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Building Regulations and Its Contribution In Improving Daylight Of A Residential Building in Cairo

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A B S T R A C T

Daylight is considered to have many benefits in its effect on the architectural space. Benefits could be qualitative and quantitative on the space as energy consumption reduction with improving daylight adequacy. However, getting access to daylight becomes hard to achieve through unstudied building regulations as setbacks in comparison to building heights where orientation may not be optimal and obstruction is almost expected, besides, building techniques and design neglects this critical problem by dealing with all the building façade in the same way which increases the problem. Therefore, this study aims to examine the effect of the regulated setbacks in Cairo city on the daylight availability inside the residential spaces. In addition, the study aims to reveal the possible solutions by using different parameters in a predefined parametric simulation process. The study was constructed on two steps to reveal the possible solution and suitable window to wall ratio for each floor. First, the window to wall ratio parameter was studied for the side facing rooms. The second step concerned about adding a shading element to the room to prevent excessive solar gains in the case of their existence. Grasshopper the parametric plugin for Rhinoceros 3D was used for modeling all the configurations. Analysis was carried out by DIVA, which utilizes the daylight simulation engines, Radiance and Daysim. The results revealed many findings concerning the façade design of each space. Furthermore, some spaces daylight levels improved through the first phase only, while other cases needed more examination in the second phase. The study concluded that designing the daylight of each space could have a high impact on the daylight levels, as many spaces were improved, while it recommends more techniques and shading types to be examined. Finally, the study is considered as a step towards improving daylight of buildings in Cairo's formal context.

Keywords: building regulations, passive design, daylighting design

1. Introduction

World's population is increasing dramatically, thus meeting the needs of the inhabitants became a critical issue facing planners and designers. Consequently, architects tackled solutions for the problem as; enlarging the city's land boundary, optimizing land usage and constructing higher and closely packed buildings. In addition, several approaches were used to control this phenomenon as; using plot ratio, increasing building height and setbacks for building (Ng & Wong, 2004). All these factors could directly affect the daylight availability on the urban scale, which leads to the difficulty of achieving adequate daylight in certain areas of the city. Moreover, insufficient daylighting could be summed up as a result of the influence of the whole surrounding built environment (Capeluto, 2003).

In Egypt, setbacks in formal areas in most of the cases are regulated as shown in Figure 1. Furthermore, average heights of buildings vary from 4 story to 12 story, while it could go out this range by the municipality of each town and zone. Consequently, no building is permitted to be built if it doesn't fulfil these regulations (Law of Construction 119, 2008). This regulation misses one of the most important factors, which is considering daylight obstruction of the surrounding buildings with respect to the setback distance regulated in the plot.

The formal context of Cairo has several characteristics as following. First, setbacks vary depending on many factors as the building's height and street width. Besides, setbacks for residential land uses vary between 3m to 4.5m as an

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offset from the land boundary and the common high rise residential buildings vary from 9 to 12 floors depending on its location and the street width.

For the last 60 years, building design is characterized by the lack of integrating local environmental passive strategies as shading, orientation, thermal mass, natural lighting and ventilation (El Araby, 2002). Consequently, this resulted unpleasant designs for residential buildings regarding thermal comfort and daylighting in most of the cases, which affected the occupants and how they use the building.

Figure 1. Urban Context in Cairo's Formal Areas

Daylight is one of the essential components of passive design that highly affects the architectural space. In other words, pleasant daylighting enhances visual comfort inside the space improving functionality of the space, occupant comfort and energy consumption reduction, which is hardly achieved using artificial lights (Ne'Eman & Hopkinson, 1970).

Many factors affect the quantity and quality of daylight. Some of these factors are internal components of the building, as the window to wall ratio, depth, shape of rooms and reflectance of interior surfaces. While, other factors are external as reflected daylight from opposite facades, ground and the obstruction of surrounding buildings (Li & Lam, 2001). However, most of these factors could be unknown in the early design stage. Furthermore, considering daylight availability outside the building could be tremendously effective in the space design to achieve daylight adequacy.

On one hand, obstructions could increase directly with the increase of building heights. On the other hand, obstructions are a result of not having the appropriate setback distance to the surrounding building heights, which consequently leads to the reduction of daylight penetration into the spaces. In addition, many European site planning guidelines were developed based to overcome this problem by studying the relationship between block spacing and daylight performance and the relationship between window size and thermal-light energy performance is considered highly effective (Hawkes, 1970; Baker & Steemers, 2003).

In a desert climate characterized by clear sky conditions as Egypt, taking into consideration daylight design of the spaces with respect to the regulated setbacks could be a highly effective strategy. These considerations will not only affect daylight adequacy in the space but also reduce energy loads, as it results less number of hours of artificial light operation.

In other words, the heat gain associated with the electric lighting can highly increase the total building cooling load during the hot summer period. Therefore, natural daylight can take the role of reducing energy consumption in two ways; reduce lighting energy consumption and the heat gains associated with electric lighting. In conclusion, the careful consideration of daylighting as a passive strategy can effectively reduce the total electricity load of the building (Choi & Selkowitz, 1984). In contrast, some cases occur excessive levels of daylight that consequently affect the thermal comfort inside the space. In this case, visual discomfort occurs in the spaces associated with higher levels of required cooling loads. Therefore, preventing excessive levels of solar radiation when it occurs could be an approach for achieving visual comfort in the space. Many studies positively revealed that the most effective method is protecting fenestrations externally from direct solar radiations, which is carried out by external shading elements (Radhi et.al. 2009). Not only preventing direct solar radiations is the role of the external shading element, but also shading elements work on improving daylight distribution inside the space. As a matter of fact, achieving adequate daylighting mainly depends on several building components, as window to wall ratio and shading the windows. Moreover, these components could be configured and added to the existing built environment to provide a positive strategy of retrofitting and refurbishment of existing building. Since that many buildings are already existing with unpleasant daylight design, adapting existing buildings is considered as a more effective strategy than limiting daylighting design for the newly constructed buildings.

Therefore, this paper aims to examine the relation between external surrounding buildings obstructions on daylighting and regulated setbacks. Besides, the research aims to provide architects and building professionals with guidelines about optimum façade configurations. Finally, it presents the work on the indoor daylight illuminance determinations for an existing case study in Cairo discussing its improvement on indoor daylighting performance in the residential spaces.

The research aims to conclude answers for the following questions:

- What is the optimum WWR for each floor of a residential building in Cairo?
- What is the cases that need shading elements to be added to the fenestrations?
- Is adequate daylight achievable in all the spaces of the building?

2. Cairo's Climate

Köppen's climate classification sorted Egypt as a hot arid climate region as shown in Figure . The allocated symbol for the climate of Egypt is BWh; where (B) refers to hot dry, while (W) specify that precipitation < ½ water consumption and letter (h) indicates that the average annual temperature exceeds 18°Ci. Hot arid climates are specified by exceptionally hot dry summer, dry winters, and continuous sunshine for the whole year coupled with maximum temperatures of 45°C (Henderson & Robinson, 1986).

Moreover, according to the Egyptian Typical Meteorological Year Authority (ETMY) report that the annual average temperature in Cairo is 22.4 ˚C with a maximum average temperature of 35.4 ˚C and minimum average temperature of 20 ˚C in the peak summer period in July and August and a maximum average temperature of 18 ˚C and minimum average temperature of 10.2 ˚C in the peak winter period in January. In Figure , the sun shading diagram and the sun chart were visualized, where it was found that 2125 hours need shading during the period between June 21 and December 21 (CIAO, 2015).

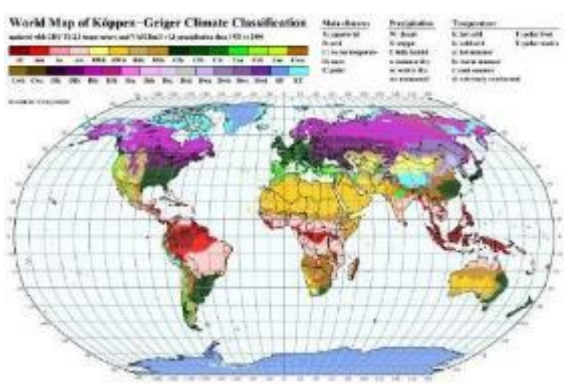

Figure 2. Koppens Climate Classification Map
Source (Köppen 2006)

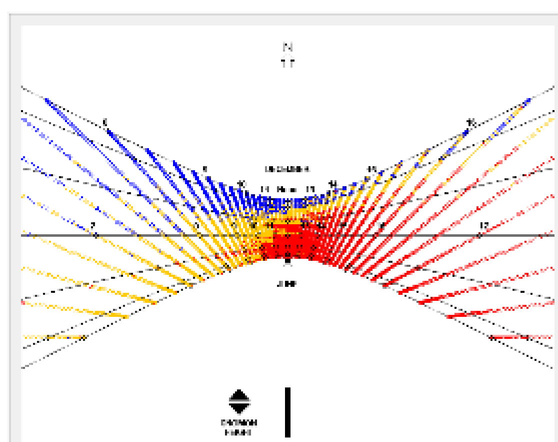

Figure 3. Sun chart

Source (Climate Consultant 6.0 2015)

3. Methodology

As a response to the research questions, the methodology of the study was formed. Besides, it was structured on two consecutive phases. Furthermore, the study was carried out on residential spaces in Cairo's formal context that was mentioned previously using a parametric predefined process to enhance the opportunity of studying several effective parameters all together. The first phase focused on examining the window to wall ratio parameter and its relation with the different floors of the building. In other words, the objective of that phase is identifying the optimum window to wall ratio for each floor. Because of considering each floor will require long simulation time, this parameter was investigated on several selected floors. Moreover, the research was carried out on a residential space in the previously mentioned context. In the second phase, the study was conducted to reach better performance by adding more parameters in the configurations by using a horizontal louver as a shading element and its properties as shown in Table 5. In other words, the second phase concerns about revealing the effect of the shading system on the visual comfort levels inside the space and how it could improve the daylight adequacy levels. Several shading system properties were studied as parameters, such as rotation angle and number of louvers.

In addition, all the parameters studied in this research were summarized in Table 1. Moreover, the daylight performance was analyzed and presented using the new approved Illumination Engineering Society (IES) approved daylight metrics that uses the combination between Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) for assessing the total dynamic qualities of a daylit space. The two metrics have been developed and utilized to assess the performance parameters of daylight as the sufficiency of daylight illuminance and the potential risk of excessive sunlight penetration (IESNA, I. 2012). The assessment method selected for this study was the LEED version 4, which launched November 2013 adopting the new metric of sDA and ASE. It requires minimum levels for daylight adequacy are (sDA 300/50%) value of 55% of the space and (ASE1000/250hr) of no more than 10%. Also, the sDA and ASE calculation grids should be no more than 0.60m at a work plane level of 0.76m (USGBC, 2016, Heschong et al., 2012).

Figure 4. View from the Context

As discussed previously, the selected case study represents a typical building block as in Figure 4 in one of Cairo's suburbs. Extreme conditions were proposed, as surrounding buildings were created to have the highest number of stories accepted by the building regulations, which is 12 story height. Besides, it has the least regulated setback distance in the zone, which is 3 meters, forming the possible worst case scenario. Simulations were carried out in the four orientations, as the window of the residential space is oriented towards the surroundings. In other words, the orientation was studied as a parameter, as the oriented fenestration is exposed to the surrounding buildings obstruction case of one of the orientations facing another residential block within the urban fabric.

4. Simulation

Regarding the simulation process, the studied urban context and the residential space were created using grasshopper, which is a parametric modeling tool for Rhinoceros 3D, and its material properties as in Table 2. The selected studied floor and the residential space used for simulation were illustrated in Figure 5 and 6 respectively.

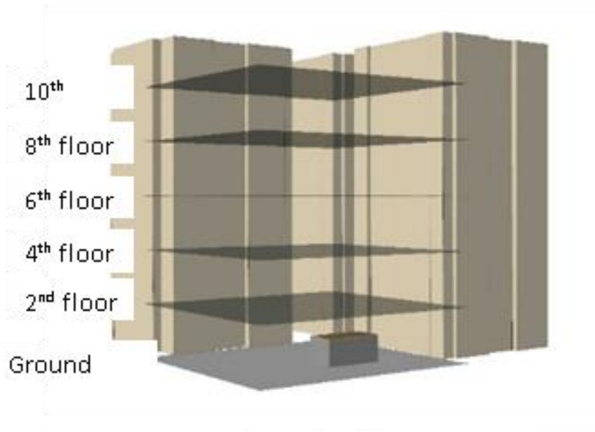

Figure 5. Selected studied floors

Additionally, the specifications of the studied residential space were illustrated in Table 3. While, the studied rotation angles of the shading element was illustrated in Figure 7. Moreover, Grasshopper was used for creating all the proposed configurations of the different studied parameters. Daylight analysis and simulation was processed using DIVA for Rhino (Solemma, 2014), which interfaces the simulation engines DAYSIM and Radiance. The simulation was conducted using the climatic data and hot arid conditions of the city of Cairo in Egypt. The radiance parameters for simulation of the two approved metrics sDA and ASE were illustrated in Table 4.

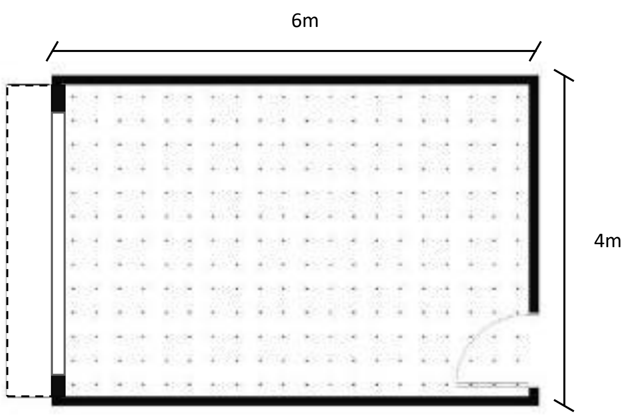

Figure 6. Architectural plan of the studied space

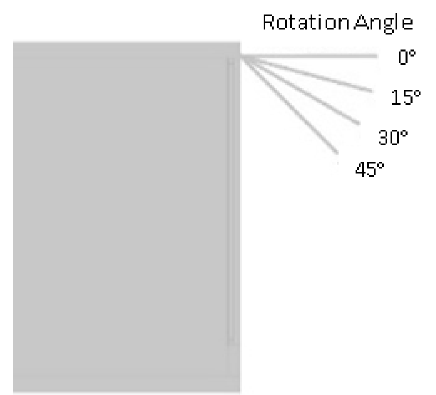

Figure 7. Louver rotation process

Table 1. Studied parameters through the simulation process

1st Phase Parameters		2nd Phase Parameters	
WWR	30% to 90% (Step = 10%)	WWR	30% to 90% (Step = 10%)
		Location of Room (Floor Number)	0 to 10^{th} (Step = 2)
Location of Room (Floor Number)	0 to 10 (Step = 2)	Louver Rotation Angle	0^o to 45^o (Step = 15^o)
		Number of Horizontal Louvers	1 to 2 (Step = 1)

Table 2. Urban context materials specifications

Materials Reflectivity of the Outdoor Materials	Ground	20%
	Walls of Surrounding	35%
	Shading Louver	50%

Table 3. Residential space specifications

Dimensions	4m x 6m x 3.2m	
Area	24m^2	
Orientation	North – South – East – West	
Materials Reflectivity of the Residential Space	Walls	50%
	Floor	20%
	Slab	80%
Occupancy	8:00 am - 6:00 pm	

Table 4. Radiance simulation parameters

Required Metric	Ambient Bounces	Ambient Divisions	Ambient Sampling	Ambient Accuracy	Ambient Resolution
sDA	6	1000	20	0.1	300
ASE	0	1000	20	0.1	300

Table 5. Shading element specifications

Side Extension	30 cm
Depth	60 cm
Distance Between Louvers	60 cm

5. Results and Discussion

Through 1169 cases, this study investigated the relation between the regulated setbacks and visual comfort in residential buildings of Cairo's context. The four main orientations were studied and the study was processed in two consecutive phases. The first phase was conducted with no shading element configuring 164 different case. The second phase was processed on the unsuccessful orientations targeting better performance by proposing a shading system simulating 1005 different configuration.

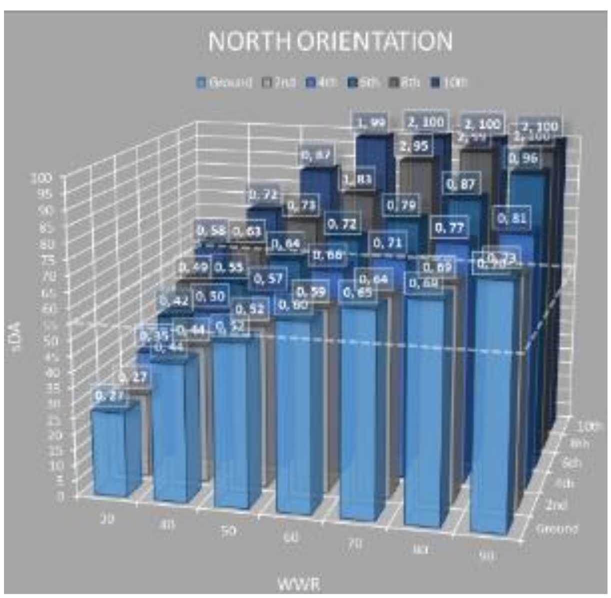

Figure 8. Stage One Cases for North Orientation

5.1 Phase one: No shading device

Starting with the north orientation in Figure 8, many successful cases were revealed in all the floors. High values of window to wall ratios were found to be optimum for the ground floor fenestrations. In other words, fenestrations of the ground floor should be 60% or higher to achieve adequate daylight levels. Moreover, accepted ranges increase by going upwards in the floors. In general, north orientation showed positive cases, which enhance daylight adequacy and low accepted values of ASE levels, which can be explained as no shading system is required.

Second, east orientation was investigated. In Figure 9, the results showed less positive performance than the north orientation cases. In detail, accepted sDA levels were not achieved except for the 4th floor and higher, as lower floors did not achieve the minimum requirements of LEED V4. While, the 8th and 10th floor cases were not successful, as all the cases exceeded the highest accepted ASE values. This can be explained as higher levels of solar penetration in the space. In general, the 4th and 6th floor had the only successful cases in both sDA and ASE. In detail, the 4th floor cases were in the 80%-90% window to wall ratios, while the 6th floor cases had a higher range of window to wall ratios of 60% to 90%. Similarly, the west orientation performed. However, the west orientation had higher sDA values in the different studied floors as shown in Figure 10. Consequently, the range of the floors having successful cases increased to include ground floor and the 2nd floor beside the 4th and 6th floor. In a similar manner as the east orientation, the ASE values were the negative side for cases of 8th and 10th floor. In general, the west orientation needs to be furtherly examined.

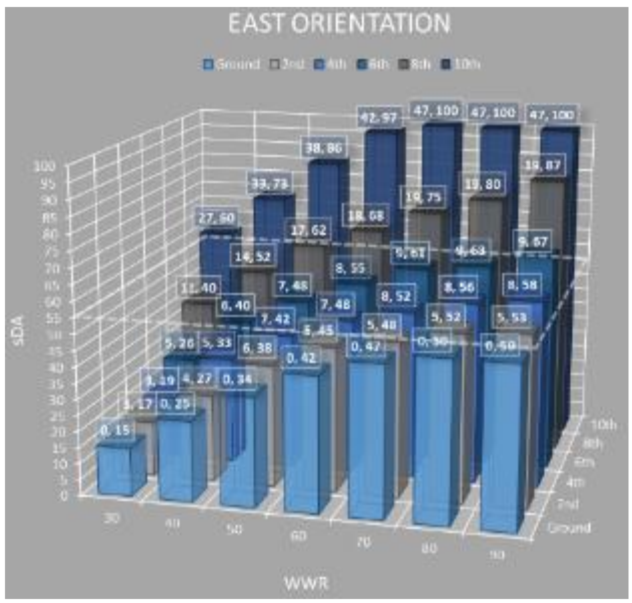

Figure 9. Stage One Cases for East Orientation

Furthermore, the south orientation was examined as well in Figure 11. Dramatically, all the cases of the south orientation didn’t achieve the successful ranges pf sDA or ASE. On one hand, floors from ground floor to the 6th didn’t have successful sDA levels, while ASE levels were accepted. On the other hand, the 8th and 10th floor cases had very high ASE levels exceeding the acceptable levels, while having acceptable sDA levels.

Finally, the studied cases concluded that the north orientation has the ideal performance. In contrast, the south orientation is the worst performing. Therefore, the orientations of east, west and south will be investigated for further simulations by examining the effect of adding a shading system to the fenestrations.

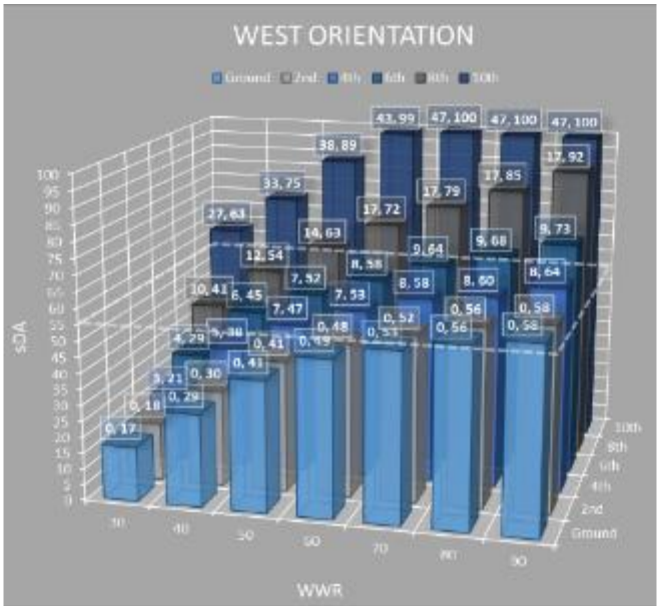

Figure 10. Stage One Cases for West Orientation

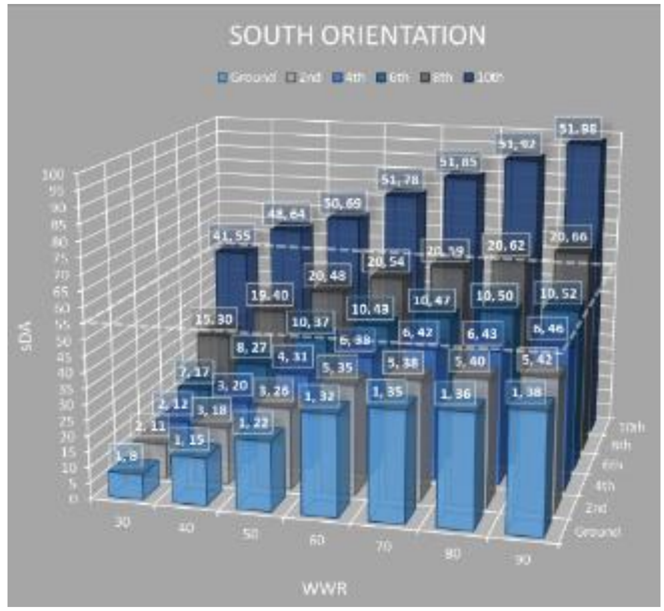

Figure 11. Stage One Cases for South Orientation

5.2 Phase two: case of a shading device

Phase one revealed the failure of many cases for the high ASE values, which is a result of solar penetration in the space. Therefore, a horizontal louver was added to the fenestration design. Besides, this phase aims to investigate the improvement that could be acquired by the louver in the sDA levels by acting as a light reflector. Furthermore, the shading system works on reducing ASE values and levels.

In the South orientation, the shading element worked on decreasing the high ASE values in the 10th and 8th floor cases by around 50% loss of the value as shown Figure 12. Consequently, sDA values decreased in consequence in all the studied floors. Moreover, levels from ground to 6th floor achieved lower ASE, sDA values than the first phase, which resulted the failure of some successful cases in the former phase. Altogether, the best performing cases for the (Ground, 2nd, 4th and 6th) occurred in the first stage of the study. While for the (8th and 10th), second stage had the best performing cases. In conclusion, the highest performing cases in this orientation didn't achieve minimum requirements in sDA and ASE together. In the East orientation, great improvement was acquired by reducing ASE levels in the 6th, 8th and 10th floor by 9%, 17% and 30% respectively as shown in Figure 14. However, the 10th floor cases didn't fulfil the requirements for succeeding in ASE levels. While, on the 6th, 8th floor level higher improvement was achieved resulting accepted cases in sDA and ASE. In the case of the 4th to the ground floor, the shading element had a negative effect resulting unsuccessful cases in comparison to the successful cases in stage one. Similarly, west orientation cases were simulated as shown in Figure 13. The cases of the 8th and 10th floor were improved regarding the ASE values by 6% and 24% respectively. However, the results didn't fulfill the minimum requirements. In the levels from ground to 6th floor, the shading element had negative effect by decreasing sDA values leading to sDA values under the minimum requirements, while being accepted in stage one.

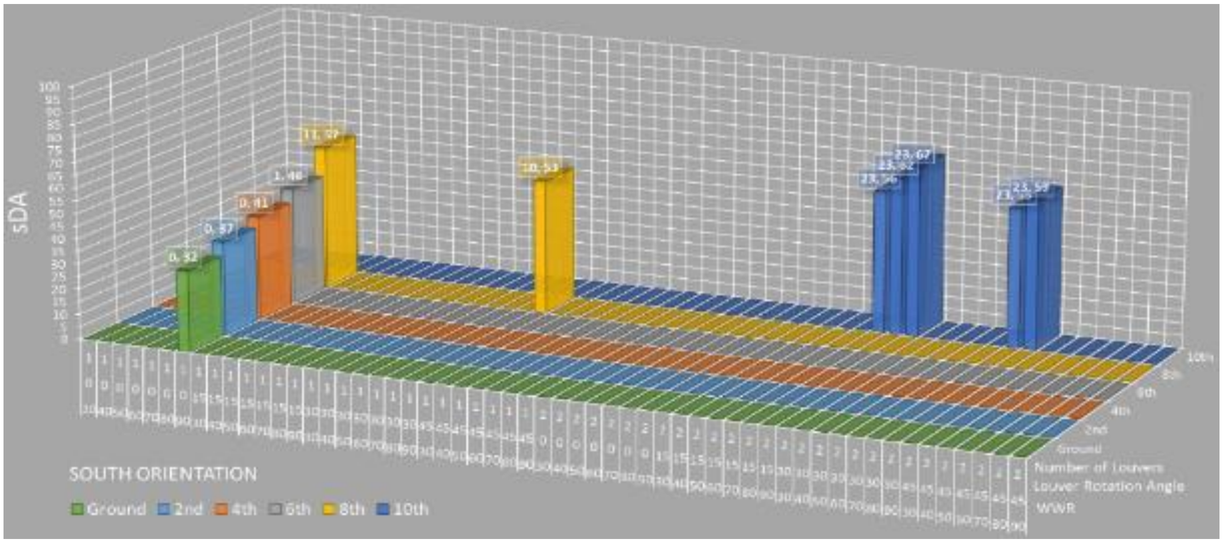

Figure 12. Stage Two Best Cases in South Orientation

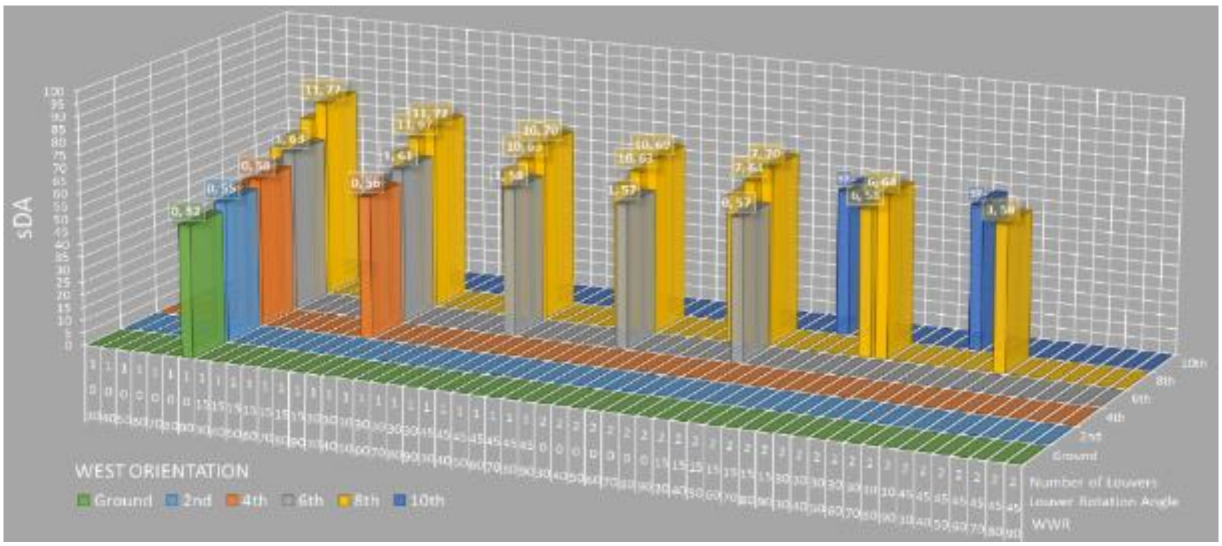

Figure 13. Stage Two Best Cases in West Orientation

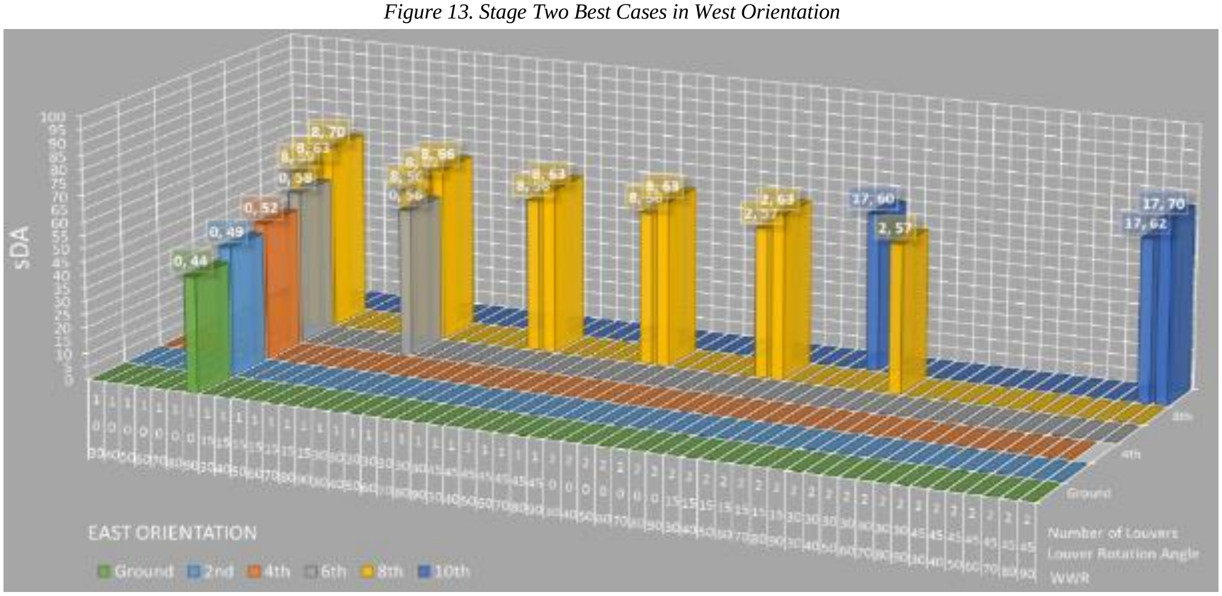

Figure 14. Stage Two Best Cases in East Orientation

6. Conclusion

Through the conducted study, many findings were revealed regarding the relation between daylight adequacy and building regulations in Cairo's formal context. Many cases showed positive results and potential in improving daylight inside living spaces. In this study, extreme conditions were proposed for the simulation. In other words, the study was conducted on the least regulated setback coupled with the highest permitted surroundings. First, phase one showed that the north orientation had ideal performance, while the other orientations needed a shading device to prevent high ASE values. Second, phase two was conducted on the unsuccessful cases of the former phase by adding a shading element. Similarly, the shading element improved the performance in many cases, but some cases didn't achieve complying result with the assessment standard of the study. Generally, the modified cases in the two phases resulted better day-lit spaces and most of them were complying with LEED V4 requirements, while in some cases were not successful. Moreover, some cases reached their best configurations in the first phase of the study (without a shading element), while other cases reached the best performance with a shading element combined. Significantly, the study revealed that building practice within Cairo's context should be considering the daylight design in the façade design of the building. In other words, the study recommends that every fenestration in each floor and orientation should have its own specific design from window to wall ratio to having a shading device or not. In addition, more research should be conducted to improve the unsuccessful cases in sDA values, through different reflection materials and techniques. While for lower ASE values more shading parameters and different shading types should be examined.

Finally, utilizing the best obtained cases illustrated in the study can significantly improve the residential spaces in Cairo's context achieving not only visual comfort but also diminishing energy consumptions inside the spaces and decreasing internal gains. Therefore, regulations by the responsible municipalities and architects should take in consideration daylight performance in the spaces referring to the exterior built environment. Not only residential buildings under-construction, but also the existing buildings which could be retrofitted to improve the visual comfort and internal gains of it.

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