

School design daylighting Analysis A study of Foundation schools in Erbil Governorate

● **Abdulqadir Bayz Hammad Amin**¹ - Assist.Lecturer ●
Dr. Faris Ali Mustafa² - Assist. Prof.
Dr. Sardar Swar³ - Lecturer

¹Department of Civil Engineering, Faculty of Engineering, Soran University

¹Department of Architecture, Faculty of Engineering, Tishk International University

^{2,3}Department of Architecture, College of Engineering, Salahaddin University - Erbil

Abdulqadir.bayz@soran.edu.iq, farisyali@yahoo.com

Received: 01/08/2018 / Accepted: 04/10/2018 / Published: 01/04/2019

DOI Link: <https://doi.org/10.17656/sjes.10084>

Abstract



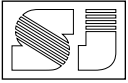
Recently, the physical building performance has been demonstrated widely by researchers and architects due to its direct and indirect influence on space usage and comfortability, particularly in learning spaces. This study was intended to assess the natural light performance of educational premises in Erbil governorate. The six foundation schools with different size, shape, and layout have been selected. The daylight illuminance level and Daylight Autonomy have been simulated and compared with design standards for the sufficient daylight. An academic-licensed Revit Architecture 2018 with plugged insight daylight analysis has been adopted as an analysis tool for daylight parameters. The results showed that the illuminance level in most of the case studies is below the satisfactory range depended on architectural standards. Similarly, the daylight autonomy in term of spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE) are dissimilar from one case study to another. The sDA and ASE have reached what is needed in three school layouts. In contrast, sDA and ASE performance was below the required levels. In consequence, the importance of daylight analysis in existing school environment, and informing the educational planners and architects have been clarified about the meaningful prediction of natural light performance. The daylight performance in school needs to be improved by using appropriate advanced technology, such as, laser cut panels, louvers and daylight shelves. The outcomes of the research are valuable for measuring the daily performance of the physical learning environment and exploring innovative strategies and techniques for improving the actual daylight performance.

Keywords: Daylight, School design, Illuminance level, Students' performance, Daylight analyses, Erbil.

1. Introduction

The natural daylight that includes direct luminance from the sun and indirect illuminance from sky, constructional boundaries and building envelopes, is a significant aspect of building design and sustainable built environment. The quantity and quality of light will influence our perception about space and it will affect our working performance. Professor Zannoni states the daylight should be considering as a fundamental architectural element during project design which affect the space perception (Cherri, 2015). The design of sufficient natural light is related to the several issues such as building orientation, opening area, glare avoidance, thermal comfort, visual needs, and perception of space and building properties. Most of current studies demonstrates the medical and psychological benefits of adequate daylight spaces (Drosou, 2016). While, Others like Tregenza and Mardaljevic (2018) highlights the importance of lighting as a knowledge transformation medium between the interior spaces and external world. They also (2018) states that the direct and indirect illuminance with visual comfortability is the main considerations for determine the natural light design through history. Furthermore, there are many researches that emphasize the role of daylight in increasing the performance and rising productivity in the last three decades (Tregenza and Mardaljevic, 2018). All the prescribed factors have raised demand and awareness for optimal daylight design. This study firstly identifies the positive aspects of using natural light on students' health and environment, and its role of energy saving. Secondly, it discusses some of





related daylight researches and their findings in the learning-built environment. Then, it highlights several daylight metrics and standards. After that, the quantitative research method for the daylight analysis have been explained in detail. Finally, the school design daylight evaluation presented in term of illuminance level and Daylight Autonomy criteria by using insight daylight analysis with Revit.

1.1. Natural light benefits

There are many issues related to the daylight in the space, the main aspect is the average illumination level, which effect on function and perception of space. While other features such as direct sunlight, glare and illumination uniformity distribution on the working plane will have direct and indirect negative influence on the space usage. The prescribed factors of daylight have both positive and negative impact on human in term of students' health and performance. Furthermore, the energy consumption for artificial light increased the significant of the daylight adaptability in built environment.

1.1.1. Health

The daylight level has an influence of user's health and well-being in number of ways. Shishegar and Boubekri (2016) confirms that the nature light will supply energy to the human body by creating Vitamin D which help bones growth. Also, daylight improves person perception of learning space. "Access to indoor sunlight is also associated with perceived cheerfulness as well as higher levels of positive mods such as joy, interest, and alertness for the occupants (Mach, 2014:42)". Therefore, having adequate daylight will provide a healthful environment for physical human body and phycological needs.

1.1.2. Student's performance

On the one hand, the learner's achievement will be reinforced through having a suitable illuminance level in a space. The daylight performance has an influence on both the teacher's and student's achievement. According to the results from the study by Tanner (2009) the

learner's performance will be increase in adequate daylight classroom especially in the reading vocabulary and science subject. Similarly, the American educational community Heschong-Mahone Group (HMG)states that having the better daylight learning spaces will improve students' performance around 20 % in Mathematics and 25% in the reading skills (Tragenza and Mordalievic, 2015). On the other hand, the lack of daylight, glare and direct sunlight will decrease student's understanding and performance. Shishegar and Boubekri (2016) have stated that the attendance ratio of teacher's and student's in the educational spaces with sufficient nature light is higher than of attendance ratio in the less daylight level spaces.

1.1.3. Energy saving

The Sufficient daylight level decreases the necessity for artificial light in space that leads to energy saving and less energy consumption. For instance, Philips (2004) have reported that the demand for the artificial light can be replaced and reduced by appropriate use of natural light. According to Tsikra and Adreou (2017) have recognized that the unsuitable building orientation and shading device leads to lack of visual and thermal comfort which in long term increases energy demand in educational premises.

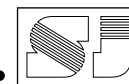
1.2. Daylight metrics and standards

1.2.1. Daylight Metric

Recently, many daylight metrics have been introduced by research community for measuring various daylight parameters. Although, there is not global acceptance on metrics for daylight performance due to lack of relationship on daylight design criteria (Tregen, 2017). The following daylight metrics are the most mentioned units which have been used for the daylight measuring.

1.2.1.1. Illuminance

It is the most extensively acceptable and simplest daylight metric which has been used by standards and regulations (Tregnzo and Mardaljevie, 2017). Illuminance has been defined as "the ratio of the luminous flux, incident on an infinitesimal



surface in the neighbourhood of the points, to the area of surface (Costanzo et al, 2017:5).” This unit have been adapted as required measurement for illuminance level measurement. For instance, in LEED V4 option2 illuminance have been referred and point have been indicated to determine the illuminance ratio as have been shown in table-1(USGBC, 2018). The range of acceptable illuminance threshold has been limited between 300 to 3000 Lux.

1.2.1.2. Daylight Factor (DF)

In England, the Troter introduced daylight factor for measuring natural light of sky. It has been introduced “as the ratio between the daylight illumination at point in the interior and simultaneous exterior illumination available on a horizontal surface from an unobstructed hemisphere of overcast sky (excluding direct sunlight expressed as a percentage (Cherri, 2015:137)”. It always presented as a percentage.

$$D = E_i / (E_a * 100) \%$$

D- Daylight factor, E_i - internal illuminance area,
 E_a - External illuminance area (Neufert,
 2013:157).

Contrary, in some states the daylight factor as light measurement unit have been replaced, for instance, the daylight factor has been replaced with climate-based daylight modelling (CBDM) by the UK Education Funding Agency (Drosou et al., 2016)

1.2.1.3. Climate based daylight Modell

Recently, the Climate-Based Daylight Modelling (CBDM) have been introduced for daylight prediction evaluation. It has defined as "the prediction of any luminous quality (illuminance and/ or luminance) using realistic sun and sky conditions derived from standard climate data" (Mardaljevic, 2015:1). The daylight performance will be calculated through all days of year by using several criteria such as Useful Daylight Illuminance, Daylight Autonomy and Spatial Daylight Autonomy.

a. Useful Daylight Illuminance (UDI): Is the defined as the fraction of time in a year when the indoor horizontal daylight illuminance at

a given point falls within a given range (Costanzo, 2017:6).

- b. Daylight Autonomy (DA)
- c. Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)

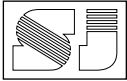
The research team which led by Lisa Heschang have introduced the sDA Spatial Daylight Autonomy, that can be defined as “the percentage of the work area or the plane of calculation on which fall 300 lux for the at least 50% of the year, basing on the calculation on a working day of 10 hours" (Gherri, 2015:138). Furthermore, the ASE has been invented as daylight metric for direct illuminance. ASE is defined as the percentage of space affected by more than 250 hours of direct illumination per year, where ‘direct illumination’ means a quantity higher than 100 lux through the apertures, excluding secondary reflections and the quote intercepted by shading devices" (Gherri, 2015:137). The LEED V4 Daylight for building performance point calculation considers both spatial Daylight Autonomy (sDA) and illuminance calculations metrics (Table -2) (USGBC, 2018).

1.2.2. Daylight Standards

The daylight regulations and codes will depend of daylight metric and daylight assessment approaches. The table-3 illustrates the daylight metric minimum and maximum limit, which is different among the standards for learning spaces.

2. Related research studies

Measuring the quantity of light and investigating quality of natural light is a great challenge in ongoing research and study of daylight design and demand. There are many metrics for measuring the daylight quantity such as, illuminance level, daylight factor, daylight autonomy. Also, many approaches and software tools have been adapted to measure daylight in spaces during the design process. The exploration of nature light degree and level is valuable in determine the degree of the physical and visual comfortability and needs for improving the space luminance level. In their study, (Drosou et al., 2016) have investigated the actual daylight performance in existing school buildings in England via using



Climate-Based Daylight Modelling (CBDM). The two classrooms with different layout and design have been monitored for a half year. True illuminance level has been indicated by using the High Dynamic Rang (HDR) image approach as part of robust method.

The study emphasizes the importance of robust method usage for assessing the real daylight existence in the learning spaces because it includes the unseeing factors that affect daylight aspects. Another advantage of used methodology is determining the human need for the visual comfortability. In addition, they study identifies the practicality of using (CBDM) measurement metrics for daylight performance in existing environment. In contrast, it is clear the study is not exclusive to take entire educational buildings. Costanzo et al, (2017) in the extensive literature review of daylight usage in the educational premises have discussed the typical relationship among the local environment, daylight demand and design approach by using innovative and advance techniques. First, the study has represented and illustrated several metrics for daylight measurement and specifications, such as, Illuminance, Daylight Factor (DF), Useful Daylight Illuminance (UDI), Daylight Autonomy (DA), the spatial Daylight Autonym (sDA), Annual Sunlight Exposure (ASE), and High Dynamic Range (HDR) (Costanzo et al., 2017). In addition, the metrics for identifying the negative aspect of daylight such as glare have been demonstrated like, Discomfort Glare Probability (DGP), and Spatial Visual Discomfort (SVD). Secondly, the number of effective advanced tool and technology for increasing the useful daylight have been identified and explored such as Classroom layout and glazing types, external shading devices, redirecting system and control system (Costanzo et al., 2017).

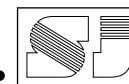
The results signified to the complexity and challenge of the natural light optimization in learning spaces and significant in calculating several climate-based metric for assessing the performance of the natural light (Costano et al., 2017). Furthermore, Yuksek at el (2015) have investigated the natural light level in three classrooms of Kirklareli University via using Velix Visualiar Simulation programme. They have identified the significant of opening properties and orientation in determine the adequate light

level (Yuksek at el, 2015). The sufficient daylight level can be provided by using a proper building orientation, window layout, appropriate shading device and daylight system like light self and lazar panels. They concluded their study by illustrating that the opening area must not be less than 1/3 or 1/5 of the floor area of educational space to achieve the sufficient daylight level. Moreover, the energy saving, and better students' achievement are the main benefit of using the natural light in the educational built environment.

3. Research methodology

The daylight illuminance level and daylight autonomy have been investigated in the six foundation school building models in the Erbil province via using the Insight Daylight Analysis with Revit 2018 programme. The licensed educational version of Revit architecture 2018 with free download licensed Autodesk insight plug in have been used to identify the daylight analysis results accurately. The two-dimensional drawings layout and three-dimensional models for the all case studies have been created by using Revit Architecture. The school layouts have been drawn base on the auto-CAD two-dimensional drawings while the three-dimensional models and material settings have been prepared according to the project specifications and guidance. The insight plugin tool has been added to the Revit programme for analysising daylight aspect. The programme creates graphical representation for illuminance level and updatable table for each individual space, which are important for recording natural light performance data during design process. The programme should be connected to the A360 rendering service that is online rendering service to provide reliable illuminance data in a short time.

There are five pre-defined analysis type tools: illuminance Analysis, Daylight Autonomy, LEED 2009 IEQC8 ot1, LEED V4 EQ C7 OPT2 and solar Access for measuring direct sunlight and daylight parameters (Forums. Autodesk, 2017). Among of those tools, Daylight Autonomy and LEED V4 EQc7 opts2 have been used for all case studies daylight analysising. The spatial Daylight Analysis (sDA) metric have been obtained by Daylight Autonomy analysis tool, meanwhile the



Annual Sunlight Exposure (ASE) data have been taken for the LEED V4 EQc7 opts2 tool.

4. Results and Discussion

The study outcomes have exemplified the natural light performance in existing built environment and needs for improving it. The results of daylight illuminance and Daylights Autonomy criteria are different according to design layout as was explained. For calculation purpose the horizontal working plane has been placed 80 Centre meters (30 inch) above the finished floor level for calculating daylight performance and illuminance level. The three-dimensional models and analysis approach has been set depending on insight daylight analysis tool and approaches.

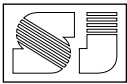
Frist of all, For the daylight illuminance the threshold has been determined between 300—3000 lux according to the LEED v4 option2. Also, the average weather data of two clear sky days within 15 days of 21- September and March from 9 am to 3 pm have been selected. According to result summaries from online insight daylight analysis, in general the ratio of illuminance is below the LEED standards in most of cases. While illuminance percentage in the 6-classroom school layout have the highest ratio 78% and get on point, the ratio in the 18L classroom is 37 % which is the lowest ratio (Table 4).

Moreover, the insight lighting graphical demonstrates illuminance level for all spaces in the case studies. For example, Table -5 illustrates the daylight luminance for the all school case studies, the area above threshold have been reveals in yellow color. Meanwhile, the red color indicates t the daylit areas bellow threshold and other gradual colors referred to the area with in threshold with values between 300 to 3000 Lux., It is noticeable that school corridors have lowest daylight performance among spaces. The program also provides the daylit details for each individual space in the case studies which can be updated (Table-6 and appendix-3). The numerical presentation for illuminance from 9:00 am is different from 3:00pm. In consequence, the natural illuminance ratio needs to be improving to create comfortable daylight environment in local schools.

Secondly, the Daylight Autonomy daylight performance in term of sDA and AES are different

from one case study to other case studies. The date has been calculated from January 1 to December 31, and from 8:00 AM to 6:00 PM which includes 3650 hours daylight simulation. The table 7 presents the obtained results from the daylight annual simulation for six school buildings in Erbil governorate and credit points according to LEED standards. The sDA and AES in the 6-classroom schools, 9-Classrooms school and 12-classroom school have reached the satisfactory level according to the LEED specifications (Table 7). Especially, the 9-classroom school have gotten three points which is the highest range. In contrast, the sDA and ASE in the other case studies are below the satisfactory percentage level (Table 7). The 18Bclassroom school has the lowest percentage of sDA and ASE performance (27%). Figure-6 show, the sDA and ASE performance for the 9-classroom school graphically. The table 8 demonstrates the sDA and AES for each individual space in the 9-classroom school layout which archived three-point credit.

The daylight performance in the local educational built environment are below the satisfactory level. So, there is necessary to improve school daylight performance for number of reasons such as, students' performance and health. Optimization of the daylight and minimizing visual discomfort and glare issues can be achieved via suitable techniques and innovative technology for the built environment. In one hand, proper spaces layout and suitable orientation can have direct impact of daylight illuminance of space, although their applicability should be analysis during the design process and before construction process. On the other hand, some innovative tools and components can increase illuminance level with out any change in opening size and shape such as, laser cut panels, louvers and light shelves. According to the Labib (2013) the usage of the laser cut panels can keep daylight factor at acceptable level at area which is near five meters away from windows (Costanzo et al, 2017). Also, it can double illuminance ratio and it make space more comfortable visually during the summer. Secchi et al (2015) in their study on the east oriented existing classrooms found out that daylight availability can be increased efficiently by louvers without any effect on thermal comfortability (Costanzo et al, 2017). Meresi (2015) highlights the



benefits of using light shelves with combined blinders for south oriented classrooms in Greece school as follows: rising illuminance ratio, increasing daylight distribution uniformity and decrease the demand for window curtains. In addition, the various design layout of light shelves can result in a significant increase of daylight illuminance level near fifty percentage, at the same time it can have a crucial role in avoiding glare issues (Moazzeni et al, 2016). To conclude, it is advisable for improving the daylight performance in the existing school building in Erbil to use the laser cut panels, louvers for the east and west oriented space, and light shelves for the south oriented spaces. The recommended solutions should be studied well to responded to the thermal and visual comfortability positively.

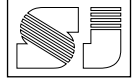
5. Conclusions

In conclusion, the level of daylight efficiency has been investigated by using new and reliable tools for the existing school environment in Erbil, and the appropriate design approaches for optimizing natural light have been identified. The daylight metrics like illuminance level and spatial Daylight Autonomy (sDA) have been used for daylight performance measurement and comparison with architectural standards. The study emphasizes the importance of daylight analysis in existing built environment and informing the educational planners and architects about meaningful prediction of daylight performance in the future constructions. The findings have revealed the low performance of case studies in term of daylight illuminance criteria when compared to the LEED guidelines for natural light (Figure 1). In addition, the performance of the sDA and AES for half of the study cases was below the acceptance range; the rest were satisfactory (Figure 2). Therefore, the natural light level needs to be more investigated and improved in term daylight illuminance and daylight autonomy criteria in the local learning spaces. The usage of laser cut panels, louvres for east and west oriented space, and light shelves for the south oriented space can increase the daylight level and improve the natural light distribution uniformity in the local educational space. The quantity and quality of daylight parameters should be studied more to

control of the daylight effect on the learner's performance and health.

References

1. Costanzo, V., Evola, G., Marletta, L. (2017). A Review of Daylight Strategies in School: State of the Art and Expected Future Trends. *Buildings* 217/7/41. Retrieved July 25, 2018 from: <https://www.mdpi.com/2075-5309/7/2/41>
2. Ferreto, L., Roush, B., Massey, A (2016) Design Tools for Daylight A Comparative Research Analysis. Hord Coplan Macht: the USA
3. Forums. Autodesk (2017) <https://forums.autodesk.com/autodesk/attachments/.../insight-lighting-analysis-help.pdf>.
4. Gherri, B. (2015). Assessment of Daylight Performance in Buildings. WIT Press: Southampton
5. Mardaljevic, J. (2015) Climate -based daylight modelling and it's discontents. Presented at the Simple Building Better Buildings? Delivering performance through engineered solutions, CIBSE Technical Symposium London, April 1617th. Retrieved July 23, 2018 from: <https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/19993/1/jm-cibse-ts-2015-04.pdf>
6. Meresi, A. (2016) Evaluating daylight performance of light shelves combined with external blind in south-facing classrooms in Athens, Greece. *Energy and building*, 2016, 116, 190-205 Retrieved July 25, 2018 from: www.elsevier.com/locate/enbuild.
7. Moazzeni, M., Ghiabaklou, Z. (2016) Investigating the Influence of Light Shelf Geometry Parameters on Daylight Performance and Visual Comfort, a Case study of Educational Space in Tehran, Iran. *Building* (2075-5309), Sep 2016, volume6, Issues 3,16-26.
8. Neufert, E. (2013) *Architect's Data* Third edition Blackwell Publishing: Oxford
9. Philips, D. (2004) *Daylighting Natural Light in Architecture*, Architectural Press: Oxford.
10. Shishhegar, N., Boubekri, M. (2016). Natura Light and productivity: Analyzing the Impact of Daylight on Student's and Worker's Health and Alertness. International Conference on "Health, Biological and Life Science" (HBLS-16) April 1819, 2016 Istanbul, Turkey
11. Tanner, K. (2008) Effect of school design on student outcomes. *Journal of Educational Administration*, 2009, 47(3), 381-399
12. Tregenza, P., Mardaljevic, J. (2018) Daylight buildings: Standards and the needs of the designer. *Lighting Res. Technol.* 2018(50)63-79.



13. Tsikra P., Andreou, E. (2017) Investigation of the Energy Saving Potential in Existing School Building in Greece. The role of Shading and Daylight Strategies in Visual Comfort and Energy Saving. Procedia Environmental Science,38(2018), 24-211.
14. USGBC (2018). Daylight. Retrieved July 25, 2018 from: <https://www.usgbc.org/credits/healthcare/v4-draft/eqc-0>
15. Yuksek, I., Gorgulu, S., Kocabey, S., Tuna, M., Dursun, B. (2015) ASSESSMENT OF DAYLIGHT PERFORMANCE CLASSROOMS: A CASE STUDY N KIRKLARELI UNIVERSTY, TURKEY. Light & Engineering, 23(1), 15-24.

تحليل الإضاءة الطبيعية في الأبنية المدرسية دراسة للمدارس الأساس في محافظة أربيل

عبدالقادر بايز حمد أمين¹ - مدرس مساعد

د. فارس علي مصطفى² - استاذ مساعد

د. سردار سوار³ - مدرس

¹ قسم الهندسة المدنية ، كلية الهندسة ، جامعة سوران

¹ قسم الهندسة المعمارية ، كلية الهندسة ، جامعة تيشك الدولية

^{2,3} قسم الهندسة المعمارية ، كلية الهندسة ، جامعة صلاح الدين - أربيل

المستخلص

في الآونة الأخيرة ، يلاحظ تناول أداء البيئة المبنية على نطاق واسع من قبل الباحثين والمهندسين المعماريين بسبب تأثيرها المباشر وغير المباشر على استخدام وراحة الفضاء ، لا سيما في أماكن التعلم. تهدف هذه الدراسة إلى تقييم أداء الضوء الطبيعي للمباني التعليمية في محافظة أربيل. تمت محاكاة مستوى الإضاءة الطبيعية النهارية والإضاءة الطبيعية الذاتية ومقارنتها مع معايير التصميم الخاصة بضوء النهار الكافي. تم اعتماد برنامج Revit Architecture 2018 المرخص للأغراض الأكاديمية المعمارية والذي يوفر ويسهل إمكانية إحتساب وتحليل الإضاءة الطبيعية كأداة تحليل. أظهرت النتائج أن مستوى الإضاءة في معظم الحالات التي شملتها الدراسة أقل من النطاق المرضي وفقا للمعايير المعمارية المرتبطة بهذا الشأن. وبالمثل ، فإن الإضاءة الطبيعية الذاتية من حيث استقلالية ضوء النهار المكاني (sDA) والتعرض السنوي لأشعة الشمس (ASE) تختلف من دراسة حالة واحدة بالمقارنة إلى أخرى. ومن بين الحالات الدراسية الستة فقد حققت ثلاث منها مستويات مطلوبة من (sDA) و(ASE). في المقابل ، كان أداء (sDA) و(ASE) أقل من المستويات المطلوبة في الحالات الثلاث الأخرى. ونتيجة لذلك ، تم توضيح أهمية تحليل الإضاءة الطبيعية-النهارية في البيئة المدرسية القائمة من خلال النتائج المستحصلة التي قد تدفع بالمخططين التربويين والمهندسين المعماريين نحو الاهتمام بالتنبؤ الهادف لأداء الضوء الطبيعي. خلصت الدراسة الى أن أداء الإضاءة الطبيعية في المدارس تحتاج الى إجراء بعض التحسينات من قبيل استخدام التكنولوجيا المتقدمة المناسبة ، مثل الألواح المقطعة بالليزر والألواح التظليل وغيرها. نتائج البحث ذات قيمة لقياس الأداء اليومي لبيئة التعلم المبنية واستكشاف استراتيجيات وتقنيات مبتكرة لتحسين الأداء الفعلي للإضاءة الطبيعية-النهارية للأبنية المدرسية.

الكلمات المفتاحية: ضوء النهار ، تصميم المدارس ، مستوى الإضاءة ، أداء الطلاب ، تحليلات الإضاءة النهارية ، أربيل.

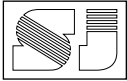


Table 1: Illuminance level -point calculations for floor area adapted from LEED V4 Option2 (USGBC, 2018).

New construction, Core and Shell, School, Retail, Data Centres, Warehouses & Distribution Centers, CI, Hospitality		Healthcare	
Percentage of regularly occupied floor area	Points	Percentage of perimeter floor area)	Points
75%	1	75%	1
90%	2	90%	2

Table 2: Spatial daylight autonomy -point calculations for floor area (adapted from USGBC, 2018).

New construction, Core and Shell, School, Retail, Data Centres, Warehouses & Distribution Centers, CI, Hospitality		Healthcare	
sDA (for regularly occupied floor area)	Points	For perimeter floor area)	Points
55%	2	75%	1
75%	3	90%	2

Table 3: Daylight metric Standards.

Metric	Range Limit	Reference
Illuminance	300>Em<3000 for 90 %of floor area.	(Costanzo et al., 2017)
Daylight	DF>2% for 80% of room	(Costanzo et al., 2017)
Useful daylight illuminance (UDI)	100 to 3000 Lux	(Mardaljevic, 2015
	300- 3000	LEED V4 opt2 (USGBC, 2018)
Spatial Daylight Autonomy (sDA)	Prefers: sDA 300/500> 75% Acceptance: sDA 300/50> 55%	LEED V4 opt1 (USGBC, 2018)
Annual Sunlight Exposure	Preferred: ASE 1000/250h<3% on occupied area	(Costanzo et al., 2017)
	Preferred: ASE 1000/250h<7% on occupied area	
	Sufficient: ASE 1000/250h<10% on occupied area	

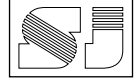


Table 4: The Illuminance level for the 6-case study schools in Erbil governorate (it has obtained from case studies analysing).

School type	Total Equinox passing ratio	Number of credit according to LEED v4 option2	Either time below threshold	Either time below threshold	9:00 am			3:00 pm		
					Passing	Below threshold	Above threshold	passing	Below threshold	Above threshold
6 - Classroom School	78	1	22	0	87	13	0	83	17	0
9 - Classroom School	70	0	9	21	78	5	16	81	8	11
12 - Classroom School	51	0	14	35	71	7	22	71	12	17
18L - Classroom School	37	0	28	36	58	22	20	62	19	19
18B - Classroom School	41	0	36	24	60	29	11	53	34	14
24 - Classroom School	41	0	14	45	64	12	25	68	10	22

Table 6: Insight lighting Schedule – the average Daylight illuminance for 18B-classroom school (taken from case study analyses)

_Insight Lighting Floor Schedule
LEED v4 EQc7 opt2Whole Building Results:36.2329483032227,44.0670471191406
9am: 60%within& 3pm: 53% &both: 41% within thresholds
Solar Values (W/m²): 9/21 9amGHI:452, DNI: 636, DHI: 84 & 9/21 3pm GHI: 478, DHI: 655, DHI: 84

Name	Floor Area Included in Daylighting m ²	Total Floor Area m ²	9am threshold results						3pm threshold results						Both time results	
			Within threshold	above threshold	below threshold	Within threshold	above threshold	below threshold	Within threshold	Area m ²	Within threshold	Area m ²				
Ground Floor Level	1706	1706	63	1071	10	177	27	458	48	818	19	325	33	562	37	630
First Floor Level	1346	1346	56	749	12	158	33	439	59	799	6	87	34	460	46	624

Table 7: The Daylight Autonomy analysis for the 6-case study schools in Erbil governorate (it has obtained from case studies analysing).

School type	Ratio of Building area meets sDA % hours in Rooms with< 20 area above ASE	Number of credit according to LEED v4 option1	sDA				ASE			
			Meet sDA % hours	sDA building area fails for room> AES	Meet sDA> 55%	Meet sDA> 75%	Building area > ASE hours threshold	Building area > ASE hours> 20 % Room area		
6 -Classroom School	55	2	80	25	75	75	12	25		
9 -Classroom School	90	3	95	5	97	97	8	5		
12 -Classroom School	63	2	86	23	97	75	13	23		
18L -Classroom School	37	0	59	32	56	56	15	34		
18B -Classroom School	27	0	88	61	96	88	31	65		
24 -Classroom School	44	0	67	22	69	65	9	22		

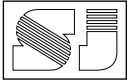


Table 8: The Insight Lighting Schedule - Daylight Autonomy for 9-classroom school
(it has obtained from case studies analysising).

_Insight Lighting Room Schedule										
Daylight Autonomy (sDA Preview) Results Summary: 36.2329483032227,44.0670471191406- 1276194										
Building scores 3 LEED points with 90% Building area passing thresholds										
At least 55% most exceed sDA 300/50 in Rooms with ASE 1000/250 <20% of Room area										
Level	Name	Number	Area	Included in Daylighting	sDA 300/50 %	sDA 300/50 Points	ASE 1000/250 %	ASE 1000/250 Points	sDA/ ASE %	sDA/ ASE Points
Ground Floor Level	Classroom -1GF	1	24 m ²	Yes	100	3pt	23	No	0	none
Ground Floor Level	Teacher's room	2	24 m ²	Yes	100	3pt	13	Yes	100	3pt
Ground Floor Level	Manager room	3	12 m ²	Yes	100	3pt	14	Yes	100	3pt
Ground Floor Level	Room	4	2 m ²	Yes	0	none	0	Yes	0	none
Ground Floor Level	Room	5	3 m ²	Yes	0	none	0	Yes	0	none
Ground Floor Level	Tea room	6	12 m ²	Yes	100	3 pt	0	Yes	100	3 pt
Ground Floor Level	Storage	7	12 m ²	Yes	0	none	0	Yes	0	none
Ground Floor Level	Classroom -3GF	8	24 m ²	Yes	100	3 pt	0	Yes	100	3 pt
Ground Floor Level	Classroom -2GF	9	24 m ²	Yes	100	3 pt	0	Yes	100	3 pt
Ground Floor Level	Hall-1 GL	10	109 m ²	Yes	93	3 pt	7	Yes	93	3 pt
First Floor Level	Classroom - 9 FF	11	24 m ²	Yes	100	3 pt	0	Yes	100	3 pt
First Floor Level	Classroom - 4 FF	12	24 m ²	Yes	100	3 pt	13	Yes	100	3 pt
First Floor Level	Hall- 2 FF	13	109 m ²	Yes	100	3 pt	10	Yes	100	3 pt
First Floor Level	Classroom - 5 FF	14	24 m ²	Yes	100	3 pt	13	Yes	100	3 pt
First Floor Level	Classroom - 6 FF	15	24 m ²	Yes	100	3 pt	13	Yes	100	3 pt
First Floor Level	Classroom - 7 FF	16	24 m ²	Yes	100	3 pt	0	Yes	100	3 pt
First Floor Level	Classroom - 8 FF	17	24 m ²	Yes	100	3 pt	0	Yes	100	3 pt

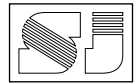


Table 5: Insight lighting- Daylight illuminance for the all case studies-classroom at 9:00am (taken from case study analyses.)

School layout	Ground Floor	First Floor	Legend
6-Classroom			<p>Lighting lx: 9/21 clear sky 9am</p>
9-Classroom			
12-Classroom			
18L- Classroom			
18B-Classroom			
24-Classroom			

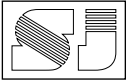


Figure 1: The daylight illuminance performance for all case studies and LEED guidance for daylight.

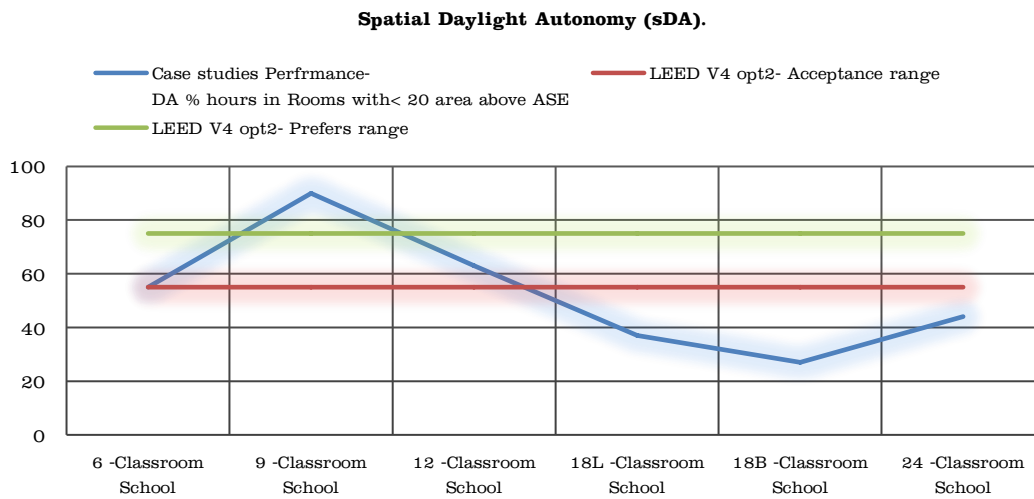
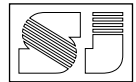
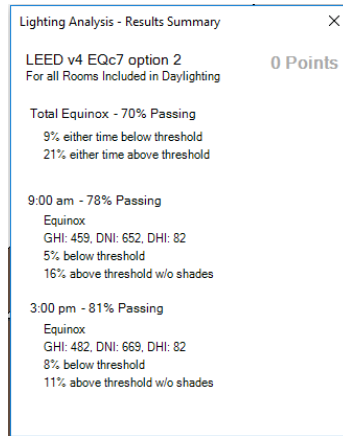


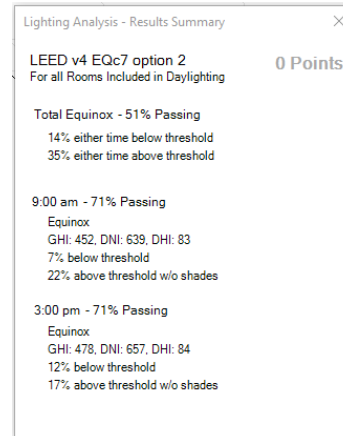
Figure 2: The sDA and ASE performance for all case studies and LEED guidance for daylight.



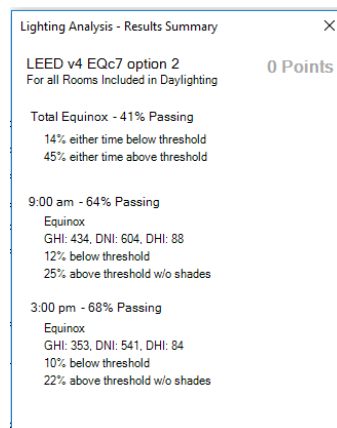
Appendix 2-: The Spatial Daylight Autonomy Illuminance calculation result summary for all case studies.



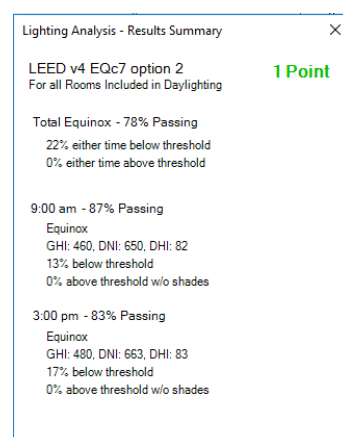
9 Classrooms School



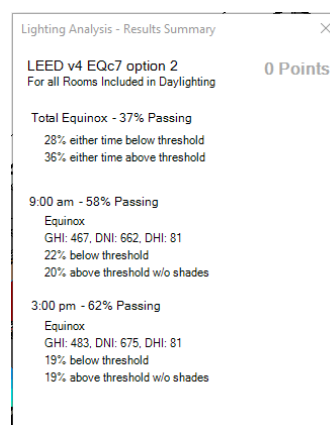
12 Classrooms School



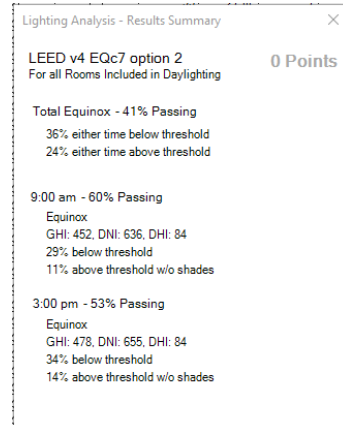
24 Classrooms School



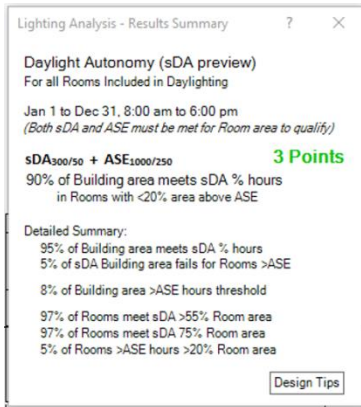
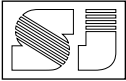
6 Classrooms School



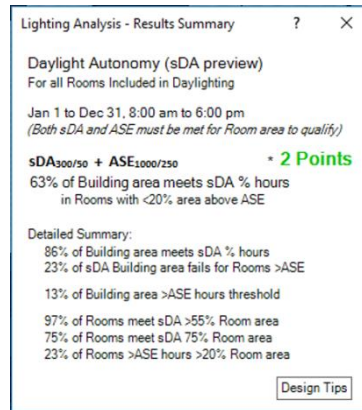
18L Classrooms School



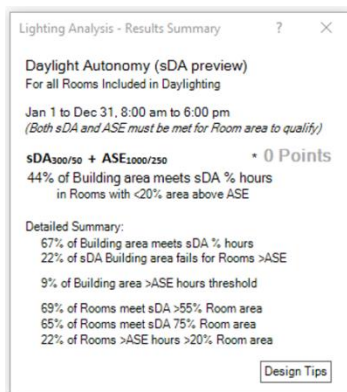
18B Classrooms School



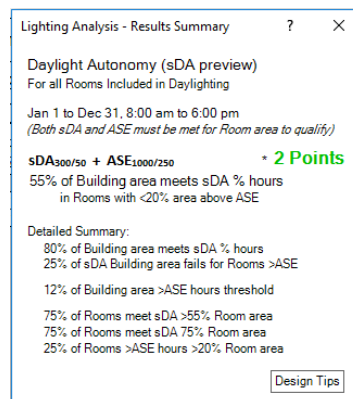
9 Classrooms School



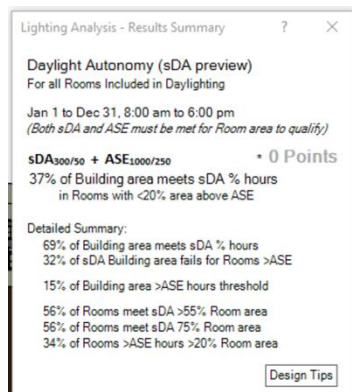
12 Classrooms School



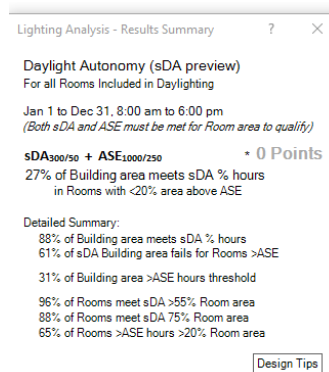
24 Classrooms School



6 Classrooms School



18L Classrooms School



18B Classrooms School