294: Prediction of Daylight Performance in Office Buildings based on LEED 2.2 Daylight Requirements

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Abstract

ABSTRACT: In the design of buildings, there is a great demand to make them sustainable and energy efficient. Especially in the U.S., certification by the Leadership in Energy and Environmental Design (LEED) is becoming a top priority for public and private projects. LEED is the most widely used green building certification system in the U.S. and the use of it as a standard is growing internationally as well. In the evaluation of daylight performance, LEED 2.2 requires that a minimum daylight illumination level of 269 lux (25 footcandles) be achieved in a minimum of 75% of all regularly occupied areas. However there is no tool to estimate this credit during the schematic design process and no consideration about daylight performance in current and past LEED-certified buildings. Therefore, this paper provides a simplified analysis method for evaluating the daylight performance, in meeting the daylight requirement of LEED 2.2. The analysis of the interactions among different floor areas, window areas and visible transmittance (VT) has been evaluated. In order to verify the influence of geographical location, three different cities (Dubai, Chicago and London) were selected. Based on a series of computer simulations using RADIANCE, the results include fenestration criteria in meeting LEED 2.2 daylight requirements. This research presents a guideline that would assist users in predicting daylight performance of an office building. It can be used as a pre-design tool to evaluate additional credits in LEED 2.2 but also to analyze the daylight performance of a building.

Keywords: LEED 2.2, Daylight Requirement, RADIANCE, Visible Transmittance, Window area, Floor area

1. Introduction

The provision of natural daylight is known to affect visual performance, lighting quality, health, human performance and energy efficiency. The admission of daylight into a building can displace the need for electrical lighting at the perimeter zone and reduce electrical energy use by 30-40% [1]. The Leadership in Energy and Environmantal Design (LEED) rating system also recognizes the importance of natural light entering a building, in terms of improving the satisfaction and productivity of occupants while reducing global energy consumption [2].

Ahmed et al. showed that a 10% energy savings could be achieved by using daylighting strategies in Malaysian buildings. Energy savings of 10–40% can be achieved via a daylighting scheme depending on the envelope of the buildings and climate zones [3]. Moreover, a recent survey showed that most occupants prefer natural light to artificial light; surely, the admission of sunlight and natural ventilation follows, at least in part, from that preference [4].

Although we acknowledge the benefits of daylight, it has been pointed out that daylight-related concerns have not been prevalent in building design, until recently [5]. Recent surveys have shown that daylighting strategies are not commonly incorporated into commercial buildings [6,7]. In fact, as an example, only 10% of U.S. commercial buildings have some daylighting schemes [6]. Moreover, there is another barrier to using the daylight simulation programs. While several detailed simulation tools are available to evaluate the benefits of daylighting, these simulation tools require lengthy input process and are too time consuming for most architects and designers to use [8,9].

Because these problems, only 14% of Colorado's LEED-certified projects have successfully earned a credit of "8.1 Daylight and view." Achieving the daylight credit can contribute to increased energy savings and so most builders should consider that fenestration is responsible for fulfilling the daylight requirement and achieving a LEED certification [10]. This paper provides a simplified method for evaluating the qualified daylight area and energy savings, based on the LEED 2.2 green building rating system.

2. LEED 2.2 Daylight Requirements

LEED 2.2 was released in November 2005. In this new version, there is a slight change in the daylight requirements. There are three options: calculation of glazing factor (Option 1), simulation (Option2), and measurement (Option 3) [2].
From among the three options, computer simulation requires that a minimum daylight illumination level of 269 lux (25 FC) be achieved in a minimum of 75% of all regularly occupied areas.

Table 1: Three Daylight Requirement Options

Option	Description
1	CALCULATION**:** Achieve a minimum glazing factor of 2% in a minimum of 75% of all regularly occupied areas.
2	SIMULATION**:** Demonstrate, through computer simulation, that a minimum daylight illumination level of 25 footcandles has been achieved in a minimum of 75% of all regularly occupied areas. Modeling must demonstrate 25 horizontal FC under clear sky conditions, at noon, on the equinox, at 30 inches above the floor.
3	MEASUREMENT**:** Demonstrate, through records of indoor light measurements, that a minimum daylight illumination level of 25 FC has been achieved in at least 75% of all regularly occupied areas. Measurements must be taken on a 10-foot grid for all occupied spaces.

3. Methodology

Table 2: Description of four office types

	Type1	Type2	Type3	Type4
W X D	75X75	110X110	145x145	180x180
Af	5,625	12,100	21,025	32,400
H	9 feet			

Note: Af; Floor area, H; Floor to Ceiling height

Table 3: Main Simulation Parameters

Parameters	Value
Model Size	Office Type 1, 2, 3 & 4
Window Size	10, 30, 50, 70 & 90% (See Fig 1)
Visible Transmittance (VT)	20%, 40%, 60% & 80%
Interior Reflectance	Wall 50 %, Floor 30 %, & Ceiling 80 %

Table 4: Three cities of Different Latitude

City	Latitude	Longitude
London	51.32° N	0.50° W
Chicago	41.59° N	87.54° W
Dubai	25.13° N	55.17° E

This research considered four typical office buildings, because the LEED green building rating system was designed to guide high-performance commercial projects [2]. A 3D model of the open-plan floor was modelled, as shown in Figure 1. The data and assumptions of the four office types are presented in Table 2 and 3. In order to verify the influence of the climatic and geographical location, three different cities in these regards (Dubai, Chicago and London) were selected. Specific location data and outdoor footcandles are shown in Table 4.

Using RADIANCE, the four types of office plans were modelled and simulated under clear sky conditions at noon on the equinox at 30 inches above the floor, based on the LEED 2.2 daylight requirement [11,12]. All the simulations were carried out to investigate the indoor FC, with various combinations of window-to-wall ratio (WWR) and visible transmittance (VT). The VT varied from 20% to 80%, and the WWR varied from 10% to 90%, as shown in Table 3. The workplane illuminance data on a grid with a spacing of 5 ft was calculated at a height of 30 inches above the floor and the total simulation points were set as 225, 484, 841, and 1,296 respectively [13]. The outdoor horizontal lux values were 48,310 (London), 60,280 (Chicago) and 74,220 (Dubai) at noon on Equinox based on RADIACE simulation.

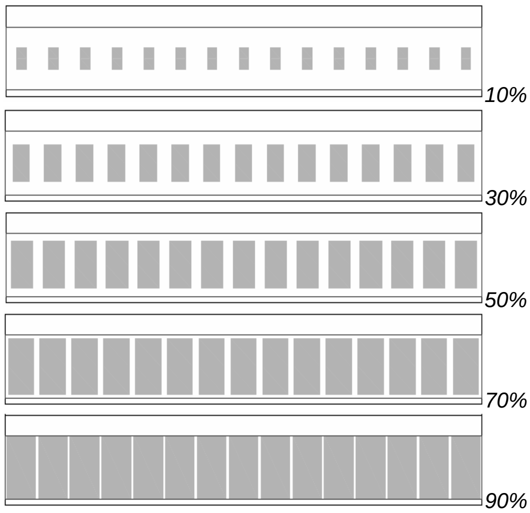


Fig 1. Proposed window configuration in simulation (Percent of Net wall area, Floor to Ceiling)

4. Results

Table 5: Results of daylight simulation, London

		Window Size				
	VT	10%	30%	50%	70%	90%
Type1	**20**	6.7	14.2	26.7	43.6	56.9
	40	6.7	42.2	65.3	79.1	87.6
	60	19.1	60	82.7	94.7	100
	80	36	76	94.7	100	100
Type2	**20**	4.5	9.7	17.8	28.9	36.2
	40	4.8	29.5	45.5	54.8	61.2
	60	12.8	42.4	59.3	69.2	77.5
	80	24.6	54.8	68.4	79.5	87.4
Type3	**20**	3.4	6.2	9.2	19.6	27.5
	40	3.6	20.5	33.3	41.4	47.1
	60	8.6	31.9	45.1	53.7	58.5
	80	18.1	42.6	54.6	62.9	69.8
Type4	**20**	3	4.7	7.3	14.5	18.9
	40	2.8	15.7	25.7	33.7	39.1
	60	4.4	26	35.1	44.9	49.3
	80	10	32.6	45.4	52.3	57.7

Table 6: Results of daylight simulation, Chicago

		Window Size				
	VT	**10%**	**30%**	**50%**	**70%**	**90%**
Type1	**20**	6.7	8	30.7	46.7	58.7
	40	6.7	40.4	67.1	81.3	89.9
	60	19.1	64.9	84	96.9	100
	80	34.2	80	96	100	100
Type2	**20**	4.5	5.8	15.9	29.8	39.9
	40	4.5	29.5	43.8	56.2	63.2
	60	10.5	44.8	59.3	69.8	77.7
	80	24.4	55.6	71.5	80.8	88.6
Type3	**20**	3.4	4.2	10.5	19.1	28.8
	40	3.4	20.2	33.1	42.3	49
	60	6.1	32.3	46.7	54.1	61.5
	80	16.2	41.7	54.3	63.7	70.7
Type4	**20**	3	2.8	6.6	14	23.3
	40	2.8	13.7	28.3	32.8	39.6
	60	3.9	26.4	36.8	45.3	50.8
	80	11.3	34.5	46.4	53	58.6

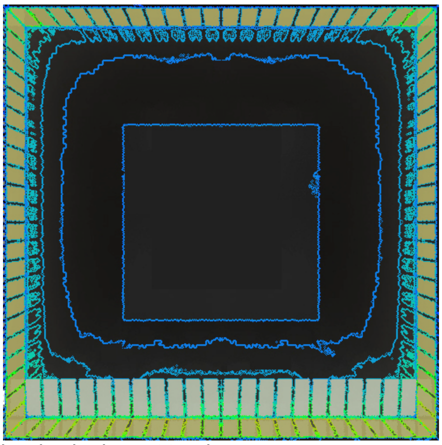
Table 7: Results of daylight simulation, Dubai

		Window Size				
	VT	**10%**	**30%**	**50%**	**70%**	**90%**
Type1	**20**	0	7.6	26.7	47.6	56
	40	3.6	44.4	67.1	80.4	89.8
	60	16.4	64.9	87.1	93.3	100
	80	32	78.2	97.3	100	100
Type2	**20**	0	5.2	15.9	28.7	39
	40	4.5	27.7	45.9	55.2	63.8
	60	10.1	43.2	62.2	70.7	78.5
	80	23.3	55.4	72.3	81.2	89
Type3	**20**	0	2.4	8.8	21	28.3
	40	1.0	18.4	33.8	42.7	49.6
	60	5.0	31.7	46.8	54.1	62.3
	80	15.8	43.3	55.4	65.4	71.8
Type4	**20**	0	1.3	6.9	17.7	27.7
	40	0.8	10.8	28.5	35.2	41
	60	2.8	28.8	37.1	46.8	51.3
	80	8.6	34.5	46.9	53.6	59.6

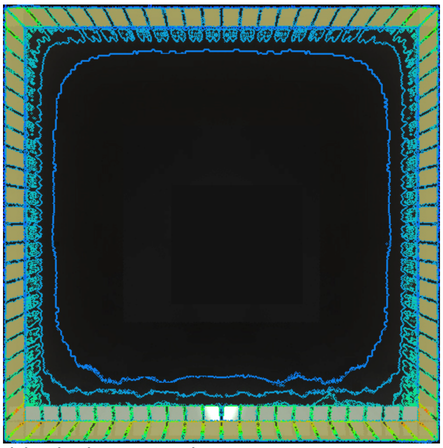
In every the simulation condition, indoor illuminance were simulated and the number of sensor points over 269 lux (25FC) were calculated based on LEED 2.2. The simulated results - namely, area percentage over 269 lux- are displayed in Tables 6, 7 and 8, respectively.

In the subsequent step, a regression analysis was conducted to investigate the effects of various parameters, such as window area, VT, and regularly occupied area. In order to verify the relationship between daylight performance and the simulation parameters, the daylighting aperture – defined here as the product of the window's visible transmittance and the window to perimeter floor area ratio - was used [8,14,15]. This relation is presented in M. Krarti et al. [14]. Although Krarti et al used "Aw/Ap; window to permeter floor area" to verify the artificial lighting energy savings in perimeter zone, we used "Aw/Af; window to floor area' to evaluate the daylight performance.

Figure 3 shows the relationship with respect to "(VT X Aw) / Af" in terms of the area percentage over 269 lux (25 FC). The coefficient of determination, R^2, is found to be 0.963 in London, 0.957 in Chicago, and 0.959 in Dubai. These results reveal a strong relationship between the area percentage over 25 FC and '(VT X Aw) / Af' [13].



London (Latitude 51.32° N)



Dubai (Latitude 25.13° N)

Figure 2: Simulation Results Using RADIANCE (Note: Office Type 1, Window size-90%, VT-60%)

As shown in Figure 3, there are small differences among cities. Because Dubai's outdoor FC is higher than that of London, under the same conditions, the area percentage over 269 lux (Dubai) was larger than that in London. However, in reverse, due to London's sun altitude being lower, more sunlight can penetrate the inside area, as shown in Figure 2. Therefore, there is a small difference due to conflicts in two factors, outdoor illuminance and sun altitude.

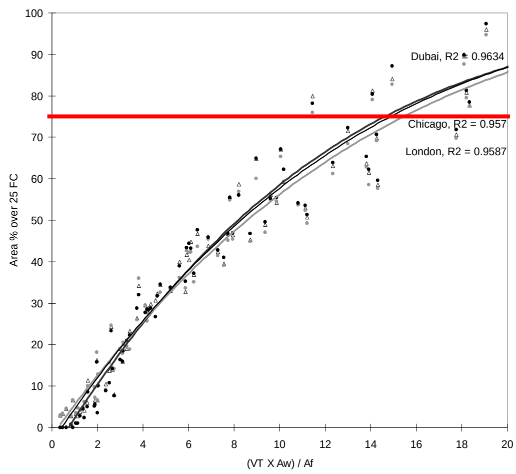


Figure 3. Correlation between area percentage exceeding 269 lux (25 FC) and (VT × Aw) / Af

With these figures and results, an area percentage exceeding 269 lux (25FC) can be predicted, based on the daylight requirements of LEED 2.2. Further, the results can be applied to other areas of the same latitude because the sun altitude on Equinox at solar noon is the same when the location is at the same latitude using a solar sun path diagram [16,17].

5. Conclusion

The guidelines for the fenestration criteria as presented in this paper are related to windows and floor area and VT in three different cities. With a parametric simulation and regression analysis, the main results provide a simplified tool to predict the daylight requirement of LEED 2.2 (area percentage over 269 lux). Significant findings are listed below.

It was found that the “Area percentage over 25 FC” reveals a relationship with “(VT×Aw)/Af”. Based on our regression analysis, the R^2 over 0.95 values indicated a strong correlation among the WWR, VT, office area, floor areas and daylight requirements as demanded by LEED 2.2. Although differences in geographical location were large, differences in terms of daylight performance results were only slight due to external lux and sun altitude. Even though the simulations were performed in three different cities, these results can apply to locations with similar latitudes, i.e., 25°, 42° and 51° N. When “(VT×Aw)/Af” is greater than 14.5 (Dubai), 15 (Chicago) and 15.5 (London), a minimum area percentage over 269 lux (25FC) can be achieved.

Therefore, these simplified tools can be used as a guideline on how to estimate daylight performance and how to design fenestration in order to obtain credit in the LEED rating system. Moreover, it is important that architects understand the importance of the role of fenestration, and how to design windows with building envelope and location in early design stage.

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