Utilizing dynamic shading system to achieve daylight performance according to LEED standards V.4: case study, university classrooms in Egypt

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ABSTRACT
In the climate-change period, all countries strived to design sustainable buildings. As environmental influenced contributes to design decisions, to save energy and to achieve the sustainable development indicator according to Egypt Vision 2030. This can be achieved by accessing the maximum of daylight, consequently the facade design has a major impact on daylight performance.

This paper aims to evaluate the daylight performance by using dynamic shading, in a university classroom in Egypt. It also aims to determine the optimal angle for each hour of the shade’s movement. Based on LEED 4 daylight requirements and IES, daylight analysis was integrated using DESIGNBUILD V6, RADIANCE, and DAYSIM programs. The simulation measured the basic case of the case study and then compared it with using dynamic shading system.

Incrementing the efficiency of daylight needs to increase spatial daylight autonomy (SDA) and reduce annual sunlight exposure (ASE); hence, the importance of this research is to take up studies of spatial daylight autonomy (SDA), annual sunlight exposure (ASE), useful daylight illuminance (UDI), working plan, and daylight factor over a year.

This paper proved the necessary of using dynamic shading system. As it helped in changing the angle of inclination shading system with change the angle of inclination the sun on the openings of the building. It adapted the change from the educational activity (the whiteboard and data shown) in the case study. If the opening has wide areas in the eastern facade, the overall value of illumination at 9 a.m. is much higher than at 3 p.m. When using dynamic shades, the daylight efficiency is raised, in detail, by UDI, ASE, and the daylight factor raised by 58%, 45%, and 4.3%, respectively. This research will help architects and decision-makers to improve lighting performance in existing university buildings. It also achieved visual comfort in the classroom.

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Introduction

Daylight is impacted on improving the indoor environmental quality (IEQ) of buildings by improving user health, efficiency, and well-being.

Literature revealed that direct sunlight illumination was classified among the top factors contributing to visual comfort. It was found that sunlight illumination could predict human responses better than illumination-based measures [1]. Reviewing literature about dynamic facades: environmental control systems. Which its results found that dynamic façade is the most frequently system used to encourage natural light, the most effective shades systems are external shades systems and movable overhangs built on the façade of buildings, which has a variety of colors and materials [2] (Figure 1) explained how a dynamic shading device can be used to manage the wall-to-window ratio, which can be changed many times during the day.

To apply the principles of sustainability and overcome the problems caused by glare, the Luminous Engineering Society (IES) issued the LM-83-12 standard in 2012 which provides spatial independence of daylight (sDA) and annual exposure to sunlight (ASE) [3].

Using the dynamic shading system completely closed offered an indoor providing a natural light quality throughout the daylight hours all year, providing visual comfort, and prevents glare in the work plan. By using the radiance software to determine the optimally visible transmittance needed, with VT = 0.2, which offer a good visual (Bourbia, F., 2016 [4]). Figure 2 showed the effect of using the dynamic shading system in providing visual comfort based on PV-semitransparent.

In daylight analysis, they suggested which combination of metrics best represents the daylighting condition. For instance, one of the SDA-metrics and the UDI-metrics must be used. A supplementary use of ASE is also important because it may seem to differ dramatically depending on the orientation [5]. A study of the new metrics for the dynamic and temporal elements of daylight has concluded that practitioners separate dynamic shades in the ASE requirement simulation methodology is a problem that not only makes it very difficult for projects to approve the scale but also nullifies the LEED Spatial Daylight Autonomy (SDA) association scale since its dynamic shades is a primary way to increase daylight while trying to control glare [6]. Figure 3 explained dynamic shades’ influence that increased the amount of daylight consequently reduce the glare.

In a study, the dependence of daylight autonomy in office spaces on the value of the daylight factor in four European cities was analyzed. The specific daylight autonomy of office rooms has been identified. It has been shown that the maximum-specific daylight autonomy in Ternopil city (at 300 lx illumination) with lateral daylight, regardless of the size of the rooms, occurs when the daylight factor is in the range of 1.7% to 1.9%. At 1.8%, Maxima. The
Figure 1. Kiefer Technic showroom, from https://www.dailytonic.com/dynamic-facade-kiefer-technic-showroom-by-ernst-giselbrecht-partner-ae/
Figure 2. The effect of using the dynamic shading system based on PV-semitransparent. From Bourbia, F. 2016.
Figure 3. Dynamic shades increased SDA while trying to control glare, from [6].
maximum specific daylight autonomy will occur at a daylight factor range of 2.6% to 3.0% with 500 lx illumination [7].

Previous studies related to the quality of daylight, some of them were interested in studying daylight factor (DF), spatial daylight autonomy (SDA), and others interested in studying annual sunlight exposure (ASE), but this research realizes the importance of studying daylight factor (DF), spatial daylight autonomy (SDA), annual sunlight exposure (ASE), and useful daylight illuminance (UDI) that affect daylight. Some studies were interested in studying the effect of glass types and the dimensions of the openings on the efficiency of daylight, others were concerned with fixed breakers and orientation, but the effect of dynamic shading system on (ASE, SDA, UDI, and Average daylight factor).

**Daylight metrics – LEED standards v4**

Illumination metrics discuss the adaptive and spatial elements of daylight. In 2012, the Lighting Engineering Association (IES) published an accepted method for daylight efficiency measures (LM-83 12 (2012) and then released LEED v4 in 2014, and the daytime balance aims to maximize daylight in zones. There are three options for measuring daylight performance by LEED: *Option 1, Simulation: SDA (300 lux, 50% hour) and ASE (1000 lux, 250 hours). Option 2, Simulation: Illuminance Levels (300–3000 lux, Equinox The time or date at which the sun crosses the celestial equator, when day and night are of equal length (about September 22 and March 20). at 9 am and 3 pm. Option 3, Measurement: Illuminance Levels (300–3000 lux, at 9 am and 3 pm)* [8, LEED, U 2014 [9]].

ILLUMINANCE LEVELS: is the amount of daylight illuminance (Mulyadi, R, 2020 [10]) It’s required varies according to the activity. <100 Lux unsuitable for paper and computer work.100–300 Lux unsuitable for paperwork/Suitable for computer work, 300–500 Lux Suitable for paperwork/Ideal for computer work, and >500 Lux Ideal for paperwork/bright for computer work [11,12]

SPATIAL DAYLIGHT AUTONOMY (SDA) analyzes the validity of daylight illumination for a designated zone at a given illuminance level for a given annual number of hours [6]. The percentage of SDA should be at least 55% or 75% to achieve 2 to 3 LEED points. SDA (300 lux, 50% hour) through simulation projects needs to show that 55% [13] or more of the total occupied floor area reach 300 lux for at least 50% of total occupied hours of the year [9].

ANNUAL SUNLIGHT EXPOSURE (ASE): This metric focuses on direct sunlight as a major source of visual discomfort, analyzing the percentage of floor area over some given number of hours that exceeds a given direct sunlight illuminance level [14] That exceeds a specified illuminance level, 1000 lux, for at least 250 hours of the occupied hours when the sky is clear. The
standard mentioned that 10% or more is unacceptable, 7% as neutral, and 3% as acceptable (LEED, U) [15].

USEFUL DAYLIGHT ILLUMINANCE (UDI): is a metric measuring the percentage of hours occupied in a year when a point in space falls inside a particular illuminance range [16]. Which classified to useful in the range (100–2000 lx), acceptable range (less than 100 lx), and Exceed the Acceptable range (over 2000 lx)) [17]

DAYLIGHT FACTOR (DF) a specification that shows the amount of daylight available within a room in comparison to the amount of natural external light [1, 3, 18, 19, 20, 21]. The requirement notes that 5% or more reflect daylight interiors and 2% or less describe the possible use of electric lighting [6]. <1% Unacceptable, 1–2% Acceptable, 2–5% Preferable, and >5% Ideal for writing activity/Too light for computer activity [11]. Figure 4 shows the metric which used in the study as DF range from 2% to 5%, ASE less than 10%, SDA more than 75%, lumination range from 300 to 500 lux, and UDI range from 100 to 2000 lux.

**Methodology**

This study focuses on the use of a dynamic shading system. Measuring its effects on daylighting, by using DESIGNBUILDER V6, RADIANCE, and DAYSIM simulation engine which provided a detailed physics-based calculation of multi-level illumination on work planes in the building. [9]

This study analysis involves that:

- By changing the use in the case of study from an educational activity that used the whiteboard (writing and reading) to an activity that used the computer and the display of data show.
- Calculating the percentage of analysis classroom that exceeded a specified Illuminance level (300 lux) for at least 50% of the total occupied hours from 9 am to 3 pm over the year.
- This study measured the sky on simulations of clear skies only (CIE).
- Simulation of SDA, ASE, UDI, and DF over a year, then compared results for the different fracture angles of each study case.
- Compare the results SDA, ASE, and UDI calculated by Daysim engine, but DF is calculated by Radiance engine.
- The Simulation measured the basic case of the case study, then compared results in two cases: (Figure 5)

First stage: – the effect of using dynamic shading is determined in the south façade. (Using one horizontal shading in case 1-A which takes numbers from 1 to 7, and using two horizontal shading with length 1 meter in case 1-B) which is numbered from 8 to 14.
Figure 4. Daylight metric and the metric used in the study.
Figure 5. Basic case and cases study in designbuilder program in drawing window.
Second stage: – the effect of using dynamic shading is calculated in the east façade in three cases: (Figure 5) (Using Vertical shading with 1-m length each 2 meters in case 2-A), that is numbered from 15 to 21. (Using Vertical shading with length 1 m each 1 m in case 2-B), that is numbered from 22 to 28. Using vertical shading with length 2 m each 2 m in case 2-C) that is numbered from 29 to 35.

Case study

The case study chosen is a classroom (7208) in the Faculty of Engineering, NUB University. It is located in the new city of Beni Suef, which included in the northern region of Upper Egypt. 3-1- description of case study: -

The building contains classrooms, laboratories, and administrative offices. Classroom study 7208 is exposed to weather conditions from the eastern and southern sides. (Figure 6).

Inputs for the simulated model

Table 1 shows the building inputs of case study to make simulation in design builder program.

Results

The percentage of floor area which calculated meets requirements. The Calculation is dependent on a regularly occupied floor space. The study is simulated the basic case by measuring the daylight metric as shown in (Figure 7). As a result of the simulation, found that the intensity of illumination reaches 2906(lux) at 9 a.m. and 1858 (lux) at three o’clock, Average daylight factor is 8.7%, ASE area rang 42 %, and UDI area rang 42%, all of these results out of metric range, while SDA area rang 100%, so the case study is outside the limits of visual comfort, Therefore, treatments must be made to improve the daylighting in the case study.

In the simulation of LEED certification cases from 33 to 35 is rejected from LEED report, and cases from 31 to 32 have one point, But the rest of the study cases got two points from the LEED. So, using Vertical shade with length 2 meter to each two meters. So (Case 2-C) is rejected. In the simulation of illumination cases, case 26 is the optimal case for presentation activity at 3p.m. (using datasshow) while case 23 is the optimal case for drawing and writing activity. However case 27 is the optimal case for presentation activity (using datashow) but case 23 is the optimal case for drawing and writing activity at 9 a.m. Therefore, the cases from 22 to 30 are the optimal cases, which mean the using of Vertical dynamic shading with length 1 meter to
Figure 6. Exterior, plan, and interior of the case study (classroom in Faculty of Engineering, NUB University).
Table 1. Inputs of the case study in Designbuilder program

| Parameters       | Sub-parameters                  | Inputs                                      |
|------------------|---------------------------------|---------------------------------------------|
| Layout           | Location                        | Beni Suef                                   |
|                  | Room Area                       | 49.14 m² (5.4 m * 9.1 m)                    |
| Activity         | Activity template               | Classroom-teaching area                     |
|                  | Equipment                       | Smart board, computer.                      |
|                  | Occupancy schedule              | From 9:00 a.m. to 15:00 p.m.                |
| Construction     | Finishing material              | Plastic paint with off white color         |
| Openings         | Opening template                | Glazing, Single, green (6 mm.)              |
|                  | Window wall ratio               | 45 including 5 c.m. frame                  |
|                  | Shades                          | Window blinds Inside room                   |
|                  | The height of session           | 110 cm with the fall of the beam 30 cm      |
| Lighting         | Lighting type                   | Headlamp lighting of four fluorescent bulbs|
|                  | Lighting control                | steps                                       |
|                  | Illuminance                     | 300 Lux.                                   |
| Simulation       | Analysis grid                   | 60*60 c. m.                                |
|                  | Working Plane height            | 90 c.m.                                    |
|                  | Altitude angle                  | 12.3 min −83.01 max                         |
|                  | Azimuth angle                   | 82.37 min −192.65 max                       |
|                  | Sky model                       | 1-Standard sky, 2-CIE clear day             |
|                  | Time of simulation              | 9:00:15:00, 21 Mar/Sep                      |
|                  | Tested façade                   | South, and east orientation                |
|                  | Simulation type                 | LEED v4                                     |
|                  | Refractor angles                | 90–75-60- 45-30-15-0                       |

each one meter in (case 2-B) in the east and two dynamic shading in the south. (Figure 8)

From simulations of UDI, cases from 12 to 35 is accomplished visual comfort but cases from 1 to 11 are rejected (Figure 9). While the simulation results of ASE indicated that cases from 22 to 31 in the range is achieved LEED requirement (Figure 10) but also cases from 1 to 21 and 32 to 25 are rejected. As a result of simulations of the working plan area, it is showed that cases from 1 to 32 is fulfilled LEED requirements (Figure 11) but cases from 33 to 35 are unaccepted. However the results of the average daylight factor of the case study displayed that cases 15 to 32 achieved visual comfort (Figure 12) but cases from 1 to 14 are unacceptable. Nevertheless The SDA simulation results proved that all cases were achieved LEED requirement (Figure 13).

By the Using of cases 26 and 24 raised the measuring of ASE from 42% to 87%, raised UDI from 42% to 100%, and changed daylight factor from 8.7% to 4.4%. Nevertheless, decreased working plan from 100% to 91%, and decreased SDA from 100% to 98, all these results accepted from all metrics.

Table 2 showed daylight metric evaluation for results according to the metric of LEED standards V.4, which explained ‘Accept cases, Reject cases, and Conclusion Optimal cases’ of cases studied.

Conclusions

This paper investigated the effect of using dynamic shading system in the Daylight Performance in university classroom in Egypt, evaluated, and
Figure 7. Results of simulation the basic case by measuring daylight.
Figure 8. Simulation of illumination for all cases.
Figure 9. Results of simulation UDI for all cases.
Figure 10. Results of simulation ASE for all cases.
Figure 11. Results of simulation working plane area.
Figure 12. Results of simulation daylighting factor.
Figure 13. Results of simulation SDA for all cases.
Table 2. Daylight metric evaluation for results of cases studied.

| Daylight metric | Accept cases | Reject cases | Optimal cases | Metric                          |
|-----------------|--------------|--------------|---------------|--------------------------------|
| ASE             | 22 to 35     | One to 21    | 22 TO 30      | More than 75% of the case area achieved less than 10 |
| UDI             | 12 TO 35     | One to 11    |               | More than 75% of the case area achieved from 100:2000 lux |
| SDA             | One to 35    | non          |               | More than 75%                |
| Daylight factor | 15 to 32     | One to 14    | and 33 to 35  | 2.5% to 5%                   |
| Working plan    | One to 30    | 31 to 35     |               | More than 75%                |

compared it with basic case at Beni Suef governorate in north Upper Egypt by measuring and recording the classroom Average daylight factor, working plane area, spatial daylight autonomy (SDA), annual sunlight exposure (ASE), and useful daylight illuminance (UDI), over a year from 9:00 am to 3:00 pm. The main Purpose of this paper is made the modeling and simulating of the dynamic shading system with its different angles of shading for a classroom as a case study by using DESIGNBUILDER V6, modeling with the RADIANCE, and DAYSIM simulation tools.

In general, this study shown that Visual comfort must be taken into determination in the initial design stages of the building. Some Studies based on an analysis of one or few daylight scales that are not realistic and may even be misleading at times. Visual comfort in a space cannot be measured by measuring daylight factor (DF), and spatial daylight autonomy (SDA) only, but also glare metering affected the visual comfort, which was measured by annual sunlight exposure ASE.

Measurement efficiency of daylight must be studied by using an effective indicator like daylight factor (DF), spatial daylight autonomy (SDA), annual sunlight exposure (ASE), and useful daylight illuminance (UDI).

In this case, the use of dynamic shading system with vertical shading its diminution is 1 meter which repeated each one meter in the east and horizontal two dynamic shading in the south. It changed its angle during the day Concurrently with changing the solar radiation Orientation so case 2-b is the optimal cases with 30-degree in the eastern facade is achieved the best illumination at 9 a.m., while the same facade needed a 60-degree

Table 3. Efficiency percentage of optimal cases from basic case.

|             | ASE | SDA | UDI | Daylight factor | Working plan |
|-------------|-----|-----|-----|-----------------|--------------|
| Basic case  | 42  | 100 | 42  | 8.7             | 100          |
| Optimal case| 87  | 100 | 100 | 4.4             | 91           |
| Efficiency percentage | 45% | 0%  | 58% | 4.3             | –9%          |

BUT it still in comfortable range
Table 4. Analyses of optimal cases.

| activity   | time | Orientation (degree) | Case no. | ASE | SDA | UDI | Daylight factor | Working plan |
|------------|------|----------------------|----------|-----|-----|-----|----------------|--------------|
|            | 9 a.m. | 60                   | 24       | 84  | 98  | 93  | 3.6            | 91           |
|            |       | [image]              |          |     |     |     |                |              |
|            | 3 p.m. | 75                   | 23       | 80  | 100 | 100 | 3.7            | 97           |
|            |       | [image]              |          |     |     |     |                |              |
|            | 9 a.m. | 15                   | 27       | 90  | 98  | 100 | 3              | 91           |
|            |       | [image]              |          |     |     |     |                |              |
|            | 3 p.m. | 30                   | 26       | 87  | 98  | 100 | 3.3            | 91           |
|            |       | [image]              |          |     |     |     |                |              |
|            | 3 p.m. | 30                   | 26       | 87  | 98  | 100 | 3.3            | 91           |
|            |       | [image]              |          |     |     |     |                |              |
shading system at 3 p.m. While the southern facade the suitable shading angle is 75 degrees, at 3 p.m. and 30 degrees 9 a.m.

This means that the best performance of using shading system in the Beni Suef governorate climate in university classrooms is dynamic shading system. Which improved the efficiency of UDI Went up at a rate of 58%, ASE raised at the rate of 45%, and daylight factor improved at the rate of 4.3%.

The working plan decreased from 100 to 91 but it still in acceptable range. (Table 3) showed comparison between Basic cases, and optimal case, so the efficiency percentages were calculated while using optimal case.

When using a fixed solar shading system, the luminous efficiency decreased with the change in the angle of the sun, so it is necessary to use a dynamic shading system.

Dynamic shading system suited the change activities in the case of study from an educational activity that uses the whiteboard (writing and reading) to an activity that uses the computer and the displays of data show. This is because the activity of reading and writing needs a light intensity ranging from 300 to 500 lux, while the use of datashow required a light intensity ranging from 100 to 300 lux that is why to achieve visual comfort from changing the activity in the same space. It is clear from the previous results that the maximum value of illumination at 9 a.m. is much higher than at 3 p.m. if the openings are with large areas in the eastern facade. This was proven by this study as at 9 a.m. the suitable Orientation is 60 degree for writing activity but 15 degree for presentation activity which at 3p.m 75 degree and 30 degree respectively are acceptable as shown in (Table 4).

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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