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Evaluation and Analysis of the Efficiency of Dynamic Metrics Evaluating Daylight Performance (Daylight Autonomy and Useful Daylight Illuminance) through Sensitivity Analysis; Case Study: Elementary Classroom in Tehran*

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ABSTRACT

To achieve sustainable, low-energy buildings, it is required to further emphasize on accurate evaluation of daylight performance. To this end, over the last few years, researchers have considerably developed more advanced dynamic metrics to overcome the limitations of static metrics. Nowadays, Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) metrics and those metrics developed based on these two are the most well-known dynamic daylight performance metrics, which do not have the same credit in terms of efficiency among different experts. The present study aims to compare the abilities of these metrics to be used in evaluating daylight performance in educational buildings. To this end, a parametric analysis is performed through simulation in Grasshopper software using Ladybug and Honeybee plugins. This analysis is performed to show the relationship between UDI, sUDI, DA, sDA, cDA metrics by examining the effects of the variations of Window-to-Wall Ratio (WWR) on them in a typical Classroom of an elementary school in Tehran. The results show that the lack of a high limit for DA and DA-based metrics, i.e. sDA and cDA, eliminates their correlations with the components related to the occupant comfort. Among various daylight metrics, UDI, due to its correlation with glare and energy consumption, can indicate the propensity for the occurrence of occupant discomfort as well as the energy consumption. Also, among UDI-based metrics, sUDI needs to increase the density of sensor points in the grid to achieve the same accuracy as UDIavg, significantly increasing the computation time. Therefore, the UDIavg metric is more suitable to use for small spatial units where the number of sensors is quite limited.

Keywords: Daylight Performance, Dynamic Metrics, Daylight Autonomy, Useful Daylight Illuminance, Classroom.

* This article is derived from the first author's doctoral dissertation entitled "Explanation of the educational interior space design principles to improve the conditions of using daylight in semi-hot and dry climate"), which was defended under the supervision of the second author and the advice of the third author at the Islamic Azad University, Science and Research Branch, Tehran.

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1. INTRODUCTION

Daylight is known as a suitable tool to reduce the need for artificial lighting in non-residential buildings. Daylight is also a source for achieving high quality interior and energy efficiency in educational buildings and thereby enhancing their sustainability. To evaluate daylight performance, static metrics such as daylight factor and uniformity have been widely used for years, but recently, considering the effects of real climate (amount and nature of daily and seasonal changes in daylight) on a given building as well as the occurrence of irregular weather events, the dynamic metrics of daylight performance have been introduced to overcome the limitations of static ones (Carlucci, Causone, De Rosa, & Pagliano, 2015, p. 1016). These dynamic metrics can be estimated by climate-based daylight modeling (CBDM) and simulation. Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) metrics, as the most discussed dynamic metrics, have been widely used under different conditions in recent years and both are useful for assessing the quality of architectural space in terms of daylight[1]. However, nowadays, the two metrics do not have design values agreed internationally (Cantin & Dubois, 2011, pp. 291-307).

Moreover, in following, other dynamic metrics based on these two metrics are introduced, as discussed in the literature review section. Few studies have compared and analyzed the results of dynamic daylight simulations based on different metrics. In their study, Reinhart and Weissman tested the characteristics of current and emerging daylight in a studio space in Cambridge, USA. The results showed that compared to other metrics, using the dynamic metric of spatial daylight autonomy, students assessed the daylight in the studio more accurately. However, the authors have suggested that the results should be further tested and evaluated in other spaces (Weissman & Reinhart, 2012, p. 155). Another study shows the simulations performed in 11 schools (Brazil (2), Canada (1), Egypt (1) and the United States (7)). In this study, the results were compared with student assessments and it was shown that there is a good agreement between the daylight autonomy metric estimated based on simulation and student assessments (Reinhart, Rakha, & Weissman, 2014, p. 200).

Despite the ever-increasing development of these metrics, none of them have design values agreed internationally. The results of these studies confirm the hypothesis that some of these metrics better predict favorable conditions in classrooms in educational buildings. This is due to the different applications each of these metrics has. Also, the literature review reveals that research on evaluations using dynamic metrics has not yet fully developed, and there is a need for further studies in this field. The present study aims to compare the abilities of two metrics (daylight autonomy and useful daylight illuminance) and those metrics based on them to evaluate daylight performance by examining their sensitivity to changes in building design. Therefore, the study first introduces daylight metrics through literature review and then, examines the changes in WWR made by variations of these metrics.

2. EVALUATION OF DAYLIGHT PERFORMANCE

To achieve sustainable, low-energy buildings, it is required to further emphasize on accurate evaluation of daylight performance. Although much attention has been paid to the goal of providing daylit spaces in our buildings, our ability to describe the variables of a favorable daylit space has not enhanced in the last few decades. The following question has always been raised: with which metric one can fully describe daylight? This question cannot be answered explicitly because in the field of daylight, there are various relevant goals with slightly different needs in terms of the level of detail, accuracy, and inlet and outlet forms, which constitute a useful daylight metric. Each metric aims to combine different factors to predict better or worse performance outcomes and thus make it possible to make decisions. More useful metrics have a perceptual meaning for their users and can also be directly measured for validation, meaning that simplicity is the top priority for choosing a metric because the simpler metrics can be understood intuitively and directly measurable results can be reached.

The number of researchers active in determining and evaluating daylight metrics is constantly growing. In 2007, a subcommittee for the development of daylight metrics was established to surveil the Daylight Metrics Project by Illuminating Engineering Society of North America. This subcommittee aims to guide the development of daylight metrics and to provide recommendations for the use of them. While several candidate metrics have been proposed, the following question still remains: Can one or more values of them consider all the needs of stakeholders in this area (Mardaljevic, Heschong, & Lee, 2009, p. 265).

2.1. Shift Paradigm in Daylight Performance Evaluation

To evaluate daylight performance, static metrics have been common for a long time (Reinhart, Rakha, & Weissman, 2014, p. 200). Fifty years after the introduction of the daylight factor (DF) metric for the first time, due to its inherent simplicity rather than its reality, this metric is still applied as the dominant metric. In the field of construction, experts often face guidelines and instructions for target DF values and they know that these values will likely be provided in buildings with high glazing through high radiation or heat dissipation. The DF metric is not sensitive to orientation and climate and this is considered as its major weakness. The concept of light uniformity, like

DF, is also applied with the standard deep cloudy sky approach and is not applicable to realistic situations where the share of direct sunlight leads to large differences between the maximum and minimum amount of daylight.

But the fact is that the amount of daylight in a space is dynamic and constantly changes in the intensity and pattern of spatial-temporal distribution due to the interaction of the two variable sources of daylight (sun and sky) with the geometry and physical properties of space, exterior and interior. This is true even for climates where the sky is mostly cloudy and therefore, the use of DF as a basis for daylight evaluation is rational. Actual daylight illuminance is significantly different from the deep cloudy sky paradigm. Natural light is full-spectrum light varying throughout the day and on every day of the year. Accordingly, the term climate-based daylight modeling (CBDM) was first coined by Mardaljevik in a title of an article presented at the CIBSE National Conference 2006 (Reinhart, Mardaljevic, & Rogers, 2006). The CBDM method predicts different amounts of daylight using actual sun and sky conditions derived from the standard annual meteorological data set. This method provides predictions of absolute values (e.g. illuminance) that depend on the region, the orientation of the openings as well as the space geometry and the properties of materials. Recently, this computational method has been developed well. Various degrees of all physical values related to visual comfort can be validated and predicted with high accuracy using these illuminance simulation techniques. Even without the values commonly agreed for candidate metrics, climate-based daylight studies conducted for the status quo of real buildings provide valuable insights and tangible design advice to designers. The predictions of time-varying lighting, such as CBDM, provide a more realistic account of actual daylight conditions compared to the ideal daylight factor approach.

Based on this approach, in the last few years, researchers have significantly moved towards more advanced dynamic metrics, indicating the consideration of the change in daylight with time due to the changes in sky conditions (Bourgeois, Reinhart, & Ward, 2008, p. 72). Numerous studies have been carried out on the advantages of dynamic daylight performance metrics over conventional static ones. Unlike static metrics, dynamic metrics take into account changes in daylight with annual and seasonal changes and are usually calculated for the comfort of residents. According to Reinhart, Mardaljevic, and Rogers, dynamic daylight performance metrics take into account the extent and nature of daily and seasonal changes in daylight throughout a year for a given building, as well as unusual climatic events. So, they adopt a more comprehensive approach to the analysis of daylight in space (Reinhart, Mardaljevic, & Rogers, 2006, p. 15). In fact, they evaluate daylight based on the location, orientation, and occupancy pattern of buildings (Piderit Moreno & Labarca, 2015, p. 885). Many studies have also verified the suitability of dynamic metrics for architectural and urban design applications because these metrics provide an opportunity for the designer to treat daylight from an annual perspective and to modify and develop their designs based on functional data (Mardaljevic, Heschong, & Lee, 2009, p. 270).

2.2. Dynamic Daylight Performance Metrics

Dynamic metrics are based on time series analysis and calculated for the construction site based on annual solar radiation data. Currently, UDI and DA are the most well-known dynamic metrics internationally used for assessing daylight illuminance. These metrics and those metrics based on them, that were studied as dependent variables in this study, are defined in the order of development and evolution as follows:

- Daylight Autonomy (DA), (DA avg)

This metric was originally proposed by Association Suisse des Electriciens in 1989 and modified by Christoph Reinhart and Walkenhorst between 2001-2004 (Reinhart & Walkenhorst, 2001, p. 689). This metric is defined as the percentage of occupied time when an illuminance threshold can be met by daylight alone under continuous overcast sky conditions.

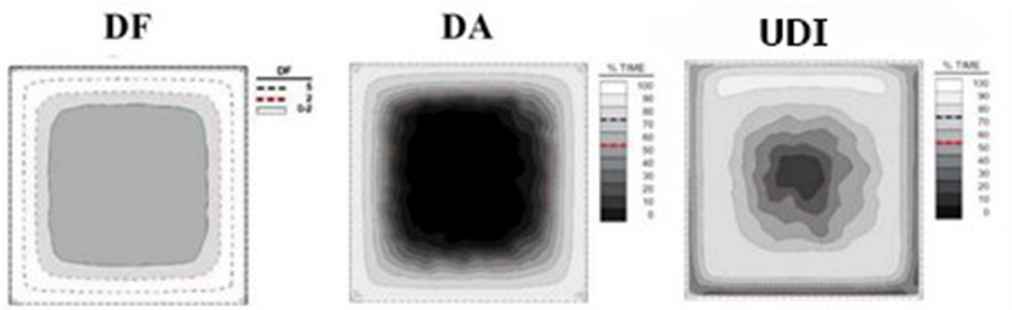

Fig. 1. Analysis of Daylight Conditions with Different Metrics in the AON Center Building by the Department of Building, University of Idaho

According to a study by IESNA, the acceptance of 300 lux as the minimum daylight threshold leads to acceptable statistical results (Standard IES LM-83-1, 2012). Another approach to this metric is to average all points measured in the area analyzed to obtain a total value, which is referred to as the average Daylight Autonomy (DAavg) (Gherri, 2015, pp. 100-104).

- Continuous Daylight Autonomy (cDA)

This metric was first proposed as a basic modification of Daylight Autonomy by Zach Rogers in 2006. If 300 lux is specified as the DA threshold (DA300), and a specific point exceeds 300 lux 50% of the time on an annual basis, the cDA300lux will be approximately 55-60%. In fact, this metric also gives relative credit for values below the minimum DA threshold. For example, if an interior grid point has 150 lux due to daylight, DA300 would give it 0 credit whereas cDA300 would give it 150/300=0.5 credit. This metric is often applied as a comparative metric relative to independent design tools.

- Spatial Daylight Autonomy (sDA)

The sDA metric refers to the percentage of floor area that receives more than a certain amount of daylight during a certain amount of standard operating hours on an annual basis (for example, 50% of the hours between 8 am and 6 pm). This metric was originally proposed by Lisa Heschong. It involves both the spatial and temporal characteristics of daylight performance and is also a regional metric. For example, since the appropriate level of illumination for reading and writing in classrooms is often 500 lux, the spatial daylight autonomy is determined as sDA500 lx50% (IESNAI, LM-83-12 IES, 2012).

- Useful Daylight Illuminance (UDI), (UDI avg)

This metric was proposed as a modification of the daylight autonomy by Mardaljevic and Nabil in 2005 to evaluate the potential of useful daylight illuminance. This metric maintains the interpretive simplicity of the conventional daylight factor method. The UDI is obtained from absolute values of time-varying daylight illumination for a period of a full year. UDI is defined as the percentage of occupied time in a year during which the internal horizontal illuminance caused by daylight is at a certain point within the specified comfort range. UDI not only determines the frequency of repetition of useful levels of daylight illuminance, but also the repetition of occurrence of excessive levels of daylight causing resident discomfort (Nabil & Mardaljevic, 2005, p. 47) In fact, the UDI metric is applied to determine a range of illuminance that is neither too dark nor too bright (Carlucci, Causone, De Rosa, & Pagliano, 2015, p. 1019). Another approach to this metric is the average of all points measured for the analyzed area to obtain a total value. This metric is referred to as average Useful Daylight Illuminance (UDIavg).

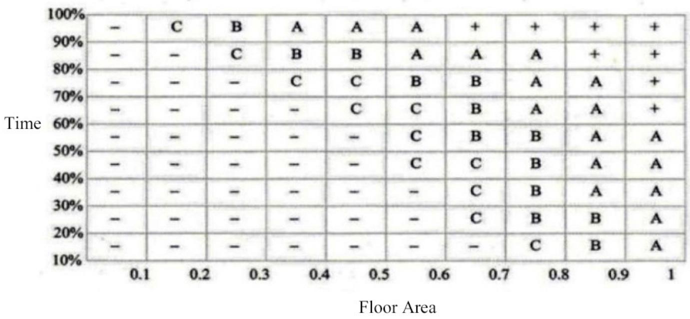

Fig. 2. Daylight Availability/ Spatial Daylight Autonomy
A: 75% Floor Area <Acceptable Daylight
B: 55% Floor Area <Acceptable Daylight
C: Inadequate Daylight
–: Lack of Daylight
(Gherri, 2015, p.115)

- Spatial Useful Daylight Illuminance (sUDI)

This recently proposed metric refers to the percentage of floor area where the internal horizontal illuminance caused by daylight is at a certain point within the specified comfort range (for example, 50% of the hours between 8 am and 6 pm) Noon. This metric also considers both spatial and temporal characteristics of daylight performance (Konis, Gamas, & Kensek, 2016, p. 167).

According to the abovementioned definition, it can be observed that different metrics provide different perceptions of daylight conditions in space. On the other hand, since the daylight performance in any space depends on various aspects, a good design of daylight should be carried out using appropriate metrics to collect data on all possible effects of daylight on that space (Zomorodian, & Tahsildoost, 2017, pp. 80-93).

In most studies in this field, this approach has not been followed and their results have been based on a metric and therefore highlighted one aspect of the problem. There are few studies that have effectively assessed several daylight metrics to select the appropriate metric for the design of optimal daylight in various spaces. Therefore, in the present study, it was attempted to investigate the efficiency of daylight metrics to determine their accordance with the needs of the classroom to select the most convergent metric with functional goals in this type of educational space.

3. METHOD

In this research, to show the relationships between UDI, sUDI, DA, sDA, cDA metrics by examining the effects of the variations of Window-to-Wall Ratio (WWR) on them in a model of an elementary classroom in Tehran, a parametric analysis was performed through simulation in Grasshopper software using Ladybug and Honeybee plugins.

3.1. Climatic and Geographical Characteristics of the Site

In this study, a typical three-storey school building in Tehran (35◦40_N, 51◦19_E) was selected as the basic model. It was located in the Bsk class (semi-warm and semi-arid climate) according to Köppen-Geiger climate classification. Tehran is a city with an altitude of 750 meters above sea level. Its average annual temperature is 17 ° C. The average annual rainfall is between 1000 and 3500 mm. The climate is generally mild in spring and autumn, hot and dry in summer, and cold in winter. The hottest month is August and the coldest one is February (average minimum and maximum temperatures are 23 and 36 °C August, and 1 and 8 °C in February). Annual climate data files were used in epw format for simulation. According to climate data, in Tehran, throughout the year, the sky is clear 67% of the time, partly cloudy 24% of the time and partly cloudy 9% of the time. So, global solar radiation in Tehran is significant. The maximum and minimum direct solar radiations occur in July and January, respectively while the maximum and minimum diffuse solar radiations occur in August and December, respectively.

Table 1. Average Monthly Sunshine Hours in Tehran[2]

	January	February	March	April	May	June	July	August	September	October	November	December	Annual
Sunshine Hours	10:02	10:50	11:55	13:04	14:02	14:31	14:18	13:28	12:22	11:12	10:15	09:46	12:00
The Altitude of the Noon Sun on the 21st Day (Solstice) of Each Month (Degree)	34.4	43.7	54.5	66.2	74.5	77.7	74.7	4.66	55	43.5	34.3	30.9	54.7

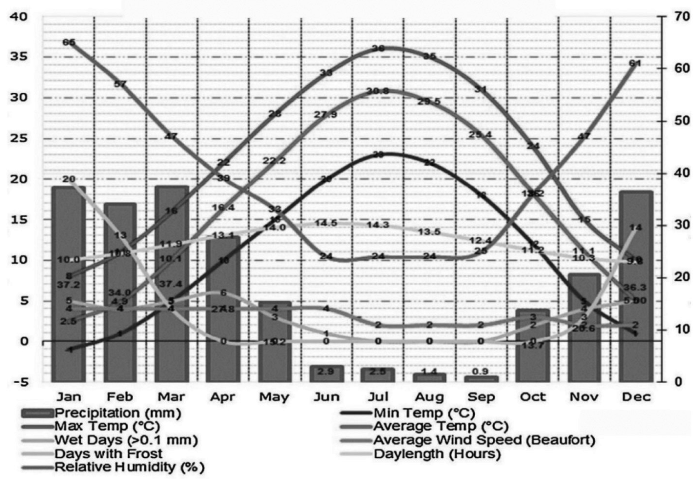

Fig. 3. Climate Chart of Tehran City[3]

3.2. Basic Sample Modeling

In the present study, the basic model is a classroom simulated with the actual conditions. It area is 48 m^2 and located on the south side of the second floor of a 3-storey building with an east-west orientation, where classrooms are along a central corridor. The interior is connected to the exterior through a south-facing window. The window was considered single-glazed, with a visible transmittance of 0.88 and a light shelf and there were no furniture and other accessories in the space. The optical properties of surfaces are listed in Table 1. The parametric analysis was performed at an elevation of 0.75 m (working surface) (Ruck et al., 2000, pp. 103-1030) along the central axis of space. This space was occupied 5 days per week (from Saturday to Wednesday), from 08:00 to 13:00. It should also be noted that the ordinary school holidays were also considered. The artificial lighting, with a power density of 9 W/m^2, and a lighting control system, as a dimmer, were adjusted to provide the target illumination of 300 lux. Photocells reduce artificial light until the overall illumination of the work surface (daylight and electric light) reaches the minimum light threshold. Then, different window configurations were modeled by changing the window parameters. Table 4 shows the ranges of these changes and the values of parameters in the basic model.

Fig. 4. Plan and Section of the Classroom on the South Side of the second Floor of the School Building

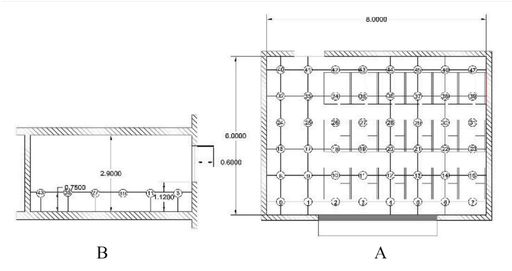

Fig. 5. East-West Orientation of the School Building and the Location of Classroom Windows on the North and South Sides

Table 2. Optical Properties of Surfaces in the Basic Model

Building Element	Optical Properties of Surfaces
Ceiling	85% Light Reflectance
Floor	40% Light Reflectance
Internal wall	45% Light Reflectance
External wall	60% Light Reflectance
Awning	80% Light reflectance

Table 3. Values of Simulation Parameters in Daysim Software

Ambient Bounces (ab)	Ambient Divisions (ad)	Ambient Super-samples (as)	Ambient Accuracy (aa)	Ambient Resolution (ar)	Direct Relay (dr)	Direct Sampling (ds)
6	2048	2048	0.2	64	2	0.25

3.3. Field Measurement

To ensure the accuracy of the simulation results, the results were first validated through field measurements. Field measurements were performed on a sunny day (December 21, 2017). The light level (illuminance) was hourly measured at three points on the table surface (0.75 cm): next to the window (A), the middle of the table (B), and far from the window (C) hourly, from 8:00 to 13:00, using ST-1301 light meter (accuracy: 5% 10d (<10,000 Lux / fc)). To achieve more reliable results, the lights were switched off and the curtains were drawn. The comparison of measured and simulated light levels shows a Mean Bias Error (MBE) of 0.19, which is acceptable. A MBE of ±0.20 is sufficient for most design purposes. MBE is calculated by Eq.(1), where N is the number of sensor points, Es is the simulated illuminance, and Em is the measured illuminance (Ibarra, 2013, pp. 1126-1135).

$$MBE = \frac{1}{N}\sum_{K=1}^{N}(\mathrm{Es} - \mathrm{Em}/\mathrm{Em}) \qquad (1)$$

Table 4. The Light Levels (Illuminance) Simulation and Measured in the Basic Model on 21 December

Times of Measurements on 21 January	Illuminance (Lux)	Point A	Point B	Point C
8:00	Field Measurement	125.02	34.77	13.15
	Simulation	145.40	42.88	15.76
9:00	Field Measurement	3121.13	4301.91	728.09
	Simulation	3354.20	4576.99	755.23
10:00	Field Measurement	8559.24	6928.25	1723.71
	Simulation	8900.60	7102.74	1957.82
11:00	Field Measurement	8787.87	10018.49	2016.15
	Simulation	9150.63	10201.22	2120.06
12:00	Field Measurement	12468.51	12082.4	2284.41
	Simulation	12870.32	12110.49	2573.35
13:00	Field Measurement	10083.51	12041.52	2274.45
	Simulation	10403.76	12105.39	2580.09

3.4. Parametric Simulation

A parametric simulation method can be used to improve building performance. According to this method, the input value of each variable is changed to see the impact on the design purposes, while keeping all other variables constant. This method can be repeatedly applied to other variables. Since only a few tools can calculate new climate-based metrics, for this simulation, the Grasshopper software was used to control the geometric parameters. Continuously, the Honeybee and Ladybug plugins were used to simulate daylight, and then the results were entered into the Daysim software to perform annual daylight analysis at 48 points using a grid resolution of 1×1 m2 and an hourly time step. In the Daysim software, the simulation parameters were set to the values listed in Table 3 . The simulation was performed on a computer with a core i7 processor (16 GB RAM, 1.70 GHz and 256 GB SSD). The Window-to-Wall Ratio (WWR) was considered as the only independent variable.

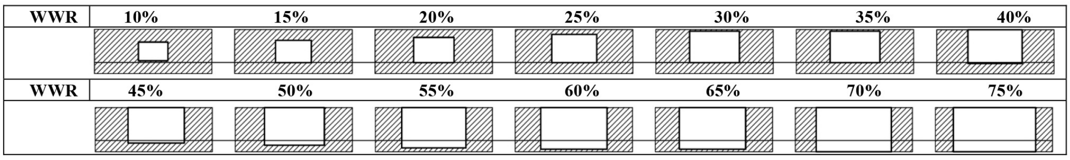

Fig. 6. Window Configuration in Models for Simulation

3.5. Daylight Metrics

The dynamic metrics used in the present study included DA and DA-based metrics, i.e. sDA, cDA, as well as UDI and a UDI-based metric, i.e. sUDI, as introduced in the introduction section. The upper and lower limits of the metrics were determined 2000 and 300 lux according to the literature review, respectively. There is a significant discussion on the selection of 2000 lux as the upper threshold: whether the values higher this threshold will actually cause glare or overheating. There is currently little research to support the selection of 2000 lux as an upper threshold. According to other studies on educational spaces as well as standard recommendations, in the present study, the lower threshold was set at 300 lux (Costanzo, Evola, Marletta, & Panarelli, 2017, pp. 57-58). To achieve the study objective, i.e. understanding the relationship between daylight metrics and the components of occupant comfort, the other two metrics of glare and energy consumption were also calculated. These metrics are defined below:

- Simplified Daylight Glare Probability (DGPs)

It is a simplification of the DGP metric, which refers to the percentage of occupied times in the year during which the daylight glare probability exceeds 0.35. For calculation, the DGPs is assumed at a height of 1.20 m above the floor, corresponding with the typical eye level when sitting. This metric is calculated by Eq. (2).

$$DGP_S = 6.22 \times 10^{-5} E_V + 0.184 \qquad (2)$$

Where Ev is the vertical eye illuminance produced by the light source. In general, any DGP value below 0.35 corresponds to 'imperceptible' glare sensation, between 0.35 and 0.40 is 'perceptible', between 0.40 and 0.45 is 'disturbing', and higher than 0.45 is 'intolerable'. In this study, the high values of DGPs>0.35 are assumed to correlate not only with perceptible glare, which leads to possible visual discomfort but also with high energy consumption for cooling, which, for simplicity, are not calculated separately.

- Total Annual Lighting Energy Consumption (EL)

It refers to the total demand for electrical lighting energy in a year and is calculated in kWh/m^2.

4. FINDINGS

The maximum, minimum, and average values of illuminance (lux) obtained from the simulations of different WWRs are shown in Figure 7. Also, the values obtained from the calculation of dynamic daylight performance metrics are shown in Figure 8. The results were evaluated in two groups. In the first part, the variation trend of 5 dynamic daylight performance metrics including UDIavg, sUDI, DAavg, sDA, cDA were examined. As shown in Figure 9, the chart clearly shows that as the WWR increases, neglecting a high limit for them, the daylight metrics, here, i.e. DA300lx, sDA300lx, and cDA300lx, also increase because more daylight penetrates into space. The lack of a high limit for these metrics makes it difficult to compare them at higher WWRs. Moreover, an ascending trend is observed for UDIavg300–2000lx, but it is descending as WWR exceeds 20%. The sUDI300–2000lx metric also shows a downward trend. The comparison of sUDI and UDI avg shows that UDIavg decreases slightly, while UDI decreases more rapidly. This is because sUDI refers to the number of points in space at which the need for daylight is met, so sUDI is less accurate than UDI. Increasing the density of sensor points in the grid can increase the accuracy of the sUDI metric, but also significantly increase the computation time.

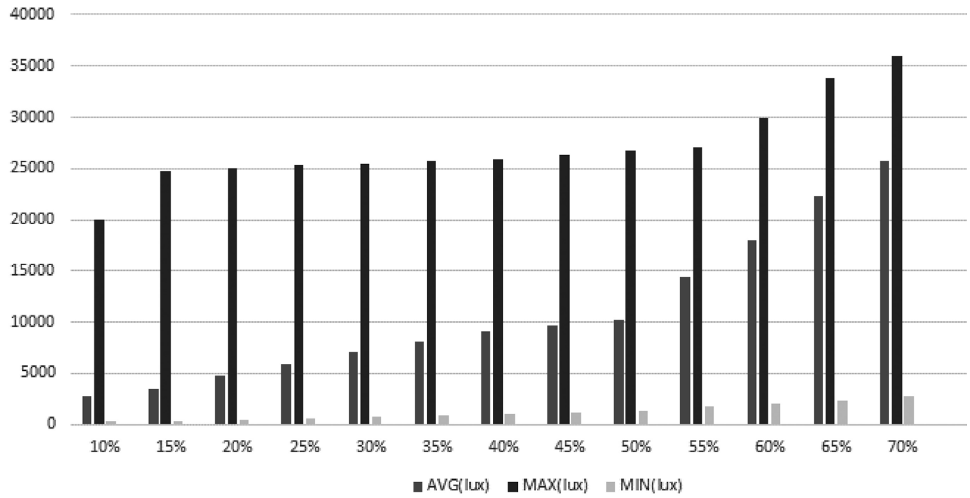

Fig. 7. Values of Illuminance (Light Level, in Lux) for Different Window Configurations

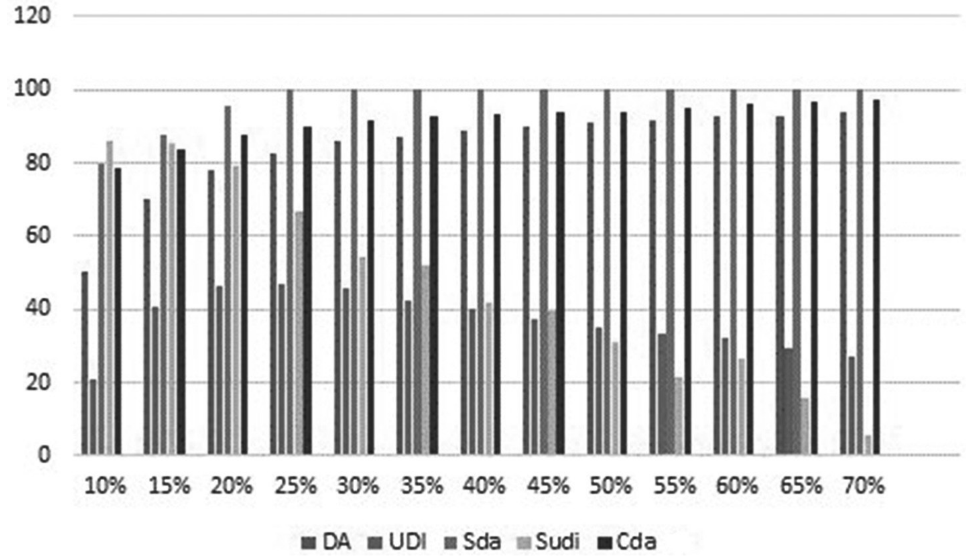

Fig. 8. Values of Dynamic Daylight Performance Metrics for Different Wwrs

In the second part, the variation trend of the two main metrics of DA and UDI were examined relative to the variation trends of DGPs and EL. The chart in Figure 10 clearly indicates that as the WWR increases, DA300lx increases, UDI300–2000lx decreases at WWRs above 20%, and DGPs> 0.35 increases because more daylight (above 2000 lux) reaches the working surface, indicating an increased risk of glare and overheating. Moreover, EL naturally decreases with an increase in WWR. However, if EL is added to the probability of increased cooling energy consumption at higher WWRs, as shown by an increase in DGPs > 0.35, total energy consumption will also potentially increase. It should be noted that the exact amount of cooling energy consumption is not calculated in this study, because the present study aimed to determine the relationship between the related variables using a simple approach.

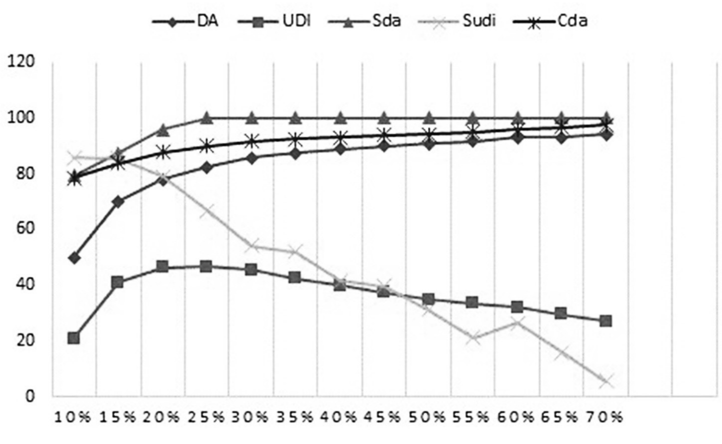

Fig. 9. Variation Trend of Dynamic Daylight Metric by WWR

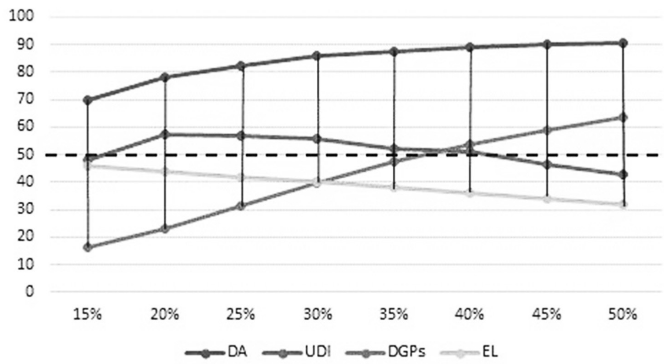

Fig. 10. Comparison of the Variation Trends of DA, UDI, DGPs and EL

The trend lines of EL and DGPs> 0.35 intersect each other at WWR of about 30%, indicating the point where the minimum lighting energy consumption is obtained. At WWRs of 30% and 40%, the average values of UDI300–2000lx are above the minimum standard value of 50%, indicating the presence of adequate daylight. Somewhere between WWRs of 35% and 40%, UDI300–2000lx and DGPs> 0.35 are 50%. At higher WWRs, DGPs> 0.35 is higher than 50%, which leads to the risk of glare and overheating during more than half the occupied time.

5. DISCUSSION AND CONCLUSION

To recognize and compare the efficiency of dynamic daylight performance metrics, in the present study, it was attempted to investigate the variation trends of the most well-known metrics, namely DA and UDI, and those metrics based on them, including sUDI, DA, sDA, cDA, relative to the variations of WWR parameter through a parametric sensitivity analysis applied to a south-facing classroom in the climate of Tehran City. The results indicated that any metric proposed for measuring realistic time-varying daylight illuminance must be somehow for a wide range of daylight levels in nature. In fact, instead of a threshold value (such as DA), a spectrum of illuminance (such as UDI) provides a more useful metric. The lack of a high limit for DA and DA-based metrics, i.e. sDA and cDA, eliminates their correlations with the components related to the occupant comfort. Among various daylight metrics, UDI, due to its correlation with glare indices, can indicate the degree of occupants' visual discomfort and also the energy consumption. The UDI metric is a straightforward approach in terms of both required data and equipment, and is only slightly more complex than the daylight autonomy method, although it can provide much broader insights into spatial-temporal changes in daylight illuminance. Therefore, in comparison with DA and DA-based metrics, UDI also includes factors indicating the propensity for the occurrence of occupant discomfort. Also, among UDI-based metrics, sUDI needs to increase the density of sensor points in the grid to achieve the same accuracy as UDIavg, significantly increasing the computation time. Therefore, the UDIavg metric is more suitable to use for small spatial units where the number of sensors is quite limited.

It should also be noted that UDI, as a daylight metric, also faces limitations in terms of illuminance values and there are various threshold values for it according to different studies. Although the high limit of UDI was initially set to prevent unwanted sunlight, direct sunlight may also be favorable for heating in cold weather in winter. Therefore, more studies should be carried out on residents' behavior to assess the efficiency of dynamic metrics through field investigations. Further studies can also provide a definition of the flexibility of dynamic metrics in different regions.

END NOTE

1. Reinhart and Walkenhorst have defined DA as "the percentage of occupied time when an illuminance threshold can be met by daylight alone under continuous overcast sky conditions" (Reinhart & Walkenhorst, 2001, p. 689). UDA, which was proposed by Mardaljevic and Nabil, is defined as "the percentage of occupied time in a year during which the internal horizontal illuminance caused by daylight is at a certain point within the specified comfort range" (Nabil & Mardaljevic, 2005, p. 47).
2. http://www.tehran.climatemps.com/sunlight.php
3. https://fa.wikipedia.org/wiki/ جغرافیای- تهران

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