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RETROFITTING SHADING UNITS TO OPTIMIZE DAYLIGHTING IN THE GOVERNMENTAL SCHOOL BUILDING IN CAIRO

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ABSTRACT

Recently**,** the influence of building skin on daylighting performance has attracted great attention. therefore, many countries have adopted the retrofitting strategy for existing buildings to improve efficiency, the main concern of this work is to improve daylighting performance inside a classroom in a public school in Cairo, through a retrofitting strategy. Multi-Objective Optimization (MOO) framework and Genetic algorithms methodology will be adopted to optimize daylighting performance. The investigations were carried out via the use of "Ladybug and Honeybee" which could gather many simulation engines, Radiance & Daysim will be adopted for daylighting computation, integrated with Rhino & Grasshopper for 3D parametric modeling, and with Octopus plug-in as a (MOO) tool.

The investigated building was designed by the General Authority of Educational Buildings, representing an example of southern oriented classroom prototype in Cairo.

Daylighting performance was evaluated by using Dynamic Daylighting Performance Metrics as objective parameters. three variables for shading units' configurations were suggested as solution parameters, these variables were: shading units' number of slats rows, depth, and inclination angle.

Results indicated that the base case has sufficient daylighting level while suffering from nonuniformity and discomfort glare. The suggested shadings resulted in a 91% reduction in the area exposed to direct sunlight, as it reduces the aSE 1000/250h on the occupied area from 31.5 % in the base case to 2.7 %, which is classified as a preferred value. Besides, helped efficiently in reducing glare probability and at the same time keeps the SDA 300/50% within preferred limits.

Keywords

Parametric Optimization; Genetic Algorithm; Daylighting levels; visual comfort.

إضافة وحدات التظليل لتحسين أداء ضوء النهار
حالة الدراسة: مبني مدرسة حكومية بالقاهرة

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الملخص

حظي تاثير تصميم الغلاف الخارجي للمبني علي أداء ضوء النهار بكثير من الاهتمام في الآونة الأخيرة، ولهذا السبب بدأت كثير من الدول في تبني بعض السياسات التحديثية للمباني القائمة من أجل تطوير كفاءتها. ولهذا كان الهدف الأساسي من هذا

البحث هو تقييم ومن ثم تحسين أداء ضوء النهار داخل فصل دراسي في أحد المباني المدرسية الحكومية بالقاهرة ، من خلال سياسة تحديثية تتمثل في اضافة وحدات تظليل علي الواجهة الجنوبية لأحد النماذج النمطية لهيئة الأبنية التعليمية.
تم استخدام منهجية عمل معتمدة علي الخوارزميات الجينية في برنامج ضبط وتنسيق متعدد الاهداف لتحسين مستويات الاضاءة الطبيعية داخل فراغ الفصل محل الدراسة؛ باستخدام (Ladybug- Honeybee) كبرامج محاكاة يمكنها التكامل مع (Radiance and Daysim) كأدوات لأداء حسابات ضوء النهار؛ بالتوازي مع (Rhino and Grasshopper) لتفعيل التصميم البارامتري ثلاثي الابعاد ، وأخيرا استخدام (Octopus) كأداة ضبط متعددة الأهداف للوصول لأفضل الحلول الممكنة لتحسين مستوي الراحة البصرية. تم تقييم أداء ضوء النهار باستخدام مقاييس أداء ضوء النهار الديناميكية ومنها : مقياس إتاحية ضوء النهار كنسبة مئوية من عدد ساعات الإشغال (Daylight Autonomy) ، وايضا مقياس آخر لحساب إتاحية ضوء النهار كنسبة مئوية من مسطح العمل (Spatial Daylight Autonomy) ، وايضا قياس إحتمالية حدوث وهج (Daylight Glare Probability) ، واخيرا مقياس اخر لحساب النسبة المئوية من مسطح الإشغال المعرضة لضوء الشمس المباشر(Annual Sunlight Exposure) . واستخدمت هذه المقاييس لقياس الأهداف المطلوب الوصول اليها (Objective Parameters) طبقا للمعايير الدولية للمدارس. كما استخدمت معايير اخري كمحددات لتصميم وحدات التظليل المقترحة (Solution Parameters) تتمثل في عدد صفوف وحدات التظليل ، عمق الوحدة وزاوية ميلها. أتت نتائج المحاكاه لتؤكد ان الحالة الدراسية تحظي بشدة اضاءة كافية في حين انها تعاني من عدم إنتظام في توزيع الضوء واحتمالية وهج عالية تسببت في عدم الراحة البصرية . كما أوضحت النتائج فعالية وحدات التظليل المقترحة في تقليل المساحة المعرضة لضوء الشمس المباشر بمقدار إنخفاض يعادل 91% من المساحة المعرضة في حالة الدراسة الاصلية قبل تثبيت وحدات التظليل ، وايضا إنخفاض واضح في احتمالية حدوث الوهج وبالتالي تحسن في الراحة البصرية.

الكلمات المفتاحية : التصميم البارامتري ، الخوارزميات الجينية، مستويات ضوء النهار ، الراحة البصرية

1. INTRODUCTION

Daylighting is a key factor in learning spaces design, it affects visual and none visual comfort, visual comfort depends on the ability to control light performance; by providing an adequate amount of daylight, avoiding acute contrast or high brightness, and preventing glare. In comparison to electric light, Studies indicated that in addition to providing visual comfort, natural light has also an important non-visual influence on human biological processes, as it is essential in synchronizing the human circadian clock, which helps in stimulating blood circulation, influencing metabolism, and controlling the levels of many hormones. So, daylight can enhance functions like subjective mood, attention, cognitive performance, physical activity, sleep quality, memory, and alertness. All these factors could be considered key aspects of ideal learning performance [1]. However, daylight can result in visual discomfort caused by glare and disturbing reflections. For this reason, keeping the balance between daylight sufficiency and the risk of glare probabilities is the greatest challenge for architects. Shading unit design significantly affects the intensity and uniformity of daylight and consequently affects indoor daylight quality, especially in clear-sunny sky zones with long sunshine duration and very few cloudy days. in conditions like these keeping, adequate daylight performance inside any space needs great effort [2, 3].

-In Egypt, the General Authority of Educational Building (GAEB) is responsible for all issues related to public school construction, planning, allocation, technical specifications, financial issues, and so on. A key problem facing GAYB is the scarcity of suitable land for new schools, especially in crowded cities. in addition, using the prototypical model of GAEB regardless of the different constraints like different climatic conditions, school building orientation, etc. which leads to poorly oriented school buildings with no feasible envelop treatment, or exterior shading units to enhance daylighting performance in such cases. [4].

2. LITERATURE REVIEW AND BACKGROUND

2.1. Visual Environment Analysis in Schools: metrics & recommendations

In order to evaluate the quality of daylighting, suitable metrics have been introduced for daylight performance assessment in educational spaces as well as recommended values according to international standards. starting from illuminance, a series of metrics called illuminance-based have been adopted, in the field of this study, the climate-based metrics will be concerned, these metrics depend on dynamic calculations over a large timespan, and on actual variable sky conditions, which is suitable for Egypt location. These metrics will be discussed below:

- Daylight Autonomy (DA) is the percentage of occupancy hours when daylight illuminance at a point keeps above a minimum threshold, according to IESNA, the 300 lux as a threshold leads to statistically significant results [5, 6].
- Useful Daylight Illuminance UDI is defined as the annual time fraction that indoor daylight illuminance at a given point reaches a given threshold. UDI is also defined as the illuminances falling within the range of 100-2000 lux. Or 300-2000 lux in some studies related to educational spaces, And UDI >2000 lux may result in visual discomfort problems. [7, 8, 9].
- Spatial Daylight Autonomy (SDA), defined as the percentage of floor area that exceeds a specified illuminance level for a specified number of annual hours (50% of the hours from 08:00 a.m. to 06:00 p.m.). According to Standard IES LM-83. (Illuminating engineering society) the Preferred ratio for classrooms: sDA300/50% >75% on occupied area, and the Acceptable: sDA300/50% >55% on occupied area. [5]
- Since SDA does not identify an upper limit for daylight illuminance, its value should be combined with the assessment of Annual Sunlight Exposure (aSE) [10, 11]. aSE is the percentage of the occupied area where direct sunlight illuminance exceeds a specific value (usually, 1000 lux) for a specified number of hours (usually, 250). Recommendations for Classrooms [5, 12]:

• Preferred: **aSE**1000/250h <**3%** on occupied area.
• Acceptable: **aSE**1000/250h <**7%** on occupied area.
• Sufficient: **aSE**1000/250h <**10%** on occupied area.

- The aforementioned metrics depend on the concept of illuminance and are used to measure daylight sufficiency. Other metrics help in assessing glare probability and belong to the category of luminance-based metrics. Discomfort Glare Probability (DGP) has been introduced and validated by Weinold (2009) [13]. This metric is used to measure the probability that a person is disturbed by glare, instead of the glare magnitude itself [14] table 1.

Table.1 Glare Range

CLASSIFICATION	THRESHOLD	PERCENTAGE OF OCCUPATION TIME
Imperceptible glare	DGP < 0.35	for 95% of the time
Perceptible glare	0.35 ≤ DGP < 0.40	for 95% of the time
Disturbing glare	0.40 ≤ DGP < 0.45	for 95% of the time
Intolerable glare	0.45 ≤ DGP	for 95% of the time

2.2. Previous studies related to the current research

- According to Zayed et al. 2018, recent technologies software packages such as “Rhino” for modelling and “Grasshopper” as a parametric interface, and “Radiance-Daysim” for daylighting evaluation, of several architectural elements, can help significantly in enhancing daylighting performance, this study has investigated louvers inclination angles parametrically, to achieve daylighting uniformity inside an office room in Cairo. An illuminance range of 500-2000 lux for the task plane and 300-3000 lux for the daylight along the depth of the office was the main target of this work. Zayed et al., 2018 adopted dynamic vertical louvers to achieve the goals. angles 62° for winter,59° for spring and autumn, and 55° for summer were found to be optimum angles to fulfil the requirement according to predefined criteria [3].
- Another study conducted by Bakmohammadi et al.2020, adopted the parametric design approach using grasshopper a plug-in for rhino, and Honeybee - ladybug for environmental

simulation analysis, combined with a genetic algorithm for multi-objective optimization with (Octopus), aimed at optimizing the architectural design features of a primary school classroom, including WWR, building orientation, wall angle, window number and glazing material as design variables. and (UDI100−2000 lux), (DA), thermal energy use intensity (TEUI), and lighting energy use intensity (LEUI), as objective parameters, using aSE and DGP as visual comfort indicators in a separate phase. optimization procedure has led to the reduction of total energy demand, up to 47.92 kWh/m2, and the improvement of occupants' thermal and visual comfort. results revealed that the suggested methodology can provide designers with a guideline for designing sustainable classrooms by introducing a MOO framework resulting in different iterations with different decision parameters in the early design stage [15].

- A parametric approach for the *early design stage* was adopted by Wagdy, A. & Fathy, F. 2015, finding the optimal solar screen configurations for a south-oriented classroom located in Cairo's desert in Egypt that achieved a remarkable daylighting performance with 100% sDA without solar penetration. where all combinations of five screen parameters (window-to-wall ratio, louvers count, louvers tilt angle, screen depth ratio, and screen reflectivity) were computed. (sDA300/50%), (ASE1000/250 h), Daylight Availability as well as (DGP), were examined. Diva-for-Rhino plug-in for Rhinoceros was used to interface Radiance and Daysim while Grasshopper plug-in for Rhinoceros was used for parametric modeling. One of the most important results obtained is that increasing screen reflectance suggests more risk of glare. Hence, Daylight Availability (DA) was calculated to examine the effect of increasing screen reflectance. the daylight distribution of the best case in both 35% and 80% reflectivity is represented by calculating the sDA mean value. 80% reflectivity shows a large spot of 'overlit 'area that reaches 44% of the space. This could indicate a possibility of visual discomfort the solutions were characterized by a maximum daylit area without excessive solar penetration. According to this study, clear sky conditions can effectively contribute to the utilization of daylighting in terms of availability. However, this sky condition may cause visual discomfort or non-uniformity of daylighting distribution; especially in a case like Cairo, which is characterized by having a sunny clear sky throughout the year [10].

- **Another paper** conducted by Eman badawy, HBRC, 2021, aims to assess daylighting performance by using dynamic shading, a university classroom in Egypt was investigated. It also aims to define the optimal movement angle of the shades in each hour. Based on LEED 4 and IES daylight requirements, daylight analysis was conducted via Designbuilder V6, Radiance, and Daysim. This paper proved that using a dynamic shading system can help in improving daylighting performance. the daylight efficiency is raised in terms of UDI, aSE, and daylight factor by 58%, 45%, and 4.3%, respectively [16].

- Another research conducted by Gadelhak M et al. 2013, aimed at finding the trade-off between daylighting performance and energy savings, different configurations of horizontal sun breakers were investigated. The effect of their number, depth, and inclination angle was analyzed for a south-oriented office space. results have reached a good balance for both daylighting and energy needs, achieving a 72% daylit area and a 34% reduction in energy loads [17].

2.3. Research gap

- In Egypt, there are limited previous studies discussing how to develop the prototype of the Educational Buildings Authority to meet the international standards of daylighting performance; by a retrofitting plan methodology (specifically, fixed shading units) which enables us to recall a huge stock of existing school building to join the Education development plans.

3. RESEARCH MAIN OBJECTIVE

Find adequate shading units' configurations (as retrofitting elements), to optimize daylighting performance in an existing governmental school building in Egypt (GAEB prototype), depending on its façade orientation, and based on climatic weather conditions.

4. RESEARCH METHODOLOGY

This research methodology adopted the analytical approach through a climate-based simulation analysis and multi-Objective optimization in three phases.

4.1 Required software programs for parametric design

This approach mainly depends on parametric design software which was first started in 2008. One of the most valid software in this field is Grasshopper which is a graphical algorithm editor linked to Rhinoceros 3D and helps designers with no formal scripting background to create fast parametric models [18, 19]. Therefore, 3D modeling was developed in rhino & Grasshopper. Then, Ladybug, Honeybee, and Honeybee +, were used as free and open-source environmental plugins for Grasshopper 3D. Radiance and Daysim have been adopted for daylighting simulation and illuminance computation [20, 21]. After that, the Octopus plug-in was used to apply multi-objective genetic algorithms and find optimal solutions [15]. Octopus can achieve the optimal tradeoffs of multiple objectives through a "survival of the fittest" role. After that, a new alternative is formed and the cycle is repeated again. The Pareto front which represents all alternatives in one single chart will be studied and the optimum solutions will be found [22, 23]

4.2 The three phases of the analytical approach methodology

This Approach methodology was conducted through three phases Fig.1, first, case study simulation analysis to investigate daylighting performance. DA, SDA, UDI >2000, and aSE were investigated. <u>the second</u> was Multi-Objective Optimization to optimize SDA & UDI >2000 (as objective parameters) with different shading units' configurations (as solution parameters or genes), to obtain an optimal solution set. <u>The third</u>, DGP and aSE were defined for each of the selected solutions to select the best one.

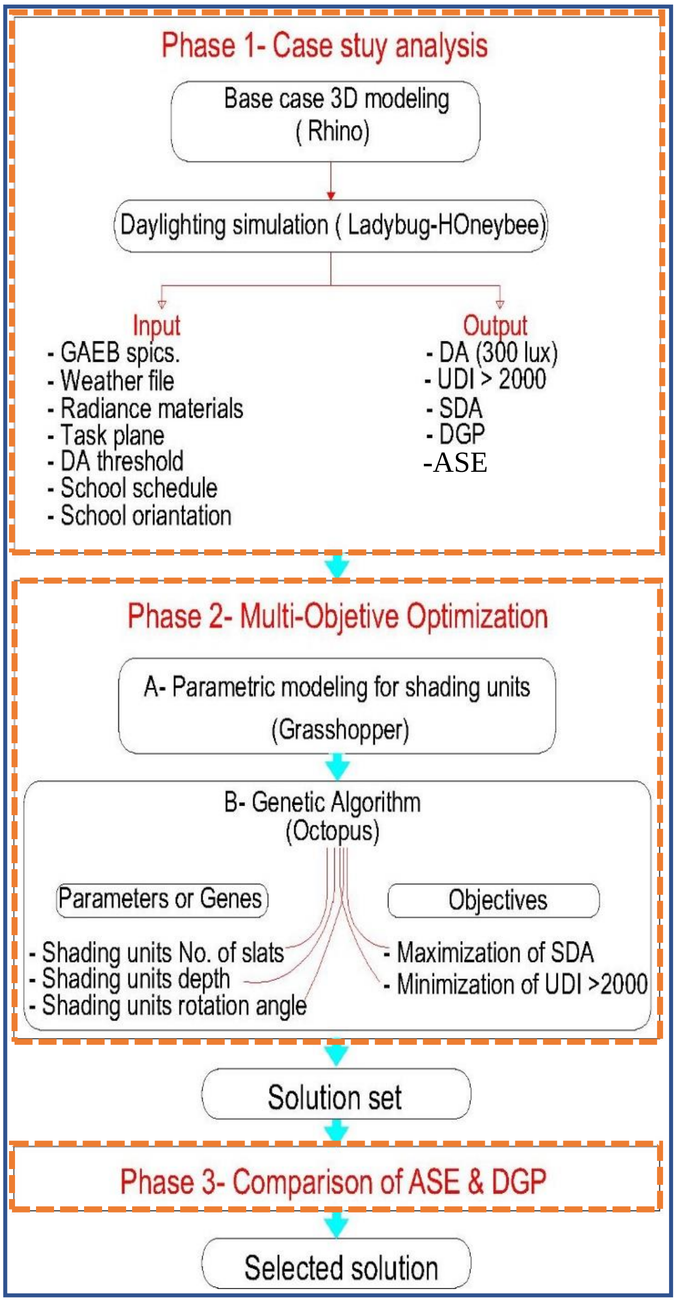


Fig. 1 Research methodology (analytical approach)

4.2.1 Phase 1: case study- Base case modeling and climate-based simulation

The aim of this phase is to analyze daylighting performance in an existing classroom (GAEB prototype) to be compared with the final selected solution.

4.2.1.1-Climatic feature and weather file of case study

The Egyptian Typical Meteorological Year (ETMY), the International Weather for Energy Calculations (IWEC), and Köppen classified Cairo's climate as a hot semi-arid climate with a hot to extremely hot dry summer and mild to warm wet winter [24]. and characterized by very high solar radiation intensity most of the year [25, 3] According to the Egyptian solar atlas, the average direct normal solar radiation ranges between 2000-3200 kWh /m2/year, while sunshine duration is 9-11 h/day with very few cloudy days [2]. E+ Weather data file represents the typical long-term weather patterns of the selected Location. weather data file used for this study is (EGY_AL QAHIRAH_CAIRO INTL AIRP9+ORT TMYx. epw).

4.2.1.2 Base Case Description: Gamal Abd El Naser public language school, Nasr city, Cairo, Egypt, the school building is consisting of 29 classrooms, serving 1250 students, coordinates are exactly 30.0428 N and 31.3338 E as depicted in the Google maps and satellite capturing in fig.2. the classroom investigated is located on the first-floor plan with a total floor area of 38.1m2, with internal dimensions of 7.25m*5.25m*3.25m (length *width* Hight). The classroom has three glass/sectional aluminum windows with no shadings, two of them in the external wall (southern elevation) with dimensions of 2.60m*1.50m (width*Hight), divided into two parts; upper with dimensions of 2.60m*1.00m, and lower with dimensions of 2.60m*0.50m. the third window is in the internal wall overlooking the corridor fig.3.

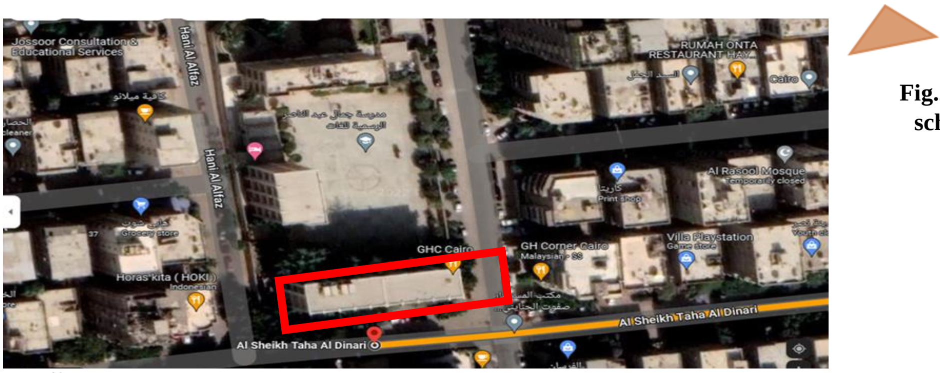


Fig.2. Gamal Abd El Naser public school, Nasr city, Cairo, Egypt, satellite capture

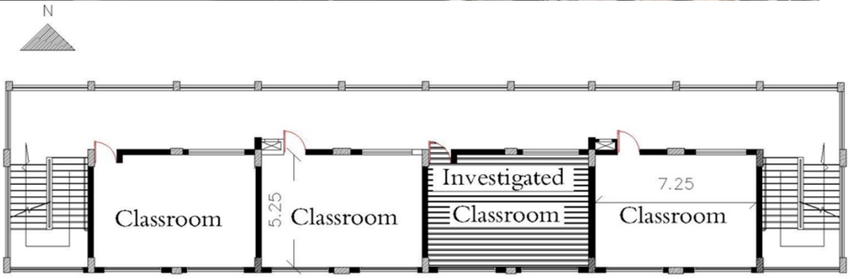


Fig.3. Typical floor plan of Gamal Abd El Nasser public school, Southern building & the selected case (classroom)

4.2.1.3 Modeling and simulation programs

The modeling was conducted by Rhinoceros 3D modeling software, Radiance and Daysim have been adopted for daylighting simulation and illuminance computation, these tools Integrated with ladybug & honeybee legacy VER 0.0.69 JUL_07_2020 & 0.0.66 JUL_07_2020 respectively, and Honeybee plus for ASE analysis.

4.2.1.4 Input parameters in Honeybee

The simulation input modeling parameters are based on GAEB spics. and data collected are shown in **Table 2**. Mention that, Honeybee has a library of default building programs using Open Studio's default schedules. This research adopted the information inside the occupancy schedule of a primary school classroom classified as default building programs presented by Honeybee (Primary School: Classroom). Sunday to Thursday day, between 9:00 am and 5:00 pm, was the nearest time schedule to our case to cover the two-period school schedule. **Table 3** shows model materials and reflectance. besides, the Window properties included Glazing Reflectance and Visible transmittance.

Table 2. Simulation input parameters in Honeybee

Element	Data
Classroom	7.25 length × 5.25 width × 3.25 height
Openings	2 ext. windows South orientation - 1 int. window northern
W.W. R	33 %
Window dimensions	(2.60 length x 1.50 Height) divided into upper & lower part
External shading	Non

Table 3. model materials reflectance & Window properties

Space	Reflectance & V. T
Walls Reflectance	Generic interior-50%
Ceiling Reflectance	Generic-80%
Floor Reflectance	Tile floor-40%
Furniture Reflectance	50%
Proposed Shadings Reflectance	50%- Medium Colored
Glazing Reflectance	Single plane-clear- 0.08%
V.T (Visible transmittance)	0.89

4.2.1.5 Annual Daylighting Simulation Metrics and Outcomes

The simulation testing was carried out hourly for the entire academic year, Daylighting performance of the selected case study was investigated. Investigations were conducted using Dynamic Daylight Performance Metrics (DDPM). DA, SDA, UDI >2000, DGP, and ASE had been investigated. The working plane contained 108 test points in a grid of 0.60m*0.6m at a Hight of 0.70m. the investigation was conducted in clear sky conditions with sun. for glare analysis, in order to calculate DGP, a specific camera view at the observer's eye height (1.1 m height) was defined in the Rhino working environment. Then the resulting High Dynamic Range image HDR is used for vertical illuminance calculations. then, the point-in-time glare analysis was conducted at 12:00 pm of the winter & summer solstices (21st of December) & (21st of June) respectively. besides, the autumn & spring equinoxes (21st of September) &, (21st of March), then a luminance map will be obtained.

4.2.2 Phase 2: Solution Set Based on Multi-Objective Optimization (MOO)

The aim of this phase is to find adequate shading units' configurations for classroom envelop Retrofitting; through a parametric analysis climate-based simulation and multi-objective optimization or Genetic algorithms (GAs). The (GAs) begin with calculating Random Solutions, then use the genetic operators to generate new solutions from the first ones, the existing potential solutions should be utilized by recombination and mutations to produce new generations with better solutions. this phase conducted by Octopus plug-in resulted in the solution set, the generation production process depends on several settings in Table 4.

'Elitism' gives the percentage of new solutions that are bred out of the Elite instead of the entire pool. 'Mut. Probability' is the probability of each parameter /gene becoming mutated with the 'Mutation Rate' A low Mutation Rate means little changes to the parameters' values, a high rate means big changes. 'Crossover Rate' is the probability of two subsequently generated solutions exchanging parameter values. 'Population Size' is the number of solutions per generation. 'Max. Generations' is set to zero by default, meaning there is no end to the search. 'Max. Eval Time' - if a solution takes longer than this to compute, it is added to a special collection of solutions that can be corrected, by reinstating them in the 'Troubleshooting' tab

.

Table 4. Input settings in Octopus

Elitism	Mutation Probability	Mutation Rate	Crossover Rate	Population Size	Max Generation	Max Eval. Time
0.50	1.00	0.5	0.8	40	5	0

4.2.2.1 Octopus main components to perform (MOO) process

A - decision Parameters: Octopus can connect to multiple Gene Pool and Number Slider components which control the design, in this research, decision parameters included the suggested shading unit's configurations (Depth, Inclination angle, Number of slats row), each parameter represented by a separate number slider Table 5.

Table. 5 solution Parameters or Genes.

No. of slats **row**	Window upper part: from **2-10 rows** & Lower part: from **1-5 rows**
Depth	Window upper part: from **50cm-10cm** & Lower part: from **50cm-10cm**
Inclination angle	From **50°** to **150°** with step of **1°** (Range 100°)

B -parametric model: Use input parameters like (3**D model**, **weather file**, **radiance materials**, **DA threshold**, **Schedule**, and **work planes**) and do some calculations/analysis/generation….

C -Objectives: Numeric objective values, it is the fitness values of a solution that we need to minimize or maximize to find the optimum solutions. This study aims to maximize SDA, and minimize UDI **>**2000, Table 6. According to the UDI definition, there is an upper limit of 2000 lux for illuminance value to reduce the risk of glare. And according to Standard IES LM-83. (Illuminating engineering society), the preferred: sDA300/50%>75%. And the acceptable: is sDA300/50%>55%.

Table. 6 Objective parameters.

SDA	Maximize
UDI >2000	Minimize

4.2.2.2 PARETO FRONT Based on Multi-Objective Optimization

"Pareto ranking refers to a solution surface in a multi-dimensional solution space formed by multiple criteria representing the objectives, The Pareto front is often used to explain the optimization results. To reach the Pareto front which is qualified to be analyzed, there are many generations of (Solutions) should be generated." [26]. In this study, five generations (G) were produced, and every generation contains 40 genomes or solutions. Pareto front seen in Fig.6 shows many solutions "genomes" which resulted in different configurations of shading units, each genome achieved different values of the objective parameters (sDA300/50%, UDI>2000), The solutions are referred by dots. Every dot had special color and transparency. Opaque cubes indicate the non-dominated solutions, transparent cubes are dominated ones. Transparent yellow cubes are elite solutions from previous generations [history], the more transparent the older. The blue curve contains 8 opaques non-dominated solutions for objective function from the fifth generation.

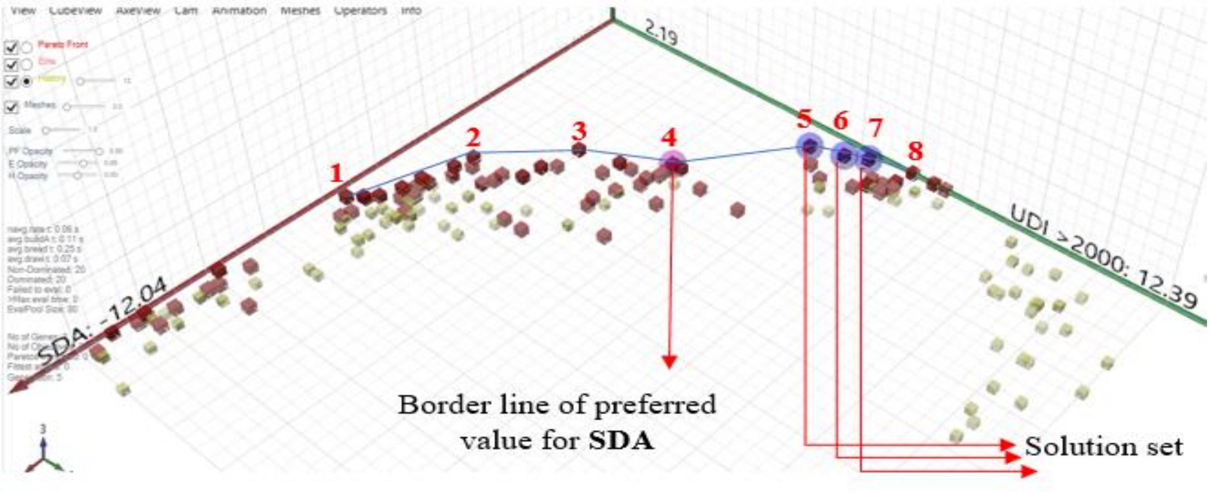


Fig.6 PARETO FRONT - Solution set

These eight solutions had been chosen to be investigated to help in selecting the solution set. It is found that the Transparent purple sphere (solution No.4) indicates the borderline for the preferred value of sDA300/50%: (75.2% of the task plane area), therefore, Transparent blue spheres (solution no. 5,6,7) were recommended to be the best solutions for objective function (solution set). while solution No.8 has the highest value of UDI exceed which indicated high DGP risk. Finally in phase three, (solution No. 5,6,7) will be investigated in terms of aSE & DGP. Therefore, the optimum solution will be obtained. All 8 solutions are listed in Table 7 with parameters and simulation results. While Table 8 represents the solution set.

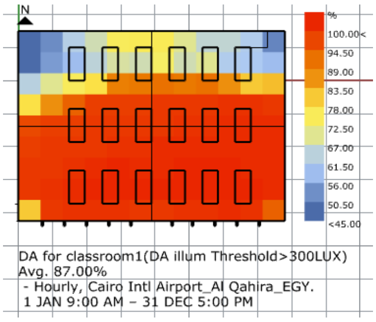
4.2.3 Phase 3: Comparison of aSE & DGP- (find the Optimum solution)

After selecting the solution set in the second phase, values of *aSE* & *DGP* which are considered valid indexes for evaluating visual comfort in international standards like IESNA were defined for each of the solution set iterations, the Values were calculated by Honeybee & Honeybee + which use the most valid simulation tools; including Radiance & Daysim. To calculate *DGP*, we used the same procedure in the case study *DGP* analysis. then, the point-in-time glare analysis was conducted at12:00 pm of the winter & summer solstices (21st of December), (21st of June) respectively and the autumn & spring equinoxes (21st of September), (21st of March) respectively. Additionally, *aSE* was simulated, and the last step was the comparison of *aSE* and *DGP* among the three solutions and finding the best one to be used for the suggested envelop retrofitting.

5. RESULTS

5.1. Simulation Results of Phase one (Base case with no shadings):

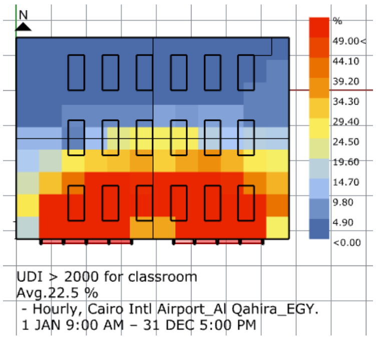
Daylight Autonomy metric (DA)



- the average annual DA estimated by calculations is 87%. Honeybee Reeds all the hourly results from the annual daylight study fig.4.

FIG.4. DA (DA Illum threshold>300LUX) - Hourly, Cairo Intl Airport_Al Qahira_EGY

Useful Daylight Illuminance (UDI>2000) simulation result for base case:



- The average percentage of time during the active occupancy hours that the test points receive more than 2000 lux is estimated by 22.5% **fig.5.**

FIG.5. UDI (UDI>2000 LUX) - Hourly, Cairo Intl Airport_Al Qahira_EGY

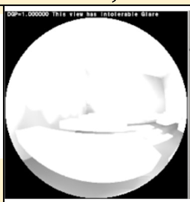
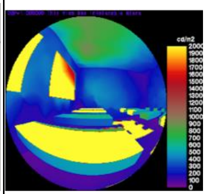
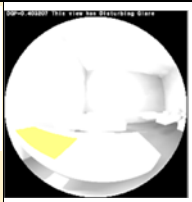
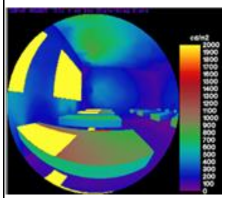
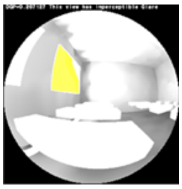
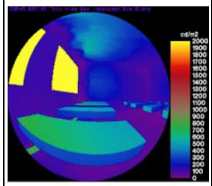
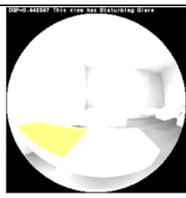
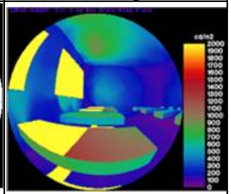
Spatial Day Light Autonomy (sDA) Simulation Result for Base Case:

the percentage of the classroom area that meets or exceeds DA illuminance value thresholds (set to 300LUX) for at least 50% of the analysis period, is estimated at 97.2%. which is considered a preferred value According to Standard IES LM-83.

Glare Analysis - Discomfort Glare Probability (DGP) Results for Base Case:

Luminance Mapping illustrates luminance values in the visual field and it is measured by cd/m2. It is a method to analyze the visual scene using software to decode the luminance values and translate the image to a false color view helps in identifying the brightest spots in the visual field. These spots often represent potential glare. Table 4 represents the DGP values and luminance map for a specific camera view at the observer's eye height (1.1 m height). as is shown in seasonal DGP luminance maps, The DGP value reaches the highest level at the winter solstice, as it reads 1.00 in 21st Dec. at 12 pm which is classified as intolerable glare, while the DGP reached its lowest value in the summer solstice, as it reads 0.27 in 21st June at 12 pm which is classified as Imperceptible glare. table 4 also showed the DGP values of the two equinoxes, 21st Sep., and 21st Mar. at 12 pm as it reads 0.40 (Disturbing) and 0.44 (Disturbing) respectively.

Table 7. DGP results for the base case

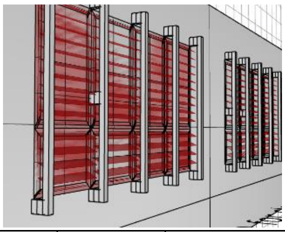
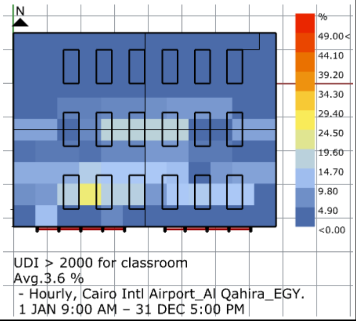
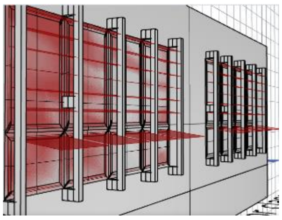
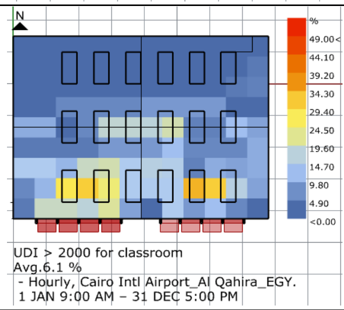
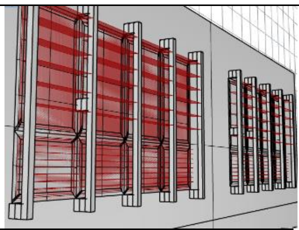
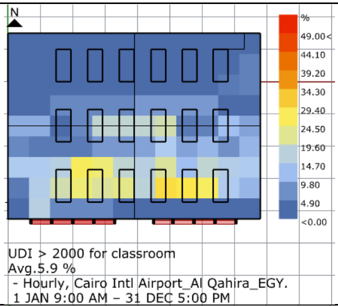
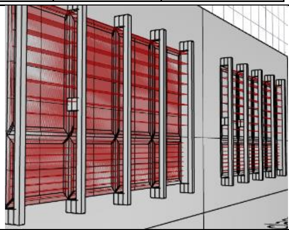
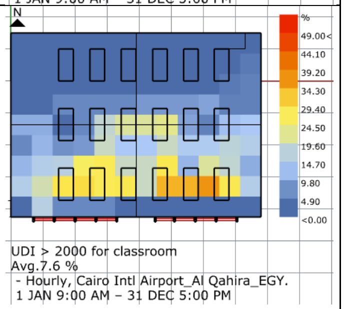
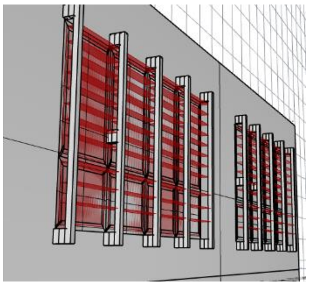
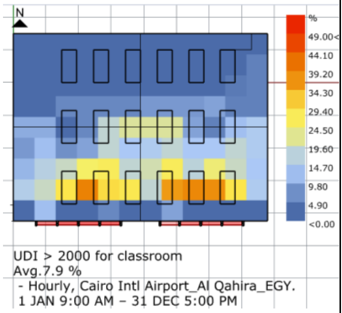
Metric / Case	DGP					
	Winter & summer solstices 21st Dec., 21st June at 12pm			Autumn & spring equinoxes 21st Sep., 21st Mar. at 12pm		
Base case	Winter			Autumn		
		1.00	intolerable		0.40	Disturbing
	Summer			Spring		
		0.27	Imperceptible		0.44	Disturbing

5.2 Simulation results of Phase 2 (solution set based on Pareto Front)

Table 8 represents eight opaque non-dominated solutions. These solutions have been chosen from the last generation to help in identifying the solution set. According to Standard IES LM-83, the Preferred ratio for classrooms: is sDA300/50% >75% on the occupied area, and the Acceptable: is sDA300/50% >55% on the occupied area. Accordingly, its noticed that solution number 4 represents the borderline of the preferred value of SDA. As it reads 75.2% with a corresponding annual average value of UDI > 2000 equals 7.6%. While the first three solutions could not reach the preferred value barrier, the first solution recorded a value of SDA equal to 50%, which is classified as (unaccepted). While the second and third solutions recorded 66.67% (Accepted) and 74.00% (Accepted) respectively. also, solutions No. 5, 6, 7, and 8 could reach the preferred value of SDA. while solution No.8 has the highest value of UDI exceed among the solution set equals 11.00% which indicated high DGP risk. therefore, (solutions no. 5,6,7) were recommended to be the solutions of the (solution set).

Table 9. represented Recommended solution set objective values, solution No. 5, 6, and 7 recorded 83%, 86%, and 94% for SDA value respectively, as the percentage of floor area that exceeds 300 lux for 50% of the hours from 08:00 a.m. to 06:00 p.m. and recorded 7.9%, 9.4%, 10.5% for UDI exceed respectively.

Table 8. Eight non-dominated solutions for objective function from the fifth generation

<table>
<tr><th>solution NO.- configuration</th><th>sDA300/50%</th><th>UDI > 2000 (%)</th></tr>
<tr><td>1 
upper | lower | angle
10 rows | 4 rows | 63°</td><td>50.9 %
(Not accepted)</td><td>Avg.3.6% 
</td></tr>
<tr><td>2 
upper | lower | angle
6 rows | 1 row | 80°</td><td>66.67%
(Accepted)</td><td>Avg.6.1% 
</td></tr>
<tr><td>3 
upper | lower | angle
6 rows | 8 rows | 86°</td><td>74.00%
(Accepted)</td><td>Avg.5.9 % 
</td></tr>
<tr><td>4 
upper | lower | angle
8 rows | 8 rows | 88°</td><td>75.2%
(Borderline of preferred value)</td><td>Avg.7.6% 
</td></tr>
<tr><td>5 
upper | lower | angle
8 rows | 3 rows | 90°</td><td>83.3 %
(Preferred value)</td><td>Avg.7.9% 
</td></tr>
</table>

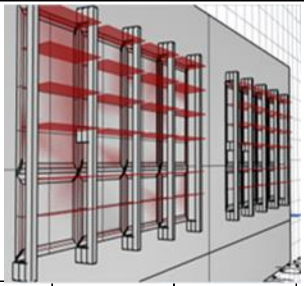
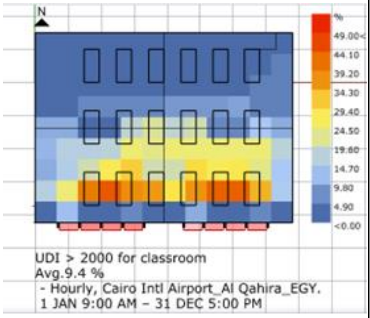
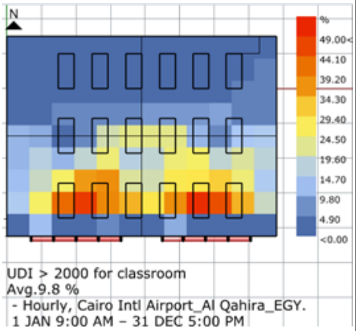
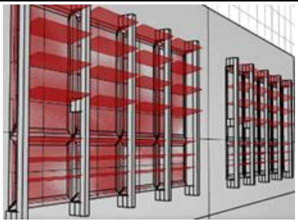
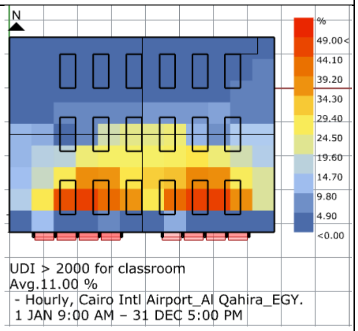
<table>
<tr>
<td>6
<table><tr><td>upper</td><td>lower</td><td>angle</td></tr><tr><td>4 rows</td><td>2 rows</td><td>95</td></tr></table></td>
<td>86.00%
(Preferred value)</td>
<td>Avg.9.4%</td>
<td>
</td>
</tr>
<tr>
<td>7
<table><tr><td>upper</td><td>lower</td><td>angle</td></tr><tr><td>8 rows</td><td>2 rows</td><td>103°</td></tr></table></td>
<td>88.00%
(Preferred value)</td>
<td>Avg.9.8%</td>
<td>
</td>
</tr>
<tr>
<td>8
<table><tr><td>upper</td><td>lower</td><td>angle</td></tr><tr><td>4 rows</td><td>3 rows</td><td>104°</td></tr></table></td>
<td>93.00%
(Preferred value)</td>
<td>Avg.11.0%</td>
<td>
</td>
</tr>
</table>

Table 9. Recommended solution set

Solution NO.	*DA%*	*UDI 100-2000*	*UDI >2000*	*SDA*
5	*76%*	*90%*	*7.9%*	*83%*
6	*79%*	*89%*	*9.4%*	*86%*
7	*84%*	*88%*	*10.5%*	*94%*

5.3 Phase 3 simulation results Comparison of aSE & DGP- (find Optimum solution)

The information listed in Table 10 represents the comparison results of aSE per area and DGP among the three selected solutions 5,6 &7. It is noticed that solution No.5 can achieve the aSE targets by a lower value than solutions No.6 & 7. For Sol. No. 5, Honeybee + estimated the percentage area where direct sunlight illuminance exceeds 1000 lux for 250 hours by 2.7 % of the classroom area. While it was 5.5 % & 6.5 % for Sol. No. 6 & 7 respectively. the values of aSE and DGP were measured for the selected solutions set, these measurements proved that the solutions with the highest value of UDI also have the highest level of DGP and aSE around the year, as it is shown in seasonal DGP luminance maps, The DGP value reaches the highest level in the winter solstice, and it is noticed that the sol.

No. 5 recorded the lowest value of DGP among the three optimum solutions of the solution set. as it reads 0.39 on 21st Dec. at 12 pm which is classified as perceptible glare, while Sol. No. 6 reads 0.43, which is classified as a disturbing glare. And Sol. No. 7 reads 0.46 which is classified as an Intolerable glare. from the aforementioned, Solution No. 5 was able to achieve the best results among the group of solutions, and therefore it was chosen as the best solution. Table 11 describes the shading units' configurations which represent the Optimum solution (sol. No. 5). It was proposed to install five vertical pillars at equal distances on the external facade facing the southern window, in order to fix the proposed shading slats.

Table 12 showed that the Sol. No. 5 can help in reducing the UDI>2000 from 22.5% to 7.9%. and also resulted in a 91% reduction in the area exposed to direct sunlight, as it reduces the aSE from 31.5 % of the occupied area in the base case to 2.7 % after installing shades. Also, information listed in Table 12 showed that, Sol. No. 5 hourly average aSE estimated by (60 hours). so, it resulted in a 66% reduction of the base case value which was (177 hours). The information listed in Table 13 showed the comparison of DGP between the base case with no shading units and after implementing shades. the suggested shading units succeed in reducing the DGP of the winter & summer solstices (respectively and the autumn & spring equinoxes. the optimum solution can achieve a dramatic reduction in winter solstice DGP value from 1.00 (intolerable) to 0.39 (perceptible), and in summer solstice from 0.27 to 0.24, and a noticeable reduction in the two equinoxes values, from 0.40 (disturbing) to 0.28 (Imperceptible) in autumn and from 0.44 (disturbing) to 0.27(Imperceptible) in spring.

Table 10. comparison of aSE1000/250h on occupied area and DGP for solution set

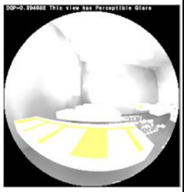
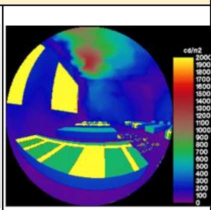
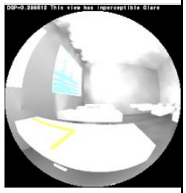
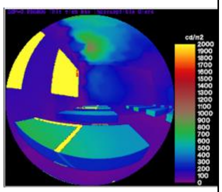
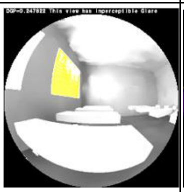
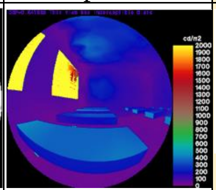
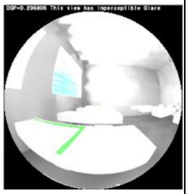
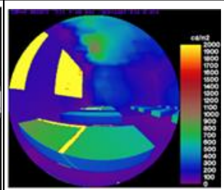
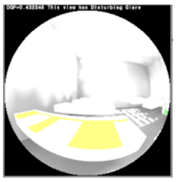
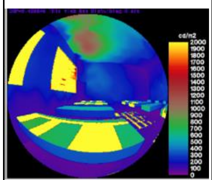
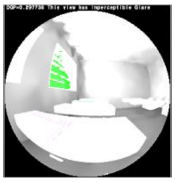
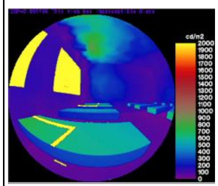
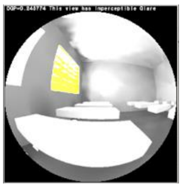
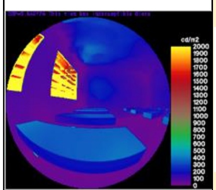
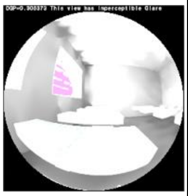
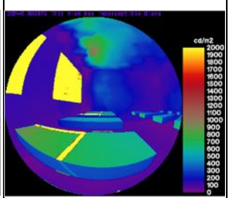
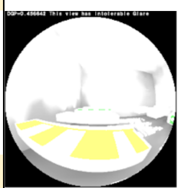
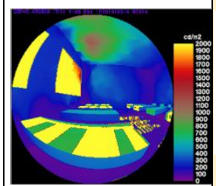
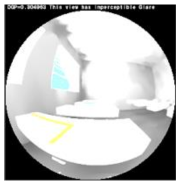
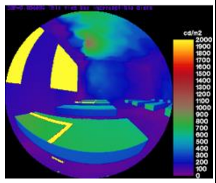
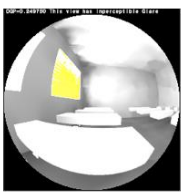
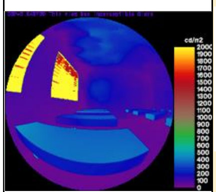
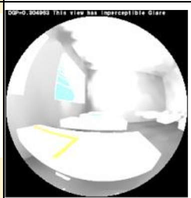
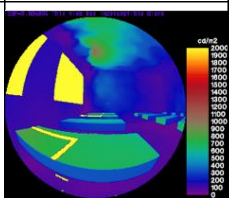
Sol. No.	**aSE per-area %**	**DGP**					
		Winter & summer solstices 21st Dec., 21st June at 12pm			Autumn & spring equinoxes 21st Sep., 21st Mar. at 12pm		
5	**2.7**	Winter	 0.39	 Perceptible	Autumn	 0.28	 Imperceptible
		Summer	 0.24	 Imperceptible	Spring	 0.29	 Imperceptible
6	**5.5**	Winter	 0.43	 Disturbing	Autumn	 0.29	 Imperceptible
		Summer	 0.25	 Imperceptible	Spring	 0.30	 Imperceptible
7	**6.5**	Winter	 0.46	 Intolerable	Autumn	 0.30	 Imperceptible
		Summer	 0.25	 Imperceptible	Spring	 0.30	 Imperceptible

Table. 11 Optimum solution- shading units' configurations (Decision Parameters)

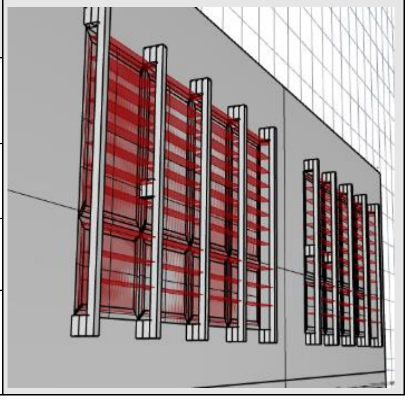
	Window upper part	Window lower part	
No. of slats row	**8**	**3**	
Depth	**12.5 cm**	**16.5 cm**	
Width	**33 cm**	**33 cm**	
Rotation angle	**90°**	**90°**	

Table 12. comparison between recommended optimum solution and base case

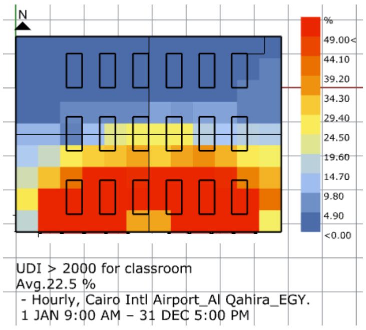
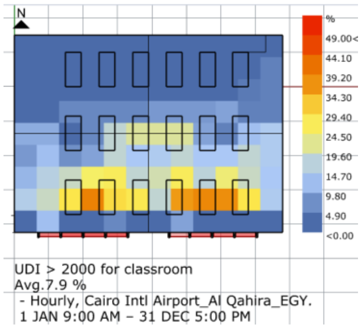
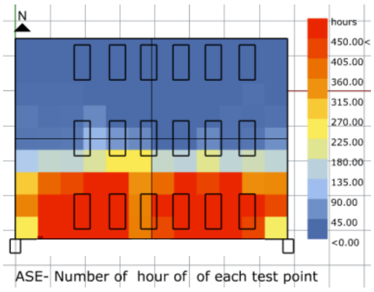
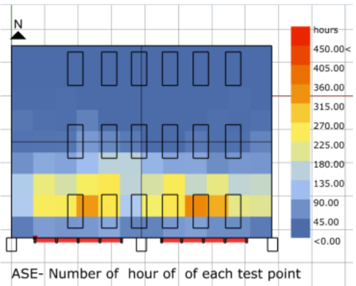
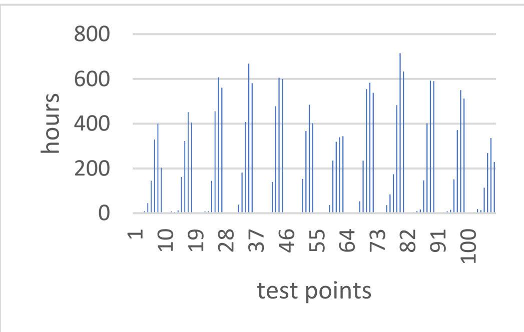
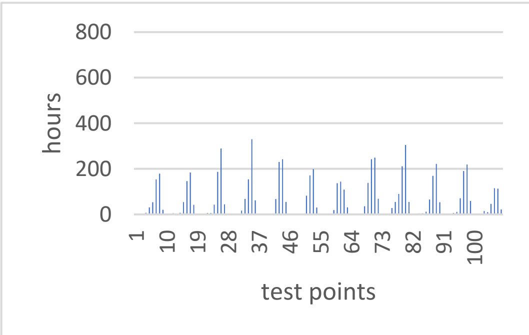
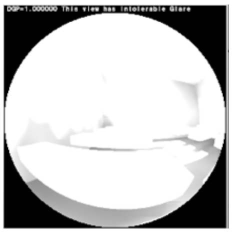
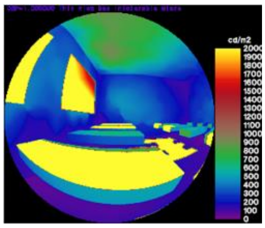
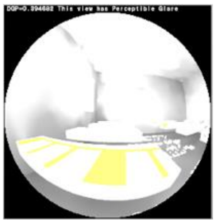
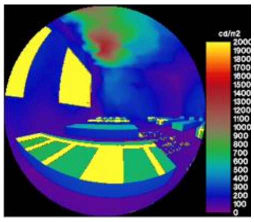
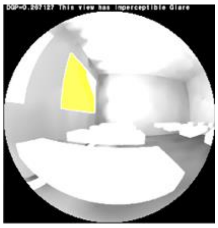
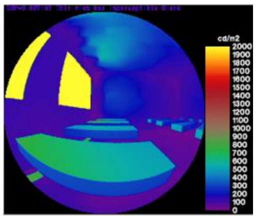
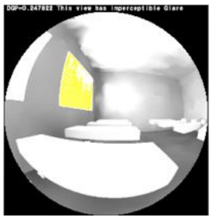
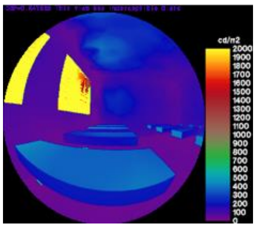
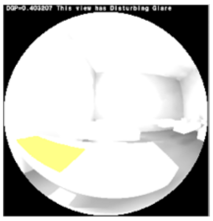
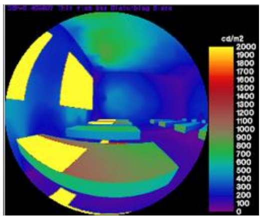
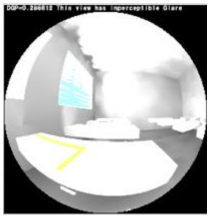
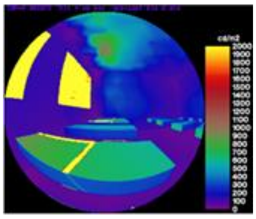
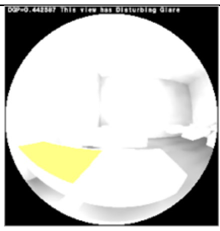
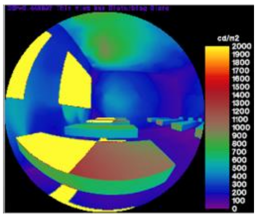
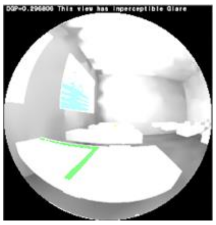
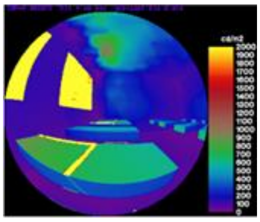
	Base case	*Optimum solution (sol. No. 5)*
DA	***87%***	***76%***
UDI > 2000	 ***22.5%***	 ***7.9%***
SDA	***97.2%***	***83.3%***
aSE per-area	 ***31.5% (not accepted)***	 ***2.7% (preferred)***
ASE per-hour	 ***Average 177 hours***	 ***Average 60 hours***

Table 13 Comparison of DGP between the base case and recommended optimum solution

12.00 pm	***Base case***		***Optimum solution (sol. 5)***	
Winter solstice 21st Dec	 1.00	 Intolerable	 0.39	 Perceptible
Summer Solstice 21st Jun	 0.27	 Imperceptible	 0.24	 Imperceptible
Autumn Equinox 21st Sep	 0.40	 Disturbing	 0.28	 Imperceptible
Spring equinox 21st Mar	 0.44	 Disturbing	 0.29	 Imperceptible

6. CONCLUSION AND RECOMMENDATIONS

This paper focused on representing parametric-based optimization, using genetic algorithms. A public-school building case study in Cairo, Egypt, was investigated to find the suitable shading units' configurations for multi-objective optimization to daylighting levels and visual comfort, through a parametric-based optimization method. The used metrics for daylighting availability were: (sDA300/50%) and (UDI >2000). while the metrics for evaluating visual comfort were: (aSE1000/250h) on occupied area and DGP. There were three decision parameters to find the optimum design, which were (shading units' number of slats rows, depth, and inclination angle). 200 solutions were produced in 5 generations. Each generation is considered more optimized than the previous ones. All of these solutions have formed the Pareto front which contains the optimal Pareto front curve where the optimum solution locates. eight of the solutions which are laying on this curve were analyzed to find the optimum solution. the optimum solution aimed at achieving a balance between daylighting availability and visual comfort. The suggested shadings helped in reducing the UDI>2000 from 22.5% to 7.9%. and also resulted in a 91% reduction in the area exposed to direct sunlight, as it reduces the aSE1000/250h on the occupied area from 31.5 % in the base case to 2.7 %, which is classified as the preferred value of aSE1000/250h. What helped efficiently in reducing the daylight glare probability and at the same time keeps the sDA300/50% in the range of the preferred value equals to 83% on the occupied area. in general, the optimal solution can be described as follows: The upper part of the base case was divided into 8 rows of slats. with an inclination angle of 90° and with a depth of 12.5 cm, and a width of 33cm. while the lower part was divided into 3 rows of slats. with an inclination angle of 90° and with a depth of 16 cm, and a width of 33cm. for further research, it’s recommended to study the impact of shading units not only on visual comfort but also on Solar Heat Gain and consequently on thermal comfort, taking into account the direct effect of shading unit features on airflow patterns and ventilation rates.

REFERENCES

[1] Moreno, M.; Labarca, C. (2015). Methodology for Assessing Daylighting Design Strategies in Classroom with a Climate-Based Method. Sustainability, 7 (1), 880-897.

[2] N. a. r. e. a. NREA, "New and renewable energy authority - Annual report - Egypt," New and renewable energy authority, Cairo 2011.

[3] Zayed, A.; Elkhateib, M.; Mahdy, M.; Elwy, I. (2018). Daylighting Distribution Enhancement for Deep Office Spaces via Dynamic Louvers System, a case study in Cairo, Egypt. Proceedings of the 12th ICCAE-12 Conference, 3-5 April 2018.

[4] Sobhy, H., (2019). Expensive Classrooms, Poor Learning, The Imperatives of Reforming School Construction in Egypt. policy paper, Alternative Policy Solutions.

[5] Standard IES LM-83–1. In Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE); Illuminating Engineering Society: New York, NY, USA, 2012.

[6] Michael, A.; Heracleous, C. (2017). Assessment of natural lighting performance and visual comfort of educational architecture in Southern Europe: The case of typical educational school premises in Cyprus. Energy Build., 140, 443–457.

[7] Costanzo, V.; Evola, G.; Marletta, L. (2017). A Review of Daylighting Strategies in Schools: State of the Art and Expected Future Trends. Buildings, vol.7, issue (2).

[8] Costanzo, V.; Evola, G.; Marletta, L.; Panarelli, D. (2017). Static and dynamic strategies for improving daylight use in side-lit classrooms: A case study. 3rd IBPSA Italy Conference, Bozen, Italy, 8–10 February

[9] Piderit, M.B.; Labarca, C.Y. (2015). Methodology for assessing daylighting design strategies in a classroom with a climate-based method. Sustainability, 7, 880–897.

[10] Wagdy, A.; Fathy, F. (2015) A parametric approach for achieving optimum daylighting performance through solar screens in desert climates. J. Build. Eng., 3, 155–170.

[11] Korsavi, S.S.; Zomorodian, Z.S.; Tahsildoost, M. (2016). Visual comfort assessment of daylit and sunlit areas: A longitudinal field survey in classrooms in Kashan, Iran.” Energy Build., 128, 305–318.

[12] U.S. Green Building Council. LEED v4 for Building Design and Construction; U.S. Green Building Council: Washington, DC, USA, 2017.

[13] Wienold, J. (2009). Dynamic daylight glare evaluation. In Proceedings of the Building Simulation” 11th International IBPSA Conference, Glasgow, Scotland, 2009.

[14] Carlucci, S.; Causone, F.; de Rosa, F.; Pagliano, L. (2015). A review of indices for assessing visual comfort with a view to their use in optimization processes to support building integrated design. Renew. Sustain. Energy Rev., V. 47, pp. 1016–1033.

[15] Bakmohammadi, P.; Noorzai, E. (2020). Optimization of the design of the primary school classrooms in terms of energy and daylight performance considering occupants’ thermal and visual comfort. Energy Reports journal, 6, 1590-1607, 2020

[16] Ahmed, E.B (2021). Utilizing dynamic shading system to achieve daylight performance according to LEED standards V.4: case study, university classrooms in Egypt. HBRC Journal, 17(1), 177-200, 2021

[17] Gadelhak, M.; Aly, M.; Sabry, H. (2013). High-performance facades: The effect of sun breakers on daylighting performance and energy consumption in south-oriented office spaces. Architectural Engineering Conference 2013. Published online ASCE Library, April 26, 2013.

[18] Lagios, K.; Niemasz, J.; Reinhart, C. (2010). Animated Building Performance Simulation (ABPS) – linking rhinoceros/grasshopper with Radiance/Daysim. Fourth National Conference of IBPSA-USA, New York.

[19] Eltaweel, A.; Su, Y. (2017). Evaluation of Suitability of Parametrically Controlled Louvers for Various Orientations throughout a Year Comparing to an Existing Case. Buildings, 7(4), 109.

[20] Reinhart, C. F.; Walkenhorst, O. (2001). Validation of Dynamic RADIANCE-based Daylight Simulations for a full-scale Test Office with outer Venetian Blinds. Energy & Build., 33(7), 683-697.

[21] Roudsari, M. S.; Pak, M., Smith, A., & Gordon Gill Architecture (2013). Ladybug: A Parametric Environmental Plugin for Grasshopper to Help Designers Create an Environmentally-Conscious Design. 13th Conference of International Building Performance Simulation Association, 3129–3135.

[22] Hong, X.; Shi, F.; Wang, S.; Yang, X.; Yang, Y. (2021). Multi-objective optimization of thermochromic glazing based on daylight and energy performance evaluation. BUILD SIMUL, 14, 1685–1695.

[23] Zhang, L.; Wang, C.; Chen, Y. (2021). Multi-Objective Optimization Method for the Shape of Large-Space Buildings Dominated by Solar Energy Gain in the Early Design Stage. Frontiers in Energy Research, 2021.

[24] Hammad, h.; Abdelkader, M.; Faggal, A.A. (2017). Investigating the Thermal Comfort Conditions in an Existing School Building in Egypt. Journal of Engineering Sciences, 45(3), 344-359.

[25] Solar-GIS. (2013). Global Horizontal Irradiation - Africa and the Middle East.

[26] Toutou, A.; Abdelrahman, M. (2019). Parametric Approach for Multi-Objective Optimization for Daylighting and Energy Consumption in Early-Stage Design of Office Tower in the New Administrative Capital City of Egypt. The Academic Research Community Publication (Archive), 3(1), 2019.