Impact of the Geometric Form of the Building Envelopes on The efficiency of Natural Lighting in the Office Space.

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Abstract: Envelopes play an important role in Office Buildings. They affect visual comfort for the user. Driven by architectural trends and the need to maximize natural light in order to realize required visual comfort conditions, advanced glazing systems, Geometric formation of the outer building envelope proper self-shading properties and control and lighting controls should be studied comprehensively. Optimized fenestration system design may improve exploitation of daylight and it can be controlled to harvest maximum daylight thus reaching the maximum depth naturally illuminated. The paper explains the design relationship between both configuration of office space and between the system of the glazing and the transmission of natural light inside the space, in terms of the design characteristics of the office space (proportions, dimensions), in order to achieve visual comfort to improve the efficiency of the environmental performance of Office Buildings. This paper discusses the study of the environmental effects of the glazing façades of office buildings and their impact on the efficiency of natural lighting and visual comfort. The paper relies on simulation using the Grasshopper program, in analyzing of the building’s Envelopes and its external elements and the architectural space, in order to find the proper form for improving visual performance.

Keywords: Visual Comfort, Glazing Systems, Natural Light, Glazing Envelopes, Simulation Program, Office Buildings.

1. Introduction
The architectural model is important in terms of depth, proportions, shape and type of space (shallow space and deep space), which mainly contribute to the thermal transmission and natural lighting in the interior space, affecting the quality of environmental efficiency (visual comfort). The architectural model needs to be determined in terms of the depth and proportions of the internal spaces of multi-level office buildings [1].

The glass envelopes that separate indoor environment from the outside environments act as a barrier against extreme temperatures, solar radiation and light transmission. However, the problem is using large glass surfaces for windows irrespective of the climatic considerations in hot dry regions [2].

The paper focuses on the building envelopes and its effect on the characteristics of the architectural space (depth) in office buildings, in order to reach the optimum level of natural lighting and visual comfort in the internal environment.

2. Study hypotheses
   a) The natural lighting can be improved within the office buildings through the characteristics of the geometric form and the glazing of the buildings envelope.
   b) Determining the design characteristics of the façade of the office space at an early stage in the designing, according to the quality, properties and of the glass area in relation to the depth and dimensions of the office space.
   c) Possibility of benefit from the geometric configuration of the properties of the building’s glass envelope in improving the efficiency of the visual environment of internal environment.
3. Problem Definition
   a) Lack of knowledge of the natural lighting criteria to improve the visual environment within the architectural space.
   b) Lack of knowledge of the properties of the geometric configuration of the building’s facade, in order to achieve the best possible environmental performance and energy saving.
   c) The envelopes of modern office buildings are implemented with glazing characteristics with less light transmittance than the permissible.
   d) No methodology to determines the relationship between the properties and systems of glazing and the architectural properties of the office space in terms of the depth and proportions of the space, to improve the efficiency of natural lighting.

4. Objectives of the study

4.1. The main objective
   a) Improve the efficiency of the visual environment in interior office spaces.

4.2. Procedural objectives
   a) Highlighting the importance of daylight in creating a comfortable visual environment suitable for the practice of office activity.
   b) Simulation analysis of the efficiency and quality of natural daylight levels within the office architectural space.
   c) An Analysis of the performance of daylight by two main criteria:
      - Annual Sun Exposure (ASE)
      - Spatial Daylight Autonomy (SDA)

5. Study methodology

5.1. First: Theoretical Study
This part deals with the study of the interrelationships between the characteristics of the office space and of its glazed outer shell, and their impact on achieving visual comfort and natural lighting levels through the glass element used in the envelope of the office buildings [3].
It investigates the impact of these properties on achieving visual comfort and getting to know the simulation programs used to measure natural lighting standards [4].

5.2. Second: Applied Study
Simulating the performance of natural daylight for a Case study in Egypt:
Methodologies used include literature review to collect data concerning different aspects of glass Properties and glazing system of Glass facades, comparative analysis study of visual environment simulation outcome to assign the optimum design for Glass building envelopes [2].
The following methodology was adopted through the proposed design for the hypothetical office space, and the steps are: [5].

   a) Design criteria for the office space and its outer envelope...
      - Systems and characteristics of glass windows and the glazing element for the building envelope.
      - Characteristics of the architectural form of the outer building envelope.
      - The depth of the office space (shallow or medium) depth.
      - The form of the office space and its relation to the office work environment.
B) Environmental criteria ... [6].
- Visual comfort: by assessing the visual design criteria and considerations which must be taken into account when designing the natural daylight in the office building.
- The integration of interior artificial and natural daylight within the office space.

5.3. Field of applied study
The study includes the use of the programs (Rhinoceros, Grasshopper, Energy Plus, and Plugins) in identifying the elements and components of the proposed approach to improve the visual performance of natural daylight of the office space at the design stage:

a) Study the geometric form of the building envelope (tilting of the glass surface).

b) Study the properties of the glazing system of the building’s envelope to achieve Visual Performance efficiency in the architectural space.

c) Study the Impact of building orientation on comfort levels for natural lighting of office space in buildings.

d) Determine the maximum naturally lit depth of the office space.

e) Determine the lowest depth that can be achieved by integrating artificial lighting and natural Lighting.

6. Properties of the geometric form of the building envelope and its effect on visual comfort
Architectural form has a great the impact on the development of the building’s envelope design in terms of transmission of natural lighting and environmental control [7].

6.1. Visual comfort:
It is a condition where human eyes receive a suitable amount of light without visual strain, which strongly relate to the illumination levels inside the office space [6].

6.1.1. Main parameters of visual comfort
The visual environment must allow seeing objects clearly without strain in pleasantly toned surroundings. Where the parameters of visual comfort are: the level of illumination of visual tasks, the harmonious distribution of light within a space, the ratios of illuminance within a building, exterior and internal shadows elements, good color interpretation, pleasant tones of light, and the absence of glare [6].

6.1.2 Glare
Glare is Visual discomfort that interferes with visual performance. Two main types of glare exist, direct and indirect (reflected), and each can have very detrimental effects on Visual comfort [8].

Direct glare is caused by a Direct light source in the field of the view that is sufficiently bright to cause annoyance, discomfort, or loss in visual performance. Reflection of light sources on the glossy surface usually cause indirect glare [6].

6.1.3 Visual comfort Vs human performance
Lighting quality is one of the determinants of human performance in the indoor environment. Where Various some studies have been conducted to compare between the effects of different lighting conditions and levels on health, productivity, and well-being and alertness level, office Work performance [6].
6.2. Glass envelope
Glass envelope is an important element in buildings and the main function of it is to protect the internal from the external environment conditions, so energy-efficient building Researchers have started to develop their researches based in this field. Today, energy usage in buildings have become an important factor hence building construction materials such as glass and modern glass technology should be considered accordingly early Design Stages [9].

a) Quality of Light ...
Uniformity of light: Light uniformity represents how light spreads over a task area. Uniform light distribution helps in avoiding the risk of visual discomfort caused by various eye adaptations to different levels of light, whether it is very bright or low light which leads to visual stress [10].

b) The Amount of light...
An adequate amount of natural daylight provides good that allows users to accomplish their work tasks. Higher or lower light levels can cause visual discomfort.
Illuminance is the physical quantity usually used to quantify the light amount that reaches a specific point of a work surface [10].

c) Light quality...
Light uniformity: This means how light is spread over an important area. Even light distribution helps avoid the risk of visual disturbance from highly lit or low-lit areas, which leads to Visual discomfort [10].

7. Description of the design proposal
The study case is a hypothetical office space model of the city of Egypt. Simulation modeling will be conducted during the four seasons of the year and during daylight hours. The case study is located in Cairo (longitude 31.5°, latitude 29.8° northeast). It has been assumed that all spaces have an open horizon and there are no external obstacles.

8. Daylighting Optimization
Study was concerned with daylighting optimization encompassing both external and internal screen configurations simultaneously. The analysis was conducted using Daylight Performance Metrics (DDPM); the IES metrics (IESNA, 2012) which give benchmark levels for the pass or fail metrics for Natural lighting. The first metric (sDA300/50%) gives an indication of Natural lighting adequacy inside the space, where a minimum illuminance of 300 lux is meant to be reached at 50% of the occupied hours across at least 55% of the space. The second metric (ASE 1000/ 250 hr) indicates excessive sunlight exposure when receiving direct sunlight of 1000 lux for more than 250 hours. This should not exceed 10% of the space area; optimal cases should reach at least 75% sDA and a maximum value of 10% ASE to avoid possible visual discomfort. Illuminance levels were calculated on the work plane set on a level 0.8 m from the ground and was divided into a grid of 0.25 m*0.25 m. The time WORK was set from 9 am to 5 pm. Radiance parameters used for sDA and ASE calculations were adjusted according to the (LEED V4 & IES) [11].
### Table 1. Natural Daylight standards in accordance with LEED V4 & IES requirements [12].

| Requirements (LEED V4 & (IES)) | Required conditions | Nature lighting standards |
|--------------------------------|---------------------|--------------------------|
| Acceptable                      | 10% or less 7% or less 3% or less of the area | 1,000 lux for at least 250 annual business hours | Annual Sun Exposure (ASE) |
| Acceptable Favorite             | 55% or more 75% or more of the area | 300 lux for at least 50% of annual working hours | Spatial Daylight Autonomy (SDA) |

### Table 2. Architectural specifications for the office space model- (Source: Researcher)

| Architectural characteristics of the space | Space elements |
|-------------------------------------------|----------------|
| North - East - South - West                | Orientation |
| Office                                    | Use |
| 4 * 6 * 2.8 m (24 m² space area)          | Space dimensions |
| Net height = 2.8m                          | Space height |
| Total height of the turn = 3.2m            | |
| False ceiling = 40cm                      | |

#### Characteristics of the glass window

| Net window height = 2.5m                  | Window dimensions |
| Window width = 4m = width of the space    | WWR |
| Building/concrete depth = 0.30m           | |
| 90% calculating the upper inclined part (solar cells) | |
| 80% glass with light transmission         | |
| 6mm double glazing                        | Glass properties |
| 20 mm gap                                 | |
| Glass color (gray)                        | |
| Light transmission 40%, 50%               | |

**Geolocation coordinates**

Located in Cairo (longitude 31.5°, latitude 29.8° northeast).

**Level of work**

| 0.80 cm | 0.25*0.25 cm |

**Divided level of work**

During the seasons of the year
During daily work hours from 9am to 5pm

**Time/period**

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9. The applied study

9.1. The applied study simulation
In this study, the performance of natural lighting will be evaluated through simulation program (Rhino - Grasshopper), for the previously mentioned hypothetical model in two successive analytical stages.

9.2. The (design proposal)
Simulate the study model with the characteristics of the geometrical formation of the building façade and to define specific items for the characteristics of the glass and to determine the best percentage of glass transmission for natural lighting of the glass, according to the previously defined natural lighting criteria.
The second stage includes simulating the study model to add characteristics of the glass and determining the optimum natural light transmission of the glass, according to the criteria for natural lighting (SDA and ASE criteria), then accessing the results of the optimization process and its impact on lighting efficiency and energy consumption.

10. Study proposal idea
The idea of research is based on the avoiding the traditional pattern of the vertical glazing system commonly used in buildings facades, the proposal for improving performance includes the concept of tilting the building façade to a specific angle (self-shading), to maximize the amount of natural lighting, as an architectural prerequisite.

a) If the outer shell is tilted at an angle of 10°, this is a small angle of inclination that does not affect the process of improving visual.

b) If the outer envelope is tilted at an angle of 30°, which is a very large inclination, the building façade protrudes 1.42m, contrary to Law 119 of 2009 regulating construction work, which states that the maximum permissible projection is 1.25 m.
c) Where work is done at this stage to tilt the outer façade by 20°, the building façade protrudes about 1 m, as it does not exceed 1.25 m, according to Law 119 of 2009 regulating construction work.

**Figure 5.** Tilting the outer shell by 20° (Source: Researcher)

**Figure 6.** Simulation program inputs for the study model – Grasshopper-Rhino, (Source: Researcher)
11. Analysis of simulation

a) Southern façade

Table 3. Analysis of the results of SDA and ASE standards for 40% transmission and interface tilt angle of 20° - (Source: Researcher)

| Annual Sun Exposure | Spatial Daylight Autonomy - SDA | Geographic orientation |
|----------------------|-------------------------------|------------------------|
| ASE = 22.13%         | SDA = 57.55%                  | Southern facade        |
| 3.45 m               |                               |                        |

The glass light transmittance is LT = 40% and the interface is tilted at an angle = 20°. (Source: Researcher)

The Glass of light transmission (40%) achieved a value of SDA is (57.55%). This is an acceptable percentage according to LEED V4 requirements. Meanwhile, the glass with a light transmission rate of (40%) achieved a significant improvement in the ASE standard in accordance with the requirements of LEED V4, and the Illuminating Engineering Society (IES), which recorded a value of (22.13%) of the room's surface. A light transmission rate of 40% was achieved, with a depth of no more than 4m (Maximum architectural depth) for the office space, naturally lit (Depth Lighted naturally = 4*3.45 m).
b) Eastern façade

Table 4. Analysis of the results of the SDA and ASE criteria for 50% transmission and an interface tilt angle = 20° - (Source: Researcher)

| Annual Sun Exposure | Spatial Daylight Autonomy - SDA | Geographic orientation |
|---------------------|---------------------------------|------------------------|
| ASE =13.05%         | SDA=75.29%                      | Eastern facade         |
| The light transmittance is LT = 50% and the interface is tilted at an angle = 20° | 4.51 m                      |                         |

The glass of light transmission of (50%), achieved a value of SDA is (75.28%). This is a good percentage according to LEED V4 requirements. Meanwhile, the glass with a light transmission rate of (50%) achieved a significant improvement in ASE, with a value of (13.05%) of the room's surface, which is a good percentage according to the requirements of LEED V4 and the IES.

A light transmission rate of 50% was achieved, with a depth of no more than = 5m (Maximum architectural depth) for the office space, naturally lit, (Depth Lighted naturally = 4* 4.5 m).
c) Western façade

Table 5. Analysis of the results of the SDA and ASE criteria for 50% transmission and an interface tilt angle = 20° - (Source: Researcher)

| Geographic orientation | Annual Sun Exposure | Spatial Daylight Autonomy - SDA |
|------------------------|---------------------|---------------------------------|
| Western façade         | ASE = 17.44%        | SDA = 79.17%                    |

The light transmittance is LT = 50% and the interface is tilted at an angle = 20°.

The glass of light transmission of (50%), achieved a value of SDA is (79.17%). This is a very good percentage, according to the requirements of LEED V4. Meanwhile, the glass with a light transmission rate of (50%) achieved a significant improvement in the ASE standard, which recorded a value of (17.44%) on the room's surface, which is a good percentage according to the requirements of LEED V4 and the IES.

A light transmission of 50% was achieved, with a depth of no more than = 5m (Maximum architectural depth) for the office space, naturally lit, (Depth Lighted naturally = 4 * 4.75 m).
D- Northern façade

Table 6. Analysis of the results of the SDA and ASE criteria for 50% transmission and an interface tilt angle = 20° - (Source: Researcher)

| Annual Sun Exposure ASE | Spatial Daylight Autonomy-SDA | Geographic orientation |
|-------------------------|-------------------------------|------------------------|
|                         |                               | Northern façade        |

The glass of light transmission (50%) achieved a value of SDA is (63.02%). This is a good percentage according to LEED V4 requirements and the IES. Meanwhile, the glass with a light transmission rate of (50%) met the ASE standard, which recorded 0% for the space area, as the northern façade is not exposed to the sun's direct rays, which is a good percentage according to the requirements of LEED V4 and the IES.

It achieved a light transmission rate of 50% was achieved, with a depth of no more than = 4m (Maximum architectural depth) for the office space, naturally lit Depth Lighted naturally = 4 * 3.78 m).
12. Analysis of artificial lighting for office space:
Integration of artificial lighting design with natural lighting

**Figure 15.** Artificial lighting distribution scheme using LED headlight units (2 units 60 * 60 cm) the power of the flashlight consumption is 35 watts using Dialux program to light for reaching the maximum depth (6 meters) of the architectural office space. (Source: Researcher)

**Figure 16.**
- The first space is naturally lit
- The Second space is artificially lit
- Artificial lighting units
13. Conclusion and recommendations

Future research is needed to evaluate the overall energy effects of the natural daylight designs. As for modern office buildings, the tilt angle for natural daylight is 20° for the exterior envelope. The architectural design should reflect the geometric form of the envelopes, taking into account the glass and the glazing system used, to achieve maximum visual and environmental comfort from the natural lighting, which helps the designer to achieve the best standards and levels of daylighting to achieve visual comfort.

13.1 Characteristics of the external architectural geometric form

Tilting the exterior glass of the building (20°), an appropriate angle in terms of maximizing the transmission of natural light, while improving both the criteria of Spatial Daylight Autonomy (SDA) and Annual Sun Exposure (ASE), with an external protuberance of no more than 1.25m, in line with Law 119 of 2009 for regulating building work.

It is very important to:
- Tilting the outer glass surface at an angle of 20°
- Determine the window area relative to the outside wall area (WWR) (a WWR of 80%)
- Achieve maximum light transmission
- Transmittance Transmission coefficient of glass window (VLT) (VLT) is 40% as a minimum for south orientation
- (VLT) is 50% as a minimum for (east, west and north) orientation.

13.2. Architectural design characteristics

- Show the maximum depth of the naturally lit architectural space, according to the analysis of simulating natural lighting criteria Spatial Daylight Autonomy (SDA).
- Create architectural spaces of appropriate dimensions suitable for carrying out office activity according to the distribution of natural lighting within the space.

13.3. Criteria and levels of natural lighting

- The SDA should conform to the LEED V4 and IES criteria to achieve visual comfort within the office space.
- The level of ASE should be reduced to improve visibility and reduce glare from direct sun, in compliance with LEED V4 and IES within the office space.

13.4. Criteria of artificial lighting

- Achieving integration between natural lighting and artificial lighting for energy saving.
- Relying on the enhancement of artificial lighting units to achieve the required levels of lighting within the office space reaching the maximum depth (6 meters) of the architectural office space.
- Increasing the depth of space to achieve large areas of office space to suit all activities and uses.

- It is important to study the architectural formation and sustainable formation, before launching on the architectural design, in addition to continuing with any design work that has already commenced.
- Replacing the Geometric form properties of traditional glazing systems, based on the vertical building façade, with Geometric form properties as one of the design solutions to improve the interior environment natural lighting and energy efficiency.
- Using these criteria SDA, ASE it is possible to achieve the depths of naturally lit designer can rely on during the first design, based on the effectiveness and results of specialized simulation programs, in order to improve natural lighting and internal environmental performance of office space.
- Achieving the maximum depth of the naturally lit architectural space according to the simulation analysis of natural lighting standards.

**Figure 17.** Maximum depth of naturally lit architectural space- (Source: Researcher)

- Southern orientation, (Maximum architectural depth) of 4 meters
- Eastern orientation, (Maximum architectural depth) of 5 meters
- Western orientation, (Maximum architectural depth) of 5 meters
- North orientation, (Maximum architectural depth) of 4 meters
Table 7. The effectiveness of the side openings in the event that the building envelope is tilted at an angle of inclination of 20° – (Source: Researcher)

| Maximum architectural depth of natural lighting | VLT | Orientation | WWR | The angle of inclination of the building envelope |
|------------------------------------------------|-----|-------------|-----|--------------------------------------------------|
| 4 m Realized to natural lighting standards     |     | Southern    | %80 | An inclination angle of 10° is not effective for improving environmental performance and natural light efficiency |
| 4 m Realized to natural lighting standards     | not less than 40% | Eastern | %80 | An inclination angle of 20° is effective for improving environmental performance and natural light efficiency |
| 4 m Realized to natural lighting standards     | not less than 50% | Western | %80 | An inclination angle of 30° is effective for improving environmental performance and natural light efficiency |
| 4 m Realized to natural lighting standards     | not less than 50% | North     |     | This is in violation of Law 119 of 2009 regulating construction work to exceed the prominence of 1.42 m |
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