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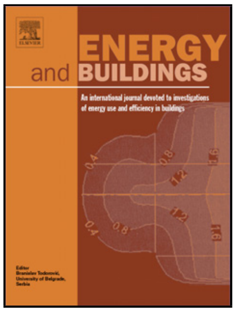


Title: Controlling venetian blinds based on parametric design; via implementing Grasshopper's plugins: a case study of an office building in Cairo

Author: <ce:author id="aut0005" author-id="S0378778816320412-ac489044edc1d9249af9b850cddc2b30"> Ahmad Eltaweel<ce:author id="aut0010" author-id="S0378778816320412-9d168215c48af1a456bce276e699b1c5"> Yuehong Su

PII: S0378-7788(16)32041-2
DOI: http://dx.doi.org/doi:10.1016/j.enbuild.2016.12.075
Reference: ENB 7254

To appear in: *ENB*

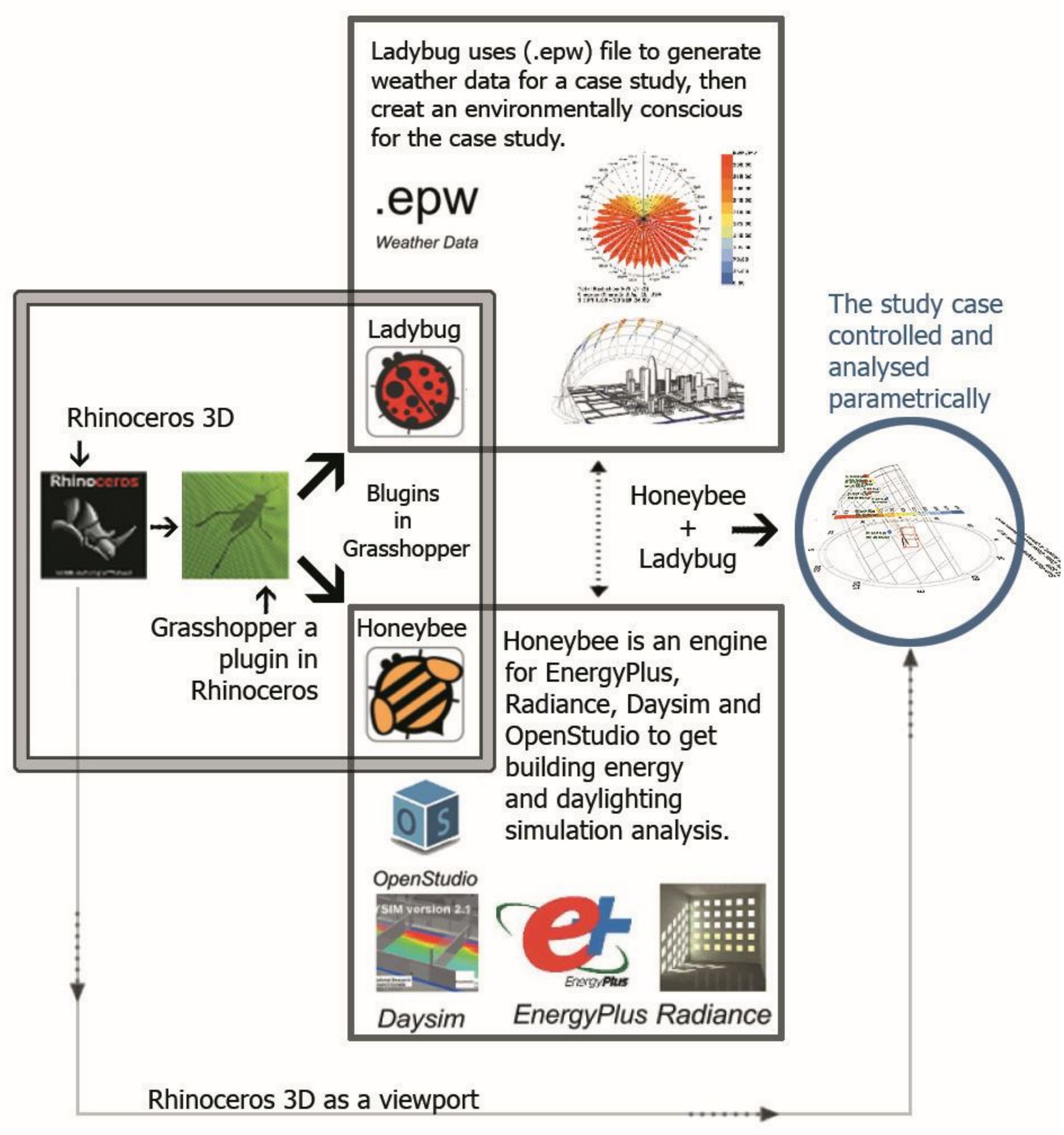
Received date: 5-9-2016
Accepted date: 26-12-2016

Please cite this article as: Ahmad Eltaweel, Yuehong Su, Controlling venetian blinds based on parametric design; via implementing Grasshopper's plugins: a case study of an office building in Cairo, Energy and Buildings http://dx.doi.org/10.1016/j.enbuild.2016.12.075

Controlling venetian blinds based on parametric design; via implementing Grasshopper's plugins: a case study of an office building in Cairo.

Ahmad Eltaweel, Yuehong SU
Department of Architecture and Build Environment, University of Nottingham, Nottingham NG7 2RD, UK
Corresponding author: ahmad.eltaweel@nottingham.ac.uk, yuehong.su@nottingham.ac.uk

Graphical abstract



Highlights:

- Utilizing daylight using automated blinds in an office building in Cairo.
- Controlling the blinds parametrically using Grasshopper.
- Analysing climatic data using Grasshopper's plugins.
- Save energy by providing sufficient daylight, and prevent heat gain.
- Keeping the light provided relatively constant during the day.
- The efficiency of using automated blinds comparing to the conventional ones.

ABSTRACT

Venetian blinds are common type of shading devices and are increasingly operated automatically to overcome the limitations of using manual operation. Automated blinds need to be controlled to maximize benefits of daylight on the aspects of redirecting sunlight, occupant comfort and energy consumption. However, the common control methods are focused on minimizing negative impacts of daylight, but they might fail to maximize the positive impacts of daylight. They may often inaccurately predict a blind’s position, resulting in the undesirable blockage of useful daylight needed.

This paper puts forward a new control method for automated venetian blinds to optimize the utility of daylight. The proposed control method can not only protect occupants from direct solar glare but also maximize daylight penetration into office rooms based on algorithmic methods. The proposed control method is designed to reflect the incident sunlight into the ceiling, then the reflected light acts as a main source of light for the occupants. The reflecting slats respond to the sun altitudes parametrically, in an individual heliotropic response, which can keep the reflected light relatively steady during daytime. Consequently, this process can exploit the optimal use of natural daylight as a main source of lighting and provide shade simultaneously.

1 Introduction

Daylighting plays a significant role in designing energy efficient buildings and involves relevant benefits both in terms of saving energy consumptions, improving visual comfort for the occupants [1], and increasing their productivity [2]. Additionally, the more uniform daylight distribution could save much more energy than the sharply changed daylight distribution [3]. Nevertheless, heat gain from the windows contributes significantly to increase cooling loads, and large windows could produce glare problems, especially in south-facing facades [4].

In general buildings, windows are the main apertures of daylighting source and they may have many obstacles like orientation, size, room depth, surrounding buildings, and many other factors which limit to receive sufficient daylight. To overcome those obstacles, some daylighting systems have been practiced in order to improve daylighting performance inside buildings; such as light shelves [5], venetian blinds [6], louvers [6-8], optical louver system (OLS) [7], roller shutters, electrochromic glazing [9-11], thermotropic windows [12], translucent insulating panels [9], photo-bioreactors, prismatic glazing [13], light pipes [14], fibre optics [15], CPCs [13, 15, 16], light wells, and other complex fenestration systems [10, 17, 18].

Many researchers investigated utilizing of venetian blinds and optical louver system (OLS) to reflect incident sunlight into buildings, which produced significant results, however, these results were limited at specific times. Probably, the reason of this obstacle is that these systems are static or manually controlled and still have the issue of changing sun locations, which influence on the uniformity of the reflected light, consequently reduces the occupants' visual comfort [7].

Other papers investigated using of light shelf which has approximately similar properties as venetian blinds and it can redirect sunlight into buildings. But, light shelf still has the same issue of changing sun locations. Nevertheless, it can, to some extent, improve uniformity and distribution at the back of a deep room. Moreover, it can protect occupants from direct sunlight, provide visual contact to the outside simultaneously, and decrease the use of electric light and cooling system which leads to energy saving [5].

Another benefit can be added to the former benefits, specifically when using automated blinds; is to keep the reflected light not just uniform but also relatively steady during the daytime. This property will be investigated in details in this paper. Additionally, we will study translucent glass combined with venetian blinds, to provide uniform and diffuse light to the users near the window.

Venetian blinds was chosen in this study because recent research has shown that this light-redirecting device is effective, and supposed to be one of the best options of daylight exploitation in office buildings [19].

Generally, there are many factors that influence on blinds state by the occupants, furthermore, a previous research [20] summarized that the most three notable factors that affect blinds state are orientation, season and sky condition. Accordingly, this paper will investigate in controlling the blinds in a south oriented façade, in all seasons, with clear sky condition in order to achieve the optimum performance of the blinds.

A case study of the proposed method will be conducted for an office building model in New Cairo in Egypt. According to previous researches [6, 21], highly glazed facades and open floor offices spaces required the use of dynamic solar shading controlled with a cut-off strategy to minimize the risk of overheating and optimize the use of daylight. Consequently, this research will investigate in controlling the blinds automatically using parametric design, which has high accuracy in controlling complex geometries and increases the versatility of the parametric process, which relies on further implementations and variations of the algorithmic models [22].

The design process will be conducted by linking parametric software 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 engines to Radiance, Daysim, and Energy-Plus, see Figure 1. Radiance is a well-known lighting simulation engine that was developed by Ward, which is based on a backward ray-tracing algorithm for daylighting calculations [23].

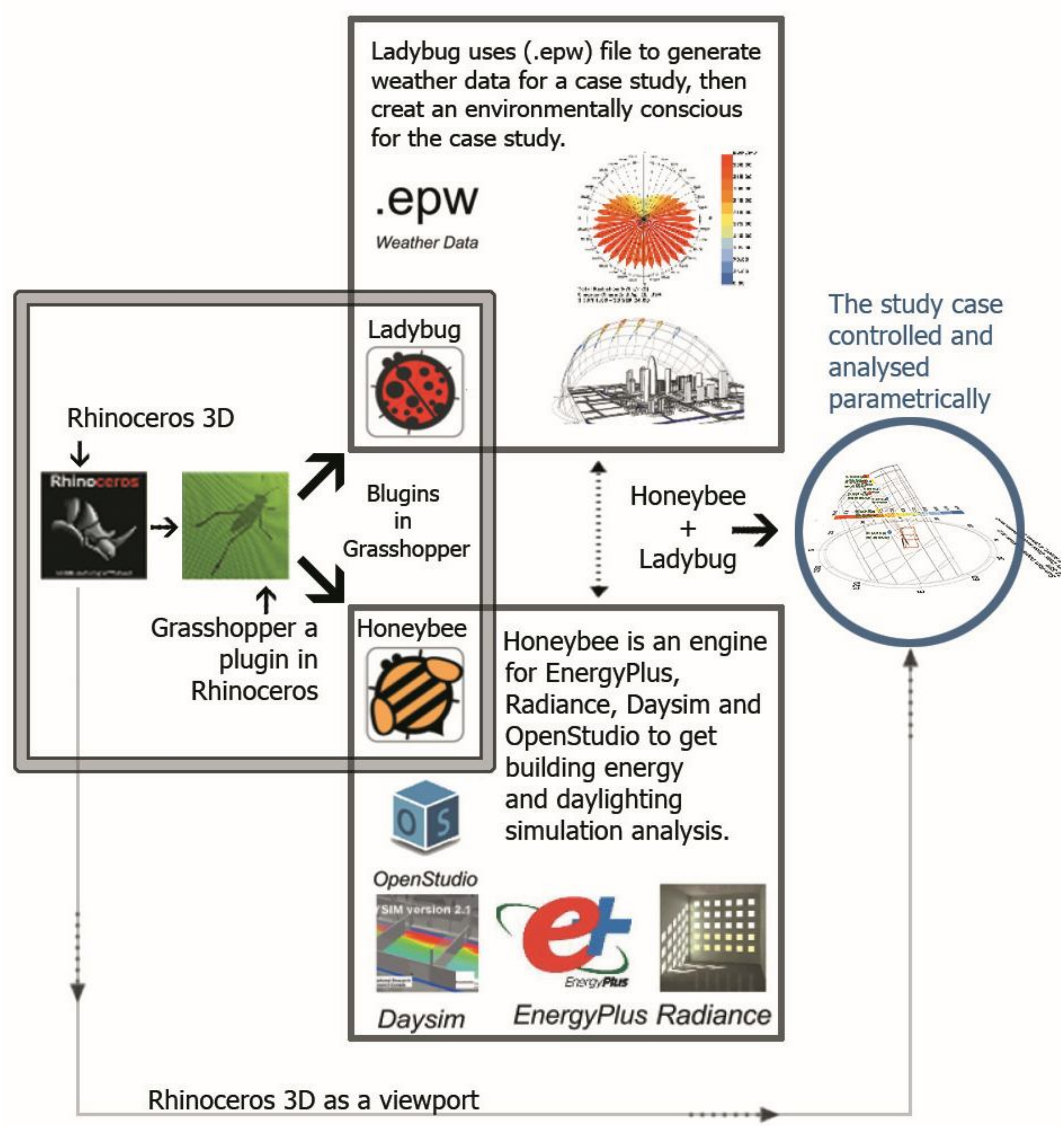


Figure 1: Links between Rhinoceros, Grasshopper, Honeybee and Ladybug to generate an environmentally conscious model.

2 Hypothesis

The new Cairo is used as a case study because it is representing a suitable territory in Egypt, while it is providing distinct weather of clear sky most of the year. Additionally, Ladybug will provide us with all data concerning the sun-direction and sun-path at any particular time.

This paper proposes a formula created in parametric software to control the slats, where these slats act like a snow buttercup flower following the sun direction to receive more light, a process known as *Heliotropic* response [24]. The software used is a combination of plugins in Rhinoceros 3D starting with Grasshopper to create the main model of the office and venetian blinds where can be controlled and changed parametrically. Then, using Ladybug plugin in Grasshopper as an engine to get the weather data, sun-path, time and date related to a specific area, by inserting EPW file to Ladybug plugin. EPW weather data file can be downloaded online from (https://energyplus.net/weather) to get any specific area around the world. Finally, using Honeybee plugin in Grasshopper as an engine to Radiance, Daysim and EnergyPlus in order to get all data related to daylight analysis as shown in **Figure 1**. Grasshopper and Rhinoceros 3D have a separated interface, where the formula is created in Grasshopper screen, and the model is revealed in Rhinoceros screen as shown in **Figure 2**.

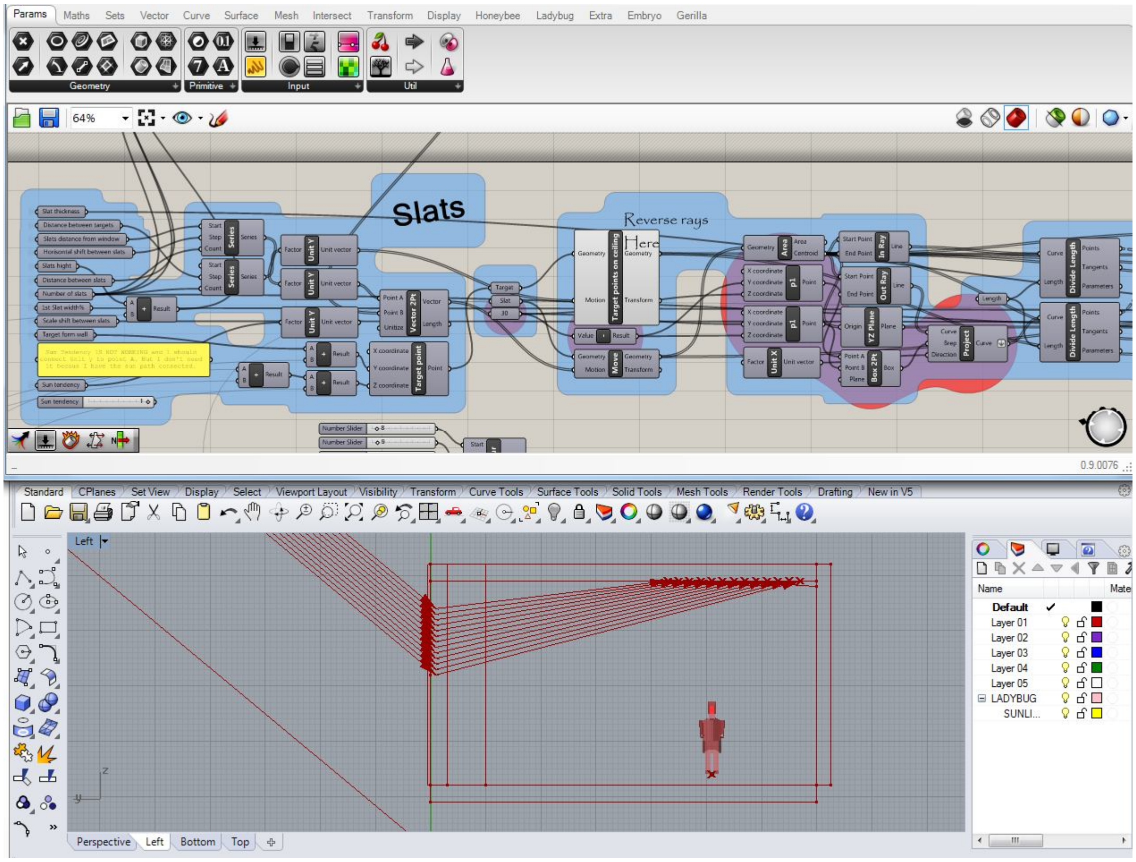


Figure 2: The top screen showing the formula in Grasshopper interface, and the underneath screen showing the model previewed in Rhinoceros 3D interface.

The reflective slats respond to the sun movement at a daytime and redirect the incident sunlight to the ceiling, then the reflected lights on the ceiling act as a diffuse light to the occupants, see **Figure 3**. The slats are working individually where each single slat has a specific rotation angle, in order to redirect sunlight to its specific targets points on the ceiling, and these targets are fixed. During the sun movement; the slats are rotating individually responding to sun direction keeping the reflected light constant at the same target. This process is controlled parametrically using algorithmic formula in grasshopper, and this formula is changeable and editable. The formula concept is depending on keeping the opposing two angles (δ) shown in **Figure 4** above the slat equal wherever the sun direction, where the first angle is the intersection between incident sunlight and slat, while the other angle is the intersection between reflected light and the slat.

(δ) Can be calculated from the next formula:

$$\delta = 90 - 0.5(180 - \alpha - \theta)$$

$$\theta = \tan^{-1} u/v$$

$$\beta = \Omega - \delta$$

Where; (δ) is the opposing two angles over the slat, (Ω) is the solar profile angle, (θ) is the angle between reflected light and ceiling, (u) is the distance from the centre of the slat to the point a, (v) is the distance from point a to the target point b, and (β) is the slat tilt angle, see **Figure 3** and **Figure 4.**

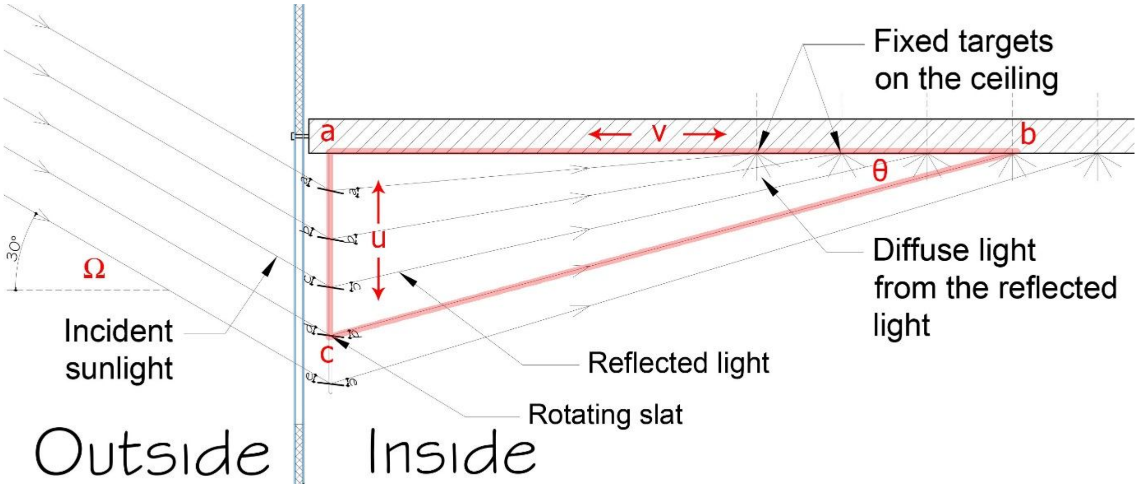


Figure 3: Cross-sectional view of the room showing the incident sunlight reflected by the rotating slats to a fixed target, resulting diffuse light to the occupants. Every single slat has a specific rotation angle according to the target position which is related to the slat.

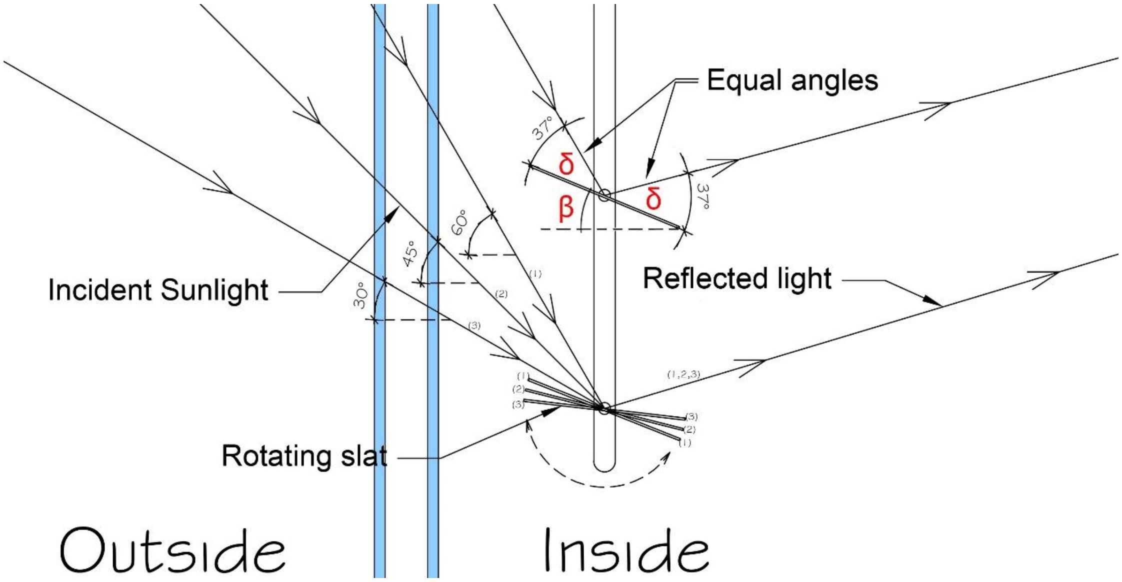


Figure 4: Cross-sectional view of the slats showing sun altitude outside is changing during daytime and the slats are rotating responding to sun movement in order to keep the reflected light towards the fixed target points on the ceiling, and this process conducted via keeping the opposing angles (Ω) equal wherever the sun position.

The required tilt angle (β) in our study should reach to the cut-off angle (β*) which is defined as the blind tilt angle beyond where no direct radiation is being transmitted through the slats. It is the most typical automatic blind control used in several previous studies [19], see **Figure 5(c)**, where: β*= β required.

Number of slats in our study are the main vital aspect, because it determines the critical distance between slats. This distance is vital because; if it is very small as shown in **Figure 5(b)**, it will utterly prevent the penetration of sunlight, but may have the risk of reducing the reflected light to the ceiling. In contrast, if the distance between the slats is bigger than a specific limit as shown in **Figure 5(a)**, it will reflect the whole coming light from direct sunlight, however, still have the risk of incident sunlight penetration. Therefore, the critical distance (y) shown in **Figure 5(c)** should be tuned to achieve the balance between the two main functions, in order to obtain the optimum performance.

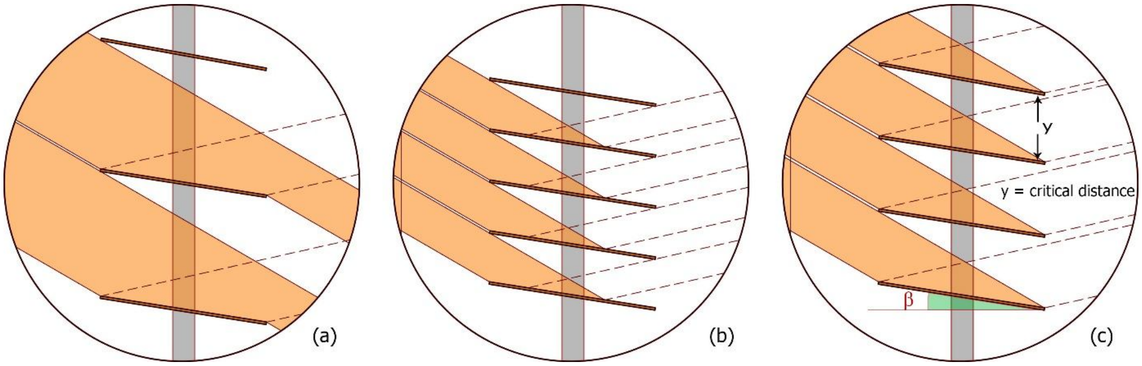


Figure 5: a comparison showing the influence of distance between slats on the light reflected; (a) big distance, (b) small distance, and (c) is the critical distance which is accepted according to the balance achieved with the cut-off angle β* (required β).

Actually, it is difficult to make a complex process to control several functions in the same time, and this should be conducted by computerizing. Therefore, utilizing parametric design in this kind of complex process is really practical, and it can be conducted via a formula created in Grasshopper. In our case, the cut-off angle (β^*) is unique angle for every single slat, see Figure 4, and the critical distance between slats (y) should be assigned depending on the top two slats, because the cut-off angles are decreasing gradually starting from the threshold height going to the top; consequently, the distance between the top two slats intuitively is suitable for other slats to prevent the direct light.

The reason of using fixed targets on the ceiling, is to keep the reflected beams horizontally constant, parallel to the window, and moving in a straight line in one path according to sun azimuth.

The idea of using parametric design in this process is to facilitate achieving maximum coverage of daylighting inside the room, via adapting the slats to receive as much as possible of sunlight and reflect it to the ceiling as shown in **Figure 6(c)**. In the same time, the slats acting as a shading devices to protect the occupants from direct sunlight and heat gain, which leads to reducing cooling demands. Additionally, the parametric slats can keep the reflected light more steady and distributed on the ceiling during the working hours; which can provide visual comfort for the occupants. Consequently, electric light can be turned off during the daytime as long as the reflected lights are constant and available, then we can save energy [25].

According to recent studies [8, 25-28] optimizing daylight can save electric lighting by 20-40% from total energy, while electric lighting is one of the most energy consumption which accounts 20-30% of total electric energy consumption [29]. Additionally, shade provided from slats can reduce cooling and heating energy demands by 30% [8, 30].

3 Methodology

The methodology depends on using automated venetian blinds, and control them parametrically through a parametric software (Grasshopper), in a hot climate territory.

3.1 Location

As mentioned latterly, the case study is an office building in New Cairo, located in 90th street. Moreover, the main entrance, offices and work stations are facing the south whilst the other services allocated in the north. Therefore, the workstations are exposed to direct sunlight during working hours all the year.

3.2 Model description

The workstation model is built in Grasshopper based on Rhinoceros 3D, which contains three main parameters: Workstation space, Venetian blinds and Time adjustment.

3.2.1 Workstation:

The proposed workstation dimensions are 4m height finish to finish, 7m depth, 18m length, 30cm slab thickness, where all these dimensions are changeable and can be controlled parametrically.

3.2.2 Venetian blinds (slats):

The proposed blinds consist of aluminium slats with 90% reflectivity; which located inside the office with a specific distance from a double glazing window and also can be controlled parametrically as follows, see **Figure 6**:

- Assigning the slat dimensions (length, width, and thickness) ignoring the curvature of the slat.
- Assigning the count of slats based on sun altitudes.
- Assigning the distance between slats (y) based on the count of slats.
- Assigning the threshold height of the slats (h). This parameter will be fixed.
- Assigning the distance between targets (L); based on the room depth and coverage area. This parameter describes the distance between centres of reflected beams on the ceiling.
- Assigning the distance between slats and window (x); based on season type.
- Tuning the horizontal shift between slats; based on sun altitude.

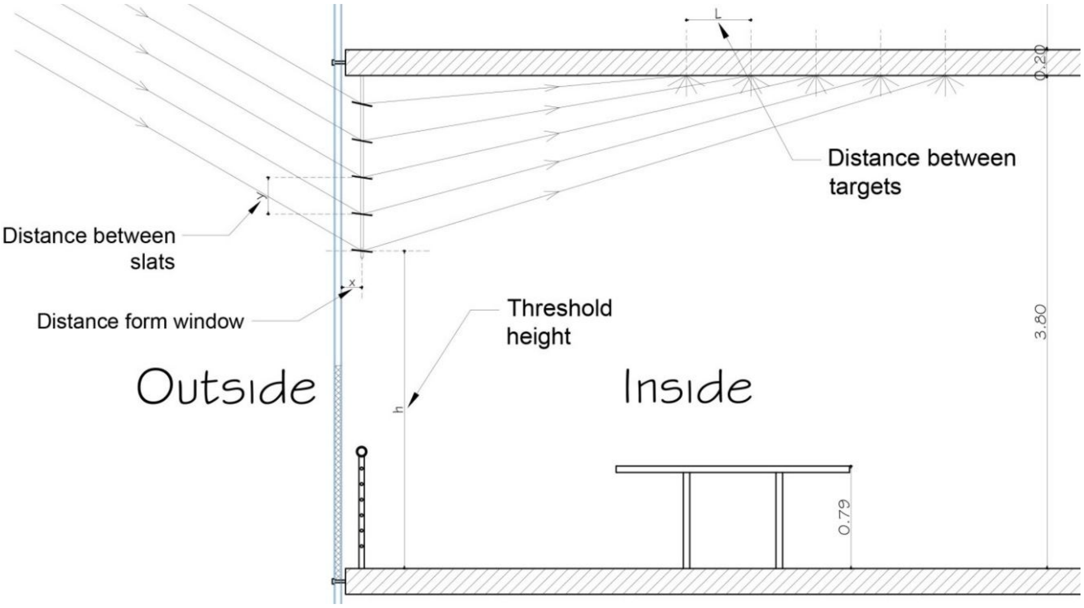


Figure 6: Cross-sectional for the office showing the controlled parameters; x: slats distance from window, y: distance between slats, L: distance between targets, h: slats' threshold from the finish floor.

The parametric slats should perform two functions simultaneously; firstly, redirect incident sunlight to the ceiling, and secondly, prevent direct sunlight from penetrating inside the workstation, through using specific cut-off angles with a specific critical distance between the slats. In order to achieve an optimum performance, these two functions should be controlled in balance; via keeping the critical distance between the slats homogeneous with sun altitude. In a previous study [19], cut-off angle was calculated using a specific formula, in order to protect the occupants from direct sunlight only, but not to redirect the light. Moreover, the slats angle in the mentioned study were equal, even the distance between slats were fixed. However, in our proposal we have two additional factors; first, is to redirect sunlight and second, is to prevent the penetration of direct sunlight.

3.2.3 Time and date:

The formula in Grasshopper is tuned to react according to sun movement when changing time or date automatically, using ACB clear sky with direct sunlight. Honeybee plugin provides full sun path parameters via (EPW) weather file. In order to understand the hypothesis of this study, we will study three different cases from winter to summer (June 21st, September 21st and December 21st), see **Figure 7**.

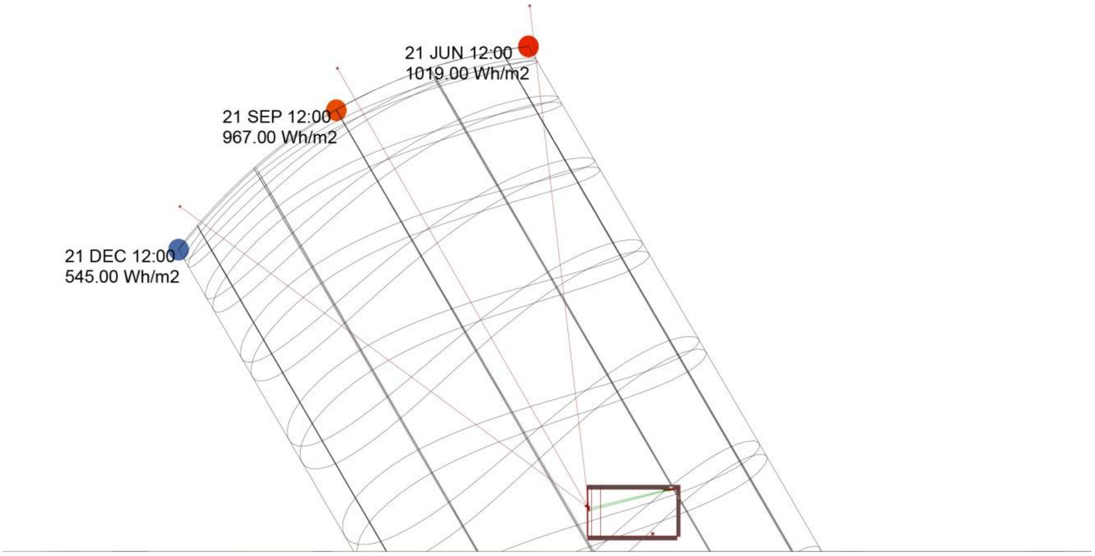


Figure 7: Sun path exported form Rhinoceros 3D, on June 21st, September 21st, and December 21st and sun altitudes 83.3°, 60.2°, and 36.4° respectively at zenith time 12 pm.

3.3 Software

As mentioned previously, the software used is Grasshopper based on Rhinoceros 3D, while Grasshopper works an engine to obtain the weather data, Radiance, Daysim, and EnergyPlus, via Ladybug and Honeybee plugins.

4 Modelling experiments and results

The modelling experiment was conducted for four cases in June 21st, September 21st and December 21st, which are representing; maximum, equinox, and minimum of sunlight availability around the year respectively, (putting in consideration that the last two cases will be conducted on December 21st). The model is south oriented workstation in an office building in New Cairo, and exposed to direct sunlight with clear sky; Average Climate Based (ACB) sky. The room length is 18m, 7m depth, and 3.8m clear height, and the slat unit in our case will be set to 10cm width and 1mm thickness. Firstly, we will study the sun-path and its coverage percentage area inside the room before adding the slats. Then adding the slats based on the analysis of sun coverage, in order to adapt the slats to react effectively with the changing altitudes of the incident sunlight. The slats are metal plated with reflectivity of 90%, allocated inside the room (for the first three cases). In the fourth case; the blinds will be placed outside the window in order to collect maximum sunlight, according to the high inclination of the sun.

The reflected lights in our cases will be concentrated in five-meter depth starting from the end of the workstation going to the window, which means that the remain two meter near to the window is not exposed to the reflected light. The reason is that the area near to the window is already lit by the window and obtained sufficient natural light. Putting in consideration that the target in our case is to cover the deep area inside the workstation, **Figure 8**.

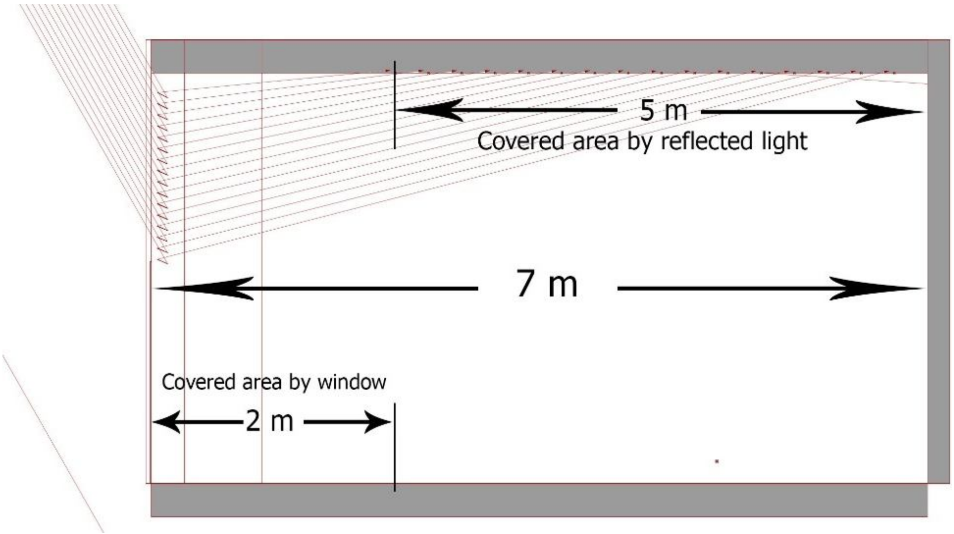


Figure 8: cross-section in the workstation showing the covered area by reflected light

4.1 Case 1: clear sky with sun on December 21st

In this case, winter season in Cairo, 21st of December sun altitude is 36.4° at zenith time, see **Figure 7**.Additionally, it can be noticed in **Figure 9** and **Figure 10** that direct sun light is low at this time and covering more than 80% of the room from 8am to 5pm. Therefore, the slats count should be increased and closed to each other in order to prevent the penetration of direct sunlight inside the room.

This process was done in Grasshopper by changing the parameters of the slats, in order to create a balance between the cut-off angle (β*), reflected light and the critical distance between the slats (y), see **Figure 11** (detailed section). The ray passes though the top outer edge of the slat is prevented by the inner edge of the bottom slat. Consequently, the amount of light passes between the two slats is prevented from passing to the room, and simultaneously, redirected to the ceiling, and so on for the other rays, see **Figure 11**.

Meanwhile, the insolation intensity of sunlight is low according to Lambert's Law, because in winter season; a unit beam of the sun ray is steep which resulting coverage of larger area, accordingly, receiving less energy per unit of area[31]. Because of the low intensity of the sun; high number of slats will compensate the weakness of sun radiation (545 W/m2) at this time, see **Table 1**, by reflecting maximum sunlight into the ceiling as shown in **Figure 11** (left). The slats settings are shown in **Table 2**.

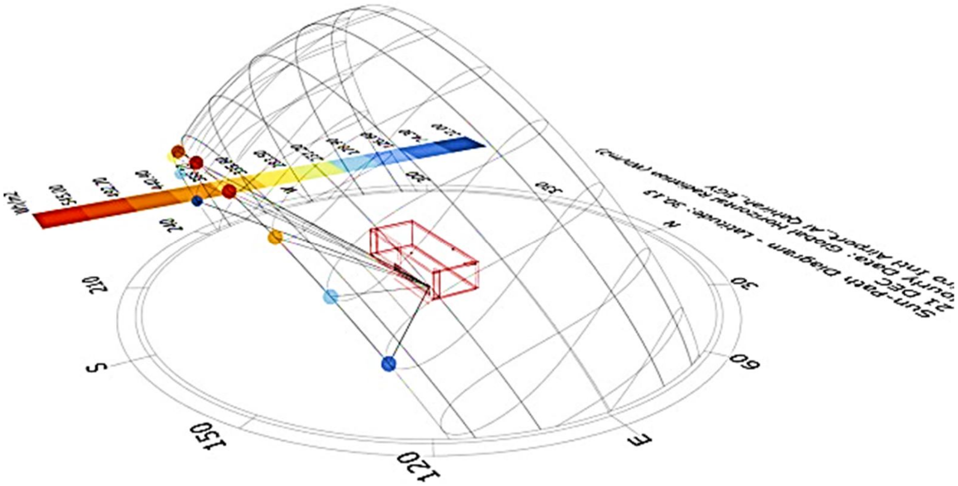


Figure 9: Sun path on December 21st from 8am to 5pm.

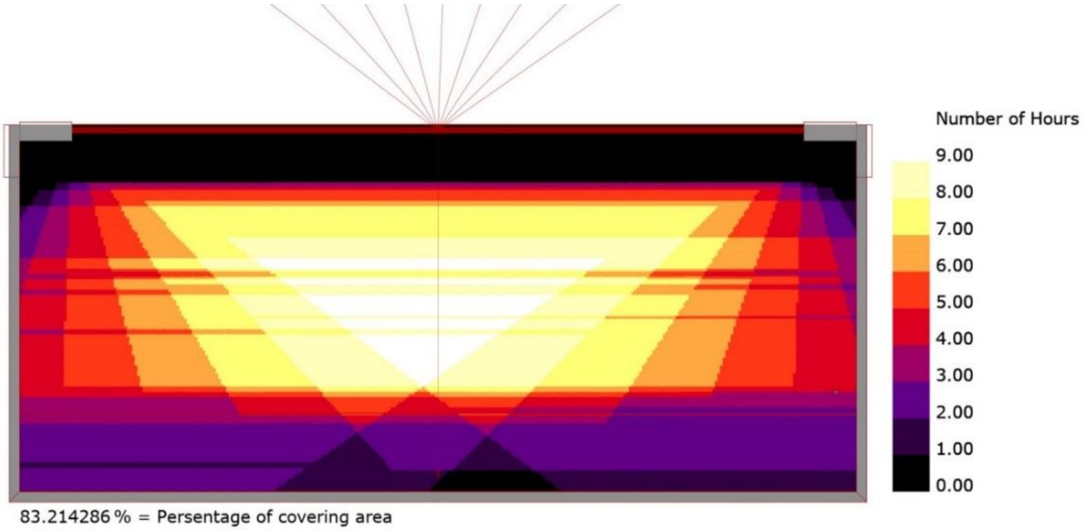


Figure 10: Plan for the workstation showing sun coverage area from 8am to 5pm, number of hours in legend par and the percentage of covering area (83.2%) in the 21st of December.

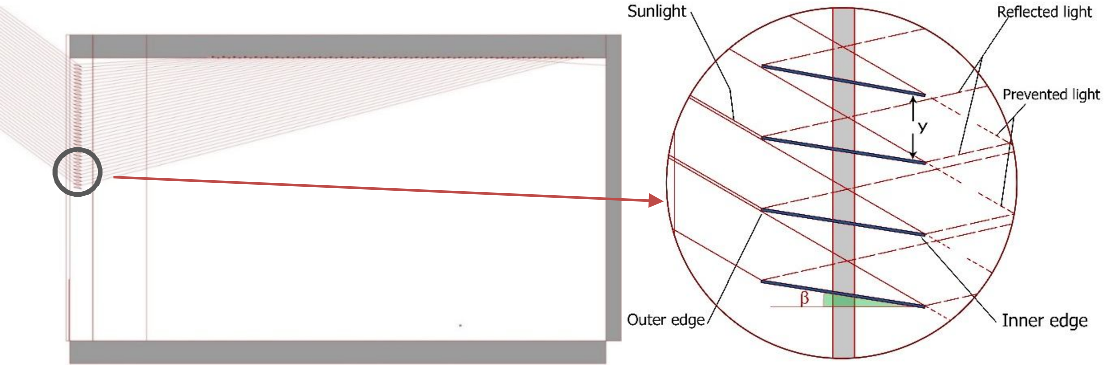
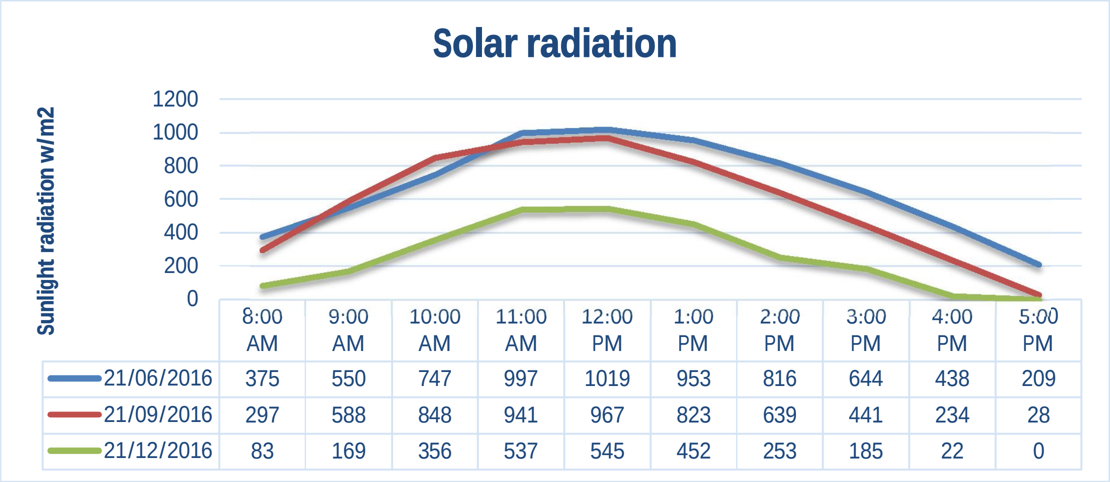


Figure 11: (left); cross-sectional view on the workstation showing sun rays at zenith time with 36.4° altitude on December 21st, using high number of slats [35 slats], (right); detailed section for the slats.

Table 1: Solar radiation in Cairo, on Jun 21st, Sep 21st and Dec 21st, from 8am to 5pm.



	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM
21/06/2016	375	550	747	997	1019	953	816	644	438	209
21/09/2016	297	588	848	941	967	823	639	441	234	28
21/12/2016	83	169	356	537	545	452	253	185	22	0

Table 2: Slats settings

Slats parameters in meter	21st Dec.	21st Sep.	21st Jun.
Distance between targets (L)	0.14	0.3	0.3
Distance form window (x)	0.1	0.1	-1
Horizontal shift between slats	0	0	0.06
Threshold height (h)	2	2	2
Distance between slats (y)"critical distance"	0.047	0.1	0.1
Number of slats	35	16	16
Target form wall	0.3	0.3	0.3

The first and last three hours of the working hours from 8am to 11am, and 2pm to 5pm respectively, sun altitudes are low, and it can be noticed in **Figure 10** (purple colour) that sunlight is penetrating deep in to the end of the room, and solar radiation at these 6 hours are very low to be redirect while maximum solar radiation at this period is 356 W/m2 at 10am, see **Table 1**. Therefore, we can utilize this opportunity by providing diffuse light at this period via using translucent glass with 30% translucency [11, 32] instead of the automated blinds (this issue will be investigated in details in a future research). The middle three hours from 11am to 2pm; sun altitudes are relatively high comparing with the first three hours. Accordingly, the intensity increases gradually as shown in **Table 1** and can be sufficient to be reflected using automated slats.

4.2 Case 2: clear sky with sun on September 21st

In this case, autumn equinox 21st of September, where daytime and night are equal (12 hours each) and sun altitude is 60.2° at zenith time. On this date it can be noticed on **Figure 12** that sunlight is covering just 22% of the room, however, daytime is longer than winter season. According to the increase in sun altitudes as shown in **Figure 13**, and comparing to winter season; number of slats was decreased and moved away from each other in order to match the intensity and angle of sun ray at this time, see **Figure 13**(right). In this case, daylight is needed to cover deep inside the room more than providing shade, whilst approximately 80% of the room is already shaded and not exposed to direct sunlight.

Indeed, higher altitude of the sun means more insolation intensity according to Lambert's Law[31], consequently this increase in solar radiation at this time, see **Table 1** will compensate the lack of slats via reflecting higher intensity of the sunlight. Therefore, we can obtain approximately the same intensity form reflected light as in winter season, however, count of slats in this case is lower than in winter season. In **Table 1** it can be noticed that solar radiation on September 21st at 12pm is 967 W/m²; however, it is 545 W/m² at the same time on December 21st, which is approximately equal to the morning of September 21st 588 W/m². This means that the minimum of solar radiation on September is approximately equal to the maximum of solar radiation on December. Therefore, this difference can be compensated by controlling the number of reflected lights (slats count). In addition, solar radiation on this date is strong enough to be reflected during daytime, except the first and last hour from the working hours. Therefore, automated slats can work effectively within six hours during daytime, and the diffuse light can be implemented in the other two hours via using translucent glass[11] as mentioned in (case 1).

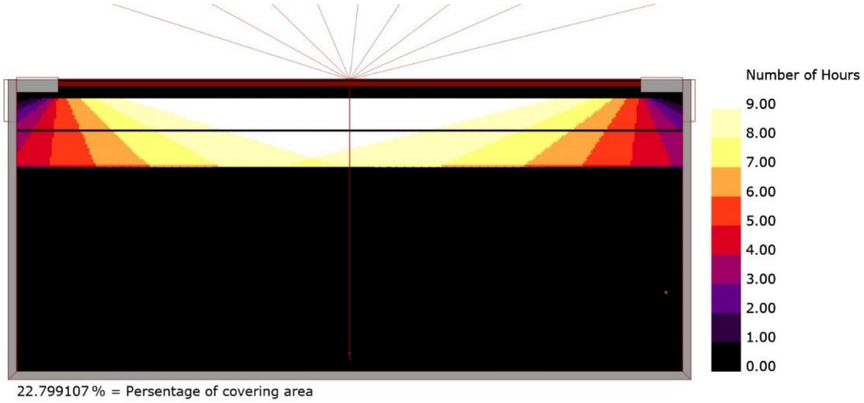


Figure 12: Plan for the workstation showing sun coverage area from 8am to 5pm, number of hours in legend par and the percentage of covering area (22.7%) on the 21st of September.

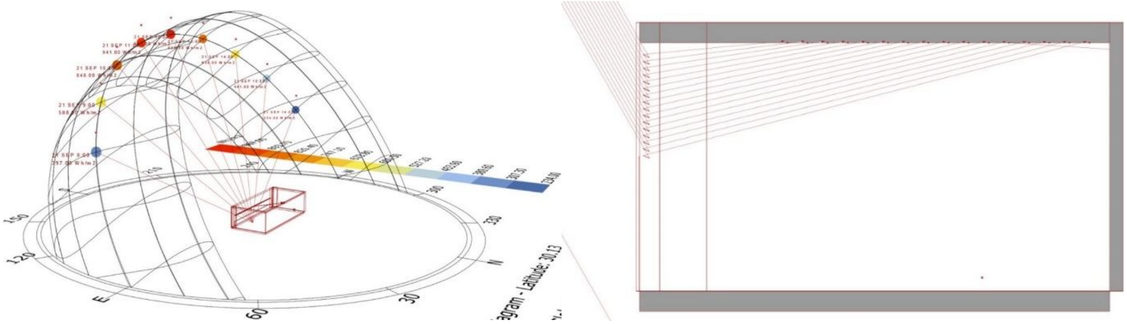


Figure 13: Sun path on 21st of September from 8am to 5pm (left), Cross-sectional view for the workstation showing sun rays at zenith time 60.2° altitude on September 21st, using low number of slats [16 slats] (right).

4.3 Case 3 & 4: clear sky with sun on June 21st

At this time of the year summer season June 21st which is the longest day over the year, and sun is approximately vertical at zenith time, see **Figure 7**, accordingly, the workstation is almost shaded during daytime as shown in **Figure 14**. Hence, sun rays cannot strike the slats as long as they are allocated inside the window (case 3); accordingly, reflected light is hardly obtained because of the vertical path of the sun rays as shown in **Figure 15**. Therefore (Case 4), the slats should be allocated outside the room in order to absorb and reflect maximum sunlight. Moreover, this action will work as a shade to protect the widow from incident sunlight during the day, which is an effective method of reducing solar heat gain inside the building by a maximum of 80% via blocking direct solar radiation before it reaches the window[8]. In this special case, the slats should be formed in an inclined sequence “tilted blinds” outside the window in order to collect maximum sunlight, **Figure 15**(right). Moreover, previous studies [33] have shown that the exterior shading in the view window provides the highest indoor quality and optimum energy efficiency, and it can reduce cooling energy consumption by almost 50% [6]. The settings of slats are shown in **Table 2**.

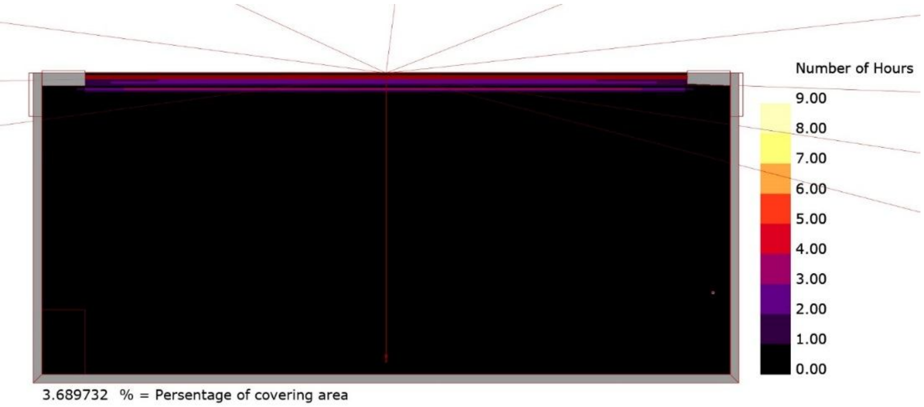


Figure 14: Plan for the workstation showing sun coverage area from 8am to 5pm, number of hours in legend par and the percentage of covering area (3.6%) in the 21st of June.

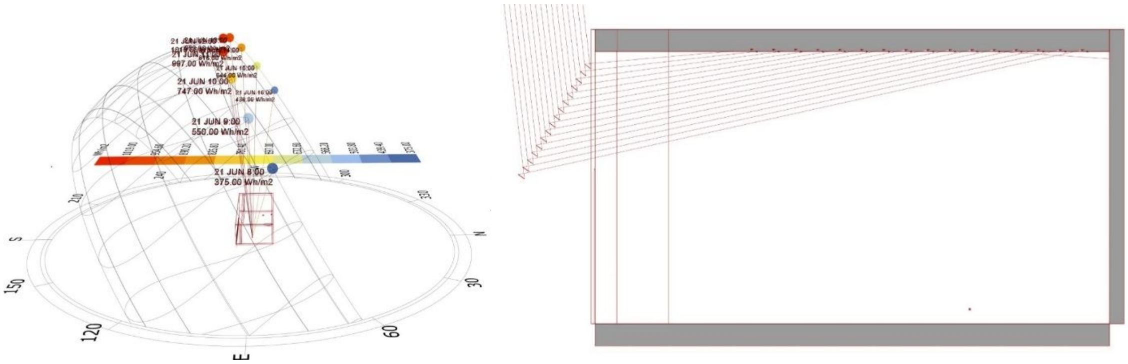


Figure 15: 21st of Dec sun path from 8am to 5pm (left), Cross-sectional view for the workstation showing sun rays at zenith time with 83.3° altitude on June 21st, using tilted blinds [16 slats] (right).

5 Discussion

An issue can be noted in the previous case (case 4); is that sun azimuth at 4pm is 278° and exceeding the façade limit by 8° which cannot be absorbed by the slats, and even for the first hour in the morning, which means that sun azimuth should be between 90° and 270° in order to reach the slats, see **Figure 14**. In this situation we are studying the influence of parametric slats in the southern façade only, therefore the utilization of the slats will not be effective in the first hour in the morning where the sun will strike the east façade only, and likewise, at the last 2 hours in the evening where the sun will strike the west façade only.

The reason of choosing the previous three dates in our cases; is that they are covering the whole possible different circumstances along the year, solstice and equinox times, which expressing the longest, the shortest, and the equal daytime. June 21st is expressing the longest daytime in summer season, while the circumstances in this time are approximately similar to the next and previous month; from May 6st to August 5st. In contrast, solstice of winter season time on December 21st which expressing the shortest daytime of the year, and likewise, this time is approximately similar to the next and previous month, form November 6st to February 5st. In addition, the in between months; spring and autumn equinox, are the middle months between summer and winter which expressing the equal daytime of the year. This special time is expressing six months in spring and autumn. From February 6st to May 5st which expressing the spring season, and from August 6st to November 5st expressing the autumn season. Therefore, these three dates are expressing the whole and maximum anticipated circumstances around the year from June to May.

It can be noticed in **Table 1,** on December 21st; that solar radiation is 545 W/m² at 12pm and sun altitude is 36.4°, hence, number of slats was set to 35 in order to achieve the critical distance 47 mm, meanwhile, the distance between targets was set to 140 mm to compensate solar intensity weakness. However, on September 21st; distance between targets was set to 300 mm according to low number of slats in this case, which will be compensated by the higher solar radiation (967 W/m²) at this time, and so forth on June 21st which have the same parameters, except the change in allocation and inclination of the slats to be outside the window, according to high altitude of the sun. These differences can be understood in the next comparison.

This study is focusing on the efficiency of the automated blinds to preventing direct light, providing natural light, and the controlling process of the parametric blinds, while, the intensity of light needed achieved by the blinds, in addition the translucent glass will be investigated in a future study.

6 Comparison

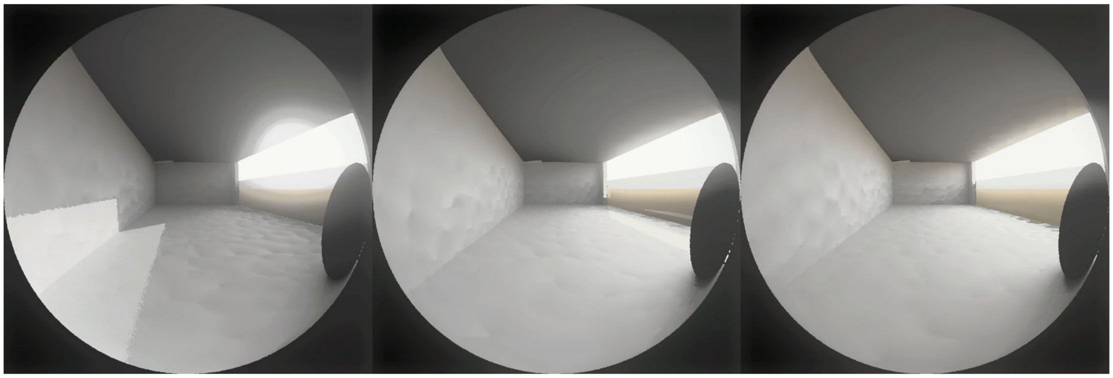
A comparison experiment is conducted between the three previous cases at 8 am, 10 am and 12 pm, using non-venetian blinds, conventional blinds and automated blinds in a workstation. The conventional blinds settings were set like the same parameters of the automated blinds, but in a horizontal state with no specific angle as the automated blinds. As mentioned before, each slat in the automated blinds has a specific rotation angle which respond parametrically to the sun movement.

Figure 16 is showing a comparison maps of daylight distribution in the workstation using non, conventional and automated venetian blinds on December 21st, September 21st and June 21st respectively at 8 am. In the automated case, sunlight is reflected and prevented successfully on September and June, however, on December the incident light is penetrating between the slats according to low inclination of the sun, and this issue will be addressed in a future study as mentioned before, using translucent glass. In the conventional case, the slats were set to be static in a horizontal state, which is considered the best static way to utilize daylight [34]. The conventional blinds at this time are showing lower efficiency in reflecting light comparing to the automated ones. Although, the reflected light is revealed on December, but still not distributed perfectly.

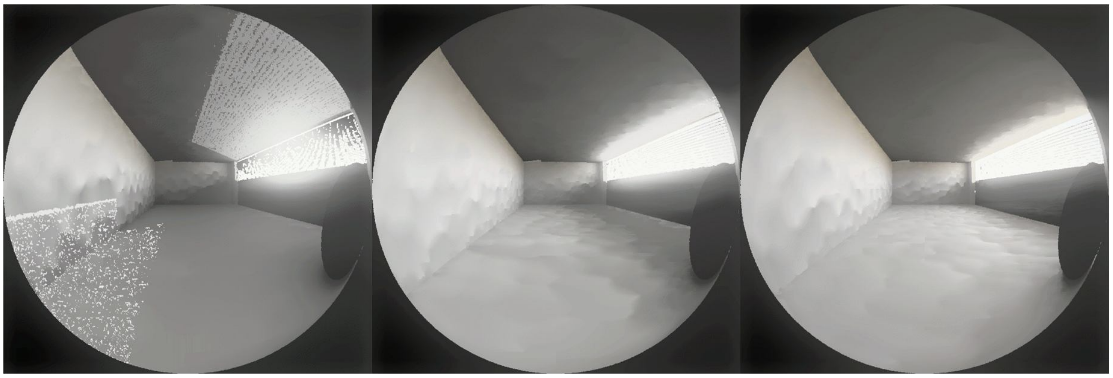
On **Figure 17,** same previous conditions but at 10 am; the reflected light on the automated blinds case are looks more steady and uniform on the three mentioned dates. Moreover, it can be notice that reflected light on December at this time is approximately reflected and prevented comparing to 8am case. The conventional slats again are not succeeded at this time as well. Nevertheless, they are showing better performance on December with reflecting and preventing sunlight, but light reflected is still not distributed.

On **Figure 18**, automated blinds are showing the best performance at 12 pm on the all dates, while they succeeded to reflect and prevent sunlight perfectly, and daylight is distributed well on the ceiling, form the window to the deep part of the workstation. On the other hand, the conventional blinds prevent light successfully, but no reflected light is revealed, except on December in the first part near the window, where the light is not sufficient to light the workstation.

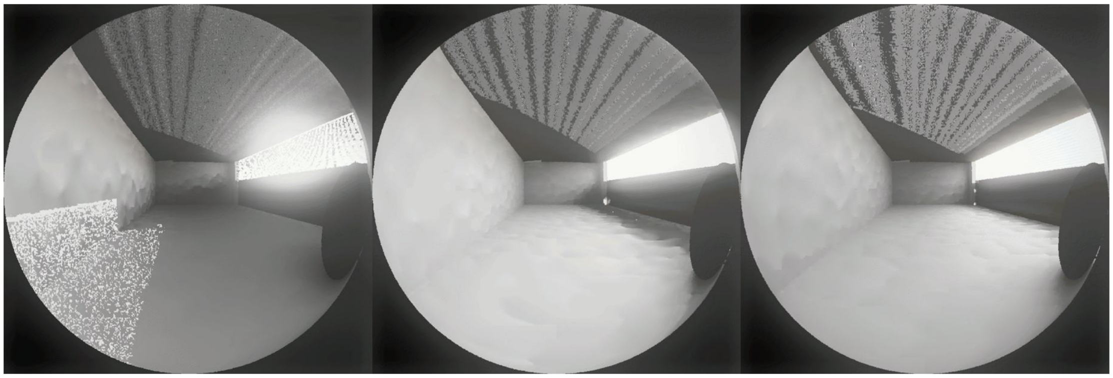
December 21^{st} 8am September 21^{st} 8am June 21^{st} 8am



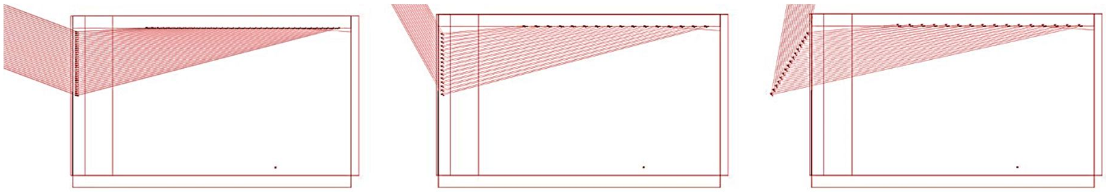
Workstation maps without blinds.



Workstation maps with the conventional blinds.

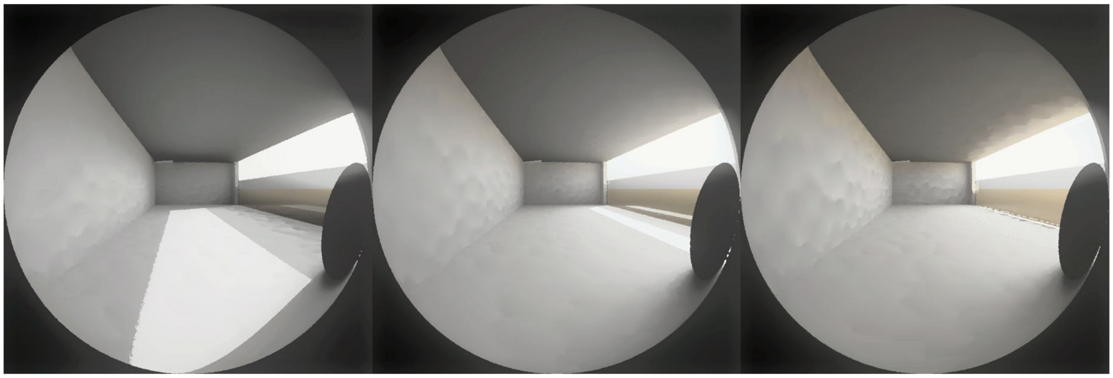


Workstation maps with the automated blinds.



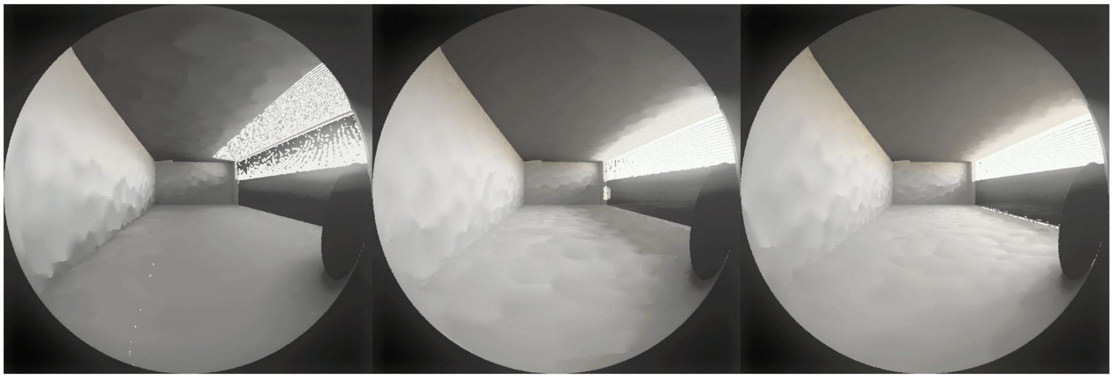
Cross-sections on the workstation showing the raytracing.

Figure 16: Comparison HDRI maps for the workstation on December 21^{st}, September 21^{st}, and June 21^{st} at 8 am, from left to right respectively. The third line of maps showing the weakness of reflected light at this time according to low inclination of the sun.

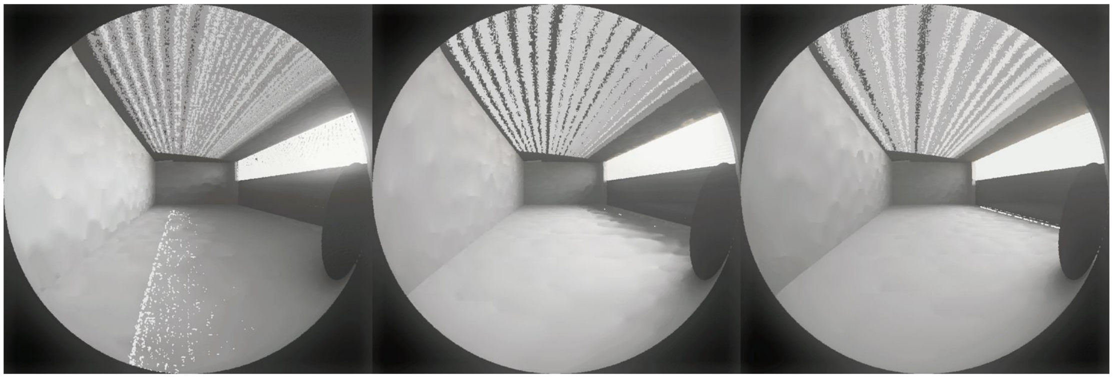


December 21st 10am September 21st 10am June 21st 10am

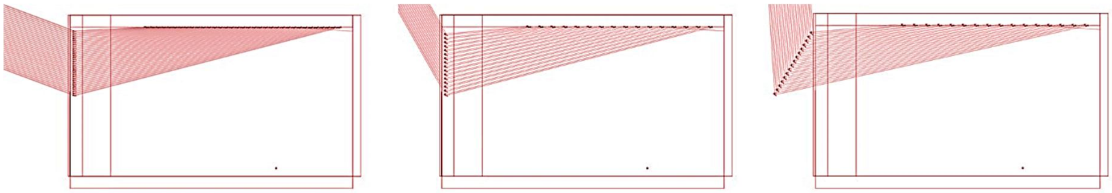
Workstation maps without blinds.



Workstation maps with the conventional blinds.



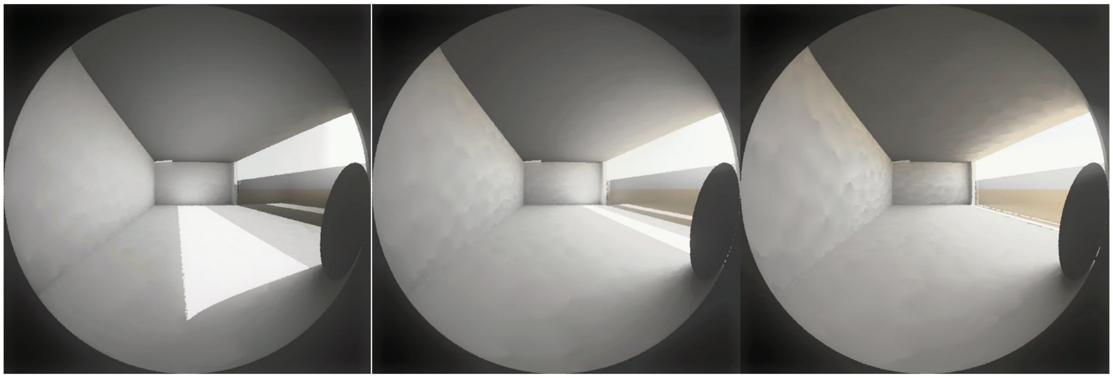
Workstation maps with the automated blinds.



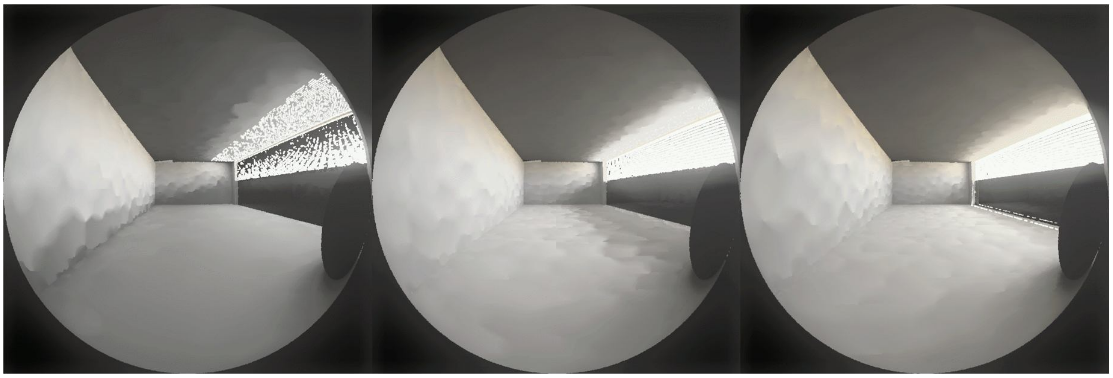
Cross-sections on the workstation showing the raytracing.

Figure 17: Comparison HDRI maps for the workstation on December 21st, September 21st, and June 21st at 10 am, from left to right respectively. The third line of maps showing the achieved balance between the reflected and prevented sunlight, via using automated venetian blinds.

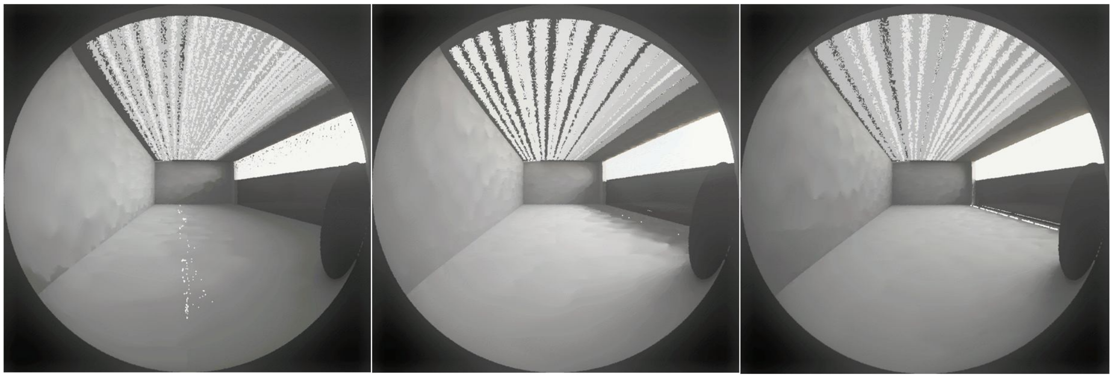
December 21st 12am September 21st 12am June 21st 12am



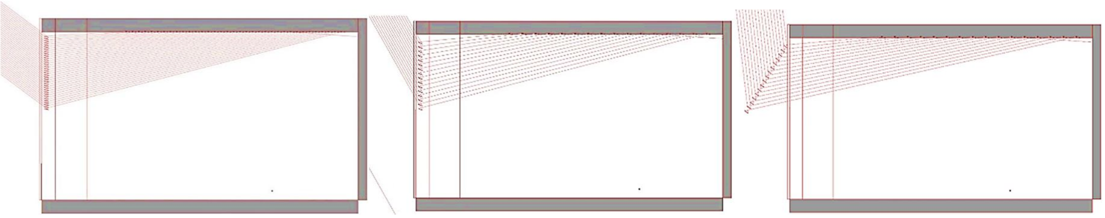
Workstation maps without blinds.



Workstation maps with the conventional blinds.



Workstation maps with the automated blinds.



Cross-sections on the workstation showing the raytracing.

Figure 18: HDRI maps for the workstation on December 21st, September 21st, and June 21st at 12 pm, from left to right respectively. The third line of maps showing the achieved balance between the reflected and prevented sunlight, via using the automated blinds case.

7 Conclusion

Automated venetian blinds were used to light a south oriented workstation in Cairo using direct sunlight, with clear sky. The blinds were controlled parametrically, and respond automatically to the sun movement in a heliotropic response. The experiment was occurred at three different times of the year; June 21st, September 21st and December 21st, and these specific dates were chosen to cover all possible circumstances of daylight exposure. While these dates are the maximum, equinox and minimum of sunlight exposure around the year.

According to sun altitudes, the blinds were set inside the workstation on December and September, where the sun inclinations are sufficient to be reflected to the ceiling and provide natural light. However, solar radiation on December was very weak at the first and last three hours to be redirect, likewise, on September, at the first and last hour had the same issue. Therefore, in order to compensate this weakness, translucent glass was proposed to provide diffuse light in these critical hours.

On June, sun altitude is very high to be caught by the inner blinds. Consequently, the blinds were set outside the work station in an inclined sequence, in order to obtain maximum sunlight. On the other hand, the tilted blinds will protect the windows form direct sunlight from striking their surface, which can help to reduce the heat gain inside the building.

Automated blinds were showing the best performance of providing natural daylight, preventing direct sunlight, and distributing light, comparing to the conventional blinds. However, conventional blinds succeeded in preventing incident sunlight and providing natural light, but the provided light is still not sufficient along the all dates, and not distributed well.

In conclusion, automated venetian blinds based on parametric design can be an effective system to provide a south oriented building with natural light, and protect the occupants form direct sunlight and heat gain simultaneously. Therefore, this system can save energy by saving electrical light, in addition, save the cooling and heating energy consumption. Moreover, daylight availability can influence positively on the occupants' health and creativity.

Acknowledgment

Thanks to the Egyptian Government for their financial support for a full scholarship, and thanks to Helwan University in Egypt for their help and support for the nomination to this scholarship.

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