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SPATIAL DAYLIGHT AUTONOMY IMPRECISION CORRELATED TO THE INCREASED APPLICATION OF DAYLIGHT DRIVEN DESIGN

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ABSTRACT

The automation across a variety of platforms of Spatial Daylight Autonomy (sDA) creates instances of imprecise results; the user must be aware of the limitations of the daylight analysis platform should they hope to pursue accurate analysis results in accordance with IES LM-83-12: Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE). The range of sDA results for an identical shoebox model assessed in a variety of software platforms that range from conceptual daylight simulation platforms to technical daylight simulation platforms will be presented. The primary contributor to the disparity between various simulation platforms is the ability for a dynamic software simulation to account for the action of occupants as they interact with the daylit space. The concern in software platforms that do not address the amount of usable daylight accurately through the behavior of building occupants is an overestimate of usable daylight levels. Specific to the simulation platforms tested, the experimental simulated sDA results will indicate the degree of inaccuracy as daylight analysis automation introduces more users to the world of daylight driven design metrics. The results of this study will help an analyst choose which platform to use for sDA analysis; weighing compatibility with IES LM-83-12, simulation time, knowledge base of the analyst, etc.

INTRODUCTION

Including daylight analysis into the design of high-performance buildings is a necessary step that ties together the impact of occupant comfort, productivity, and energy consumption. There are a variety of tools in the industry that aide the architect, designer, engineer, and/or analyst in evaluating the daylight performance of a space. Provided that a range of skill and expertise levels are incorporating daylight analysis into the design process a tool exists on the market which will meet the need of virtually any user.

Historically, as the urban fabric became denser in the early 20th century in tandem with air pollution as a byproduct of industrial growth, office buildings and school began to lose daylight quality. The loss of accessibility to daylight meant that electric lighting began to be more widely used to provide adequate light levels during the daytime. (Heschong, 2012)

It wasn't until the embargo declared by the Organization of Arab Petroleum Exporting Countries (OPEC) that triggered the 1973 oil crisis increased the price of operating a building that energy and daylight efficiency started to grow. National research efforts were convened to develop window technologies, lighting controls, energy simulation programs and daylight simulation programs such as Radiance to address the market's demand for better performing buildings. (Heschong, 2012)

Radiance was developed to model and visualize daylight; it is open source and uses a backwards ray tracing engine to model spaces. An early interface that used the Radiance daylight coefficient method to perform annual simulations was DAYSIM. (Reinhart, et al., 2000) With this method the sky is divided into 145 divisions which reverse calculates coefficients to relate the luminance of each sky division to the illuminance of a point inside the space. This method provides illuminance results that are accurate for individual time steps as well as averaged over the year. Radiance continues to be modified to adapt to the demands of the design community for fast, reliable results. (McNeil, et al., 2012)

To quantify the dynamic behavior of daylit environments requires a different methodology than those that were previously developed for spaces looking solely at electrical illumination. The spatial context of the room and aperture, interior furniture/ finishes, the location of the sun, quality of the sky and clouds varying in luminous strength and position over the course of a year, and daylight control devices are all variables at play in these dynamic, annual daylight simulation metrics. (IES, 2012)

The intent behind the development of IES LM-83-12 Approved Method: IES Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) was to define a consistent methodology that would allow for daylight design comparisons to be evaluated in a common language by building codes or design guidelines. Fundamental daylight metrics were lacking in the industry that could be used to assess the entire daylit area for an entire year, considering climatic variables. The two metrics described in IES LM-83-12 allow for the calculation of adequate daylight illuminance and the potential risk of excessive sunlight entering the regularly occupied floor area. (IES, 2012)

"The first metric is Spatial Daylight Autonomy (sDA), a measure of daylight illuminance sufficiency for a given area, reporting a percentage of floor area that exceeds a specified illuminance level for a specified number of annual hours. The second metric is Annual Sunlight Exposure (ASE), which provides a second dimension of daylight analysis, looking at one potential source of visual discomfort: direct sunlight (IES, 2012)."

METHODOLOGY

The intent of the methodology provided herein is to present the approach in evaluating identical daylight models across different platforms. The sDA metric measures an illuminance threshold on horizontal surfaces to first assess the number of hours per year that each analysis point within a given analysis area meets or exceed this value from daylight along. The Daylight conditions are based on typical meteorological year (TMY) data with an analysis time period extending from 8AM to 6PM local time. Interior blinds must also be modeled for the spaces (IES, 2012). $sDA_{300/50\%}$ sets the illuminance threshold at 300 lux which must occur for 50% or more occupied hours of the year.

IES LM-83-12 methodology requires that all exterior windows be modeled with blinds or shades unless it is known that blinds will not be installed or if the Annual Sunlight Exposure has less than 250 hours per year with an illuminance measured of 1,000 lux ($ASE_{1000,250h}$) of direct sunlight. The blinds must be closed if more than 2% of the grid points receive direct sunlight per window group based on coplanar window and orientation.

Four daylight simulation plugin/software programs were chosen to evaluate the $sDA_{300/50\%}$ results:

- Software A: ClimateStudio
- Software B: DIVA-for-Rhino
- Software C: LightStanza (Revit)
- Software D: Sefaira Plugin (Sketchup)

Table 1 Plugin/ Software Comparisons

Tag	Plugin/ Software	Platform	Compatibility[1]	Software Analysis Extents		
				Daylight	Energy	CFD
A	ClimateStudio	Local	1	Y	Y	N
B	DIVA-for-Rhino	Local	1	Y	Y	N
C	Lightstanza	Cloud	4	Y	N	N
D	Sefaira	Cloud	2	Y	Y	N

[1] *Number of softwares the plugin is compatible with*

These daylight simulation platforms are widely used in the A/E industry; each offering an unique user experience and array of daylight metrics outside of $sDA_{300/50\%}$. The platforms range in user operability and learning curves associated with each tool as well as a variety in input customization and visualization options. Many firms and individuals may not have the luxury of time or fee to employ various platforms to run daylight simulations; having a robust understanding of the benefits and limitations of each tool is part of the workflow of daylight analysis.

Each tool uses the Radiance engine for the annual climate-based simulations. The inherent stochastic calculations of Radiance it is expected that results may vary slightly between identical simulations run on the same platform. Within the Radiance engine there are various climate based daylight modeling techniques which can be employed: 4-component method, DAYSIM, 2-phase method, 3-phase method and 5-phase method. These five methods have been shown to express annual daylight results in terms of daylight autonomy to be in agreement with an overall uncertainty to be expected of daylight simulation i.e. $\pm$ 15-20%. (Brembilla, et al., 2019)

Given the flexibility of changing inputs for the $sDA_{300/50\%}$ calculation as many variables as possible were held constant in each platform. The massing was identical with each platform featuring a 5,500ft^2 (511m^2), one story building, with a 18° hip roof, 20% window to wall ratio with identical window configuration, and 15'(4.5m) perimeter zones located in Denver, CO with the same orientation. The weather file used for each simulation is the typical meteorological year (TMY) file from Denver International Airport. The remaining inputs that were held constant included: VLT of glass = 60%, opaque material reflectivity of 40%, a grid height of 30" (76 cm), grid size of 24" (61cm), and ambient bounces = 4. These values were determined based on the thresholds of Software D.

Table 2 Daylight Model Inputs per Plugin/Software

Tag	Plugin/ Software	Ability to Customize					
		VLT	Material Reflectance	Grid Height	Grid Spacing	Ambient Bounces	Weather File
A	ClimateStudio	Y	Y	Y	Y	Y	Y
B	DIVA-for-Rhino	Y	Y	Y	Y	Y	Y
C	Lightstanza	Y	Y	Y	Y	Y	Y
D	Sefaira	Y	N	Y[1]	N	Y[2]	N

[1] *Height customization is limited by preset options*
[2] *Maximum threshold is ab=4*

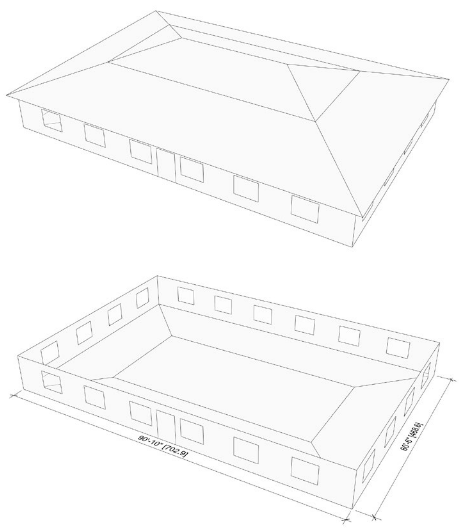

Figure 1 Model Massing (with/without Roof)

RESULTS

The intent of the sDA300/50% studies is to garner a better understanding of the range in results across various platforms. Gaining greater insight as to how to balance adherence to IES LM-83-12, graphic quality, user expertise and other nuances of daylight modeling will help in deciding the most appropriate tool for each individual task.

The overall trends in the floor plate's results vary greatly with a range of 40%. Prior to running a simulation; understanding the sun path for a city in the northern hemisphere (Denver, CO) an experienced daylight analyst would expect the east, south, and west perimeter zones deploy blinds to limit the analysis grid points' exposure to illuminance levels greater than 1,000 lux. Of the perimeter zones the greatest range is seen in the southern zone of 59%. The results clearly indicate the platforms that do and do not take into blind operations per Section 2.2.6 of IES LM-83-12 as we see sDA300/50% at the east, south and west reflecting an overestimate of illumination levels given percentages greater than 90%.

Per the results of Software C2 the blinds are deployed on average for 0.1% of the occupied hours of the north zone, 10.9% of the east zone, 29.7% of the south zone, and 18.1% of the west zone.

Table 3 sDA300/50% Results

Tag	Plugin/ Software	sDA300/50%					
		Overall	North	East	South	West	Core
A	ClimateStudio	46%	80%	77%	41%	67%	0%
B	DIVA-for-Rhino	78%	100%	59%	44%	61%	100%
C1	Lightstanza (Revit)[1]	66%	75%	91%	98%	94%	22%
C2	Lightstanza (Revit)	49%	68%	75%	76%	80%	0%
D	Sefaira (Sketchup)[1]	86%	100%	100%	100%	100%	55%

[1] *Blinds not deployed per IES-LM-83-12 methodology*

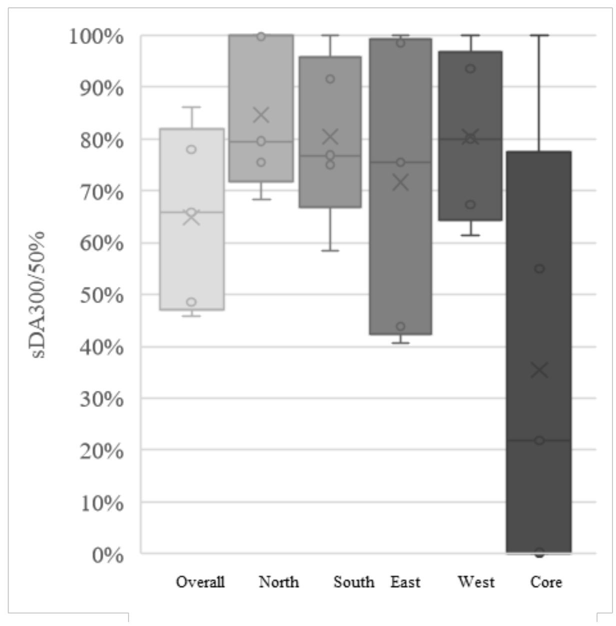

Figure 2 sDA300/50% Range

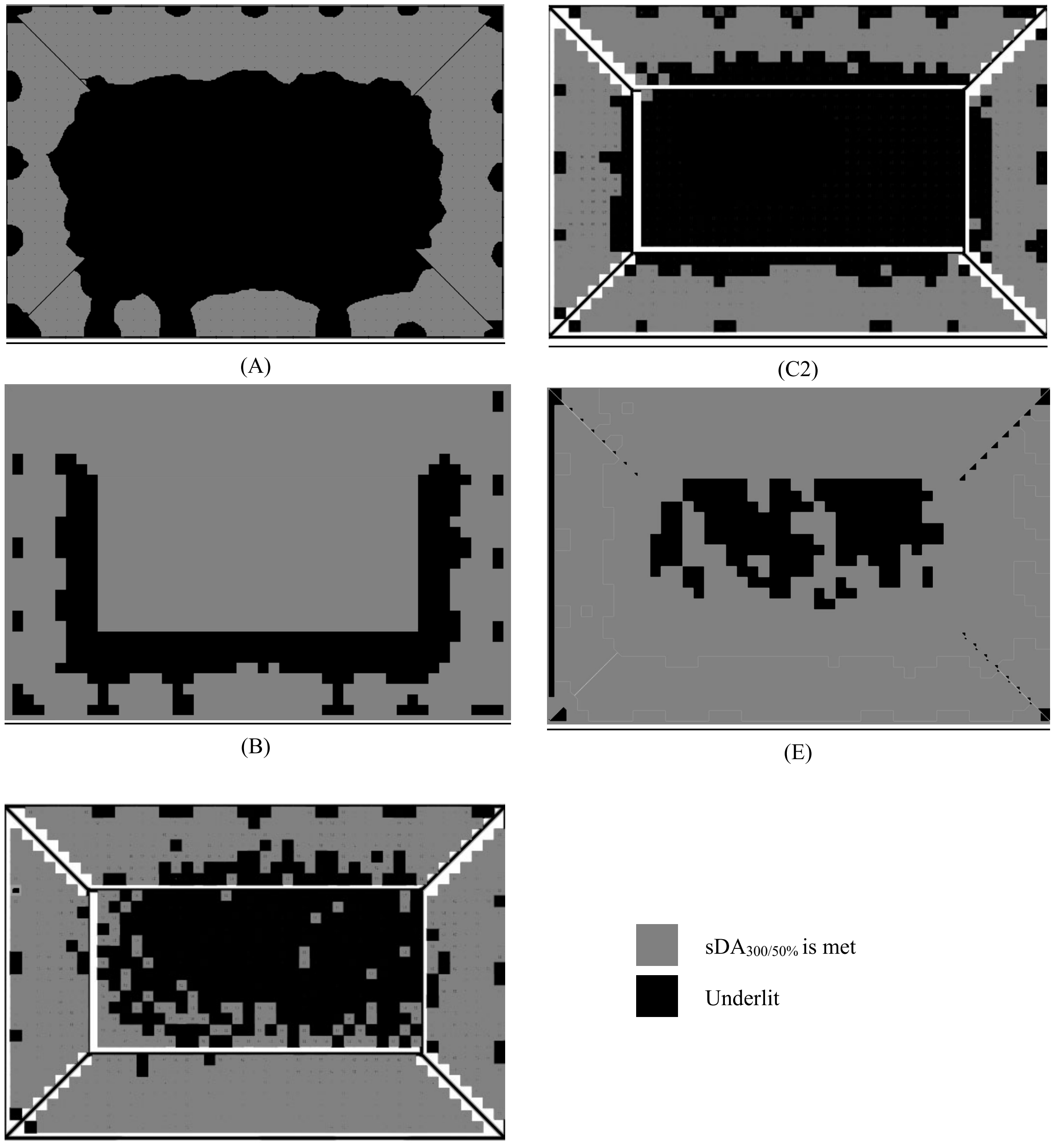

Figure 3 sDA300/50% Results (A) ClimateStudio (B) DIVA (C1) LightStanza1 (C2) LightStanza (D) Sefaira

In analyzing the $sDA_{300/50\%}$ results on a zone by zone basis an unexpected result arises. Software B indicates the core zone has 100% of the area meeting $sDA_{300/50\%}$. Yet when looking at the visualization of the results the grid in the core does not blend with the inner values of the perimeter zones. As modeled using the standard toolbar for Software B the core sDA group is not being impacted by the blind deployments of the adjacent zones; whereas, Software A and C2's core has reduced $sDA_{300/50\%}$ hours when any adjacent zone's blinds are deployed. This is particularly telling when the result for the core zone of Software B is replaced with 0%; the overall $sDA_{300/50\%}$ value of Software B becomes 48%; Software A and C2's overall $sDA_{300/50\%}$ value is 46% and 49%, respectively. The overall range has been reduced from 32% to 3%. This range can be more readily explained by assumptions made regarding the blind deployment of the window groups per each tool and the stochastic Radiance engine.

Table 4 Software A, B and C2 Comparison

Tag	Plugin/ Software	$sDA_{300/50\%}$					
		Overall	North	East	South	West	Core
A	ClimateStudio	46%	80%	77%	41%	67%	0%
B	DIVA-for-Rhino	78%	100%	59%	44%	61%	100%
C2	Lightstanza (Revit)	49%	68%	75%	76%	80%	0%
B*	DIVA-for-Rhino	48%	100%	59%	44%	61%	0%

* *Core set to 0%*

The implementation of analysis with Software B can occur either through a default toolbar workflow in the plugin platform or and alternative scripting methodology that allows for greater customization of inputs. This paper solely used the toolbar workflow which is intended for single-sided lighting conditions and is limited by the shared light between adjacent zones.

CONCLUSION

Specific to the range of $sDA_{300/50\%}$ results from this study, the simulated analysis indicates that care must be taken when selecting a daylight plugin/software. A robust understanding of whether strict adherence to IES LM-83-12, simulation speed, beginner user interface, or advanced customization are important for the scope of analysis must be considered. Each program has its own benefits but the lack of correlation between each platform is concerning. This lack of precision of $sDA_{300/50\%}$ results leads one to speculate why daylight simulation platforms are not governed by a similar standard for validation of daylight analysis software that energy modeling software has.

The wide range of $sDA_{300/50\%}$ results show the limitations of DIVA in controlling the core zone, the limitations of Sefaira to correctly account for blind deployment per the methodology outlined in IES-LM-83-12. The range of results in calculating $sDA_{300/50\%}$ poses as a cautionary notice to design professionals relying on daylight analysis software to comply with building certification requirements; such as the daylight credt in LEED v4. While the software platforms may all be used as a design tool to understand the impact of fenestration area, glass performance, material refelctivity, etc. for daylight quality; they may not be reliable studies of whether the scope of the project can meet the certification thresholds set.

ASHRAE Standard 140 specifies a standardized testing and validation protocol for energy modeling software. The testing procedures are robust to identify and diagnose differences across different software platforms. The parametric range of tests that each software is tested with across a spectrum of outputs minimizes the likelihood of concealment of algorithmic differences by compensating error. (ASHRAE, 2017) It stands to reason that if daylight analysis suites were guided by a testing methodology for validation that there would be less confusion and range results across different platforms.

While the evaluations provided only consider one daylight metric, $sDA_{300/50\%}$, in isolation, the deviation of results gives cause to evaluate a variety of daylight metrics across multiple daylight plugins/ software in order to generate an all encompassing narrative of the nuances and differences across the multiple tools.

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