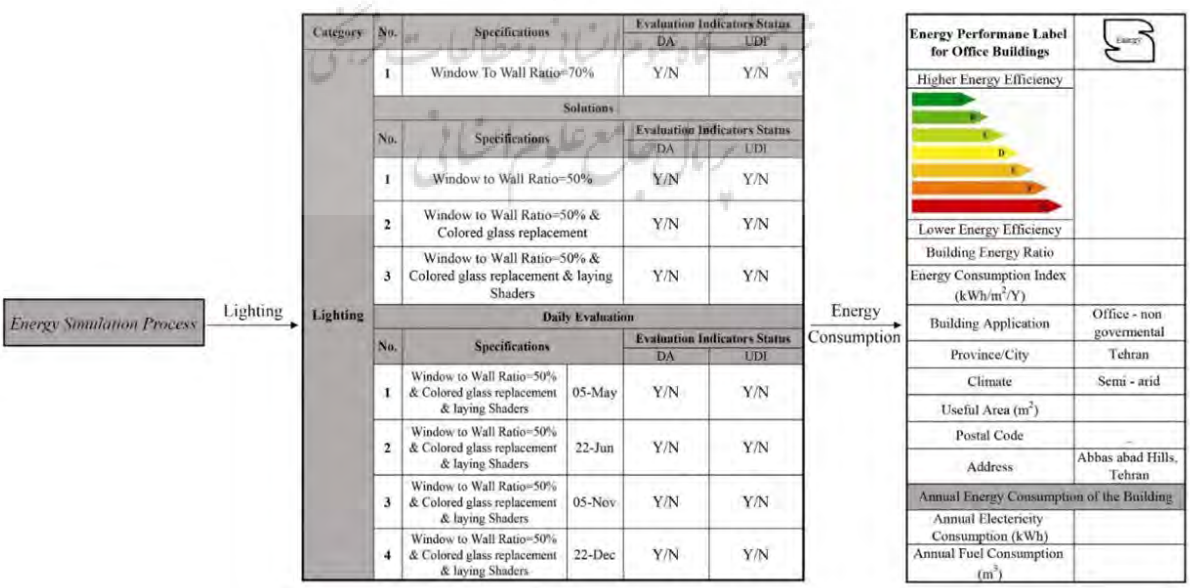


Fig. 1: Energy simulation process of the present study

Fig. 2: Solar radiation potential in Iran (Bashiri & Alizadeh, 2018)

Table 1: Required illuminance intensity of office spaces (Ministry of Roads and Urban Development, 2017).

Offices	Min(Lux)	Suggested(Lux)
Office Duties	200	500
Typing	300	600
Accounting Department	300	600
Archive Room	100	300
Drawing Room	500	1000
Conference Room	200	500
Waiting Room	150	500
Stairways	100	150

the minimum and recommended values for the intensity of standard illuminance of office spaces. This amount is at least 200 lux for office duties and the recommended amount is 500 lux (Ministry of Roads and Urban Development, 2017). Table1 shows the intensity of illuminance required for different parts of an office building. In addition to the quantity of light, its quality is also important. Avoidance of glare and sharp contrast in space should also be considered (Al-Obaidi et al., 2014; Amiri, 2015). 3 factors influence receiving daylight and are examined in this study including:

- WWR (window-wall-ratio)
- Daylight transmission coefficient: which is available in the technical specifications of the outer wall. (technical specifications which are mentioned in Figure 3 is considered for this research)
- Shading: This could be determined and calculated based on article 19 of the national building regulations of Iran (2017). (Table 2 is set up according to article 19 of the national building regulations of Iran (2017) and features of the sampled building in this research)

Architectural Model

Phyllotaxis is derived from the combination of the two words "Phyllon" meaning "leaf" and "Taxis" meaning "arrangement". In botany, the order and arrangement of the leaves along the stem are called phyllotaxis (Shi & Vernoux, 2019; Brukhin & Morozova; 2011). Saleh Masoumi introduced the idea of using phyllotaxis in plants in the design of high-rise residential buildings for the first time (Masoumi, 2012). Buildings and plants have common features such as fixed location and the necessity to adapt to environmental conditions. Since plants have to contend and interact with environmental conditions and changes to survive, they can, therefore, provide an appropriate model for the exploitation of natural resources (Lopez et al., 2017). In this research, nature-inspired design is selected to create an architectural model. Biomimicry is a functional science that solves human problems by studying systems and processes of nature and benchmarking them (Maglic, 2012). Biomimicry

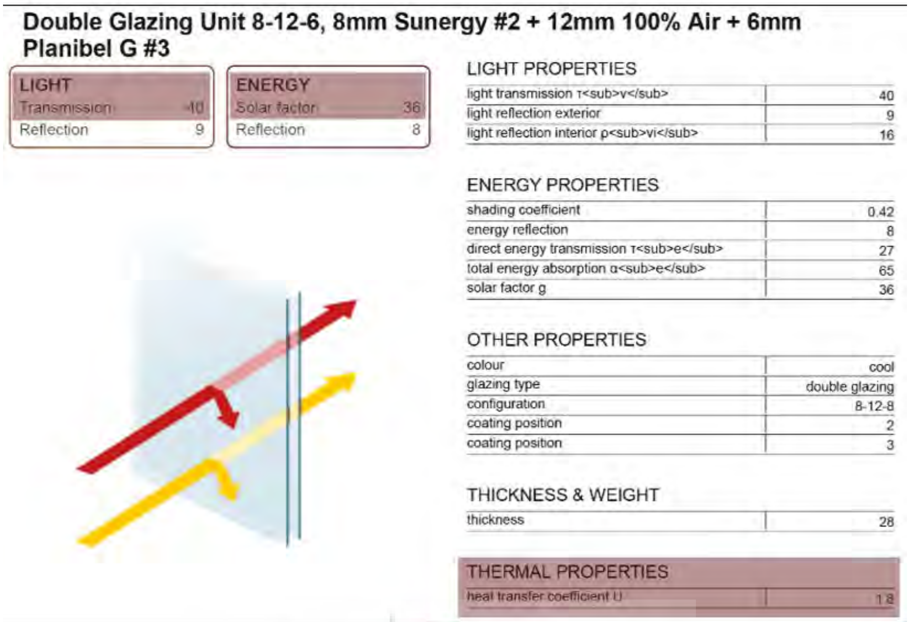


Fig. 3: Specifications of the glass selected for replacement (National Glass Association, 2017).

Table 2: Specifications of type, length, and the number of shaders by window orientation (Ministry of Roads and Urban Development, 2017).

No.	Window orientation	Type	Number	Length(cm)
1	60° N.E.(North East)	-	-	-
2	150° S.E.	Horizontal	4	50
3	120° S.W.	Horizontal	5	80
4	30° N.W.	Horizontal	6	60

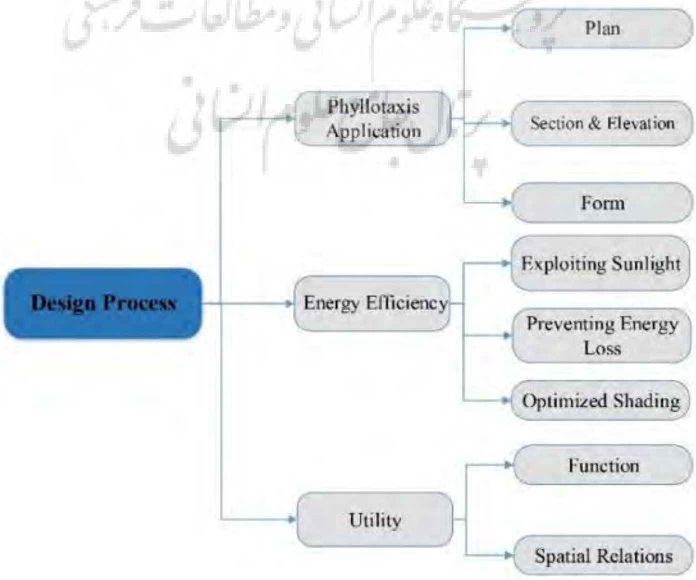


Fig. 4: Architectural design steps with biomimicry approach

has defined structures to benchmark nature systematically. Nature benchmarking with the biomimicry problem-based approach involves two general stages: perceiving nature and applying it to architecture. The perception stage of nature is devoted to identifying and analyzing biological solutions that answer three questions about what, why, and how. The implementation phase in architecture investigates the inspiration by the principles of the first stage and transforming them into technical and applicable solutions in architecture. This step, also, is summarized by answering three important questions about how to use the idea (application idea), innovation, and design idea generation (Lopez et al., 2017; Maglic, 2012). This benchmarking method has been implemented in the present study. Phyllotaxis is the placement of plant elements. Most plants require sunlight for the photosynthesis process, so they have arranged their configuration to give them maximum sunlight (Ruban, 2015; Janzadeh & Kalantari, 2013). The unique spatial arrangement and position of the leaves provide the foliage arrangement, which is a major contributor to the solution of the problem of daylighting in plants. So that green leaves grow in a spiral geometric system to get maximum radiation. The spiral geometry causes the leaves not to shade over each other so that there is no obstruction for receiving sunlight (Strauss et al., 2020; Najafi, 2017). How to apply this idea in architecture is to use a spiral geometric pattern in form creation. To achieve the idea obtained the form, a hierarchical process was designed that could be generalized and used in all projects (Figure 4). In this method, the phyllotaxis pattern is applied to the plan, facade, and design form, respectively. The way it is applied is that the phyllotaxic diagram of a ternary-type cyclic arrangement (Figure 5) is the basis of the modeling, and two important features of this diagram can be found in the plan design. The first feature (shown in Figure 6) is the radial positioning of the leaves relative to the stem, which results in the functional spaces being positioned relative to the core in the building. The second characteristic is the important role of the stem in transplanting plant components and transferring the load to the ground, leading to the central core role of

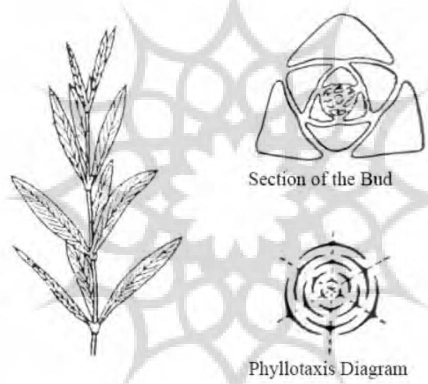


Fig. 5: Leaf arrangement in a ternary cycle (Ghahraman, 2012)

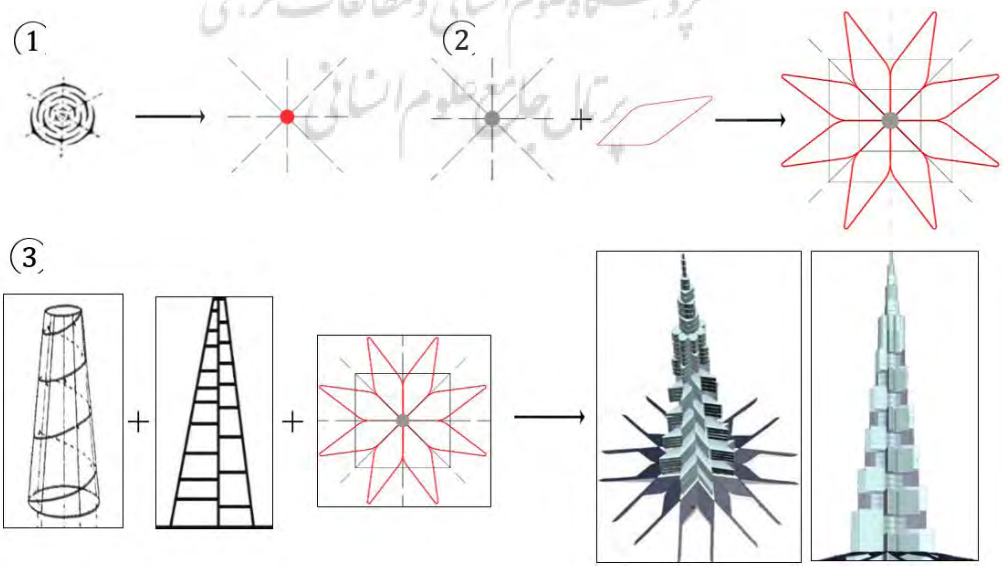


Fig. 6: Plan idea-processing by designing a leaf-inspired module and form generation using a spiral pattern inspired by phyllotaxis.

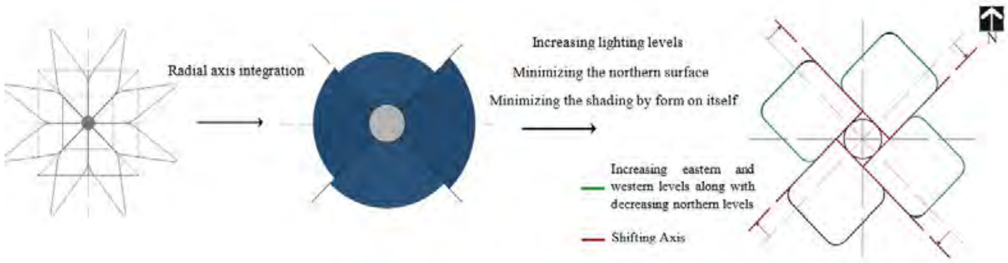


Fig. 7: The final form acquisition process.

Table 3: Modeled Building Specifications.

No.	Category	Sub-categories		Value	References
1	General Specification	Location		Tehran	
		Time	Working Hours	8 to 17	
			Working Days	Saturday to Thursday	
		Number of People (Ppl/m²)		0.1	
2	Size	Total Floor Area (m²)		3152	
		Floor Area (m²)	North	725	
			South	725	
			East	626	
			West	626	
			Core	450	
		Floor Height (m)		5	
		Ceiling Height(m)		3.5	
		Window-to-Wall Ratio (%)		70	
3	Architectural Specification	Use		Office	
		Plan Type		Open Office	
		Floor Level		20	
		Height Code		+ 104.00	
		Desktop Height (Evaluation Plane)		76 cm	(Neufert & Neufert, 2014)
		O.K.B (In the state of WWR: 50%)		80 cm	(Neufert & Neufert, 2014)
4	Heating & Cooling (Heat Transfer)	Heat Transfer Coefficient(W/m²K)	Wall (Curtain Wall)	1.5	
			Roof	Adiabatic	
			Floor	Adiabatic	
		HVAC System		VAV w/Reheat Cold Generator: Absorption Chiller Heat Generator: Hot Water Boiler	(American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2013)
5	Thermal Comfort Parameters	Predicted Mean Vote		-0.5 ≤ PMV ≤ +0.5	(American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 2013)
		Percent Dissatisfied		10	
		Clothing (Clo)		1	
		Metabolic Rate (Met), (1 Met = 55 W/m²)		1	
6	Lighting Specifications	Artificial Lighting Density (W/m²)	With LED Bulbs	3	Energy plus Software Guide
		Reflection Coefficient	Interior Wall	65	(Ministry of Health and Medical Education, 2017)
			Ceiling	65	
			Floor	30	
		Ambient Bounces		2	Radiance Software Guide
		Ambient Division		512	
		Ambient Sampling		128	
		Ambient Accuracy		0.25	
		Ambient Resolution		16	
		Direct Threshold		0.5	
		Window (Curtain Wall) Technical Data	Solar Factor (SF)	0.64	
			Light Transmission (LT)	0.73	
7	Visual Comfort Parameter	Illuminance Threshold (Lux)		500	(Ministry of Roads and Urban Development, 2017)
8	Test Points	Zones	Open Office	Mesh 2*2 (m)	Figure 8
			Conference Rooms		
			Manager's Office		
9	Equipment	Loads (W/m²)		5	Energy plus Software Guide

the high-rise building in managing spatial relationships and interconnecting functions (Figure 6). Then, spiral geometry (which is the main feature of phyllotaxis) could be used to obtain a three-dimensional final form (Figure 6). In the final step, the following steps were taken to increase the efficiency of the form (Figure 7):

• Integrating two radial axes to reduce the shading by form on itself.
• Increasing lighting levels by designing the corbels in the plan form.
• Shifting the main axes of the plan to minimize the shading of the form on itself.
• Minimizing the northern surface to prevent energy loss.

Daylight Simulation

In this study, a tower designed by benchmarking plants is evaluated by computer simulation. Based on the resulting form, typical plans are designed and one of the middle floors (20th floor) is selected for simulation. More precisely, four administrative units in the four northern, southern, eastern, and western directions have been considered for simulation. The daylighting analysis was performed by Daysim V4.0.0.0 and Radiance V5.1.0 the specifications of the model building and the simulated office units have been presented in full in Table 3. Figure 8 shows the plan of the floors and indicates the points examined in the daylight analysis.

RESULTS AND DISCUSSION

There are two valid evaluation indicators for measuring the lighting status of interior spaces: Daylight Autonomy and Useful Daylight Illuminance. Daylight Autonomy is a dynamic daylight assessment indicator, and for a given indoor point is equivalent to the percentage of time of year the building is used and where the intensity of required space lighting (which is determined by the type of space use) is accessible by daylight alone. Useful daylight illuminance is a dynamic daylight assessment indicator and it indicates that to what extent the daylight available in the building is useful and usable at the time it is occupied (between 100 and 2000 lux) and to what percentage it is too dark (less than 100 lux) or too bright (over 2000 lux) and unusable (Bagheri et al., 2013; Miri & Kompany Saeed, 2014). Figure 9(a) shows that in 90% of the time the building is operated during a year, the illuminance intensity of 500 lux at 86% of the points of the investigated grid is provided by daylight. However, a few points in the grid that are deep in space and do not exceed 14 percent have the least share. This indicates that except for 10% of the operating time during a year and except in points located deep in space; for the rest of the year and the rest of the points, there is no need for artificial light. The UDI index in Figure 9(b) illustrates two important points:

• 70% of the points surveyed, at least 20% of the operating time in a year, have illuminance intensity of over 2000 lux.
• 89% of the points have an illuminance intensity of over 2000 lux at least one hour of operation time per year.

This will result in the occurrence of glare at the desktop during work hours of the year. The southern unit has the maximum glare and the northern unit contribution is the least because of the absence of radiation on the northern side. Then, a series of actions which are mentioned in Visual Comfort will be applied in the following order (these specifications is obtained from Figure 3 and Table 2):

• Decrease in WWR (window-wall-ratio): WWR was initially assumed to be 70%. Reducing this rate to 60 and 50%, respectively, produced similar results, and WWR was considered to be 50% due to lower glare problems at some

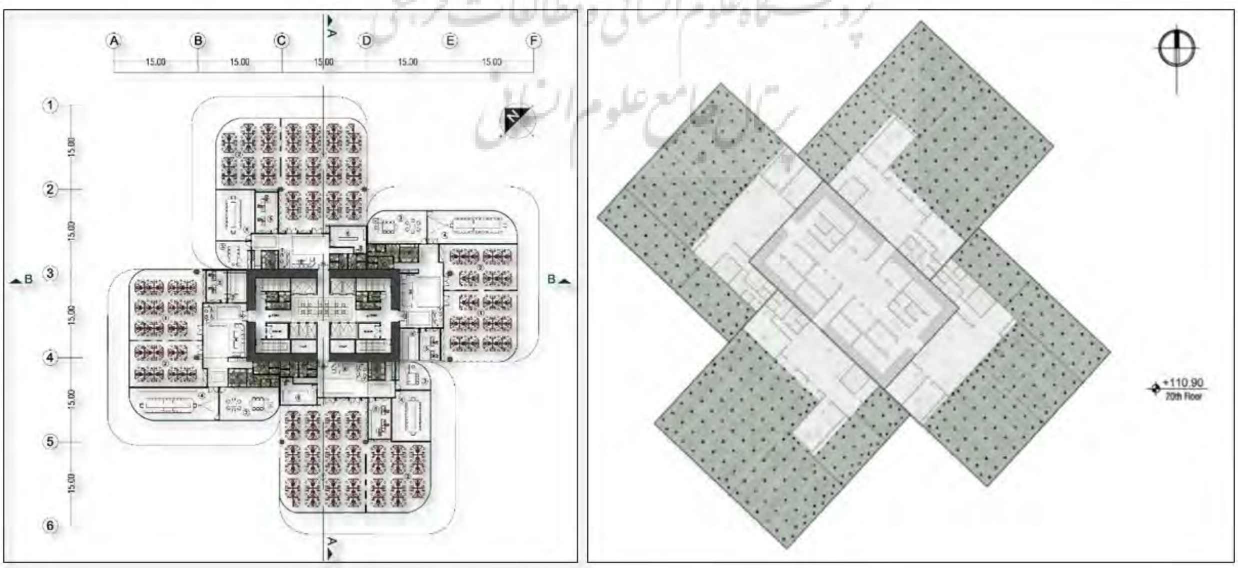


Fig. 8: Plan examined with office units on different fronts and mesh points for simulation.

points in the latter case (Figure 10 (a) and Figure 10(b)).

• Reduced light transmission coefficient: applied by the use of colored glass instead of ordinary glass to control the light entering the space (Figure 3). The results of this case are evident in Figure 10 (c) and Figure 10 (d). The wall heat transfer coefficient, in this case, is 1.8 W/m^{2}K.

• Shading: To determine the dimensions and technical specifications of shading devices, annex 10 of Code No. 19 (2017) of the National Building Regulations of Iran was employed. Using this appendix, the type (horizontal or vertical), number, and the correct dimensions of the shaders were determined and calculated (Table 2). The cross-section of all shaders is rectangular. Their material is aluminum and its reflectance coefficient is 0.7 (Ministry of Health and Medical Education, 2017).

Figure 10(e) shows that the illuminance intensity of 500 lux at 50% of the points is provided by daylight, at 50% of the operation time and that amount goes up to 100 percent in points where daylight is received through several directions. The UDI index in Figure 10(f) indicates that only 2% of the points in more than 20% of the operating times in a year experience the illuminance intensity of more than 2000 lux, the glare rate does not exceed 30% of the operating time during the year in none of these points. Subsequently, in 98% of the points surveyed, the problem of glare is solved or its amount is less than 20% of the operation time per year. Thus, with the set of above three measures, glare on the desktop is prevented and daylight is controlled. To clarify the daylighting analysis, the daylighting status at 4 days of the year is also examined. The illuminance intensity through daylight has been studied at 12:00 pm on May 5, June 22, November 5, and December 22 as representative days of four seasons. As shown in Figure 11(a) to 11(d), the form performance in providing daylight is similar for these days

Figure 12 (left) illustrates the percentage of points where the illuminance intensity is 500 lux or more on different days of the year. Figure 12 (right), on the other hand, shows the rest of the points that need to be artificially illuminated to achieve the visual comfort level of 500 lux. The potential to provide an illuminance intensity of 300 lux with daylight for a percentage of these points can be observed in this Figure. Overall, the results indicate that visual comfort through daylight is provided in more than 50% of the points throughout all days.

To find and analyze thermal performance, OpenStudio V2.5.0. has been used. The results of thermal analysis have been presented as the sum of the energy required for heating, cooling, lighting, equipment, fan, and pump of office units in Table 4.

To achieve the energy label of a building following Standard No. 14254 (2016) presented by the Institute of Standards and Industrial Research of Iran, after determining the type of climate of the city in which the building exists, the annual energy consumption index of the building should be calculated based on the useful built-up area (Equation 1). According to the climate of the city in which the building is located, and its governmental or non-governmental usage, the ideal building energy consumption index can be obtained based on the table which is shown on the standard. Then, using Equation 2, and by comparing it with the labels and figures introduced in the standard, the energy consumption label of the proposed building could be obtained (Institute of Standards and Industrial Research of Iran, 2016).

$$E_{actual} = ((\sum_i (Q_{Fi} * HV_i * 0.278) + Q_E * F_C) / A_F$$

Equation 1: Annual energy consumption index (Institute of Standards and Industrial Research of Iran, 2016).

Where:

Eactual: Annual Energy Consumption Index of the Building (kWh/m^2/

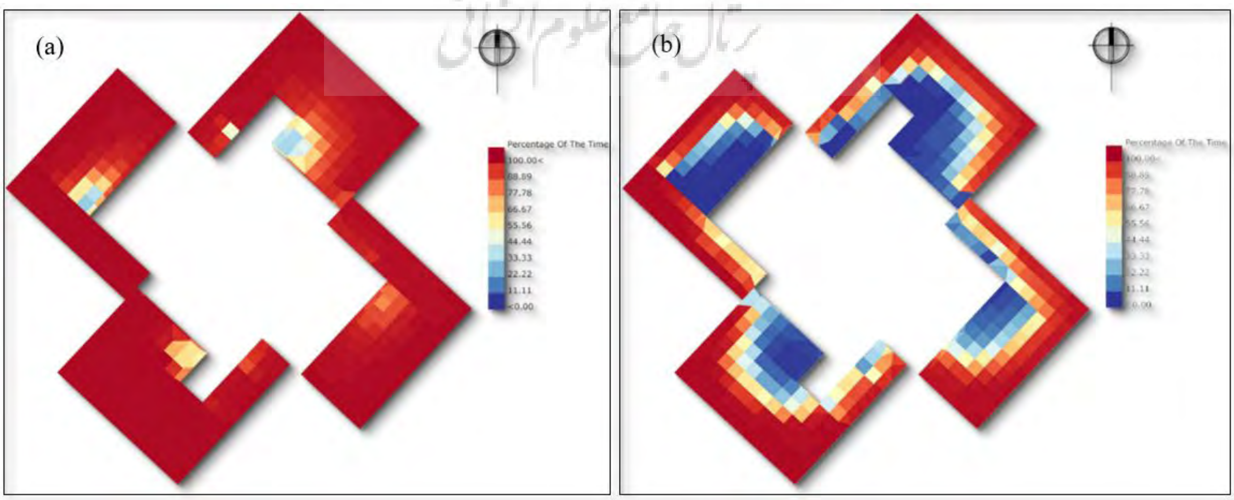


Fig. 9: Daylight autonomy (left) and daylight illuminance over 2000 lux (right) by applying 70% WWR.

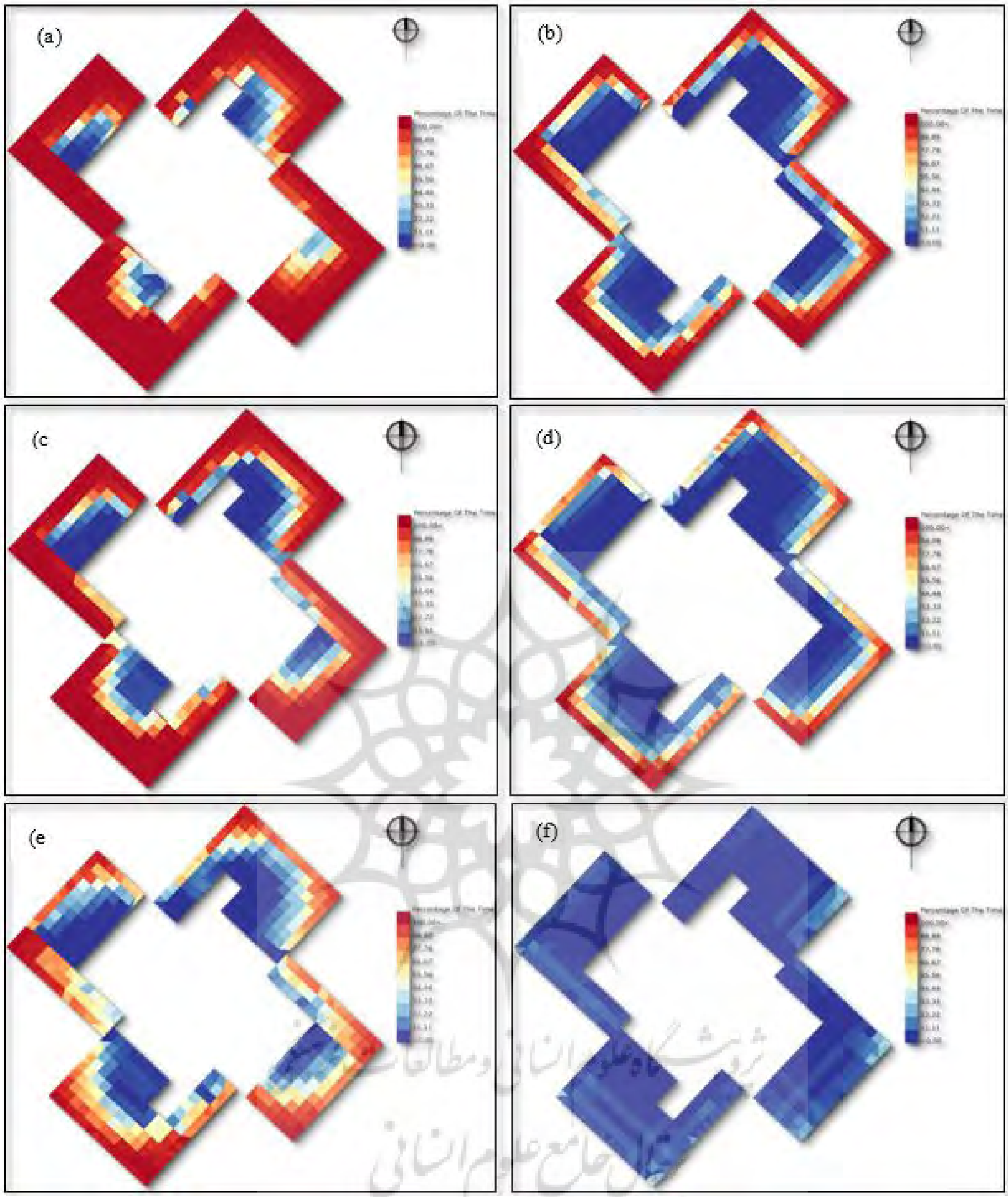


Fig. 10: Daylight autonomy (a) and daylight illuminance over 2000 lux (b) by applying 50% WWR, daylight autonomy (c) and daylight illuminance over 2000 lux (d) by applying 50% WWR and replacing the colored glass with transparent glass, and daylight autonomy (e) and daylight illuminance over 2000 lux (f) by applying 50% WWR and replacing the colored glass with transparent one and placing the shaders.

year)

QFi: Total Consumption of Energy Carrier (Natural Gas, Gasoline, Mazut) (respectively Nm3, lit, lit.)

HVi: Thermal Value of Energy Carrier (Conversion Factor to kWh)

QE: Total Power Consumption (kWh)

FC: The Conversion Factor of Electricity to Primary Energy

AF: Useful Built-up Area (m^2)

R: Energy Ratio

Eactual: Annual Energy Consumption Index of the Building (kWh/m^2/year)

Eideal: Ideal for Annual Building Energy Consumption (kWh/m^2/year)

For more accurate examination, the thermal loads per square meter are compared between the designed building and a similar existing building in Tehran. The technical specifications and building information have been obtained from field surveys and energy audits (Naderi et al., 2014). The energy consumption for cooling per square meter per year in the designed and existing building is 8.7 and 295.4 kWh, respectively. The energy consumption for heating per square

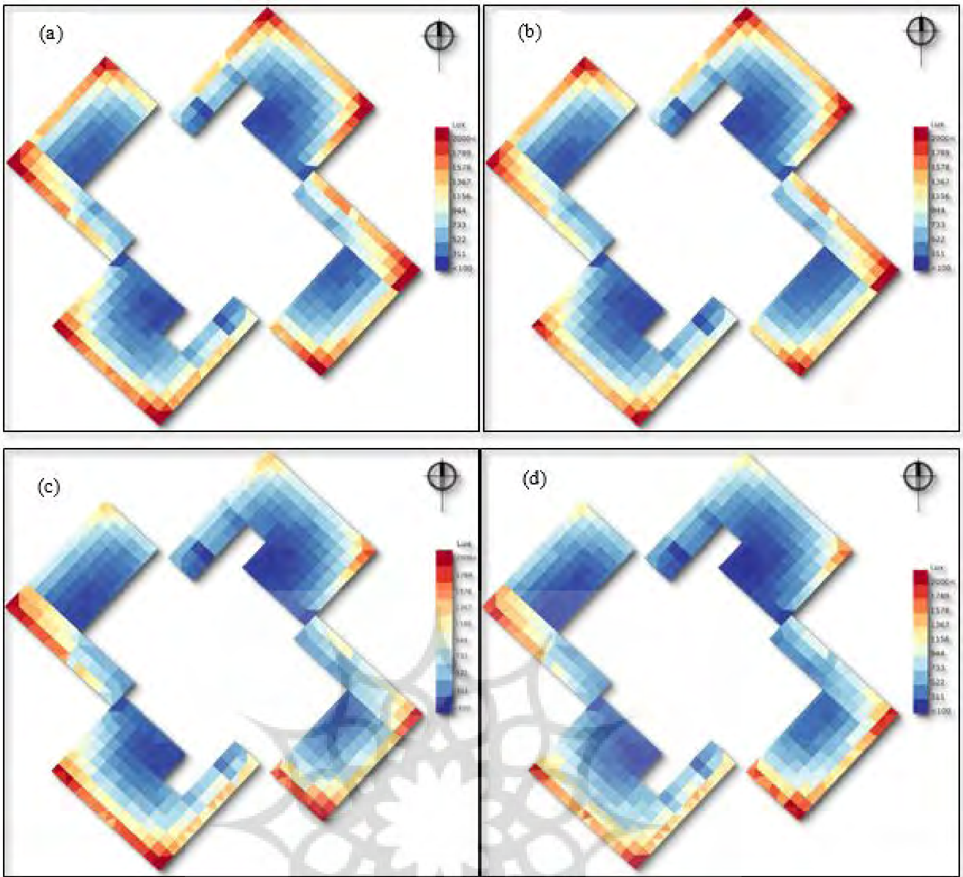


Fig. 11: Daylight Illuminance: 5May (a), 22June (b), 5November (c), 22 December (d).

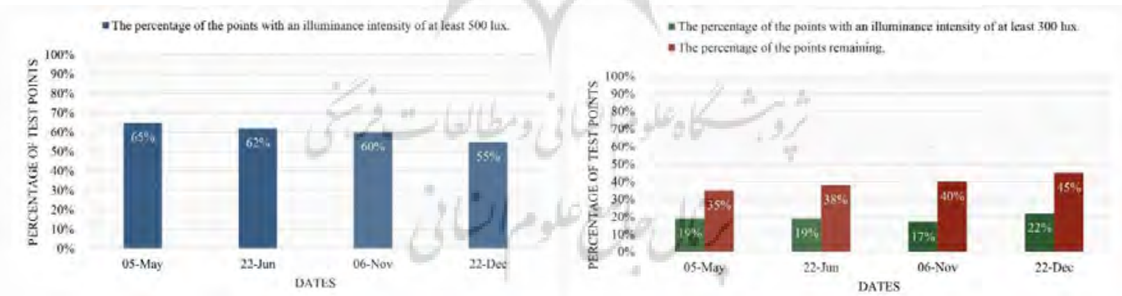


Fig. 12: Percentage of the points where illuminance intensity of 500 lux can be obtained (left) and where illuminance intensity of 300 lux can be obtained (right).

Table 4: Annual Energy Consumption in a level of the designed tower by category.

Consumption Title	Cooling	Heating	Lighting	Equipment	Fan	Pump
Energy Consumption of 20th Level During a year (kWh)	27,281.5	148,869.7	17,672.5	80,085.3	6,080.4	16,449.4

meter per year in the designed and existing building is 47.2 and 102.9 kWh, respectively. The energy required for cooling per person per year in the designed and existing building is 86.6 and 2701.9 kWh, respectively. The energy required for heating per person per year in the designed and existing building is 472.6 and 941.1 kWh, respectively. In a study conducted by Naderi et al. in collaboration with Iran's Vice President for Strategic Planning and Supervision,energy consumption data has been collected for 40 office buildings in Tehran by energy audit in terms of energy carriers and consumption points; and based on this, the building's energy consumption label has been calculated and determined. In another study carried out by the Ministry of Energy, conducted by Bagheri et al. (2013), the characteristics of five office buildings in Tehran, along with their electricity and gas consumption, were gathered through a three-year billing and field measurement. Using this information, the energy label of these buildings is calculated and determined in the present study. The energy label status of the 45 office buildings in Tehran compared to the designed building can be observed in Figure 13. It should be noticed that following the table of standard No.14254, each city has just one specific climate, and all of the areas and zones of each are assumed to be in the same climatic condition. The energy consumption index for a single floor (20th floor including four office units) has been calculated by Standard No. 14254 (2016), the energy consumption class B is obtained (Figure 14).

To examine in detail the building performance in different months, the thermal loads of the three floors of the designed tower (including floors 19, 20, and 21) have been analyzed. Figure 15(top) shows the energy consumption status for cooling. As expected, except for the coldest three months of the year, December, January, and February, the remaining months of the year require cross-sectional or general cooling. This cooling rate comprises a spectrum that its maximum amount (58 kWh) occurs between 12 pm to 6 pm in June, July, and August. The minimum value of this spectrum also corresponds to the transitional period of the year, which means that in March, April, and November, intermittent use of up to 23 kWh is visible. The curved lines on the chart represent the hours of sunrise and sunset and the length of day and night on different days of the year. The amount of energy consumed during the day and compared to the night is visible on the chart. Figure 15(bottom) shows the energy consumption amount for heating. According to the figure, it is observed that there is no need for heating in summer (July, August, and September) and June of the spring, and the color spectrum is shown on the chart is related to the supply of hot water. For the rest of the months, concentrated energy consumption is observed in the early hours of the morning. The maximum amount of heat required is in December, January, and February. In March, April, and May, the heating demand decreases and is required for specific times. Then, in October and November, the ascending spectral heating is needed and its peak is in the early hours of the morning again. It is worth mentioning that on the heating chart as the sun rises on cold days of the year, resulting in a significant reduction in the need for heating. This value in the early hours of the day before sunrise is between 480 kWh to 560 kWh, which decreases with sunrise to 270 kWh to 427 kWh and it is then reduced to 50 kWh to 213 kWh during the day and again, at sunset, the values are from 213 kWh to 270 kWh (depending

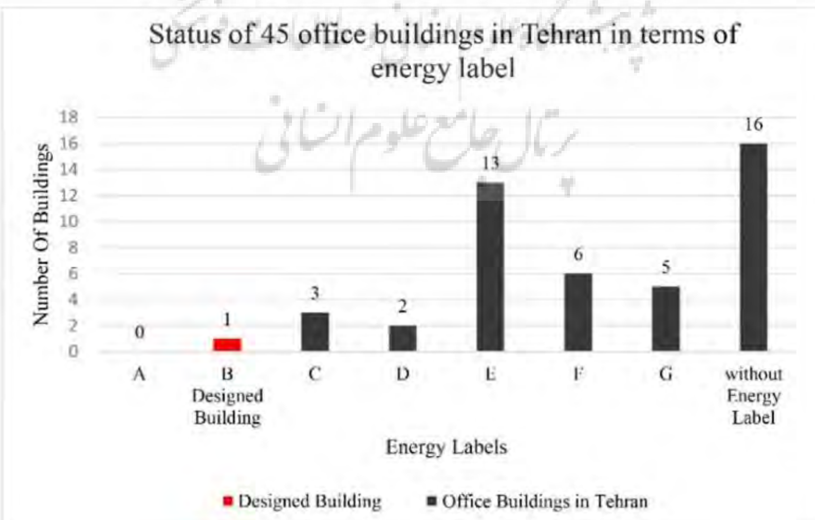
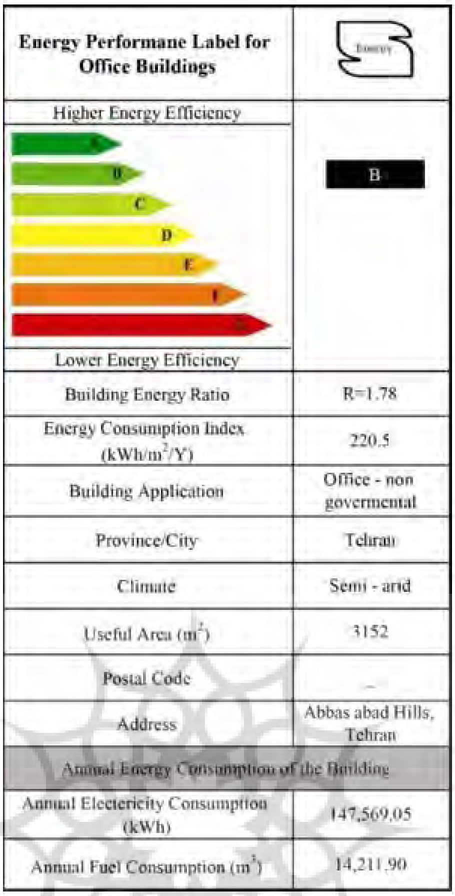


Fig. 13: Energy label status of 45 office buildings in Tehran.



Energy Performane Label for Office Buildings	
Higher Energy Efficiency	B
Lower Energy Efficiency	
Building Energy Ratio	R=1.78
Energy Consumption Index (kWh/m^2/Y)	220.5
Building Application	Office - non govermental
Province/City	Tehran
Climate	Semi - arid
Useful Area (m^2)	3152
Postal Code	-
Address	Abbas abad Hills, Tehran
Annual Energy Consumption of the Building	
Annual Electericity Consumption (kWh)	147,569.05
Annual Fuel Consumption (m^3)	14,211.90

Fig. 14: Model building energy consumption label (Bagheri et al, 2013).

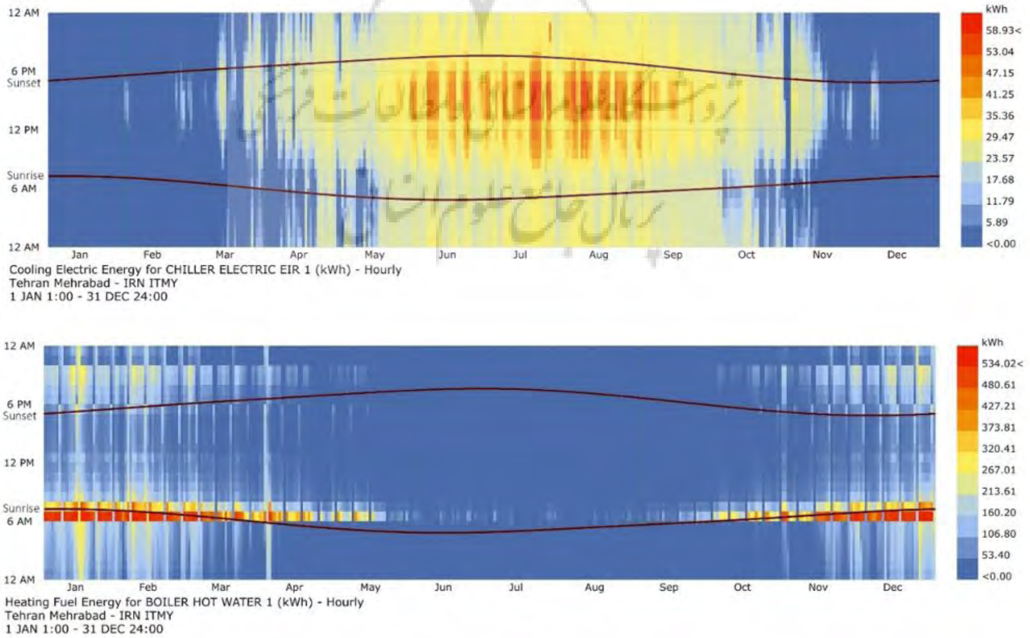


Fig. 15: Cooling (top) and heating (bottom) energy consumption per year for three-story office units of the designed tower.

Table 5: Comparison of the results

Evaluation Title	Results		Differences (%)
	ASHRAE 140-2017	Present Study	
Annual Heating Load (MWh)	4.378	4.596	4.7
Annual Cooling Load (MWh)	6.740	7.079	4.8

on the day of the year). This difference in the amount of heating required before and after sunrise and sunset can be observed in January, February, November, and December.

Validation of the Results of Computer Programs

ASHRAE Standard 140-2017 published by the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. has been used to evaluate the accuracy of the simulation results and to obtain their deviation from the actual and experimental values. In this regard, case number 600 of this standard is simulated by the software used in this study, and the results are compared with the results of the standard. Table 5 indicates the comparison of results. This comparison shows a 4.7% and 4.8% difference between the standard results and the simulation results. Given that their similarity is more than 95%, the software used is calibrated and all the results obtained from the software in this study are valid.

CONCLUSION

Given the energy situation of today's world, the decision to use sunlight in middle east countries with a hot arid climate, and high energy consumption such as Iran, is not an option, rather, it is a necessity and inspiration from nature as a solution may lead to this objective. So, in the present study, the focus is on using the phyllotaxis model to evaluate the appropriate utilization of daylight. To achieve this goal, a sample building designed with the phyllotaxis approach is evaluated by computer simulation. The results show that office units can get daylight illuminance of 500 lux at 50% of operating time per year. Also, the designed building has achieved the Energy consumption label B and has the best performance among 45 existing and similar office buildings in Tehran all of which have similar climatic conditions based on the tables of standard No.14254. Moreover, In the case of heating, the energy consumption of the designed building compared to an existing building with the same area decreased by 54.1%. More precisely, the energy consumption for cooling per square meter per year in the designed building is 8.7 kWh/m^2, whereas, in the existing building with the same specifications is 295.4 kWh/m^2. Energy consumption for heating per square meter per year in the designed building is 47.2 kWh/m^2 and the existing building with the same specifications is 102.9 kWh/m^2. Doing this research is the beginning of a different and prominent perspective that needs to be further developed. It is hoped that this research provides a capable platform for future research.

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