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Optimizing Visual Comfort in School Buildings Through Parametric Design

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Abstract:

Achieving a well-lit classroom that meets the standards of visual comfort and high daylight quality is a real challenge, so to achieve this goal, several variables must be combined, including the quality of the glazing and the shading device provided, a particularly difficult task in semi-arid climates. Therefore, this paper proposes an analytical approach to the parametric components of daylighting and visual comfort of a classroom in order to achieve an accurate estimate in a short time frame. A specific dataset is generated from parametric modelling developed in grasshopper for Rhino and daylight simulations were conducted using ladybug tools for Grasshopper, sDA -ASE values were applied for daylight and visual comfort assessments. The proposed solutions for mitigating solar gains and controlling the daylighting distribution is the installation of interior light shelves on the south windows with material reflection of 90 % and glass of 80% transparency, An acceptable daylighting performance can be achieved also when the classroom has on the south windows exterior louvers with different sizes (mostly have similar performance to each other) with an angle of rotation of 0^0 associated with interior light shelves. With material reflection of 90 % and glass of 80% or 65% transparency on the south glass windows and 80% on the north one.

Key words: *visual comfort, daylighting performance , school building, classroom, parametric design.*

I. Introduction

Visual comfort in school buildings is one of the defining parameters influencing environmental quality and student satisfaction. Furthermore, the positive impact of optimal daylighting use on providing an ideal environment in terms of visual comfort for students is a significant factor in improving their health and well-being. (Acosta & al., 2018; Dolnikova& al.,2019; Kontadakis & al.,2017. Nocera& al.,2018; Reinhart& al.,2001). Furthermore, daylight enhances the aesthetics and physical character of a learning space while limiting the potentially harmful effects of prolonged exposure to artificial light.(Heschong & al .,2022; Mirrahimi & al,.2012; Nocera& al.,2018) As a result, several studies' findings have confirmed that good levels of daylight in classrooms may enhance school students' learning performance. (Bakmohammadi &al.,2020;. Heschong & al .,2022; Yu& al.,2014). Aside from improving overall mood, morale, and the importance of maintaining a good biological clock, daylighting has been shown to improve the general mental and psychological well-being of building users. (Bellia& al .,2011; Edwards &al.,2002; Ibañez &al.,2017; Küller &al.,1998). Unsatisfactory visual comfort levels in

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educational spaces, on the other hand, can reduce both physical and intellectual performance of teachers and students.(Lakhdari&al.,2021).

In this regard, numerous studies have been conducted regarding conditions of visual comfort and daylighting performance in school buildings, where it was found that ensuring good lighting quality in classrooms is a rather complex task. (Al-Khatatbeh&al.,2017; Nocera&al,.2018) Because of the variability that characterizes the conditions under which daylight is sensitive (location, orientation, climate, season, and time of day), the user's visual needs are also affected. (Bellia&al.,2017; Caetano&al .,2020). Thus, previous research on daylight performance in the real world has primarily focused on building properties and architectural elements. (Ayoub &al.,2019; Edwards&al.,2002)Many studies have confirmed that the internal environmental conditions in school buildings are heavily influenced by architectural and construction characteristics such as internal layout, space configuration, surface reflectivity, thermal envelope properties of buildings, window-to-wall ratios, and external shades. (Tabadkani&al,2018). As a result, it is certain that proper building design must allow for the entry of the appropriate and necessary amount of sunlight into the space, with the main goal of these designs being to control the amount of interior light. (Egan&al.,2002).

To understand these factors and their effects, several selected articles on this topic are reviewed in depth, a study by Ivana T et al (2018) an assessment of the factor of daylight, daylight illumination, and luminance as an important criterion for the amount of daylight in the classroom. And its relationship with the correct spatial layout of the classroom using field measurements and simulations with the DIALux software, The results of the study confirmed that the deficiencies in amount of daylighting in the classroom are due to a defect in the design of the classroom due to the distortion caused by the neighboring buildings, which led to the insufficient flow of daylight into the room;Another study carried out by Yu (2019), in which he studied the efficiency of daylight in educative building and its relationship to the architectural and physical factors through field measurement and computer simulation using RELUX software, Zomorodian et al (2017) also examined the impact of orientation, window configurations and glazing Visual Transmittance on spatio-temporal visual comfort by dynamic simulations and field measurements.

Another study by Zomorodian et al (2017) in which the student’s visual comfort and was evaluated is evaluated using field survey and simulations the study also confirmed that providing the right amount of light evenly distributed in the space while providing protection from glare is an important factor in the design of the classroom. Research done by Sureepan S (2014) This study aims to investigate the impact of classroom facade designs on user’s visual comfort while reducing energy consumption in classrooms at the College of Architecture in Thailand In terms of classroom form, brightness levels, user behaviors and attitudes. Through several survey methods: lighting measurement, observations, questionnaires and interviews; executed. Also computer simulations using the Design Builder package.

Baraa J et al (2019) investigated the influence of various retrofit methods for passive daylight technique in northerly oriented classroom on enhancing visual comfort using real measurements and computer simulation by means of ecotect. A study was done by Choul W et al (2018) in which the indoor natural illuminance was assessed by combining a passive approach and advanced

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software to design external shading devices for daylighting in a classroom with different orientations and shading forms. in Korea using ecotect, for the shading coefficient, and DaySim software for daylight autonomy. Cristian A et al (2017) also exanimated the quality of illumination in technical drawing classroom by means of on-site measurements and HDR (High Dynamic Range) pictures, the study indicated the necessity of changing the paint colors of the interior walls and ceilings in order to allow a better distribution of lighting.

With the above in mind, and giving that researchers have used a wide range of methods and Techniques to overcome the challenges associated with different daylight scenarios in order to enhancement the visual performance of building (Boyce&al.,2003;.Duffy&al.,2009;. Karanouh & al.,2015; López & al.,2015; Lavin&al.,2017; Gunay & al.,2017) , However, with the increasing use of computational design (CD) methods due to their increased computational capacity of tools have enabled researchers to explore and evaluate several complex solutions for the enhancement of building's performance and efficiency (Lee&al,2019), Hence computer-assisted parametric techniques can be used for daylighting assessment in a simple and much more accurate way (Lee &al,2016). However, much work remains to be done on parametric shading, daylighting, and visual comfort measurements through the use of computational simulations.(Pesenti.,2015 ; Edwards &al.,2002. Mahmoud & al.,2016). especially with regard to educational buildings in semi-arid climates, where according to the research background, it is evident that the conducted studies in this context is limited, the present study is an attempt to address this gap.

It is extremely important to highlight that school building in Algeria, were executed regardless of climate variation or the standards requirements for lighting, and regardless of the well-being of the occupiers. Therefore they frequently show severe problems in terms of visual comfort dissatisfaction and wellbeing. In order to identify and solve these problems in modern Algerian school an analysis of the current state is necessary for creating comfortable and heathy indoor environments. Therefore the present study aims to investigate the use of an alternative advanced analysis method to study the impact of architectural elements at the level of indoor lighting in Algerian modern primary schools in order to achieve the near-optimum balanced solution for lighting and visual satisfaction and enables understanding the effect of each element and their interactions together in semi-arid climates.

Several works has been done to date to improve the quality of daylight and visual comfort in within classrooms demonstrate that daylight increases the students health and wellbeing, however In order to achieve an optimum level of indoor illumination in such interiors, the amount of daylight entering the classroom must not exceed the limit at which it would cause discomfort to the occupants. Hence numerous daylight metrics have been developed to analyze the quality of the visual ambient in recent years (Egan.,2002) therefore to fill the identifying gab, and to incorporate the study objective the parametric metrics below were identified through a literature review.

1.1 Metrics for Assessing Daylight

- *Useful Daylight Illuminance (UDI):* the most commonly used indicator for assessing daylight availability in a specific place, it is defined as the annual percentage f illuminance values on the reference point. In studies dealing with educational spaces, the lower threshold is set to 300 lux, coherently with standard recommendations (Costanzo& al., 2017). Carlucci

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et al. (2015) and Hafez (2015) also defined UDI as the illuminances in the 100–2000 lx range based on data from extensive field studies of occupant behavior.

- *Daylight Autonomy (DA)* This metric signifies the percentage of the hours of occupancy when daylight illuminance at a point keeps above a minimum threshold (Galatioto & al.,2016; Reinhart & al.,2001). According to a study carried out by IESNA, the adoption of 300 lux as a threshold leads to statistically significant results (Reinhart & al.,2001).

- The spatial Daylight Autonomy (sDA) describes the percentage of floor area that exceeds a specified illuminance level for a specified amount of annual hours thus sDA is a zonal metric because it shows a single value for each room

-. Annual Sunlight Exposure (ASE). is the percentage of the occupied area where direct sunlight illuminance exceeds a certain value (usually, 1000 lux) for a specified number of hours per year (usually, 250) (Reinhart & al.,2001).When calculating ASE, blinds and shadings must not be taken into account. ASE1000.250h was proposed by the Illumination Engineering Society of North America (IESNA), as one of the metrics codified in LEED v4 and must not exceed 10% of the floor area. (IES.,2012).

-. *Discomfort Glare Probability (DGP)*it is intended to measure the probability that people who disturbed by glare ,it has been suggested by Wienold and Christofferson in 2006. According to its original formulation, DGP is nowadays recognized as the most appropriate metric to assess glare issues, due to its strong correlation with the user's response in terms of glare perception. (Reinhart & al.,2001).

As mentioned, although the UDI and DA calculations are the most used in order to assess the daylighting in space, The DA metric does not indicate whether the environment is visually uncomfortable. Because it does not have an upper threshold for lighting. Unlike other daylight metrics, as the studies on present indices affirmed that the spatial daylight autonomy (sDA) metric forms a clear image of daylight areas and visual comfort eventually.((IES.,2012). Its main advantage on DA is the return of one value sDA representing the whole analyzed area Furthermore, because $ASE_{1000,250h}$ is only assessed on a horizontal (floor or work) plane, a supplemental metric calculated through the observer's field of view is required to better represent the risk of visual discomfort. Based on the information gathered from the literature review, the sDA and ASE are considered as the main indices to assess the visual comfort in the present study.

1.1.2 Parametric design

As the theoretical basis for this research, parametric design is a computational method that can use both generative and analytical approaches in the context of design explorations, indicating a fundamental shift from design alternatives to design logic. (Costanzo & al.,2017). W. Jabi defined parametric design as "a process based on algorithmic thinking that allows for the expression of parameters and outcomes that define, encode, and clarify the relationship between design intent and design response." (Zhang & al.,2020)

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According to Qingsong and Fukuda (2016) Exploring parameter variation within a design space is what parametric design is all about, and it can be used as a decision tool to determine a set of solutions that satisfy (or come close to satisfying) a given problem with multiple requirements. As a result, architects and designers are increasingly using it to solve complex design challenges related to environmental issues. Predicting, assessing, and quantifying a building's performance, for example, can allow users (architects, researchers, etc.) to modify parameters such as building shape, spatial form, and building envelope to ensure that their designs are energy efficient while avoiding the additional cost.(Qingsong & al.,2016), parametric analysis allows the exploration of building performance for various combinations of design specifications (Zhang & al.,2020). The required software programs for parametric design were first discovered in 2008 and then developed by companies and software developers. Grasshopper, a graphical algorithm editor that provides as a parametric modeling tool connected to Rhinoceros 3D and allows designers without formal scripting knowledge to quickly generate parametric shapes, is one of the most widely used software (Leach.,2009).

This study is a parametric study that investigates the role and effect of architectural elements in a study space for better and more balanced natural light distribution. The primary goal is to assess the role of these elements in facilitating work and studying logical order. Where the sDA and ASE metrics were chosen for the daylight assessment. With this objective, a set of data is mainly created based on simulation-derived results. That appeared in grasshopper for rhino and its associated plugins (Ladybug tools). The paper is organized as follows. Section 2 describes the methods. Sections 3 and 4 provide the results and discussion, whereas Section 5 concludes the paper

2. Method and Materials

As mensend before, it is only through parametric design can various design solutions be found using algorithmic methods in response to architectural design difficulties. Therefore, in this research, three-dimensional parametric modeling of a primary school classroom was created in Rhinoceros. After that, Grasshopper plug-ins and Ladybug tools were used to perform environmental analysis. Finally for each of the chosen solutions, sDA and ASE were calculated as indicators of visual comfort. The framework is summarized in (Fig. 1).

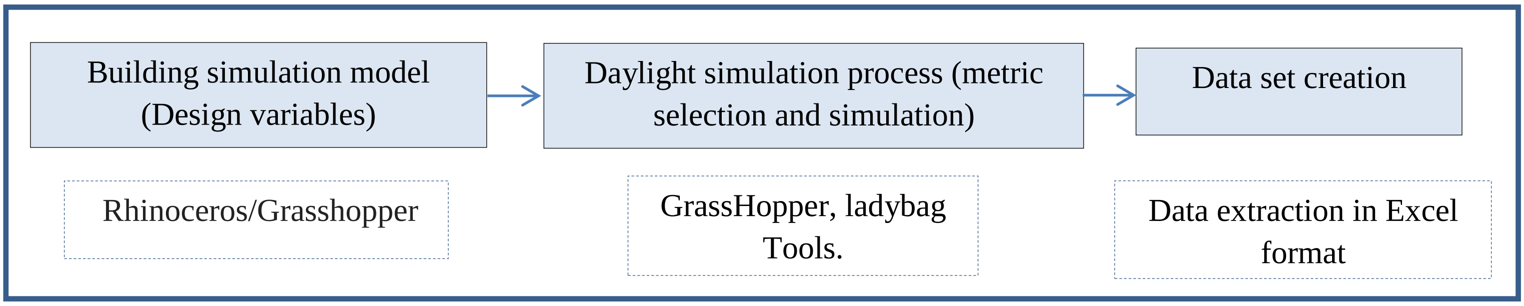

Figure 1 : Research method framework

2. Presentation of case study and design variables

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For the purpose of this study, A typical classroom within primary school located in Ain Mlila, northeast Algeria (latitude: N 36^0 022, longitude E 6^0 56) , was selected as the study case (as shown in Fig. 2). The classroom is located in the first floor of the building and faces north-south.

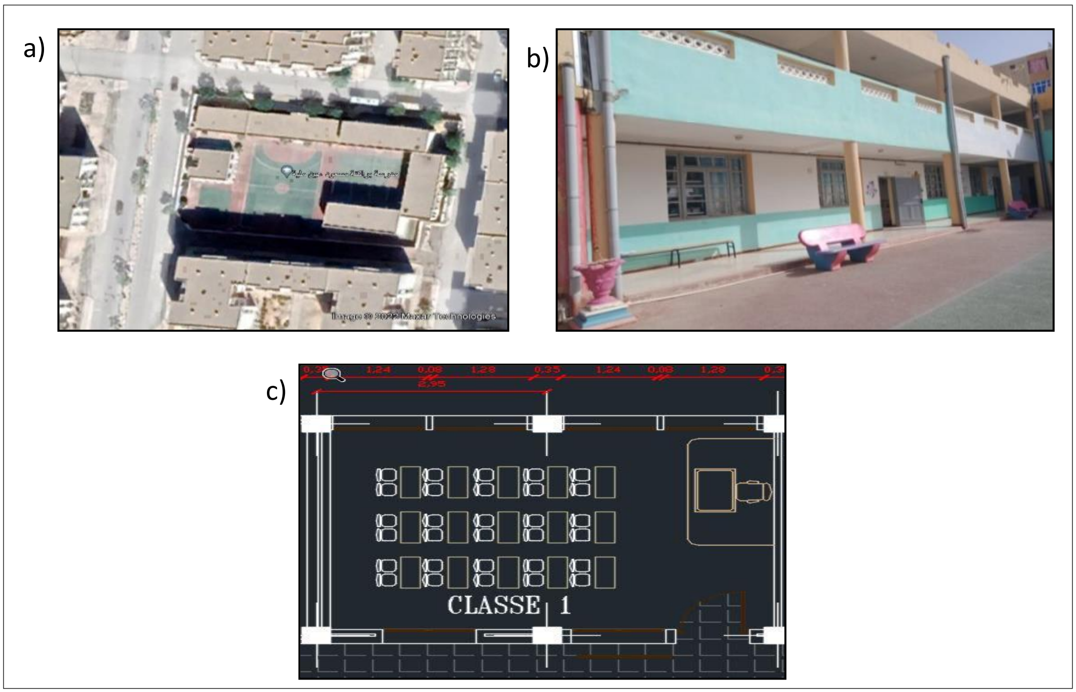

Figure 2 : a) Case site b) detailed information on the school building c) classroom layout

The classroom 3d modeling has been developed in Grasshopper for Rhinoceros, with total surface of 57.81 m^2 (9.25m 6.25 m) 3.20 m height.the work plane is set at 76 cm and the analysis grid is determined at 0.3*0.3 m according to LEED credit's requirements. The spacing between the lighting analysis calculation nodes is set to the program's default value of 0.423m. The WWR is assumed 0.22% in the south façade and 0.47%.on the north façades with 3mm simple glass the daylighting simulation for this model is then run using the lady bag tools for grasshopper to obtain base values for the sDA 300/50% and ASE1000/250hr.(see Figure 3)

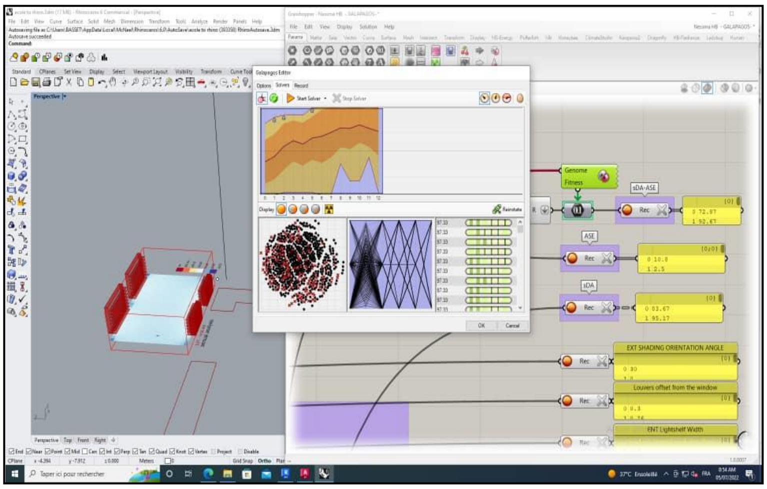

Figure 3: Optimization Process in Grasshopper

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The dependent variables selected for the present work include Louvers material reflection, Glass material transmittance, shading type, intern light shelf width; louvers offset from the window, external orientation angle, These variables were chosen to cover the main parameters that may affect the distribution of daylighting inside the building As shown in Figure 3, some variables were kept constant, including geographical location, climate conditions, orientation, and space dimension.

		Variables in training dataset	Number of alternatives	Variables in validation dataset	Number of alternatives
Independent variables	Location	Ain Mlila	01	Ain Mlila	01
	Occupation	Classroom (Occupancy Time: 08:00 A.M– 15:00 P.M)	01	Classroom (Occupancy Time: 08:00 A.M– 15:00 P.M)	01
	Space dimension (m)	(9.25x6.25x3.20) m	01	(9.25x6.25x3.20) m	01
	Orientation	North-South	01	North-South	01
	interior surfaces reflectance factor (%)	0.2 - 0.4 – 0.7	03	0.2 - 0.4 – 0.7	03
Depend Variables	Louvers material reflection (%)	0.7- 0.9	02	0.7- 0.9	02
	Glass material transmittance (%)	0.47- 0.65 - 0.8	03	0.47- 0.65 - 0.8	03
	shading type	0 – 1 - 2	03	0 – 1 - 2	03
	intern light shelf width (cm)	0.2 – 0.3 – 0.4	03	0.2 – 0.3 – 0.4	03
	louvers offset from the window (cm)	[0,0.3]	30	[0,0.3]	30
	External louvers orientation angle (^{0})	0 – 30 - 45	03	0 – 30 - 45	03

		Variables in training dataset	Number of alternatives	Variables in validation dataset	Number of alternatives
Independent variables	Location	Ain Mlila	01	Ain Mlila	01
	Occupation	Classroom (Occupancy Time: 08:00 A.M– 15:00 P.M)	01	Classroom (Occupancy Time: 08:00 A.M– 15:00 P.M)	01
	Space dimension (m)	(9.25x6.25x3.20) m	01	(9.25x6.25x3.20) m	01
	Orientation	North-South	01	North-South	01
	interior surfaces reflectance factor (%)	0.2 - 0.4 – 0.7	03	0.2 - 0.4 – 0.7	03
Depend	Louvers material reflection (%)	0.7- 0.9	02	0.7- 0.9	02
	Glass material transmittance (%)	0.47- 0.65 - 0.8	03	0.47- 0.65 - 0.8	03
	shading type	0 – 1 - 2	03	0 – 1 - 2	03
	intern light shelf width (cm)	0.2 – 0.3 – 0.4	03	0.2 – 0.3 – 0.4	03
	louvers offset from the window (cm)	[0,0.3]	30	[0,0.3]	30
	External louvers orientation angle (^{0})	0 – 30 - 45	03	0 – 30 - 45	03

Table 1 : Selected parameters and their values

shading types :

0- North façade: int light shelfs, south façade: ext vertical louvers
1- North façade: int light shelfs, south façade: : int light shelfs
2- : North façade: int light shelfs, south façade: : int light shelfs + ext vertical louver

3. Results and Discussion

This paper addressed the utilization of several architectural parameters for the improvements od daylighting performance in typical classroom of primary schools in Algeria, the effect of changing the alternative scenarios on the amount of ASE,sDA and sDA-ASE values in the classroom was identified to analyze glass amount and daylight quality. It aims to keep the sDA as high as possible while reducing the ASE values to below 10%.

3.1 ASE simulation analysis

As can be seen from the graph below (figure 06), it shows and illustrates the simulation results for ASE values for the base-case that were obtained for each scenario, it can be observed that the lowest ASE values in the classrooms were observed for each of scenario 6,9,13,16,1718,19,40 and 41 with values of ASE = 0 % followed by scenario Scenario 4 (ASE = 3%), Scenario 10,45 and 5 (ASE= 5%,7% and 8%) respectively. While it slightly increased in scenario 43, 44 reaching the values of 1.5% Scenarios 31, 36, 34.35, 32.27 and 39 were therefore the least favorable of all alternative scenarios with values of ASE 7.5%, 7.3% 6.7%, 6.5% 6.2%, 5.7% respectively.(see figure6).

According to the LEED, the ASE values should be less than 10% to avoid glare occurrence based on the standard. After optimization, the low amount of ASE = 7.5 % can ensure a glare-free interior space.

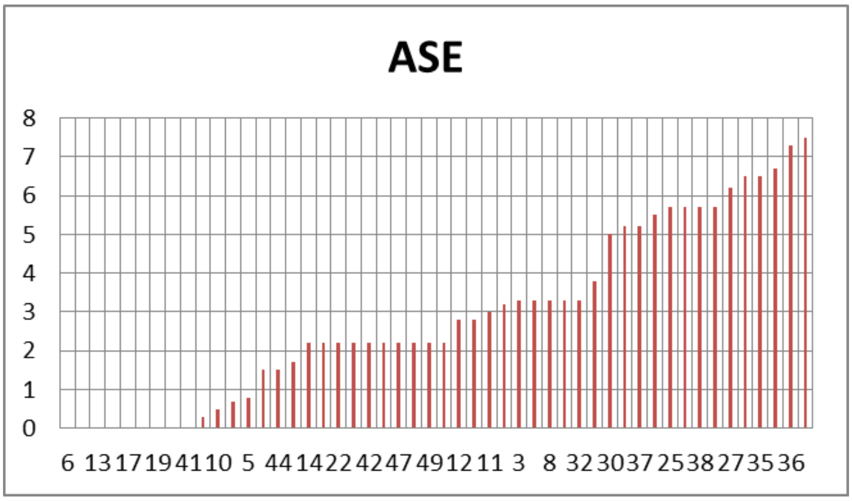

Figure 06: Results of simulated ASE1000,250 for alternative Scenarios.

From the graph above, it can be seen that the best scenarios to Avoid the risk of glare are when:

- the windows on the south side with external louvers with a width of 0.3 m and a distance between them of 0.2 to 0.3 m at an orientation angle of 0^0,30^0,45^0 with material reflection of 90 % ,With glass of 80% transparency.

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- The south window with interior light shelves with a width of 0.3 meters and a distance between them of 0.3 m with material reflection of 90 % and glass of 80% transparency.
- The south window with exterior louvers with a width of 0.3 and 0.2 m distance between elements with at an orientation angle of 45^0 with material reflection of 90 %. And interior light shelves with with a width of 0.3 m and 0.3 m distance between elements or south window with exterior louvers with a width of 1.5 and 0.3 m distance between elements with at an orientation angle of 30^0 with material reflection of 90 %. and interior light shelves with with a width of 0.3 m and 0.3 m distance between elements or South window with exterior louvers with a width of 0.2 and 0.2 m distance between elements with no orientation angle with material reflection of 90 %. and interior light shelves with a width and distance between elements of 0.2 m. with glass of 80% transparency
- the north window with interior light shelves of 0.2 m width and 0.3 m distance between elements and south windows with interior light shelves of 0.2 m width 0.3 m distance between elements at an orientation angle of 30^0 and exterior louvers with 0.1 m of width and 0.3 m distance between elements at an orientation angle of 30^0 with material reflection of 90 % with glass of 80% transparency

In this case, it is also important to notice that the integration of light shelves (int or ext) on the north windows associated with external louvers on the south windows increases the values of ASE in the space. Those results demonstrate the effectiveness of changing the type and position of the light shelves on the ASE values and the difference in the angle of louvers orientation where it was noticed that the lower angles performed better than the upward tilting angles because it blocks the sun's direct radiation.

3.2 sDA simulation analysis

According to the graph (figure 07), sDA values started to reach a plateau of 94.33% for scenario 14, then 94.17% for scenario 31 followed by 93.5 % for scenario 23, and 92.83% for scenario 29,92.67% for scenario 13 Respectively. While it slightly decreased in scenario 1 to reach the values of 67.83% and scenario 16 with value of 63 %. To reach the lowest estimated value of 28.5% for scenario 49 and 50.(see figure 7).

The LEED v.4 requirements was sDA was to kept greater than or equal to 75 %.

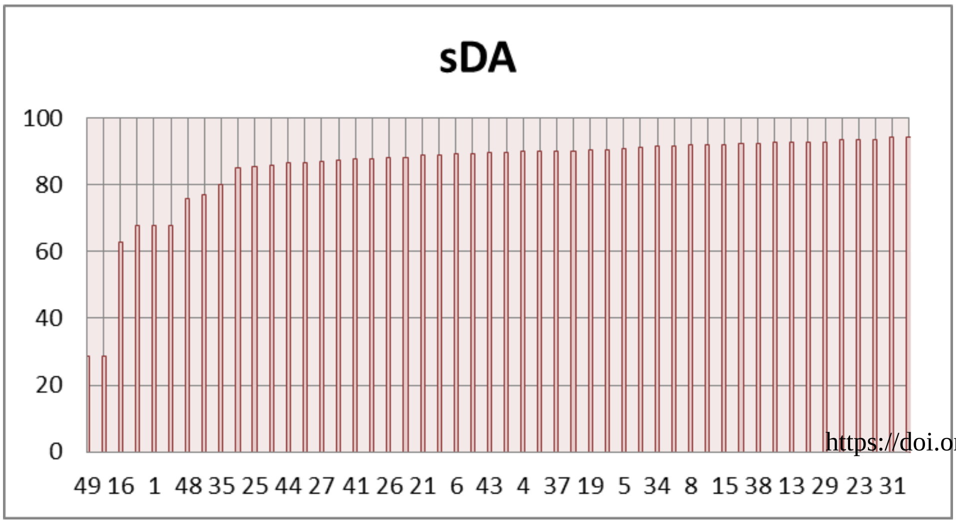

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Figure 07: Results of simulated sDA300/50% for alternative Scenarios.

The simulation results indicates that the classrooms having a north window with interior light shelves and south window with exterior louvers with an angle orientation of 0^0 and 80% glass transmission or an angle of 45^0 with 65 % glass transmission on the south window Produced a very acceptable daylight performance, the highest values of sDA was 94.33%.

The results also indicates that the classroom having interior light shelves on the south window with width of 0.3 m and distance between elements of 0.3 m and 80% glass transmission on and 90 % material reflection. Or having an exterior light shelves on the north window and exterior louvers on the south ones with and angle of orientation of 30^0 and width of 0.4 m and distance between elements of 0.4 m for the light shelves and width of 0.1 m and distance between elements of 0.3 m for the louvers and 80% glass transmission and 90 % material reflection also produced an acceptable daylight performance with sDA was 92.67% and 92.5% respectively.

However, the lowest values of sDA were observed when the classroom having on the north window an interior light shelves with width of 0.3 m and distance of 0.4 m associated with interior light shelves and exterior louvers on the south ones with 47% glass transmission and with no angel of orientation of louvers. Or the classroom having exterior louvers with width of 0.3 m and 0.2 m of distance and an angle of 45^{0} and interior light shelves with width and distance between elements of 0.3 m on the south windows and 80% glass transmission produced unacceptable daylight performance. (see figure 8).

It can be seen that the sDA values whanged with the change of type and positon of light shelves and the angle and glass transmission on the south windows.

3.3 sDA-ASE simulation analysis

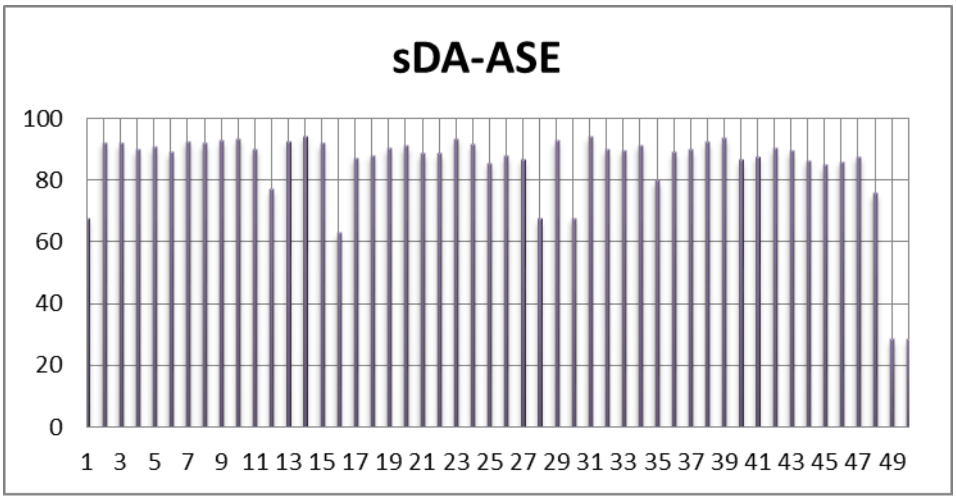

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Figure 08: sDA and ASE values

According to the graph (figure 08), sDA-ASE values started to reach a plateau of 92.83% for scenario 9, then 92.67% for scenario 31 followed by 92.13 % for scenario 14 While it slightly decreased in scenario 20 ,21 and 22 to reach the values of 88.97%,87.63% and 87.13 % respectively, The value decreased further in scenario 16 to 63%. To reach the lowest estimated value of 26.3% for scenario 49 and 50.

Figure 8 shows that the best results support user comfort at the end of the optimization are when the classroom has an interior light shelves on the south windows, because it faces the sun paths and reducing direct glare and allows balancing the uniformity of illuminance at the working plan and the visual environment with material reflection of 90 % and glass of 80% transparency. Also the best performing configuration is when the classroom has on the south windows exterior louvers with different sizes (mostly have similar performance to each other) with an angle of rotation of 0^0 associated with interior light shelves. With material reflection of 90 % and glass of 80% or 65% transparency on the south glass windows and 80% on the north one. And to a less extent when classroom have on the north windows interior light shelves, and on the south windows exterior louvers with an rotation angle of 45^0 and glass of 47% transparency on the south glass windows and 80 % on the north one, that proves the effectiveness of the difference in the angle of louvers orientation and glass transmission in controlling the amount of daylighting that is admitted on the south side, where it was noticed that the lower angles performed better than the upward tilting angles because it blocks the sun's direct radiation. This configurations Allow sufficient amount of daylight and reduce exposure to sunlight at a level that will not disturb the user While the lowest values were observed when the classroom has on the north windows an interior light shelves associated with interior light shelves, and exterior louvers on the south windows du the ineffectiveness of light shelves on the north –facing windows.

Conclusion

The results reposted in this paper demonstrates the importance of shading devices, glass transmission and Louvers Material Reflection in visual comfort of school's users, the aim was to arrive at solutions that improve daylight distribution and at the same time reduce glare to acceptable levels (sDA-ASE values).the proposed solutions for mitigating solar gains and controlling the daylighting distribution is the installation of interior light shelves on the south windows with material reflection of 90 % and glass of 80% transparency. An acceptable daylighting performance can be achieved also when the classroom has on the south windows exterior louvers with different sizes (mostly have similar performance to each other) with an angle of rotation of 0^0 associated with interior light shelves. With material reflection of 90 % and glass of 80% or 65% transparency on the south glass windows and 80% on the north one. And to a less extent when classroom have on the north windows interior light shelves, and on the south windows exterior louvers with an rotation angle of 45^0 and glass of 47% transparency on the south glass windows and 80 % on the north façade.

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It is important to note that this paper only tested specific conditions and other factors may require further research, all the configurations only refer to the city of AIN Mlila. It is suggested also that further research would be conducted to test other variables such as the effect of different WWR on the sDA and ASE values.

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