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Evaluation of Static Horizontal Louvers on Annual Daylighting Performance in Classrooms

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ABSTRACT

Daylighting has a great impact on student's health, learning performance, and productivity. The goal of this paper is to enhance daylighting performance by examining the year-round daylighting performance of Southern facades in the case of one central window in a classroom located in Cairo, Egypt by using static external horizontal shading devices during the Fall, Spring, and Summer semesters The scope of the study is to evaluate and assess the effect of the window-to-wall ratio (WWR) in addition to the louvers' configurations of depth and count parameters of the classroom on annual daylighting performance metrics for classrooms' southern facades by using Rhinoceros, Grasshopper interface and Honeybee Plus plugin which uses the Radiance engine for annual daylighting Simulations. Annual Sunlight Exposure, Spatial Daylight Autonomy, and upper and lower limits of useful daylight illuminance are incorporated for an efficient annual daylighting performance. Based on geographical location and sun altitude angles that are gathered from ladybug tools, three alternative configurations of fixed horizontal louvers were investigated to evaluate the difference between them. Results show a low difference with the proposed louver configurations cases and a high reduction in annual sunlight exposure by 78% which complies with LEED v4 and IES-LM-83-12 criteria.

1. Introduction

School classrooms should be designed not only considering high academic performance but also for the wellbeing of the students. What if some factors, like daylighting, could have a positive impact on students' academic performance as well as their well-being? Egypt is classified as a desert and hot-arid climate according to Köppen's climate map [1]. In Egypt, educational buildings are being constructed with large areas of glass in their facades and this makes them more aesthetically pleasing but, the downside to this trend is that such buildings, especially in hot arid countries have great potential for year round high solar radiation, primary school students spend around 5 hours a day in classrooms and their environment can have a significant impact on their academic performance [2]. In terms of design, it is essential to consider sun path and building orientation. This is not only essential in terms of building performance to avoid overheating and glare, but also a key in providing the best environmental conditions for students, especially for daylighting performance. Findings showed that horizontal sun breakers have a strong influence for increasing protrusion in the southern façades. [3]. Because of the high position of summer sun in southern facades, several authors recommend that horizontal shades be implemented to these facades. [4]. Similarly, another research in a comparable climate of Egypt found that horizontal shades can save up to 18.6% of energy in south-oriented facades [5]. In this paper, simulation is used to guide design decisions for annual daylighting performance in classrooms' southern facing facades.

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Nomenclature

ASE	Annual Sunlight Exposure	LEED	Leadership in Energy and Environmental Design
EPW	Energy Plus Weather file	sDA	Spatial Daylight Autonomy
IES	Illuminating Engineering Society	UDI	Useful Daylight Illuminance
HL	Horizontal Louvers	WWR	Window-to wall ratio

1.1. Impact of Daylighting performance

Several studies have highlighted the impact of daylighting in learning environments for both students and educators. It was proven that taking these impacts into consideration will generally enhance the lighting status in classrooms.

- **Energy performance in buildings**

According to the Architectural Energy Corporation, daylighting can significantly increase a space's energy efficiency when electrical illumination and solar heat gain are adequately controlled ***[6]***. There is an approximately 40% of the energy used in the world, including up to 65% of electrical energy, is consumed by buildings. Additionally, a significant amount of the electrical energy used by non-residential and commercial buildings is for lighting ***[7]***. Hence, in recent years reducing the energy consumed for lighting is one of the key strategies for this sector to increase energy efficiency ***[8]***.

- **Daylighting and Students' Academic Performance**

Students and teachers can benefit from adequate daylighting integration and management. Saving energy, improving student's leaning performance, health and creating a less stressful atmosphere for students are just a few of the advantages of appropriate daylighting in educational environments [9]. Heschong and Mahone investigated how daylighting affected students and found that it increased test scores by up to 20% [10].Taylor declared that students in classrooms with the most daylighting made 20% and 26% faster progress compared to classrooms with little or no daylight [11]. Another study by Kim et al. on daylighting quality in South Korea's educational facilities showed that daylighting had an impact on the quality of the learning environment and students' learning performance [12].

On the other hand, a school with poor lighting design may demote students' ability to learn. Students may experience eye strain, a reduction in their learning ability and information processing, and an increase in stress levels due to the poor lighting quality in the classroom [13].

- **Human body and health risks**

Daylighting can have positive psychological and psychological effects on human beings, which can range from improving alertness, mood, and productivity. According to Shishegar and Boubekri's investigation, workers and students who are exposed to daylighting instead of artificial lights show better performance and more alertness [14]. Studies have shown that daylighting has an impact on humans' well-being, happiness, and attentiveness. Daylighting has an impact on circadian rhythm, which synchronizes the human's body internal clock.

1.2. Annual Daylighting performance metrics

These metrics give an indication of daylighting adequacy and visual comfort. The metrics applied in this paper are Spatial Daylight Autonomy ($sDA_{300/50\%}$), Annual Sunlight Exposure ($ASE_{1000/250h}$) and Useful Daylight Illuminance ($UDI_{300\text{-}2000lx}$).

- **Spatial Daylight autonomy (sDA)**
  According to IES metrics, sDA describes the percentage of floor area that receives at least 300 lux for at least 50% of the annual occupied hours, also it describes the annual sufficiency of ambient daylighting levels in indoor areas. It is defined as "The percentage of an analysis area that reaches a minimum daylight illuminance level for a specific fraction of the operational hours per year".[6]
- **Annual Sunlight exposure (ASE)**
  ASE describes how much of the space receives too much direct sunlight, which can cause visual discomfort (glare). According to IES and LEED v4 metrics, ASE measures the percentage of floor area that receives at least 1000 lux for at least 250 occupied hours per year, no more than 10% of the points in the analysis grid should fail this measure [15], [16]. It describes how much of a space receives excessive direct sunlight, which can increase heating loads or cause visual discomfort (glare).
- **Useful Daylight Illuminance (UDI)**
  There is a set of three evaluation metrics for each test point in the classroom. The percentage of time of a point that receives less than the minimum threshold (300 lux) may produce visual or thermal discomfort. The useful daylight illuminance is achieved between the lower and upper limits (300 - 2000 lux) [17]. When the illuminance values exceed (2000 lux), it starts to predict glare conditions in space.

2. Methodology

2.1. The Goal

The goal of this paper is to enhance daylighting performance by examining year-round daylighting performance of Southern facades in the case of one central window in a classroom located in Cairo, Egypt by using static external horizontal shading devices during the Fall, Spring and Summer semesters and evaluating their different configurations of depth and count.

2.2. Scope:

The paper focuses on the southern facades of a classroom by using different configurations of external static horizontal shading louvers' **depths and count** in relation to WWR% to provide optimal illuminance values.

2.3. Methods and tools:

The current paper used Radiance computation engine which is used for calculating, visualizing, and analyzing light. It is based on backward ray tracing, and has been proven valid in various studies related to daylighting, as it is applicable to a wide range of daylighting devices, materials and geometries [18], [19]. Radiance engine version (5.4a 28-3-2021) **is** used for annual daylighting simulation through the interface of Rhinoceros, Grasshopper, and Honeybee Plus plugin version (0.0.06). As shown in Figure 1, horizontal louvers' depths are determined by sun altitude angles through Ladybug Tools plugin, sun altitude angles are used at 12:00 pm noon during Fall semester (Sep. to Jan.), Spring semester (Feb. To June) and summer semester (July to August) due to its high radiation on southern facades in Cairo, Egypt. A virtual prototype of classroom has been constructed using Rhinoceros interface and Grasshopper plugins. As shown in Table 1, the study will iterate 7 different values of WWR% starting from 15% to 45% by 5% increments with a fixed wall area of $24m^2$ including windowsill 0.9m and 1.5m window height. In Table 2, the study also iterates three different configurations of static horizontal louvers to evaluate their effect on annual daylighting performance. The simulation results of the classroom were recorded by the TT toolbox plugin and compared with each other, then the best cases are chosen according to IES and LEED v4 metrics criteria [15], [16].

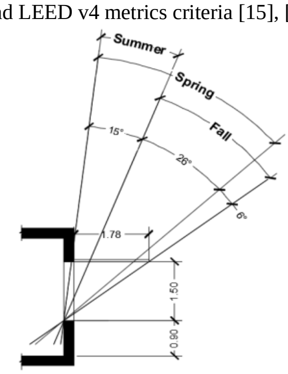


Figure 1: Sun altitude angles for educational semesters

Table 1: Base case alternatives with WWR%

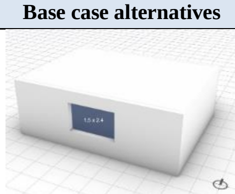
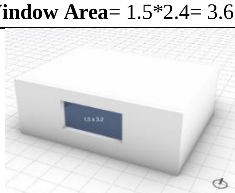
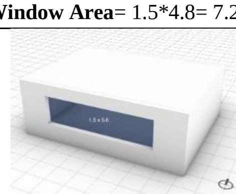
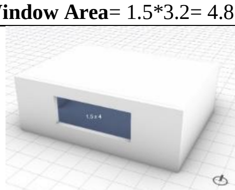
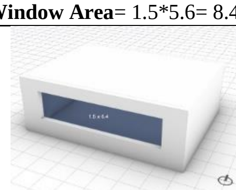
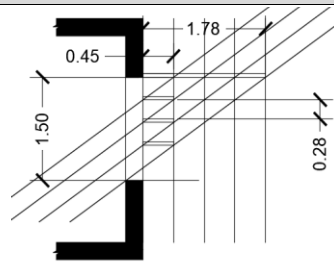
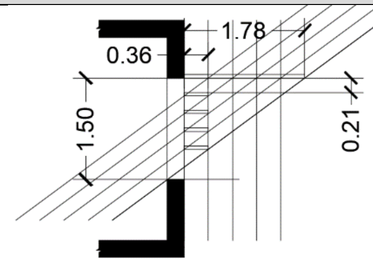
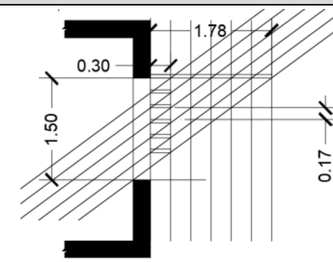
Base case alternatives	WWR%	Base case alternatives	WWR%	Base case alternatives	WWR%
 **Window Area**= 1.5*2.4= 3.6 m^2	**15%**	 **Window Area**= 1.5*4.8= 7.2 m^2	**30%**	 **Window Area**= 1.5*7.2= 10.8 m^2	**45%**
 **Window Area**= 1.5*3.2= 4.8 m^2	**20%**	 **Window Area**= 1.5*5.6= 8.4 m^2	**35%**		
 **Window Area**= 1.5*4.0= 6.0 m^2	**25%**	 **Window Area**= 1.5*6.4= 9.6 m^2	**40%**		

Table 2: Louvers' depths and count configurations

No. of louvers	4 Louvers	5 Louvers	6 Louvers
Configuration			
Louvers parameters	Louver depth= 0.45m Louver spacing= 0.28m	Louver depth= 0.36m Louver spacing= 0.21m	Louver depth= 0.30m Louver spacing= 0.17m
WWR%	15%, 20%. 25%, 30%, 35%, 40%, 45%		

2.4. Simulation framework

The simulation study passed through four main consecutive phases:

- Parametric Modeling of the classroom prototype and static external horizontal louvers using (Rhinoceros and Grasshopper)
- Annual Daylighting Simulation is performed by (Ladybug Tools and Honeybee Plus plugins)
- Analyzing and Recording Results using (TT Toolbox Plugin and Microsoft Excel)
- Conclusions and Recommendations will be conducted, and best cases are chosen by minimizing ASE, maximizing both sDA & UDI metrics.

The occupied time of the classroom was assumed to be from 8:00 AM to 6:00 PM, with one weekend day on Friday. As shown in Figure 2, test points were constructed based on a grid of 0.5 x 0.5m at work plane of height 0.762m (30") above the floor to test the daylighting performance of the classroom.

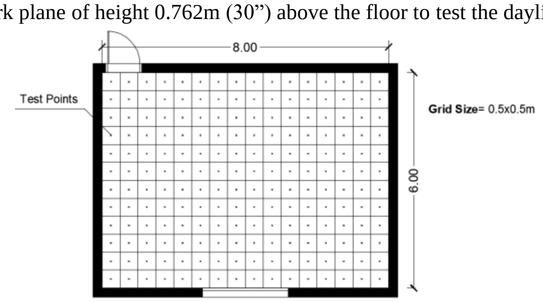


Figure 2: Analysis grid of classroom prototype

Daylighting performance simulation is done by using different parameters that affect the quality and quantity of data, in this section all parameters are set by Grasshopper to conduct the daylighting simulation using Honeybee Plus Plugin. Based on numerous publications and classroom guidelines such as Montana State University Classroom Design Guide [20], simulation study parameters are divided into modelling parameters, finishing materials and simulation settings as shown in Table 3:

Table 3: Simulation study parameters

Modelling parameters	
Prototype Dimensions	8.0m length x 6.0m width x 3.0m height
Floor Level	Typical Floor
Location (EPW File)	Cairo.Intl.AP_QH_EGY (30.12200, 31.40600)
Examined Façade	Southern Facade
Windowsill height	0.9m
Window Height	1.5m
WWR%	15%, 20%, 25%, 30%, 35%, 40%, 45%.
Louvers' count and depths	4 louvers, 5 louvers, 6 louvers with depths 0.45, 0.36, 0.30 Respectively
Finishing materials (According to numerous publications & Montana State University Classroom Design Guide [20])	
Walls	50% reflection "radiance opaque material", Matte Specular, perfectly smooth surface.
Floor	20% reflection "radiance opaque material", Matte Specular, perfectly smooth surface.
Ceiling	80% reflection "radiance opaque material", Matte Specular, perfectly smooth surface.
Louvers	50% reflection "radiance opaque material", Matte Specular, perfectly smooth surface.
Glazing	Tinted double glass material (visual transmittance = 74 %)

Simulation settings												
Sky Matrix	Reinhart Sky (for more accurate results than Tregenza sky)											
Analysis Grid	0.5m x 0.5m											
Work plane Height	0.762m (30 inch)											
Radiance Parameters for daylighting matrix calculation (Honeybee plus plugin defaults)	-aa 0.2	Ambient accuracy	-ab 7	Ambient bounces	-ad 1000	Ambient divisions	-ar 64	Ambient resolution	-as 2048	Ambient super-samples	-dc 0.5	Direct certainty
	-dj 0.5	Direct jitter	-dp 256	Direct presamp density	-ds 0.25	Direct sampling	-dr 1	Direct sec relays	-dt 0.25	Direct threshold	-I true	Irradiance calc
	-lr 6	Limit reflection	-lw 6.67e-07	Limit weight	-c 1	Sampling rays count	-ss 0.7	Specular sampling	-st 0.5	Specular threshold		

2.5. UDI, sDA and ASE Results

Based on LEED v4 and IES-LM-83-12 requirements [16], [15], three daylighting acceptance criteria had to be satisfied in this paper: ASE to be minimized below 10% to receive at least 1000 lux for at least 250 occupied hours per year, sDA to be maximized above 75% to receive at least 300 lux for at least 50% of the annual occupied hours and UDI to be maximized above 60% to receive more illuminance values within the year between the lower and upper limits (300 - 2000 lux).

Three UDI evaluation levels are used in this paper to be “Under lit”, “Daylit” & “Over lit” areas as follows.

- The “Under lit” areas which indicate minimum Illuminance values below 300lux and may produce visual or thermal discomfort.
- The “Daylit” areas which are considered the most Useful Daylight Illuminance that lie between 300-2000lux [17], those areas receive sufficient daylighting for efficient learning through at least half of the year-round occupied time.
- The “Over lit” areas expressed as maximum Illuminance values that received an overabundance of daylighting levels above 2000lux, and it is not desired due to possible occurrence of glare and/or overheating.

3. Results & Analysis

3.1. Results of Base Case Alternatives

Figure 3 shows an increase in ASE starting from 12% to 33.3% and sDA from 62% to 100% without any louvers which does not comply with LEED v4 and IES criteria in ASE Results. The useful illuminance for learning described by “Daylit” areas in Figure 3 shows a highest percentage 69.2% with 25% WWR. Percentage of “Over lit” areas has increased from 7.6% to 32.5% which is not desired due to possible occurrence of glare and/or overheating. In the case of 25% WWR, it is considered as the best of the worst cases in this figure which needs more shading to reduce ASE metric.

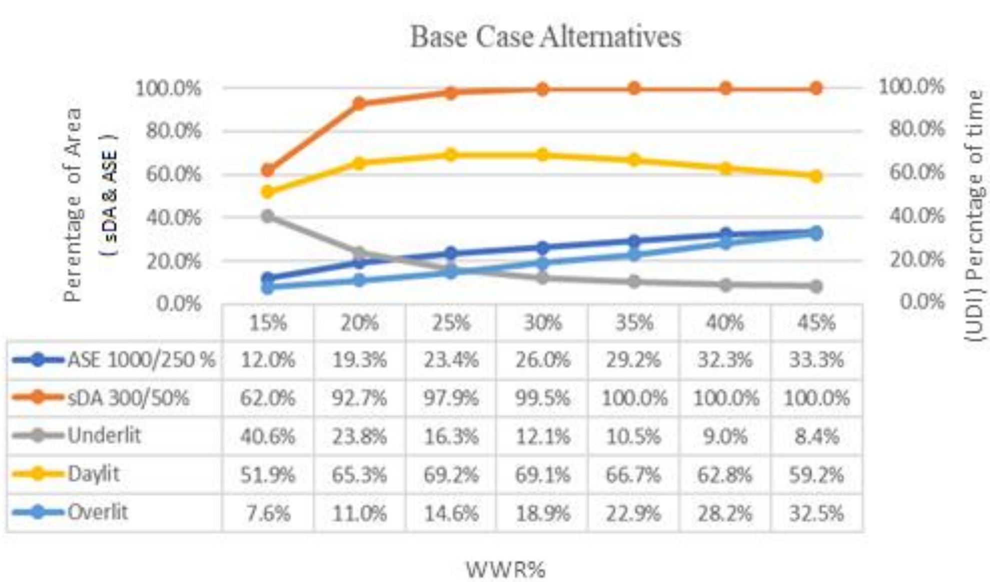


Figure 3: Results of base case alternatives

3.2. Results of Horizontal Shading Louvers

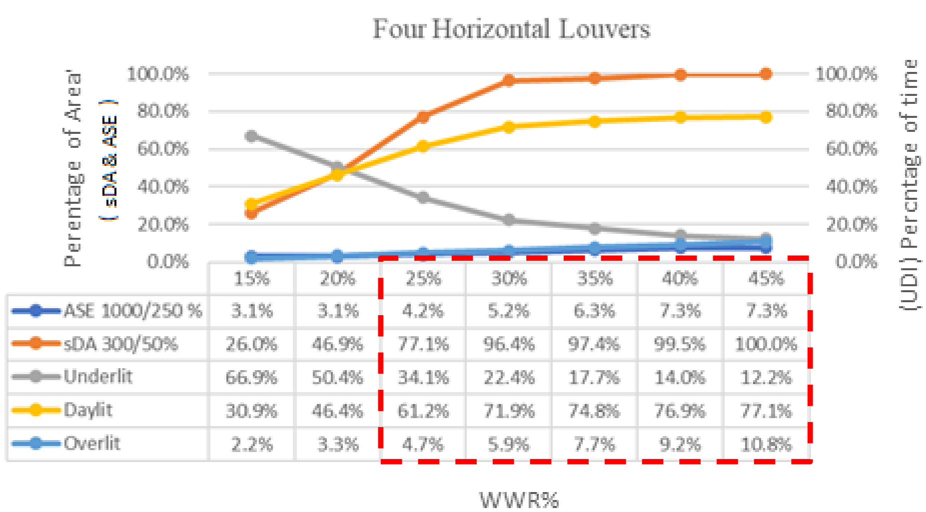
By changing the louvers' depths, different cases are proposed to examine the difference between them in relation to their count and the WWR% as shown in Table 2.

In Figure 4, 5 & 6, Results of the different configurations of horizontal louvers show a significant change in ASE that is decreased by approximately 78% in all base case model alternatives, which complies with LEED v4 and IES criteria[16], [15]. For the Southern façade, the three cases are almost similar in ASE and sDA, but slightly differ in UDI results.

Also, starting from 30% WWR cases, results show the following:

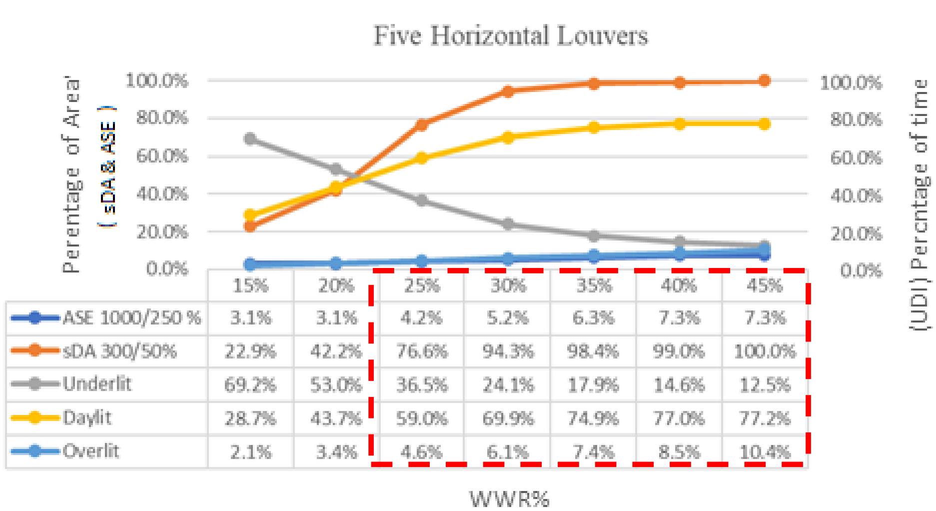
- The "Daylit" and "Over lit" areas are directly proportional with the increase of WWR%.
- ASE & sDA comply with "preferred" LEED v4 [16] and IES-LM-83-12 [15] annual criteria.
- An increase in UDI in relation with the results of the base case alternatives increases the percentage of "Daylit" areas and decreases ASE values.
- Below 35% WWR, a lower number of louvers is slightly better than a greater number of louvers, but glare simulations would be recommended to evaluate the percentage of "Under lit & Over lit" areas.

Results also show that all cases of the horizontal louvers achieved the same ASE values, however the highest sDA & UDI values below 35%WWR are achieved in case of four horizontal louvers as in Figure 4. On the other hand in case of five & six horizontal louvers in Figure 5 & Figure 6, the transformation of results starting from 35% WWR show a slightly higher value of "daylit" areas (77.4%), which means that above 35% WWR, the percentage of "Daylit" areas is higher in case of greater number of louvers. In Figure 6, the option of 25%WWR is not preferred as it shows 67.2% sDA which gives 2 credits not 3 credits in LEED v4 annual criteria [16].



	15%	20%	25%	30%	35%	40%	45%
ASE 1000/250 %	3.1%	3.1%	4.2%	5.2%	6.3%	7.3%	7.3%
sDA 300/50%	26.0%	46.9%	77.1%	96.4%	97.4%	99.5%	100.0%
Underlit	66.9%	50.4%	34.1%	22.4%	17.7%	14.0%	12.2%
Daylit	30.9%	46.4%	61.2%	71.9%	74.8%	76.9%	77.1%
Overlit	2.2%	3.3%	4.7%	5.9%	7.7%	9.2%	10.8%

Figure 4: Results of four horizontal louvers



	15%	20%	25%	30%	35%	40%	45%
ASE 1000/250 %	3.1%	3.1%	4.2%	5.2%	6.3%	7.3%	7.3%
sDA 300/50%	22.9%	42.2%	76.6%	94.3%	98.4%	99.0%	100.0%
Underlit	69.2%	53.0%	36.5%	24.1%	17.9%	14.6%	12.5%
Daylit	28.7%	43.7%	59.0%	69.9%	74.9%	77.0%	77.2%
Overlit	2.1%	3.4%	4.6%	6.1%	7.4%	8.5%	10.4%

Figure 5: Results of five horizontal louvers

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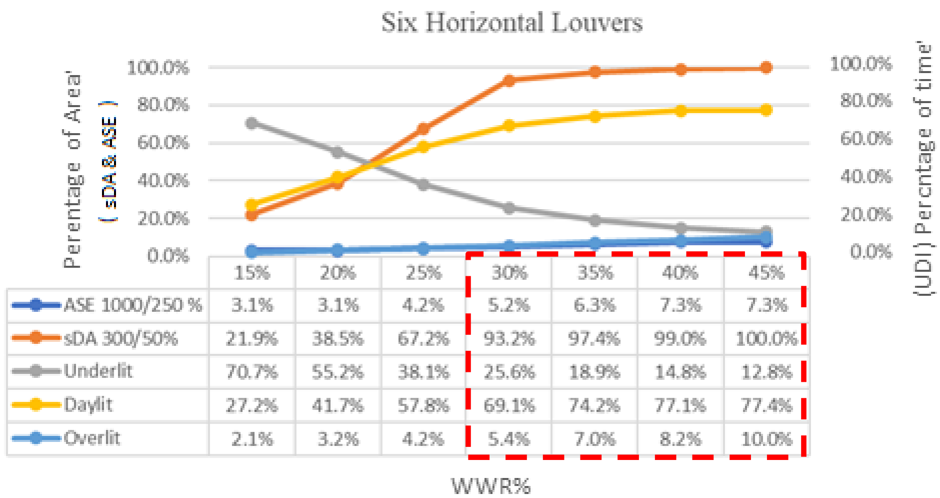

Figure 6: Results of six horizontal louvers

4. Conclusions

By using static external horizontal louvers, results show that:

- When designing classrooms windows consider starting from 30% WWR.
- Blocking sun radiation at 12:00 noon with horizontal louvers in southern facades during educational semesters minimizes the ASE values by 78% from the base case.
- There is an inversely proportional relation between static horizontal louvers' count and the percentage of "Over lit" areas, as glare simulations would be recommended to evaluate the percentage of "Under lit & Over lit" areas.
- There is a directly proportional relation between the static horizontal louvers' count and the WWR%, as by adopting the suggested methodology, using a low number of louvers is preferred when WWR% is below 35%. However, when WWR% is greater than 35% it is better to use greater number of louvers.
- The Suggested methodology have the same results of ASE metric in the three different configurations.
- As shown in Figure 7, the different configuration alternatives of the horizontal louvers' (HL) depths and count within the suggested methodology show a slight difference in UDI results and transformation of results starting from 35%WWR.

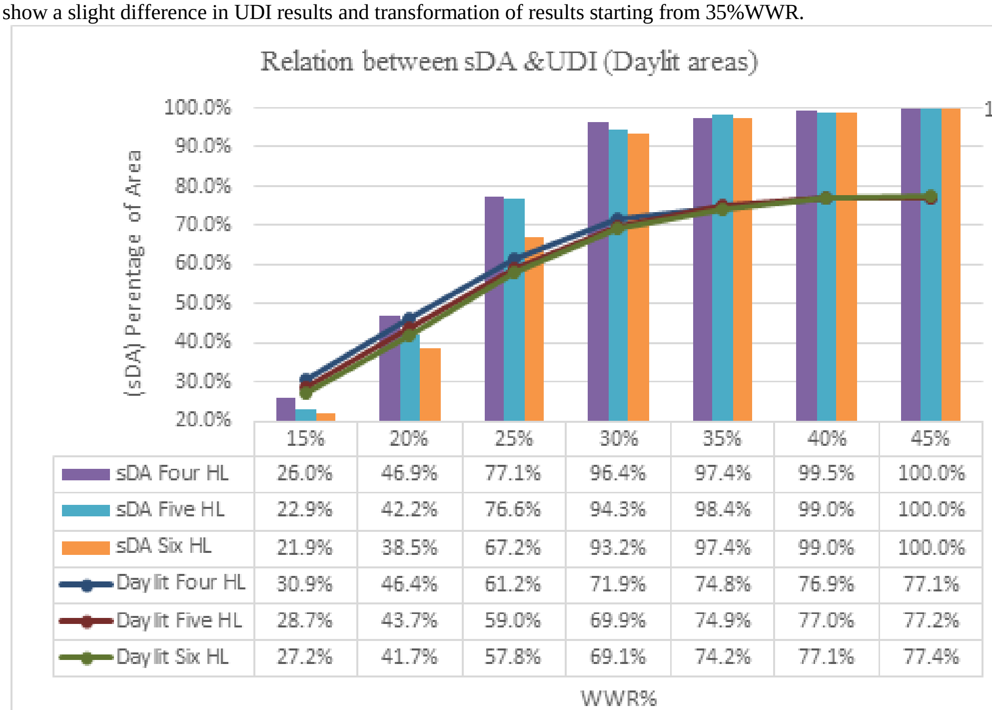

Figure 7: Relation between sDA &UDI (Daylit areas) results

5. Recommendations

To control annual daylighting performance when using louvers in classroom's window design, it is recommended to:

- Conduct a glare analysis simulation considering the UDI metric to evaluate the low or high percentage of glare occurrence or visual discomfort.
- Further investigate and evaluate different configurations of movable louvers to different classrooms' facades orientations.
- Considering the effect of various window configurations on annual daylighting performance.
- Explore the effect of different finishing materials and colors of classroom's louvers systems on daylighting and energy performance.

Acknowledgements

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