Parametric design on daylighting and visual comfort of climatic responsive skins through Iranian traditional girih tile

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This study has conducted on developing an innovative approach for the parametric analysis of daylighting and visual comfort through a sun responsive shading system as well as proposed a parametric pattern of Iranian Traditional Girih Tile (ITGT). On this basis, using parametric methods, the authors could change the parameters of a pattern to build modern geometric patterns and a bridge between traditional architecture approaches and modern technologies. The model was simulated in the Rhinoceros 3D as well as the Grasshopper, Honeybee, and Ladybug plugins were performed in order to evaluate daylighting and visual comfort performance. The objectives are estimating the annual daylight metrics and glare discomfort during four months from spring to summer when 3 variables (opening and getting closed, mass to space ratio, and time hours) that affect incoming daylight and visual comfort performance in a room. The results showed that the proposed model could significantly improve the shading flexibility to control daylight metrics and glare, through a full potential adaptive pattern to achieve the maximum visual comfort.

keywords: *Parametric stud, algorithmic simulation, daylight performance, visual comfort*

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1. INTRODUCTION

Daylight, as one of the most recognized visual features of buildings, greatly impacts the psychological and physiological needs of people who are dealing with it [1]. Daylight has potential positive impacts on the indoor environment comfort which have been investigated since the ancient architectural typologies [2, 3]. Daylight has some visual discomfort as well; for instance, unwanted reflections, glare, and affecting the thermal balance of rooms through overheating are some of the significant ones (Pauley 2004). Therefore, the most challenging part of an effective daylighting design is to keep the balance between maximizing daylight harvesting and managing to have the least potential discomfort [4]. Inside buildings, where on average 87% of people's lives are spent [5], electrical sources often supply conventional lighting which is sufficient to perform visual tasks, but lacks the required spectral combination and quality to stimulate the circadian rhythms [6].

Since daylight is one of the most important regulators of human circadian rhythms [7], there should be more empirical studies on parametric adaptation devices and the possibilities of maximizing the visual performance and its integration with building's envelope [8]. Studies such as the one by López et al. [9] have developed adaptive architectural envelopes as a result of biomimetic principles in architecture. There have been enough studies on daylight simulation techniques as well. So a wide range of technologies have been used by some investigators to overcome the challenges concerning the multiple daylighting scenarios [9–11]. However, there are still needs for deep investigation on daylighting, parametric shading and visual comfort metrics through computational and parametric simulations.

In this regard, Pesenti et al., [12] presented a study on the optimization of a shading system visual comfort, useful daylight illuminance, daylight autonomy, daylight glare probability, and total energy consumption through origami pattern. Ahmed Mahmoud and Elghazi [13] have conducted a study on evaluation of kinetic facades system performance using experimental method. Improving daylight performance was investigated as the research objective. The results included some suggestions to enhance daylight performance. Furthermore, many research paper have been published in the regarding of the thermal performance as well as energy conversation as a vital part of the building construction. Hoseinzadeh [19] studied on the performance of the Electrochromic Smart Window in order to evaluate its thermal performance under different climate zones of Iran included Yazd, Tehran, Bandar Abbas, Tabriz, and Sari through EnergyPlus simulation. The results indicated that the best climate was Tehran which has warm and semi-humid climate in which the average energy consumption decreased by about 34% for the warm months and also by about 42% for the warmest month of the year. Hoseinzadeh et al., [20] performed a simulation study on energy consumption of some buildings under a humid mountainous of Qa'emshahr climate using DesignBuilder software. They were calculated the power generation capacity and economic considerations.

In the following, architectural practices are used to integrate daylighting which is the desired method to optimize visual comfort performance via translating scientific knowledge into actionable information that can be applied to increase the well-being of building occupants [15–17]. This synthesis has to be accurate in order to get the proper quality and quantity of daylighting and avoid excessive light. Accordingly, shading devices and window to wall ratio (WWR) are vital physical aspects of establishing a harmonization between the building envelope components and solar passive strategies, in order to balance daylight and to avoid visual discomfort [18]. To fill the identified gaps, the present study approaches to construct an innovative method towards an acclimated skin pattern for a residential place in Iran, in which annual daylighting and visual comfort and energy optimization performance are calculated through parametric modeling principles. The design process will be conducted by linking parametric soft-ware known as Grasshopper with Radiance and Daysim through a particular algorithm. Grasshopper is a plugin for Rhinoceros 3D-modelling software used to generate 3D parametric models and to run (Honeybee and Ladybug) plugins, which are used as an engine to Radiance, Daysim, and Energy-Plus as shown in Fig. 1. Radiance is a well-known lighting simulation engine that was developed by Ward that is based on a backward ray-tracing algorithm for daylighting calculations [18]. According to what was described, the result of the presented designing method is expected to satisfy the aesthetic needs of the spirit of its own time and preserve its past authenticity. Its performance and efficiency are, also, expected to improve. The purpose of this study is to create a dynamic work-oriented geometry in the openings of the pilot building that can alter the position due to the people's need and desire for lighting, visual comfort, and control of the entry of sunlight.

A. Research hypothesis

The historical township of Masuleh which is situated in Guilan province, Iran with 37^o0918N and 48^o5923E coordinates. The houses in this township have been constructed on the slope of a mountain southwardly in a cascade form to intercept sunlight. The arrangement is so that the roof of a house is the yard of the upper house. The view of the township is to a wide lush green mountain with breathtaking scenery to those who live in this township whose extensiveness has been influenced by the extensiveness of the mountain. So, the houses have a lot of southward awning windows with impressive girih tiles to allow residents to enjoy sunlight and scenery. As was mentioned, the awning windows of houses in Masuleh have a lot of Girih tiles. These tiles and intricate networks are very beautiful from outside, but it lacks an optimal view from inside while the outside scene is a tourist attraction of the township [26, 27].

To have an optimal view, the windows should be opened at the expense of disturbing the thermal comfort of the interior space. On the other hand, these awning windows partially limit sunlight and solar energy admission into the interior space so that artificial sources should be used to supply the lighting of the house even during the day. The Noormohammadi historical house was selected for the case study in this township. Four people live in this house. Thy get together at noon to have lunch, conversation and a little rest. The work station was a room with the length, depth, and height of 7, 4 and 3 m, respectively. The building was northward with 20º rotation to the east. It had a 4-m-long window at the height of 2 m in the south part. The window was wholly made of traditional wooden Girih tile that is associated with the traditional texture of Masuleh (Fig. 1).

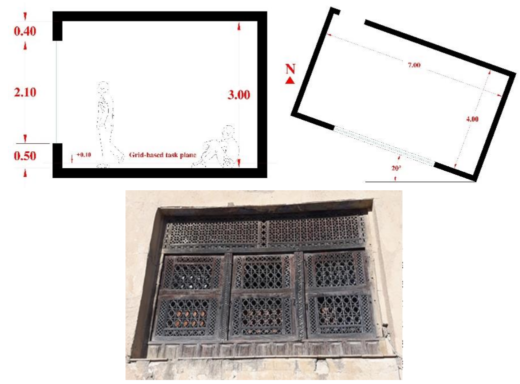

Fig. 1. Model description.

The purposes of this study are to create a dynamic as well as adaptive geometry in the building's envelope (façade) which be able to change and regulate its position based on the human needs of daylighting and visual comfort, and also, to control the entry lighting threshold as well.

2. LITERATURE REVIEW

A. Visual comfort indices

Visual comfort is among the major parameters in interior architecture that should be considered at the design phase. Some parameters of visual comfort that are derived from a paper about the fundamentals and concepts of measured parameters of daylight and glare are provided in Table 1 [19].

The present paper examines two metrics of daylight, i.e. DA and SDA, and a metric of glare, i.e. DGP, to compare the proposed model with the status quo. Daylight autonomy (DA) is the percentage of occupied hours in a year in which the minimum illuminance is provided by the sole daylight [12]. In the literature, particularly in the European standard of EN 12464-1 (ECS 2011a), the interior home has a reference value of 300 lx [20, 21]. In order to analyze DA design precisely, two more codified metrics in LEED v4 are used to analyze daylighting. These are spatial daylight autonomy (SDA) and annual sun exposure (ASE) metrics that give us a clear picture of daylight spaces and visual comfort ultimately (Carlucci et al. 2015). According to the Illuminating Engineering Society of North America, SDA defines how much an interior space receives sufficient daylight of 300 lx in more than 50% of its occupied hours [22]. Daylight glare probability (DGP) is a glare-related index that was first

Table 1. Parameters to assess glare and daylight

Daylight	Glare
Daylight Autonomy	Daylight Glare Index
(DA)	(DGI)
Continuous Daylight Autonomy	Visual Comfort Probability
	(VCP)
Useful Daylight Illuminance (UDA)	British Glare Index (BGI or BRS)
Spatial Daylight Autonomy (SDA)	Daylight Glare Probability (DGP)
Annual Sunlight Exposure (ASE)	Simplified discomfort Glare Probability (DGPs)
Daylight Factor (DF)	CIE Glare Index (CGI)
Mean Illuminance (MI)	Unified Glare Rating (UGR)
Vertical eye Illuminance	j-Index

introduced [23]. Table 2 presents the range of DGP values and their acceptable values.

In this sense, Eltaweel et al [24] presented a case study in order to propose a new control method for automated venetian blinds to optimize the utility of daylight on an office building in three different months from summer to winter (December 21, September 21, and June 21) in Cairo. This paper proposed a type of internal movable horizontal slats to automatically control daylight and glare factor and optimize internal energy. At hours when light causes user glare, the angle and inter-slat spacing are changed with sun elevation automatically to reflect the incident sunlight to the ceiling. This reflection provides general lighting for the office, reducing energy use, and prevents the glaring of employees. Fig. 2 shows how slats rotate and Fig. 3 displays how their spacing is changed. The simulation of the proposed model by the Honeybee plugin of the Grasshopper plugin revealed that this process could introduce daily use of natural sunlight as a major source of internal spacing lighting and prevent sunlight-induced glare.

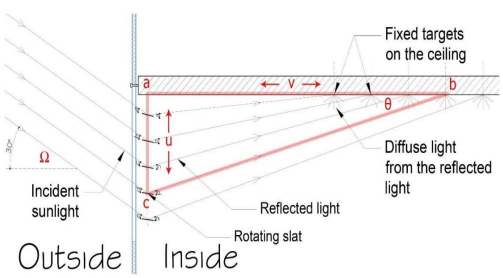

Fig. 2. How horizontal slats rotate and its effect on sunlight interception and reflection [24].

ElGhazi [25] investigated a parametric technique for kinetic cellular façade to optimize daylight, control sunlight, and optimize energy performance in four months (21st of December, September, June, and March). The studied geometry was based on origami papers that could be opened and closed and were in the form of a movable skin. The examination of the design with the Grasshopper and Diva plugins yielded promising results.

3. RESEARCH METHODOLOGY

To introduce a performance-based geometric method for Girih tile designing for transparent awning windows, a research methodology was used that was composed of three main sections. Section 1 deals with designing a movable and efficiency-based approach for Girih tile in a parametric way, which is based on the traditional geometry of the Iranian Girih tile. This process is performed by the Rhinoceros 3D simulation software package and the Grasshopper plugin. Section 2 addresses parametric Girih tile to accomplish optimal visual comfort and its comparison with the Girih time in the status quo. In Section 3, the proposed model is run by the Honeybee plugin for four different months from spring to winter (December 21, September 21, June 21, and March 21) at a certain day and time with respect to the schedule of the presence of people in the desired room in order to optimize energy use. In Section 4, the same procedure of Section 3 is repeated to control sunlight-induced glare. According to the sun path diagram in different months of the year, from spring to winter, were considered to reveal the effect of different seasonal radiations (kW/m²) of each month and its effect on the building.

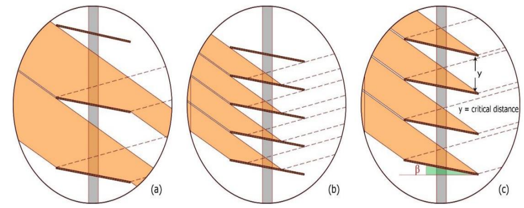

Fig. 3. Different states of the changing distance between the slats versus one another and its effect on sunlight interception and reflection [24].

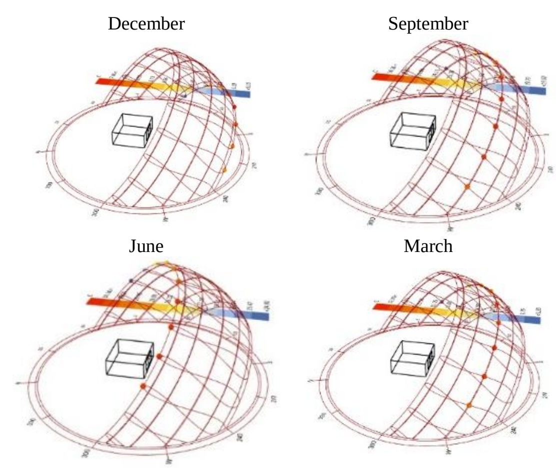

Fig. 4. Sun path on 21st of December, September, June and March from 08:00 a.m. until 05:00 p.m..

A. Model configuration

The proposed Girih tile was drawn in parametric form using the Rhino software package. To draw the proposed Girih tile pattern in a parametric form, the author use a dodecagon pattern adapted from the Shamsah (Sun) pattern (Fig. 5) that has a special place among Iranians and is most commonly applied in Girih tiles of Masuleh. As can be observed in Figs. 6 and 7, the Girih tile is parametrically programmed in Grasshopper in the Rhinoceros 3D software package.

Table 2. Assessment of glare indices

Glare Comfort range			
Imperceptible Glare	Perceptible Glare	Disturbing Glare	Intolerable Glare
[0.35>DGP]	[0.4>DGP>=0.35]	[0.45>DGP>=0.4]	[DGP>=0.45]

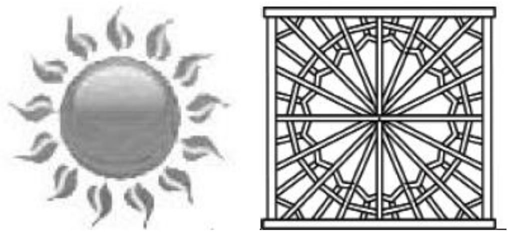

Fig. 5. Shamsah pattern in girih tiles of Masuleh Township.

To draw the proposed Girih, first the research team create a dodecagon in Grasshopper. Then, it is duplicated on the X and Y axes as many times as required. When these dodecagons are placed next to one another, a star shape is formed which was drawn again and link it to the dodecagon so that its duplication and the changes in its parameters happen along with the dodecagon. It is also duplicated on the X and Y axes as many times as required. Now, the authors have a dodecagon geometric pattern and a star-shaped geometric pattern that can be duplicated on the X and Y axes as many times as desired.

Then, the dodecagon pattern is copied twice and their scales are so adjusted that they can be placed inside the original dodecagon. On the first dodecagon, a line is drawn from center C to the angles, and the intersections are labeled A. Again, a line is drawn from center C to the middle of the sides, and the intersections are labeled B. Then, point D is specified on the line connecting C to A. After that, a continuous line that passes through D and B is used to specify the line required for creating the first pattern. By mirroring and arraying this line, the authors create a parametric pattern and it can be opened or closed under the influence of point D that moves on the lines connecting centers to the angles of each side, i.e. line CA whose movement interval is shown in Fig. 8.

For the second dodecagon too, center C is connected to the angles, and the intersections are labeled A. Again, a line is drawn from C to the middle of the sides, and the intersections are labeled B. Then, a point labeled D is specified on each line that connects C to B. Then, a continuous line is drawn from D to A and it is used to create the first pattern. By mirroring and arraying this line, the authors create a parametric pattern and it can be opened or closed under the influence of point D that moves on the lines connecting centers to the angles of each side, i.e. line CA whose movement interval is known (Fig. 9).

The same procedure used for the first dodecagon is repeated for the third dodecagon (Fig. 10).

Now, the authors program the three dodecagons linked to one another so that the opening/closing pattern happens commonly (Fig. 11).

B. The desired view

This paper proposed a pattern of Girih tile that can be opened/closed parametrically and efficiently and it was incorporated with elastic planes to turn into an efficiency-based shading. In the studied building, family members enjoy an optimal view for resting and socializing at 12 p.m. every day. In the present Girih tile, the geometry is composed of small repeated networks, so the viewers cannot have an optimal view to outside unless the awning window is opened, but this has adverse effects on interior thermal conform in different seasons and increases energy use (Fig. 12). Accordingly, to have an optimal view at hours that it is required, one can choose the fully open form of Girih tile, i.e. state D in which the widest vision is attained with no intruding factor (Fig. 13). When the Girih tile pattern is set at fully open, in addition to the optimal view, more sunlight and energy are intercepted by the interior space. However, the main challenge of this pattern is the problem of glare, which is discussed in the next sections.

4. DISCUSSION AND RESEARCH FINDINGS

A. Daylight Autonomy (DA) and Spatial Daylight Autonomy (SDA)

SDA is measured by the Grasshopper and Honeybee plugins in the Rhinoceros 3D software package. Specifications and climatic data (EPW) are fed by the Meteonorm software package. Accordingly, the illuminance of the studied residential space is set at 300 lx, the time of space occupation is set at 12:00 p.m., and since people in Masuleh do not use furniture to sit on and instead, they sit on the floor, the height of calculations is set at 10 cm from the floor. The model of row D that is a fully open state is used for the Girih tile of the awning window, and the experiment is compared with the existing sample model. As can be seen in Fig. 14, the parts of the space that receives over 300 lx illuminance in the year or in the occupied hours are specified.

According to the comparison of the results in Daylight Autonomy (DA), Fig. 14 the interior space of the room with the proposed Girih tile model receives more sunlight during the year and in the occupied hours than the existing tile, and the dispersion of sunlight is wider in the proposed model so that whole the room receives standard lighting. So, there is no need for artificial lighting in the interior space over the occupied hours. The SDA value that is obtained as a numerical output of the Honeybee plugin was 60.71 for the room in the proposed model while it was 5.98 in the status quo. This implies that in the proposed model, 60.71 percent of the interior space receives over 300 lx sunlight, which is the minimum illuminance for a residential place.

B. Glare evaluation

This section addresses the glare factor in four months from spring to winter (21st of December, September, June, and March) at 12:00 p.m. under the clear sunny sky for the proposed Girih tile model of row D that is in a fully open state versus the status quo. To this end, the Grasshopper and Honeybee plugins in the

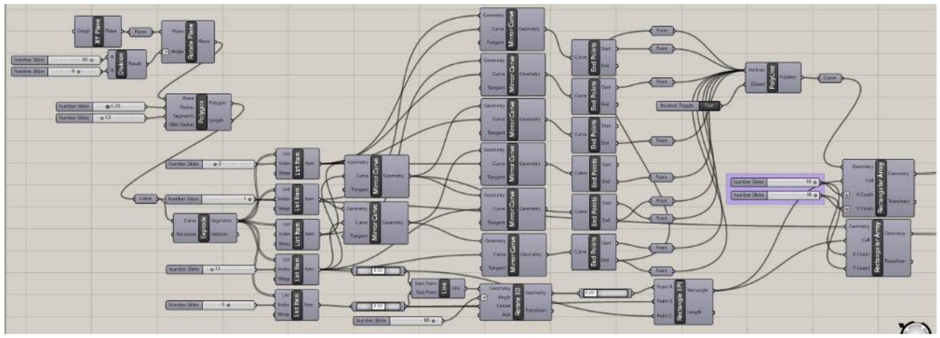

Fig. 6. The programming of dodecagon pattern.

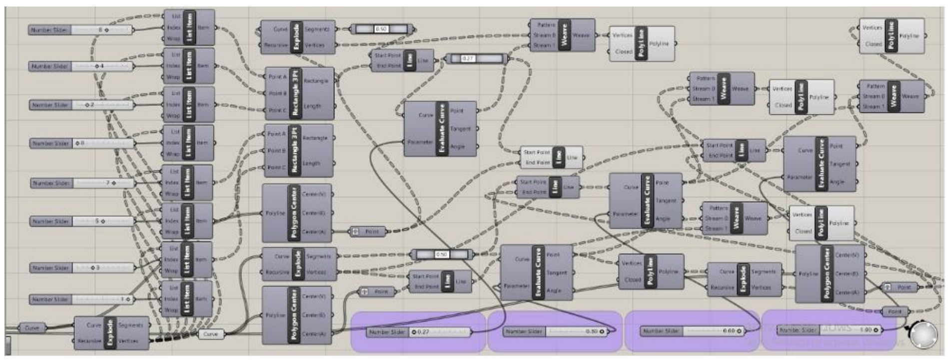

Fig. 7. The programming of girih instruments and its movement axes to open and close parametrically.

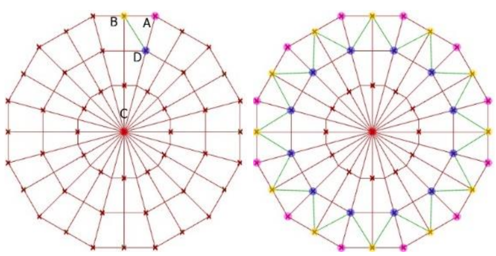

Fig. 8. How to draw the first parametric dodecagon pattern.

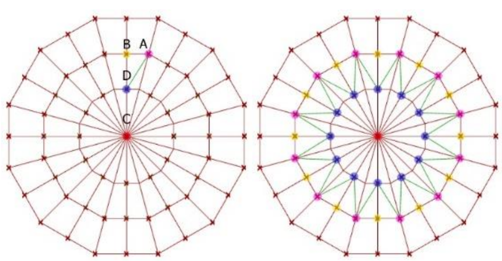

Fig. 9. How to draw the second parametric dodecagon pattern.

Rhinoceros 3D software is used to calculate the glare index is shown in Fig. 15. The Meteonorm software is used to feed the specifications and climatic data (EPW).

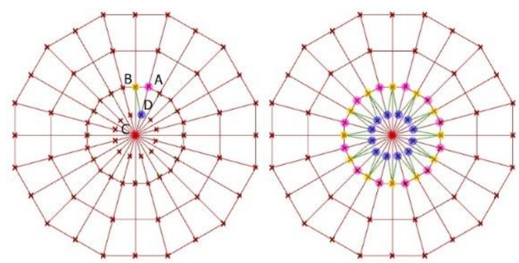

Fig. 10. How to draw the third parametric dodecagon pattern.

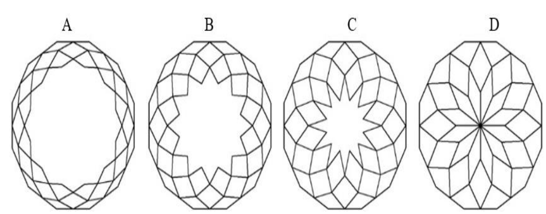

Fig. 11. The opening and closing matter of all three dodecagons in connected and parametric way in four steps.

As Tables 3 and 4 in glare section present, glare index (DGP) in state D Girih tile is almost equal and smaller than that in the status quo and is still within the standard range of imperceptible glare.

Table 3. Daylight glare index for form D at certain hour, day and month versus the existing girih tile

	December 21st 12am	September 21st 12am	June 21st 12am	March 21st 12am
Form D Daylight Glare Probability (DGP)	0.316347	0.282147	0.274035	0.282902
Main view Daylight Glare Probability (DGP)	0.325586	0.299976	0.284358	0.301051

Table 4. Standard daylight glare index for form D (Source: Researcher)

	Glare Comfort range			
Form B	Imperceptible Glare	Perceptible Glare	Disturbing Glare	Intolerable Glare
	[0.35>DGP]	[0.4>DGP>=0.35]	[0.45>DGP>=0.4]	[DGP>=0.45]
December 21st 12am	*			
September 21st 12am	*			
June 21st 12am	*			
March 21st 12am	*			

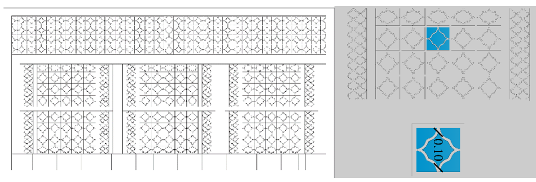

Fig. 12. The view range of girih tile form under status quo.

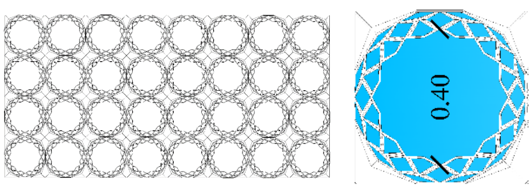

Fig. 13. The view range of girih tile form in fully open state (D).

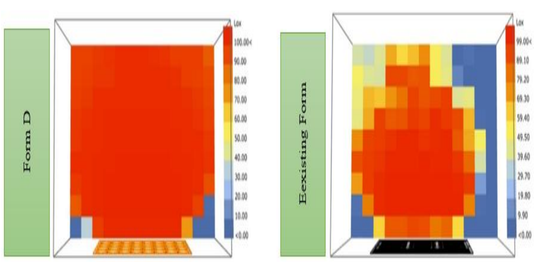

Fig. 14. The graph of receiving

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300 lx sunlight at hours the house is occupied during the year for the form D and the existing form.

5. CONCLUSION

The present study aims to propose a modern parametric model of Girih tile derived from the traditional tile geometry of Masuleh with the same material and manual construction method to both preserve historical authenticity and identity and display the beauties of Girih tile in different states of opening and closure. This will allow one to open the window to have an optimal view and will control such factors as glare induced by the opening of the tile and will use the sunlight to optimize energy use so that the model can be applied at hours when there is no need for sunlight or sunlight is a troubling factor. The results reveal that by modifying the geometry of traditional Girih tile patterns, the authors can accomplish modern geometric patterns that can improve their performance and efficiency. This can help us convert this structure from a fixed state into an efficiency-based movable state and in its fully open state, it can provide residents with an optimal vision and allow more sunlight and energy to enter into the interior space. So, there will be no need for artificial lighting and the energy use will be optimized. At the same time, the glare of the sunlight will be avoided. On the other hand, the Girih tile will be appeared to outside people in different forms over a day so that it will be indifferent opening states from 08:00 a.m. to 12:00 p.m. and in different closing states in the afternoon. In addition, the pattern can be set at a semi-open or fully closed state on certain days when there is less or no need for sunlight.

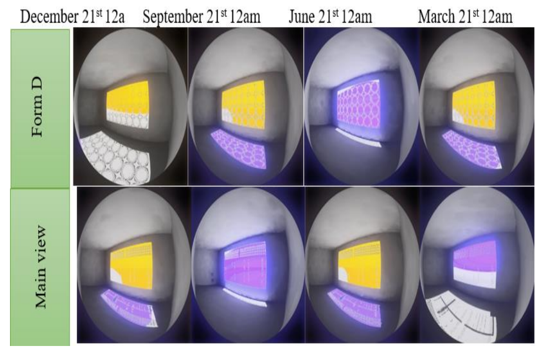

Fig. 15. Different states of the proposed and existing forms of girih tile to calculate glare ad certain hour, day, and month.

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