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Optimal Window Area of a Kinetic Facade to Provide Daylight in an Office Building in Tehran

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Abstract

Window-to-wall area ratio (WWR) is an important parameter that significantly affects the energy efficiency of a building. This research aims to achieve the optimal level of the window area with a squared geometry rotational kinematic model having a horizontal axis in the south facade of an office building in Tehran. to evaluate the indoor daylight level, dynamic daylight indicators with WWR from 50 to 90 % and facade kinematic model have been simulated using the Grasshopper tool and Honeybee Plus plugin version 06 and Ladybug Lbt version 1.5.0. through parametric simulation were studied parametrically. First kinetic facade and its movement structures are introduced, then the daylight indices and the required lighting level for office space been discussed. The simulation is carried out using two models of optical and thermal properties in the office building, wherein the base model, the ratio of the optimal WWR is up to 60% for a facade with a square geometric model and a rotating kinematic model with a horizontal axis.The reflection coefficients of the floor, wall, the glass's visual transmission coefficient, and the viewing angle (45 to 95 degrees) were parametrically studied to optimize the results. The results showed that on the south facade of the office building in Tehran, using a kinetic facade with a rotational kinematic model and horizontal axis, the optimal WWR is 50%.

Keywords: Window-to-wall ratio; Kinetic façade; Kinematic model; Dynamic daylight; Simulation; Office building

1. Introduction

Window size directly affects the total energy consumption of a building through the availability of solar radiation and daylight. About half of the energy loss in buildings relates to windows.

WWR is one of the most critical factors in a building envelope, as the high heat transfer coefficient of windows results in a high amount of heat loss in the buildings (Hesaraki, 2017). A kinetic facade can be responsible for sun shading, natural lighting efficiency, and providing visual and thermal comfort inside (Kontovourkis, Michael, Alexandrou, & Vassiliades, 2015). Kinetic facade adapts the state and structure of the building to the changing external conditions by controlling and adjusting the environmental conditions of the interior space to respond to uncertain external conditions, so that comfort conditions are always maintained. One of the main benefits of this facade is controlling the daylight entering the interior. Its other advantage is increasing daylight quality, and improving the quality of vision, especially in office and public spaces. This research aims to achieve the optimal WWR using a kinetic facade in the south wall of an office building in Tehran. In this research, the angle of the rotational kinematic model with the horizontal axis is identified and analyzed according to the optimal percentage of the window area and the use of natural daylighting; according to this objective, the following questions are raised:

- Which window area in a kinetic facade with a square geometric model and a rotating kinematic model having a horizontal axis on the south wall of an office building in Tehran performs the best?
- What is the optimal angle of the kinetic facade of the office building in Tehran concerning the surface of the window in the south wall?

2. Research Background

According to the studies, less attention has been paid to the relationship between the kinetic facade and the optimal ratio of window area to the wall. In a study, Shaeri et al. (Shaeri, Habibi, Yaghoubi, & Chokhachian, 2019) investigated the optimal WWR for different facades in an office. They simulated a building model using Design Builder software to investigate the amount of annual solar heat gain, cooling load, heating load, and lighting consumption for three cities, Bushehr, Shiraz, and Tabriz. Based on the results, the optimal WWR for

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the north facade for all climates is 20-30%. This value is 20 to 30%, 10 to 30%, and 20 to 50% for the south facade of the building in Bushehr, Shiraz, and Tabriz, respectively. The optimal WWR for the east and west facades of the building in Bushehr is 30 to 50%t. In Tabriz, it is 40-70%, and in Shiraz, it is 20-60% and 40-70%, respectively. The difference between maximum and minimum energy consumption with different windows positions in Bushehr and Shiraz is 20-100%, and in Tabriz is 25-16%. Jewel et al. (Jewel , Rakibul , Habibur , & W. Y. Tam, 2020) studied the effect of WWR on the energy consumption of air-conditioned office buildings in subtropical regions of Bangladesh. They suggested a WWR of 10% to 80% and a wide range of WWR, with 30% to 40% as the optimal one for air-conditioned office buildings in Bangladesh. In a study by Sayadi et al. (Sayadi, Hayati, & Salmanzadeh, 2021) different cases to obtain the optimal window-to-wall ratio in seven different climates based on the Köppen-Geiger climate classification were examined. Based on thermal comfort indices for south-facing exposure, the optimal WWR for a double-glazed window for hot and cold climates is 60% and 70%, respectively. The optimal percentage for a triple-glazed window is 40% or 50%, depending on weather conditions for hot weather and 70% for cold weather. Nadeem et al. (Nadeem, Sharipov, & Abzhanov, 2021) focused on optimizing the window features of buildings in Nursultan, Kazakhstan to improve energy efficiency and daylighting performance. A simulation was carried out using Design Builder software to investigate the effects of WWR, glass type, shading, and building orientation on building energy performance and thermal comfort level. It was found that triple-pane windows with 10-15% WWR primarily south facing perform better than other configurations. Johnson et al. (Johnson, et al., 1984) investigated the effect of daylight on the building's energy consumption. They concluded that effective use of daylight through optimal WWR can help reduce building energy consumption. A study (Ghisi & Tinker, 2005) observed that daylight could help reduce the amount of energy used for artificial lighting in interior spaces. Heidary (Heydari, 2012) suggested using the following equation to calculate the area of a window. In equation (1), the room's height is considered to be 3 meters. As a result, for a room with a width of 5 meters, the room's depth should not be more than 6.25 to be able to use daylight.

$$s\ \text{window} = H \times W \times 20\% \tag{1}$$

Where:

s Window area

H (m) Floor height below the upper threshold of the window

W (m) room width.

Haddadzadegan et al. (Haddadzadegan, Tahsildoost, & Zamardian, 2020) investigated three types of office buildings with open plans in three cities of Tehran, Bandar Abbas, and Tabriz representative of three different climates. The WWR of 40% on the south and north facades was suggested for a high-rise office building with a rectangular shape in Tehran. Nasiri et al. (Nasiri, Hafizi, Tahsildoost, & Zomardian, 2019) studied the optimal WWR as 29% using a genetic algorithm for the Tehran climate. Moulai et al. (Moulai, Pileh Chiha, & Shadanfar, 2019) compared WWR in the best models considering the specifications of the glass optical transmission coefficient of 40%, the 60% reflection of the walls, 80% reflection of the ceiling, and the 30% reflection of the floor on all fronts and with an angle of 90 degrees to the east, 180 degrees to the north and an angle of 45 degrees to the northeast, the WWR of 20% to 28% in Tehran had the lowest energy consumption. By comparing the length and width of the optimal models of Reinhardt's standard office room (Christoph F, Alstan Jakubiec, & Ibarra, 2013), It was determined that the optimal window length in the city of Tehran is between 6.40 meters and 6.80 meters, and the optimal window width is between 0.8 and 1 meter. According to Code No. 4 of Iran's national building regulations (National Building Regulations Office, 2017) if the facade of a building is covered with at least 60% glass, it is called a glass facade. In research by Sarihi et al. (Sarihi, Faizi, & Mehdizadeh Siraj, 2022) studied the effect and priorities of thermal insulation parameters, type of window, and shading devices for energy efficiency in existing office buildings with south orientation in Tehran.

The results show that in facades with a high U value, the priority of the parameters to reduce the total energy consumption is installing a shade with appropriate depth, adding thermal insulation, and Window replacement. On the other hand, in facades with a low U value, the use of a proper window after installing shading is a priority. These studies mention the importance of WWR in different cities and its effect on energy consumption. In a study by Khatibi et al. (Khatibi, Shahbazi, & Tarabi, 2022), the lighting condition of the rooms in a four-story office building in Tehran is studied by simulation and field methods. The field evaluation results show that the intensity of the local lighting is higher than the recommended standard values, and this has caused users to be dissatisfied with the lighting condition and visual comfort. Then, he suggests a moving facade and compares the results using simulation. It has been determined that the moving facade controls glare and interior lighting. In a study by Mangkuto et al. (Mangkuto, et al. 2022), the window area was optimized using a combination of responsive and fixed shades in four main geographical directions in a high-rise office building in tropical areas. The results showed that the spatial daylight index and Annual sunlight exposure with a fixed facade are responsive only in the north and south directions. these indexes respond to daylight only in the east and west directions with a responsive facade. Most of these studies have measured the optimal WWR on the south facade without shading devices. This research evaluates the WWR in combination with kinetic shading and its effect on interior daylighting through simulation.

3. Theoretical Framework

3.1. Geometric model and movement structure of kinetic façades

The geometric and kinematic models are essential parameters in kinetic façade design. The geometric and kinematic model plays an influential role in understanding the way of opening and closing the facade, the controller, the materials, and the stability of the structure. Mobility in the facade (or its modules) requires the geometrical ability of its components to maintain their structure and continuity while changing shape (Sharaidin, 2014). Unlike a static one, the design of a moving facade requires an interactive design process through the selection of geometry and analysis of its movement, the creation of digital and physical models, to the selection and design of required connections and materials, considering the movement mechanism. Table (1) Several researchers ("Rostamzadeh, Faizi, Sanyayan, & Khakzand, 2021","Mohaghegh, Falah Zavareh, Turkashund, & Faizi, 2021" "Moloney, 2011" "Korkmaz, 2004" "Elghazi, Wagdy, & Abdalwahab, 2015") have suggested various geometric and kinematic models. Some mechanical and technical principles must be mentioned and explained to achieve an intelligent kinetic design in architecture. These principles are divided into three general categories: aspects of construction and materials, the method of controlling changes, and the kinematic model.

Table 1
Classification based on geometric and kinematic models

Iran		
Author	**Research approach**	**modeling**
Rostamzadeh, Faizi, Sanyayan, & Khakzand, 2021	facade improvement	• Horizontal rectangular geometric pattern •material
Mohaghegh, Falah Zavareh, Turkashund, & Faizi, 2021	Geometry in Islamic architecture	Nodes are a combination of polygons and suns
the world		
Author	**Research approach**	**modeling**
Moloney, 2011	Architecture that changes with time.	• Geometric interpretation in space • Deformation of materials
(Korkmaz, 2004)	The role of movement conceptually and functionally	• The concept of physical and non-physical movement • The building responds to structural pressures through its form. • The mechanical approach to form
Elghazi, Wagdy, & Abdalwahab, 2015	Folding tetrahedron (origami) with a rotating movement	Changing the shape of the folding geometry from hexahedral to tetrahedral

A) Aspects of construction and materials: in the construction of kinetic systems, for the best structural solution, methods (sliding, expansion, folding, transforming), tools (pneumatic, magnetic, chemical, natural, and spatial), and materials (ceramic, polymer and gel, nanomaterials and metal compounds and composites) are of great interest. According to Fox (Fox, 2009), kinetic structures are divided into embedded, expandable, and dynamic movement structures. In an analytical study of design potential in kinetic architecture, a complete classification of dynamic structures is presented, including soft-form buildings (kinetic capacity through stretched membranes or pneumatic cable network structures) and rigid-form buildings (kinetic capacity through expandability, folding, expanding or rotating and sliding with rigid materials and joint connections) (Korkmaz, 2004). In 2011, the classification of kinetic systems in architecture was introduced according to the geometrical change of the system (Moloney, 2011). In 2014, the components of existing mobile architecture were classified as: structure, communication, actuators, materials, and control systems (Elkhayat, 2014)**.**

B) Embedded Computation: The importance of Embedded Computation is limited to the ability to sense the change in the environment and depends on the control ability to respond to the change. Embedded Computation combines computing processors and information such as computing sensors, cameras, and microphones. The trends of embedded computing, the level of the machine control mechanism, and the types of space controllers are shown in Figure (1).

c) Kinematic model of kinetic façade: Kinetic architecture is a field of research that accepts the concept of movement as design input. A kinetic structure can be classified depending on the type of movement, materials used, and kinetic building elements. Mainly, the type of movement is generally classified as sliding, rotating, opening and closing, and folding.

Depending on the design of the mechanism, different types of movement can be built into the same structure.

For example, an end folding type is formed by connecting two structural members so that the two structural members move from one side to the other, and the resulting ends of the elements are constrained in a scissor sha (Başar, 2014). At the same time, the materials and elements from which this movement is derived are related to each other. For the general classification, the materials used can be classified as rigid and deformable elements, and the kinetic elements can be classified as surface and volume elements (Schumacher M. S., 2010). Schumacher et al. (Schumacher, Marcus, Luis A, & Krumme, 2019) divided the kinetic movement structure into partial displacement and total displacement. Herzog et al. (Herzog, Krippner, & Lang, 2017) divided the movement structure of the facade and window into vertical flat, angular, vertical and horizontal flat, horizontal curve, vertical curve, and a combination of horizontal and vertical.

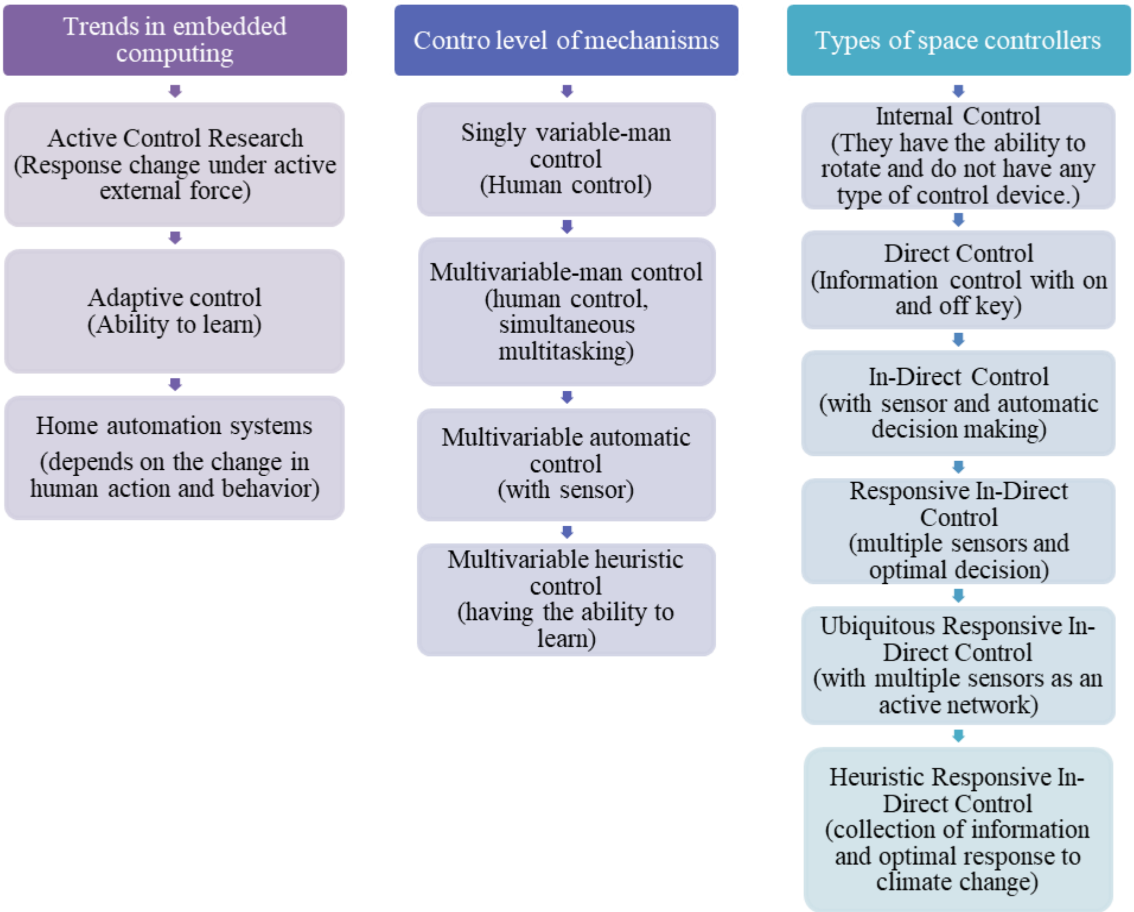


Fig. 1. Controllers in kinetic facades (Fox, 2009), (Mohamed Abd El-Hady Fouad, 2012)

3.2. Daylight

Several indicators have been provided to evaluate the daylight in the interior (Daylight Autonomy, glare, light distribution). Photometric indices in this field are divided into static and dynamic groups. A): Static index: static indices are evaluated for a fixed situation under cloudy sky conditions, and the "daylight factor" index is one of them (Pourahmadi, Khan Mohammadi, & Muzaffar, 2020). B): Dynamic index: due to the limitations of the static approach, dynamic indices were introduced, which, due to the consideration of design parameters, climate, and changes in the state of the sky, and consequently, lighting changes based on meteorological data, evaluate the lighting conditions of the space and the visual comfort of users throughout the year. Table (2) introduces dynamic daylight and glare indicators. According to European standards (BS EN-12464-1, 2021) Minimal lighting requirements highlight an actual work area rather than an entire room. In this standard, 500 lux lighting is required for a typical office workplace. Regarding Code No.13 of Iran's National Building Regulations (Compilation and promotion of national building regulations, 2017), the required lighting level for a regular office is 500 lux. The optimal lighting intensity in office spaces is 600 to 650 lux, and the lighting intensity between 600 to 550 lux also provides comfortable conditions. A light intensity of less than 550 lux is not desirable for occupants (Fakhari, Fayaz, & Mehravar, 2021).

Table 2
Dynamic daylight and glare indices

	Indicators	Description
Dynamic daylight	Useful Daylight (UDI)	This index is a percentage of the occupancy period during a year when the horizontal illumination at a certain point is within a specific range. Generally, the value of 300 to 3000 lux is suggested as the range of light sufficiency (Nabil & Mardaljevic, 2006).
	Daylight Autonomy (DA)	It shows the sufficiency of daylight in the interior space. . It is equal to the percentage of the period of space occupation during one year in which the amount of lighting required at a certain point of the space can be provided by natural lighting alone. The American Society of Lighting Engineers recommends 50% of SDA 300 for light adequacy analysis, that is, the percentage of surface points that receive illuminance greater than 300 lux during at least 50% of the occupied time (from 8 a.m. to 6 p.m.) (Fedai Ardestani, Naseri Mubaraki, Ayatollahi, & Zamardian, 2018).
	Spatial Daylight Autonomy (SDA)	Daylight received on a work surface during standard working hours annually. The target is 300 lux for 50% occupancy (Hosseini & HeiraniPour, 2020).
	Continuous Daylight Autonomy (CDA)	The continuous daylight Autonomy method is obtained by adjusting the daylight autonomy method, which represents the measurement of the percentage of an area or space that provides the amount of daylight autonomy for a certain period (Rogers, 2006).
Glare	Annual sunlight exposure (ASE)	It the amount of space that is exposed to excessive direct sunlight (Elghazi Y. , Wagdy, Mohamed, & Hassan, 2014) and becomes a source of visual discomfort or glare. It is defined as the percentage of the analyzed area that receives the level of direct sunlight illumination (1000 lux) for more than a specified number of hours (250 hours) (Erlendsson, 2014). According to Illuminating Engineering Society (IES), when SDA 300,50% ≥ 55%, the space is considered "neutral" or "nominally acceptable," and when SDA 300,50% ≥ 75%, the space is considered "preferred" (LM-83-12, 2012).
	DGP	It is one of the common indicators in the evaluation of glare in space, where the amount of brightness in contact with the eye is calculated according to the time. In this index, the values of 0.4-0.35 are perceptible, 0.35> is imperceptible, 0.4-0.45 is disturbing, and >0.45 is intolerable (Suk, 2016).

4. Research Methodology

The current research is applied research that analyzes and evaluates the optimal level of the window using a quantitative method through simulation to evaluate the performance of a kinetic facade. According to Figure(2), This research is carried out in the following steps:

- First, the software is validated. Rhino software version 6.32, Grasshopper plugin and Honeybee Plus plugin version 0.0.06, and Ladybug version 1.5.0 with a registered sample from Berardi et al.'s (Berardi & Khademi Anaraki , 2015) were used in this research.
- Then, after comparing the results obtained by the simulation, a kinetic facade with a square geometric model and rotational kinematic models with a horizontal axis was chosen, and an algorithm was written in the Grasshopper environment.
- The facade opens and closes according to the vector perpendicular to the surface and the movement of the sun, so that the facade opens and closes gradually according to the position of the sun in the sky.
- Finally, an open plan office room (Office of technical affairs and compilation of budget program organization criteria, 1998), (Resolution of the Supreme Administrative Council, 2011), and the Rinehart model (Christoph F, Alstan Jakubiec, & Ibarra, 2013) With WWR of 90% to 60% in 10 intervals, was simulated. Through Excel 2020 the data obtained from the simulation were compared and analyzed. Then, the most suitable WWR was suggested for the city of Tehran.

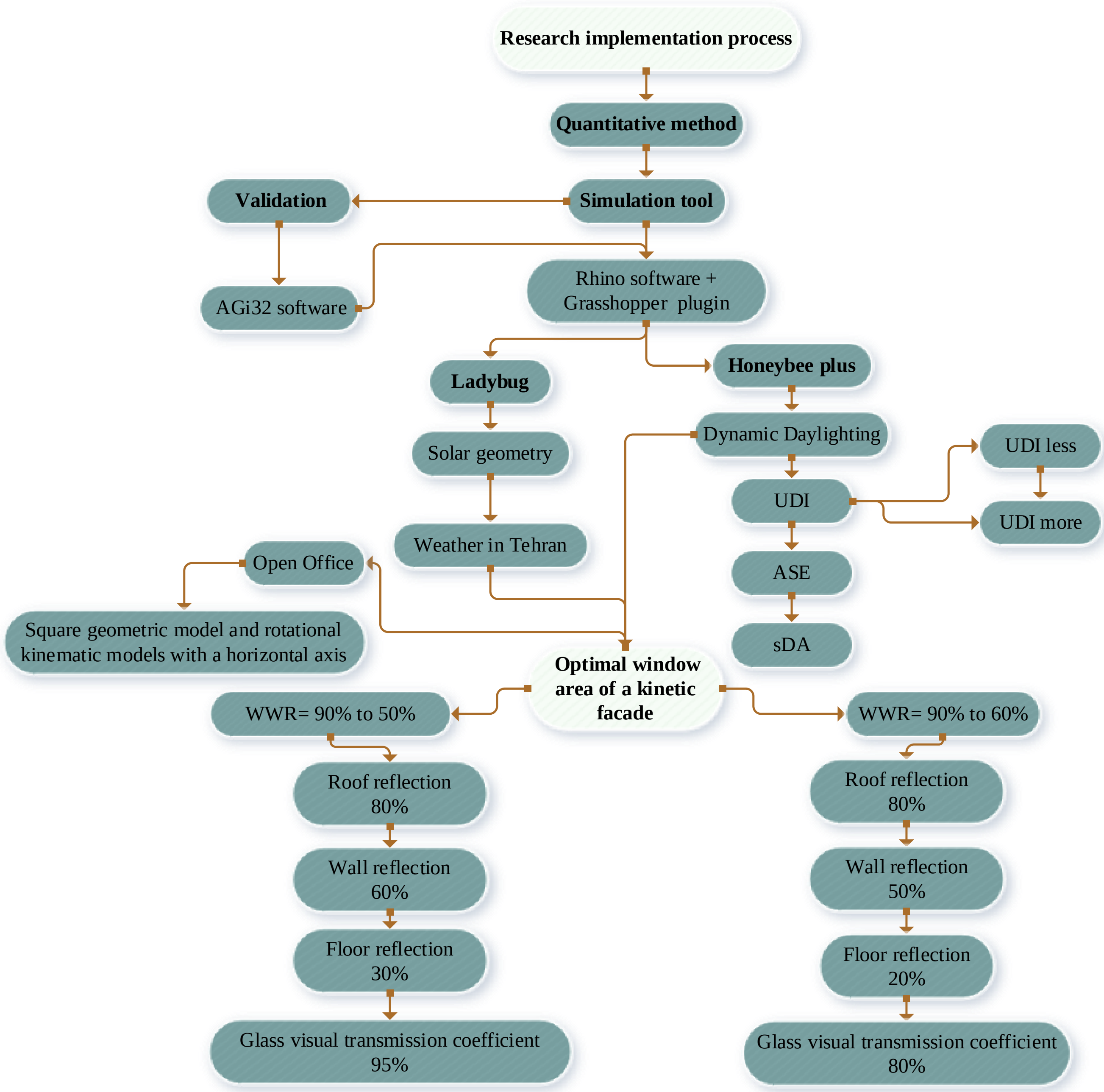


Fig. 2. Research implementation process

4.1 Validation

In a study by Berardi et al. (Berardi & Khademi Anaraki , 2015) the WWR of an office room in Toronto, Canada, was simulated with and without a canopy. The simulation was done using AGi32 software. The specifications of the simulated sample are specified in Table (3). The WWR was changed from 55% to 25% in 5 intervals. The Useful Daylight Index (UDI) is studied according to various percentages of the window area and distance to the window in Figure (3) without any shading. 0 to 25% UDI with black color, 20% to 25% UDI with rich gray color, 50% to 75% UDI with light gray grade 1, and 75% to 100% UDI with a very light gray color were achieved. UDI with 55% WWR is more than 25% WWR. The results show that adding a canopy to 55% WWR does not significantly affect UDI, and the room receives excessive light with the increase of the window area. The data results without shading in Berardi et al.'s research (Berardi & Khademi Anaraki, 2015) were obtained using Grasshopper software and Honeybee Plus plugin. It can be seen in Figure (4) that the results of the simulation without shading are consistent with the previous research.

Table 3
Specifications of the simulated sample (Berardi & Khademi Anaraki , 2015)

Room Dimensions	10 m width, 15 m length, and 4 m height
Roof reflection	80%
Wall reflection	60%
Glass visual transmission coefficient	70%
The dimensions of the floor grid	0.5 m
Floor points	551 point
The height of the reference plane from the floor	0.8 m
Window dimensions	3 m high and 1 m wide

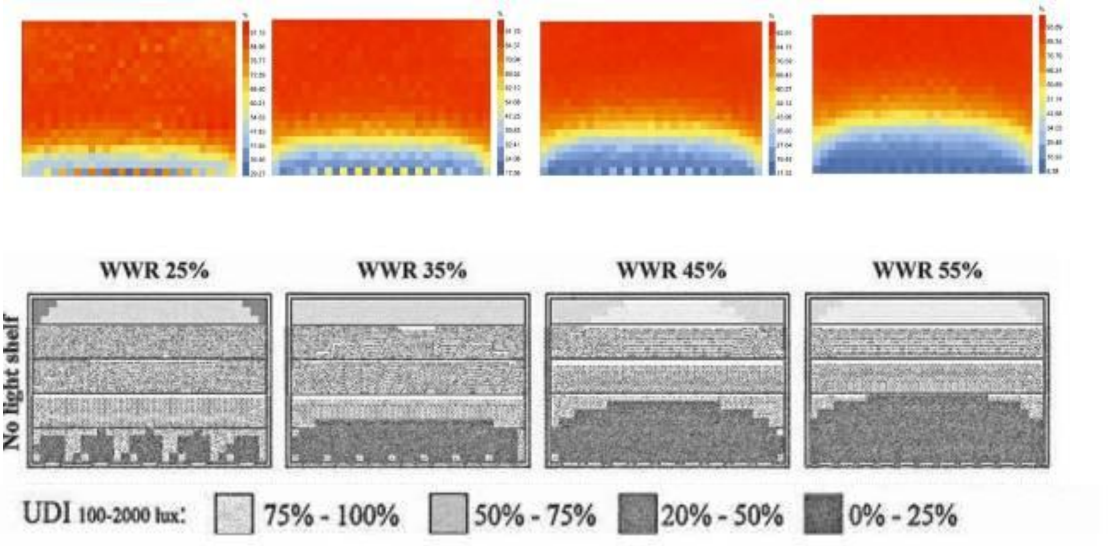


Fig. 3. Comparison of the simulated data without shading in the research of Berardi et al. (bottom) and the simulation results with Grasshopper software and Honeybee plugin (top).

Figure (3) shows a comparison between the average UDI of 100-2000 lux as a function of the distance from the windows with Grasshopper software (Honeybee) and Berardi et al.'s research (Berardi & Khademi Anaraki , 2015). Increasing WWR reduces UDI levels in the first few meters in front of the window while increasing daylight in the back of the room. Except for the window-to-wall ratio of 25%, without awnings, the useful daylight reaches below 50% at a distance of 3 meters from the windows. The maximum UDI level for cases without shades occurs at a distance of 3 meters, 4 meters, 5.5 meters, and 6 meters from the windows for 25, 35, 45%, and 55% of the WWR, respectively. According to Figure (4), the window with WWR of 55% is matched with brown color in both software, the amount of UDI at a distance of half a meter from the window is less than 25%, and gradually with an increase in the distance from the window, this value reaches to 90%, which indicates the reliability of the software.

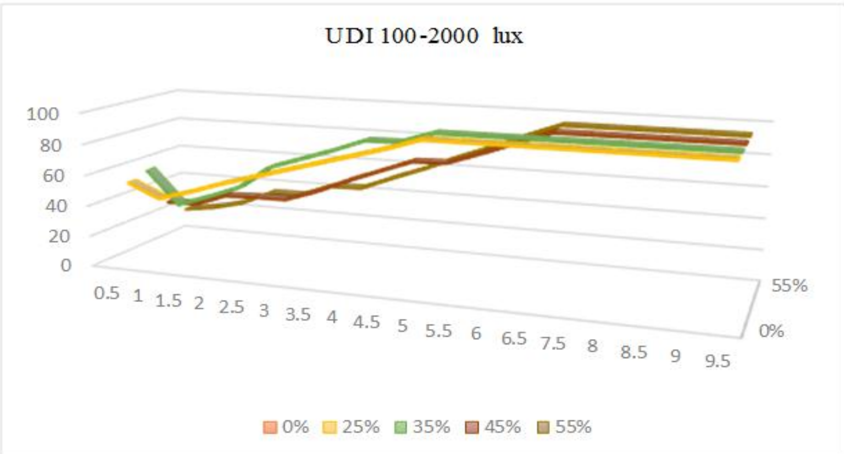


Fig. 4. Comparison of the average UDI of 100-2000 lux at an equal distance from the different window percentages.

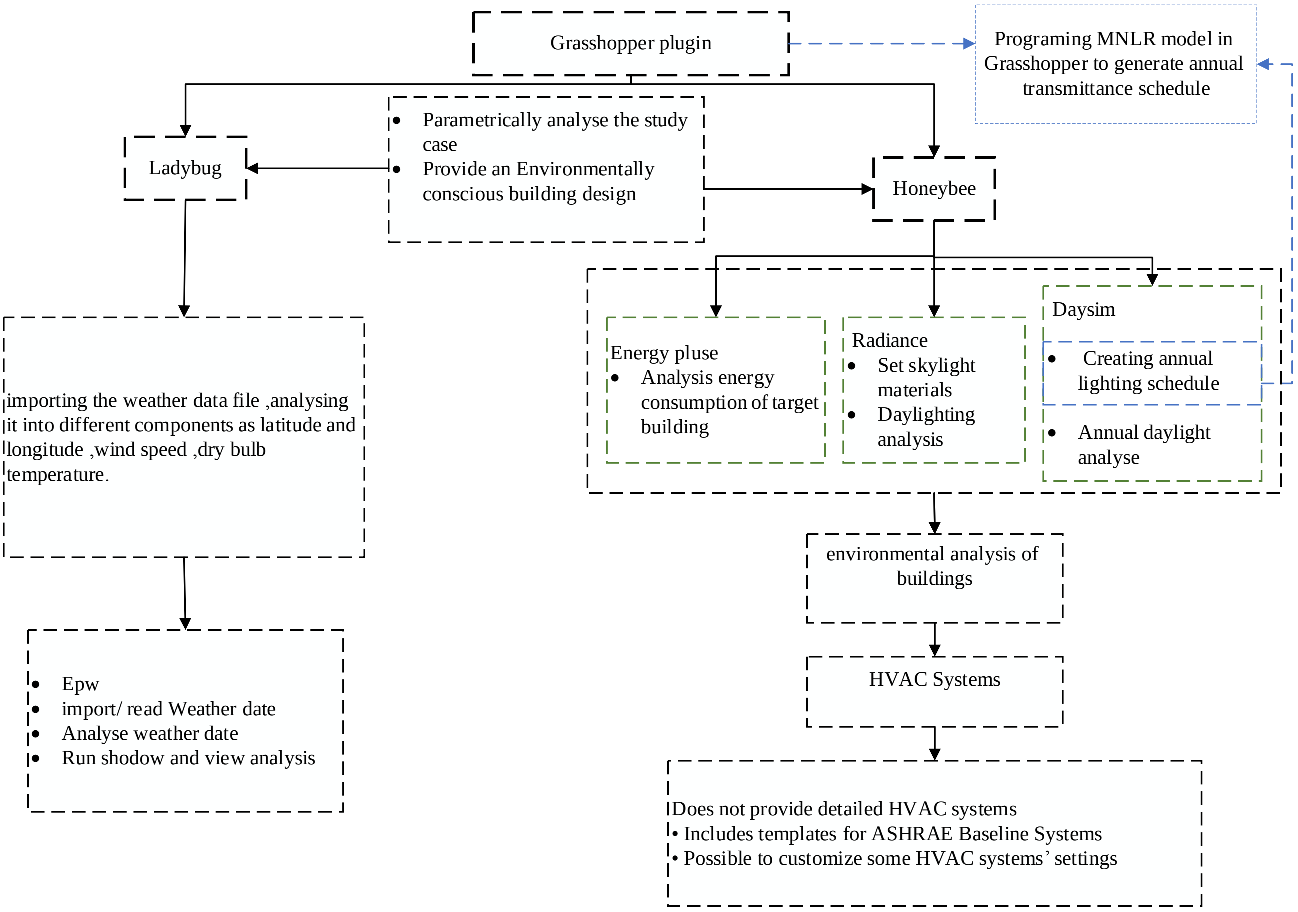


Fig. 5. Ladybug and Honeybee

4.2 Simulation

To analyze the natural lighting, simulation was used. This research used Honeybee Plus and Ladybug plugins to analyze natural lighting, which is shown in Figure (5). in the first step, according to Figure (6), the geometry of the simulated room with a width of 4 m, a length of 6 m and a height of 3 m with an area of 24 square meters for 4 employees are considered (Office of technical affairs and compilation of budget program organization criteria, 1998). Figure (7) shows the WWR is from 90 to 60 percent in the south window. The simulated model is located in Tehran, and there are no shading obstacles around it. According to Figure (8), the facades will open and close with the position of the sun and the perpendicular vector on the square geometric model. The weather file of Tehran Mehrabad in 2004-2018 was used (climate.onebuilding.org, 2022). The simulation is for three days of the year, 21st of March (spring equinox), the 21 st of June (summer solstice), and the 21st of December (winter solstice), (due to the similarity of the autumn equinox with the spring equinox, the latter is not considered) and in each hour of the working day is from 8 a.m. to 4 p.m. According to Figure (9), the geometric model under study is a square model, and this article focuses on the rotational kinematic model with a horizontal axis.

The facade is simulated with a square geometric pattern and a rotating kinematic model with a horizontal axis, according to Figure (10). The size of each square is 0.35 m. In the first stage, the facade angle was simulated from wholly closed (zero degrees) to completely open (90 degrees) in 10 degrees intervals. It should be noted that the degree of opening of the facade is from zero to 110 degrees, but the most suitable degree to respond to the best WWR is with an angle of 40 to 90 degrees in 5 degrees intervals.

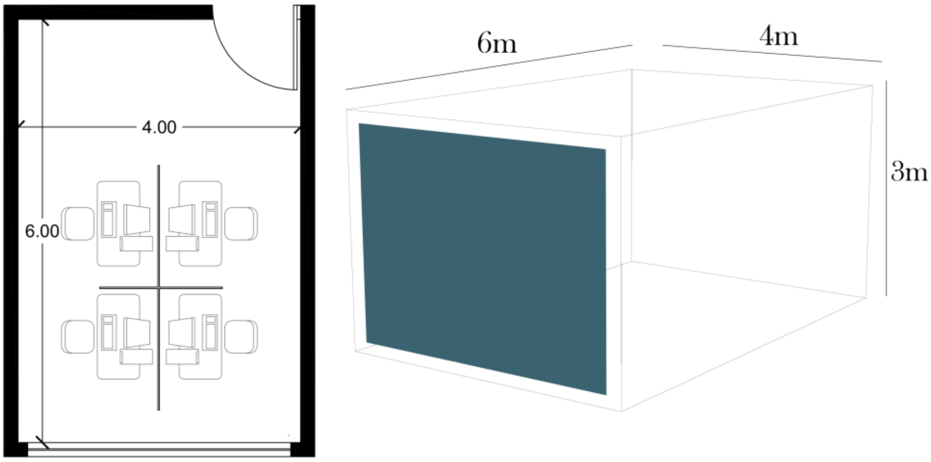


Fig. 6. Simulated model, floor plan (Right), 3D Model (Left)

50%

Fig. 7. Various WWR

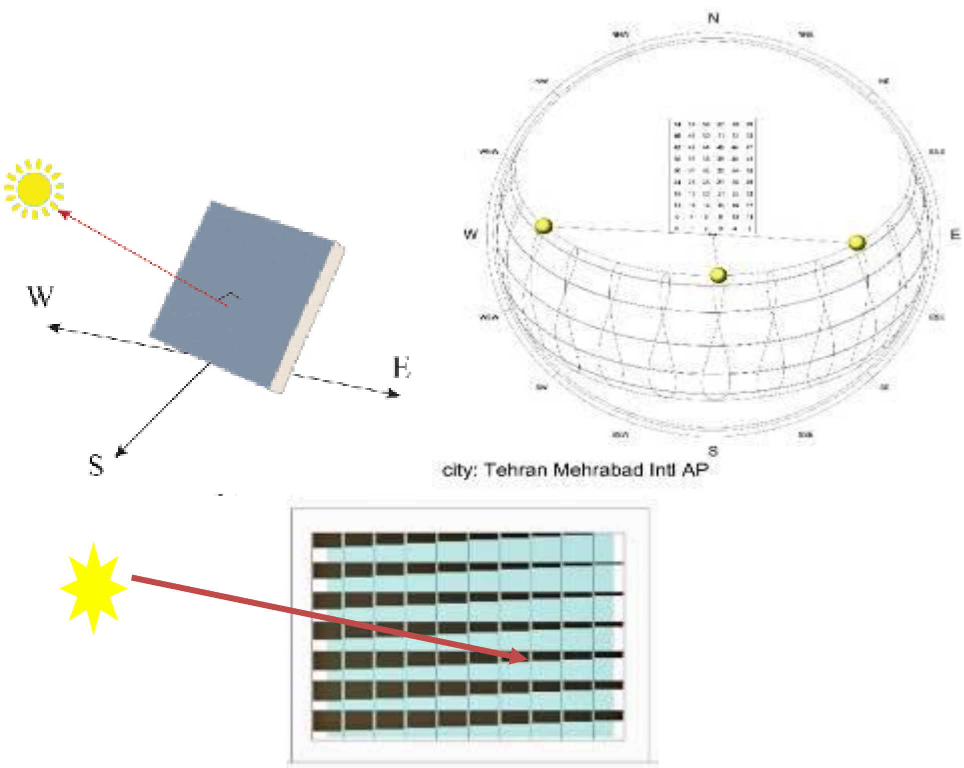


Fig. 8. Sun path diagram for 35.69^{O} North latitude, (Top, Right) and vertical vector (Top, Left)

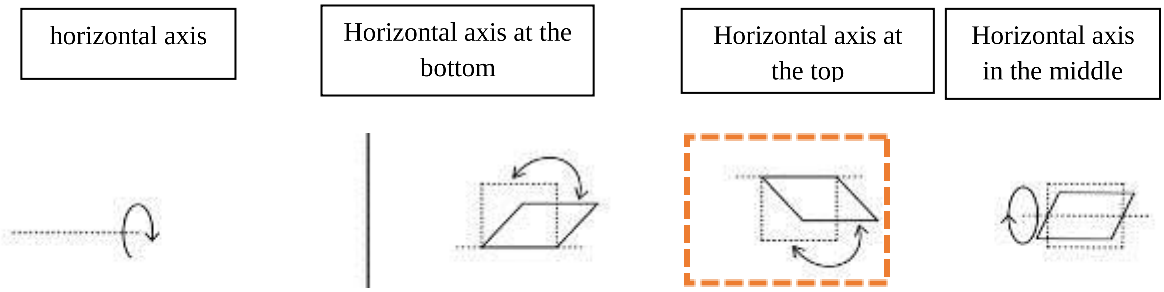


Fig. 9. Rotational kinematic model with horizontal axis, using upper horizontal axis in this research

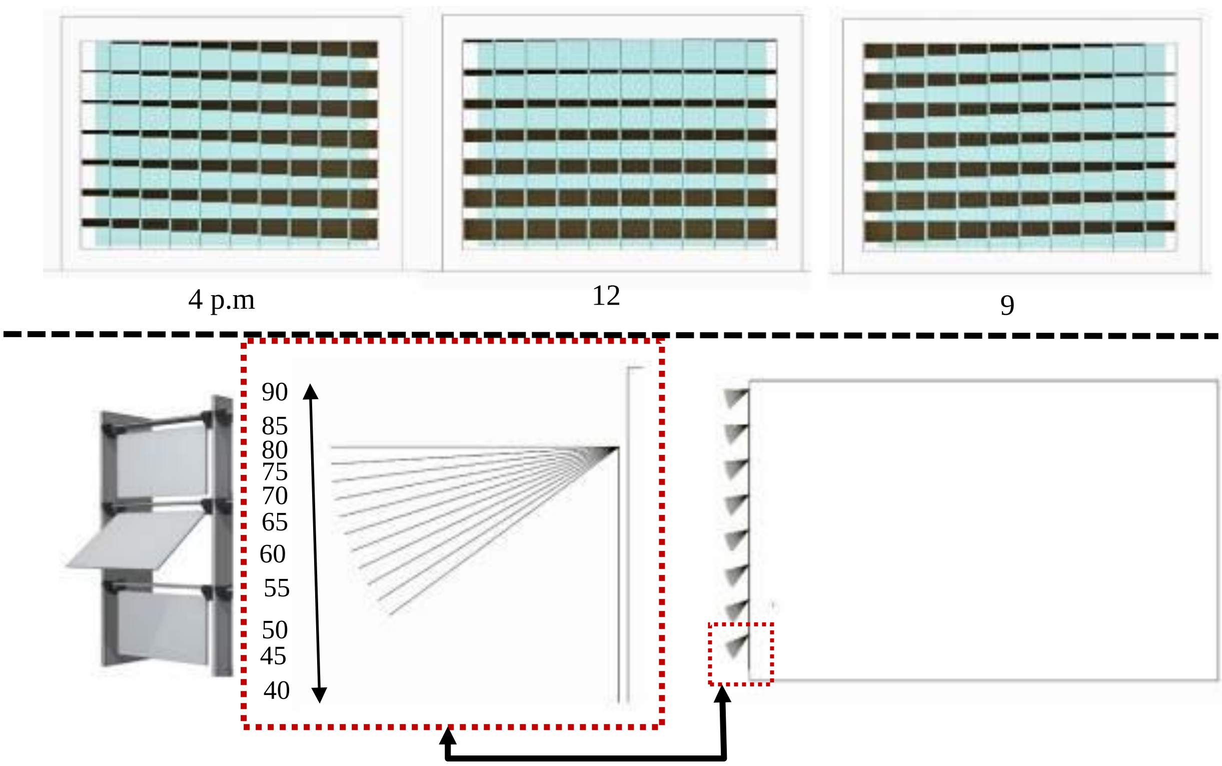


Fig. 10. Viewing angle according to the movement of the sun at 9, 12, and 4 p.m

4.3. Determining the reflection coefficients of internal surfaces

One of the most influential factors in the distribution of lighting inside the office room is how the interior surfaces of the building reflect the light. Therefore, it is recommended that the average reflection coefficient of the roof should be the highest value and preferably 0.7 or higher, the suitable coefficient for the walls should be around 0.5, and the suitable coefficient for the floor should be between 0.1 and 0.3. In lighting design, the average coefficient of internal surfaces can increase the light efficiency of the lighting system up to four times, and inappropriate reflection coefficients can weaken the lighting efficiency by a quarter (Guide for measurement and evaluation of lighting in the work environment, 2017). in this research, The parameters and materials of the base model applied in the simulation are shown in Table (4). The optical and thermal properties of the model components are defined from 0 to 100 percent for each index in the Grasshopper plugin. The coefficient of visual transmission of glass varies between 0 to 100 percent; the higher the ratio, the higher the amount of visual transmission. In the first stage, the simulation was done with the parameters of the basic model; then, according to the simulation results, the parameters of the Tehran office building were used for the optimal window-to-wall ratio and to improve the results. According to Table (5), due to the presence of the kinetic facade, the visual transmission coefficient of the glass can be increased up to 95%. Also, the wall and floor's reflection coefficient is changed in the range of 5 to 10 percent. The working days are from Saturday to Wednesday, and Thursday and Friday are assumed as holidays. Employees' lunch time is considered from 12:00 to 13:00. The critical assumptions of radiance parameters are according to table (6). The higher the numbers in this setting, the better the quality of the daylight analysis output is. For example, Ambient Divisions can be increased from 512 to 2.

Table 4
Optical and thermal properties of the base model's components

Roof reflection	80%
Wall reflection	50%
Floor reflection	20%
Glass visual transmission coefficient	80%
The dimensions of the floor grid	0.6 m
Floor points	59 point
The height of the reference plane from the finished floor	0.76 m (LEED v4, 2019)

(Source: Elghazi, Wagdy, & Abdalwahab, 2015)

Table 5
Optical and thermal properties of common office buildings in Tehran

Roof reflection	80%
Wall reflection	60%
Floor reflection	30%
Glass visual transmission coefficient	95%
The dimensions of the floor grid	0.6 m
Floor points	59 point
The height of the reference plane from the finished floor	0.76 m (LEED v4, 2019)

(Source: Moulai, Pileh Chiha, & Shadanfar, 2019)

Table 6
Radiance parameters for daylight availability metric

Ambient Divisions	Ambient bounces
512	2

5. Results and Discussion

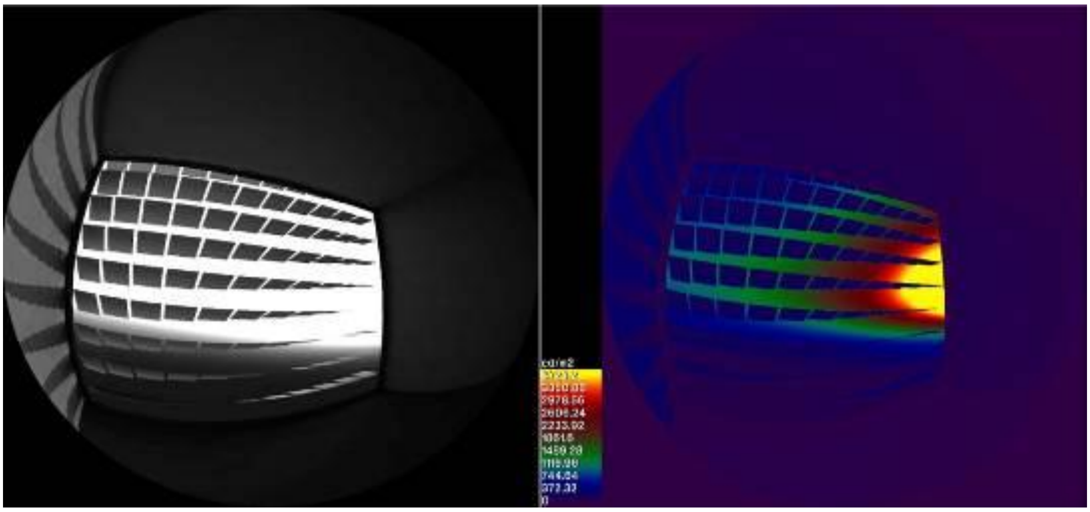
After simulating the facade on the 21st of the three months of June, December, and March at 9 a.m., 12, and 4 p.m., the percentage of the window to the wall surface in Tehran has been determined (Table 7). Critical numbers are marked in red, indicating that glare and low daylight levels may occur during these times. In the case of 90% WWR in January at 16:00, there is a possibility of glare and lack of visual comfort, ASE has reached 11.66%, and at 9:00 a.m. in December, it has reached 10%, which is acceptable. The Table also shows that WWR up to 60% is acceptable using a kinetic façade on the south elevation of an office building in Tehran.

To improve the results obtained from Table (7), the optical and thermal properties in Table (5) have been used. With 60% WWR, the wall reflection coefficient was changed from 50% to 60%, and the floor reflection coefficient from 20% to 30%. The results for January at 12:00 and 4 p.m. show a UDI of less 500 lux only in points 59 and 54 of the corners of the space, reaching 94.03%-94.66%, respectively. The SDA is 100%, but the ASE remained unchanged. By changing the rotation angles ranging from 45 to 95 degrees with a step size of 5 degrees, the visual transmission coefficient from 80 to 95% SDA reached 80.32% and ASE to 8.33%. In June at 4 p.m., UDI less 500 lux reached 94.45% only in points 55 and 59. By changing the rotation angles ranging from 45 to 95 degrees with a step size of 5 degrees and the visual transmission coefficient from 80 to 95%, the value of this index UDI less reached 92.41%.

The amount of ASE with WWR of 90% reached at 4 p.m. in December with the change of the reflection coefficient of the wall and floor from 11.66 to 10%. The amount of UDI less reached 18.05%. By changing the rotation angles ranging from 45 to 95 degrees with a step size of 5 degrees and changing the visual transmission of the glass from 80% to 95%, the value of the UDI less index reached 8.01%, and the ASE index was 13.33%, which requires glare analysis. In Figure (11), the results show that the glare is perceptible.

Table 7
Daylight and glare indices for various times of the year and WWRs

Indicators	WWR=90%								
	Months								
	June			March			December		
	9	12	4 p.m.	9	12	4 p.m.	9	12	4 p.m.
DA	99.58%	99.42%	99.69%	99.69%	99.48%	99.69%	99.69%	99.48%	99.74%
UDI	90.95%	91.63%	91.63%	90/95%	92.26%	91.52%	91.58%	93.46%	92.46%
UDI less	53.43%	37.68%	48.09%	43.43%	32.91%	48.40%	42.75%	34.38%	48.09%
UDI more	92.41%	91.63%	92.99%	92.99%	90.42%	93.09%	93.30%	91.58%	93.62%
SDA	100%	100%	100%	100%	100%	100%	100%	100%	100%
ASE	6.66%	1.66%	1.66%	6.66%	1.66%	3.33%	10%	5%	11.66%
	WWR=80%								
DA	99.32%	99.32%	99.32%	99.48%	99.22%	99.48%	99.63%	99.32%	99.58%
UDI	91.84%	90.69%	90.95%	90.63%	90.42%	91.84%	89.64%	90.89%	91.63%
UDI less	74.67%	72.53%	82.94%	76.87%	67.66%	80.38%	83.15%	69.54%	86.55%
UDI more	80.27%	76.09%	75.09%	84.62%	79.07%	84.56%	90.89%	78.91%	90.84%
SDA	100%	100%	100%	100%	100%	100%	100%	100%	100%
ASE	6.66%	6.66%	8.32%	8.33%	6.66%	8.33%	10%	8.33%	8.33%
	WWR=70%								
DA	98.85%	98.69%	99.06%	99.01%	98.69%	99.32%	99.32%	98.80%	99.48%
UDI	88.70%	89.38%	88.32%	90.37%	89.12%	89.17%	90.01%	91.58%	90.48%
UDI less	93.51%	78.18%	92/36%	91.63%	87.07%	87.76%	92.46%	87.02%	91%
UDI more	65.83%	58.66%	68.86%	68.29%	55.73%	79.12%	82.57%	59.50%	90.32%
SDA	98.33%	100%	96.66%	100%	100%	100%	100%	100%	100%
ASE	0%	0%	0%	0%	0%	0%	0%	0%	1.66%
	WWR=60%								
DA	99.32%	99.32%	99.48%	99.06%	99.32%	99.58%	99.53%	99.32%	99.69%
UDI	89.80%	87.02%	84.44%	87.96%	88.85%	87.91%	87.23%	88.12%	89.27%
UDI less	98.12%	97.70%	99.74%	98.74%	96.81%	97.96%	97.59%	99.11%	99.53%
UDI more	79.54%	77.45%	82.25%	80.59%	71.79%	84.93%	90.01%	74.67%	89.53%
SDA	78.33%	78.33%	76.66%	78.33%	83.33%	80%	80%	81.66%	76.66%
ASE	6.66%	3.33%	5%	6.66%	3.33%	5%	8.33%	3.33%	6.66%



DGP=0.29   ASE=%13/33

Fig. 11. Glare on the right side based on candela and on the left side based on luminance

A simulation was carried out to improve further the indings for WWR of 55% and 50% (Table 8). Critical numbers are marked with red, indicating that during these months and hours, the indoor space will be exposed to low light levels .

Table 8
Daylight and glare indices for various times of the year and two WWRs

Indicators	WWR=55%								
	Months								
	June			March			December		
	9	12	4 p.m.	9	12	4 p.m.	9	12	4 p.m.
DA	99.48%	99.32%	99.48%	99.58%	99.27%	99.63%	99.63%	99.32%	99.90%
UDI	92.73%	92.83%	91.73%	89.06%	91.68%	90.37%	89.59%	91.89%	92.26%
UDI less	89.01%	84.82%	91.63%	96.65%	88.44%	90.06%	88.38%	88.12%	91.26%
UDI more	85.77%	87.23%	89.59%	90.85%	77.24%	91.21%	88.33%	81.95%	91.37%
SDA	100%	100%	100%	98.33%	100%	100%	100%	100%	100%
ASE	1.66%	0%	3.33%	1.66%	0%	3.33%	3.33%	0%	3.33%
	WWR=50%								
DA	99.42%	99.27%	99.58%	99.42%	99.32%	99.69%	99.69%	99.32%	99.95%
UDI	91.37%	91.37%	90.69%	89.17%	92.78%	90.42%	91.47%	88.49%	91.84%
UDI less	94.77%	94.82%	98.01%	96.86%	95.60%	97.38%	96.13%	94.77%	97.91%
UDI more	83.15%	78.18%	90.16%	88.54%	78.49%	92.57%	91.42%	82.57%	93.35%
SDA	91.66%	93.33%	90%	95%	93.33%	91.66%	91.66%	95%	91.66%
ASE	3.33%	3.33%	3.33%	3.33%	3.33%	3.33%	3.33%	3.33%	5%

6. Conclusion

The current research was carried out to achieve the optimal WWR using a kinetic facade in the south wall of an office building in Tehran. For this purpose, a facade with a square geometric model and a rotational kinematic model with a horizontal axis, with an angle of 40 to 90 degrees and WWR of 90 to 60%, was simulated, where the center of the window was placed in line with the center of the wall. Changing the facade angle or the amount of its opening and the performance of the kinematic model is open according to the sun's position. The optical and thermal properties of the office building are designed in two models. In the base model, WWR with a kinetic facade is up to 60%. The optical and thermal properties of internal surfaces and windows were changed to improve the simulation results. The simulation was carried out with the WWR of 55% to 50% to make the results more precise. The interior with a 50% WWR at 4:00 p.m. in June, March, and December may encounter low light in some points. The best horizontal view angle for a kinetic facade in Tehran is between 45 and 95 degrees, and the most important of optical and thermal properties is primarily the visual transmission of the glass and then the reflection coefficient of the floor and wall. As a result, a WWR of 90% to 50%, on the south facade of an office building in Tehran, combined with the proposed kinetic facade (rotational kinematic model with horizontal axis), will perform optimally. In this way, if the window-to-wall ratio is less than 50%, the interior will be dimly lit

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