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Contrasting daylight simulation, measurements, and occupant's perception in a LEED Office building in Arid Climate

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Abstract. Daylight is vital to building occupants as it impacts health and productivity of humans in the indoor environment. No doubt that green building rating systems contribute to the awareness of the significance of daylight in buildings, they enhances the indoor environmental quality by awarding credits to daylight harvesting in buildings. LEED as one of the predominant green building rating systems sets specific daylight criterion, and offers more than one option for project teams to assess and comply with the set criterion; either using manual calculations, using computer simulation (during design), or by daylight measurement (by substantial construction). This article presents a case study of a LEED Gold building in Cairo, Egypt. Within this specific case, three daylight assessment approaches were implemented; Daylight simulation (on design drawings), daylight measurement (after substantial construction), and Post Occupancy Evaluation (POE) (after 9 months of building occupancy). This paper contrasted the results of the assessment methods, this contrast in daylight assessment methods revealed the significance as well as drawbacks of each assessment method compared to the other, and distilled valuable insights about the reliability of each of the available assessment methods.

Keywords. Green Building, LEED, Office Building, Daylight, Simulation, Measurement, Post Occupancy Evaluation (POE).

1. Introduction

Humans spend more than 90% of their time indoors [1]; hence, the quality of the indoor environment is crucial to be considered for their health, wellbeing, and productivity. One of the most significance indoor environmental quality aspects is daylight. Daylight is an important factor which impacts building occupants' health and well-being. Daylight has a clear leverage on our body clock and metabolism, and therefore it can affect our circadian cycle [2]. Accordingly, the availability of daylight can keep the occupants healthy and effective in their works. As well as for buildings, daylight is a primary source of lighting and a special element in enhancing architecture [3].

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“Even a room which must be dark needs at least a crack of light to know how dark it is. Architects in planning rooms today have forgotten their faith in natural light. Depending on the touch of a finger to a switch, they are satisfied with static light and forget the endlessly changing qualities of natural light, in which a room is a different room every second of the day.” [Louis Kahn, as cited in [4].

Egypt is one of the countries that receive huge amount of solar irradiance, Fig. 1, so either green rated or noon-rated buildings in Egypt must harvest daylight to allow for better human comfort, and to maximize energy savings as well.

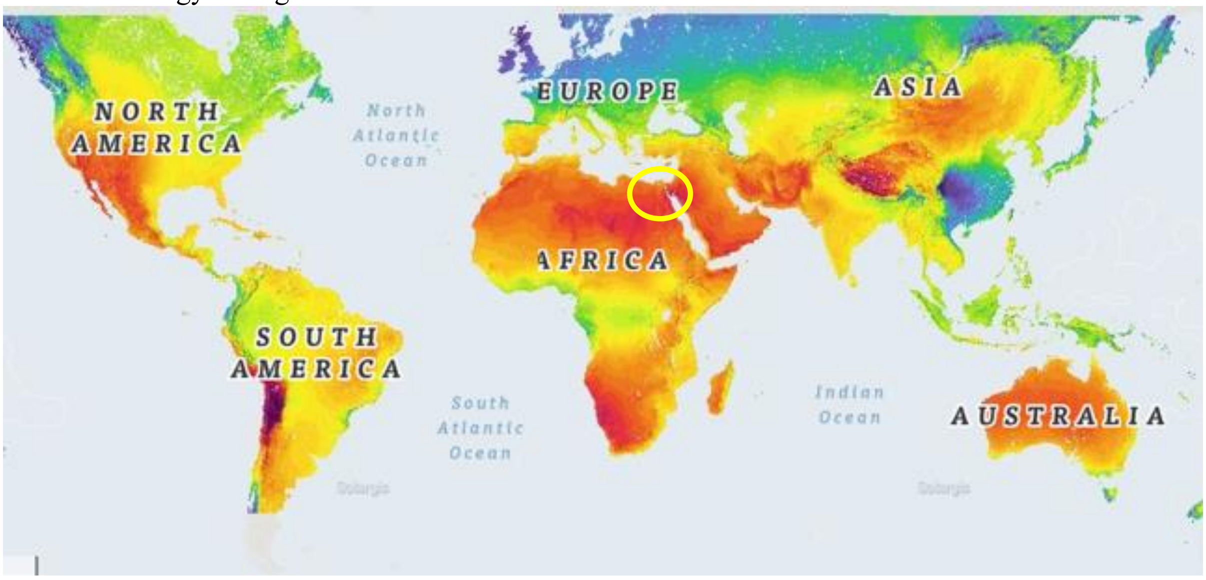

Figure 1. Solar availability map. Retrieved from [5]

LEED is an acronym for ‘Leadership in Energy and Environmental Design’, which has number of requirements to be certified [6]. One of the LEED V3 requirements indicates that, at least 75% of all regularly occupied spaces should receive daylight luminance between 10 and 500 foot-candles (fc) (107 and 5380 Lux), in order to achieve 1 LEED credit; projects should opt for daylight simulation or measurement to verify the daylight credit requirements, in both cases criteria is the same, however, if project’s team opts for daylight measurement; projects may achieve 2 points if they demonstrate more than 90% of regularly occupied space areas to be compliant [6].

Several research publications did question the uncertainty within daylight simulation, and attempted to evaluate different daylight simulation tools, different sky models to test simulation accuracy and uncertainty using large datasets [7] & [8].

Besides daylight quantity, research extended to question the essence of daylight quality. [4] Presented a significant categorization of daylight quality aspects, in addition to illuminance levels, it assessed the presentation modes of contrast, distribution, steadiness, directivity, glare, and colorization. All those aspects are highly impact building’s occupants. Based on recent work by [9] , the study revealed that colorization can impact users’ thermal comfort perception.

More research exceeded questioning about daylight quality, to question how building users perceive and experience their indoor environmental quality aspects [10], including daylight perception [4].

Previous research assessed daylight simulation in comparison with measurement [[11], [12], [13], & [14]]; however, almost no previous contributions did put measurement, simulation, and users’ perception in comparison, especially in a LEED awarded buildings.

The objective of this paper is to evaluate two dominant daylight evaluation methods; simulation and measurements, and to compare both with the actual building user’s perception in a LEED awarded building.

2. Methodology

The research follows mixed method approach; simulation, field measurements, and survey of occupant's feedback on the quality of daylight in their office spaces.

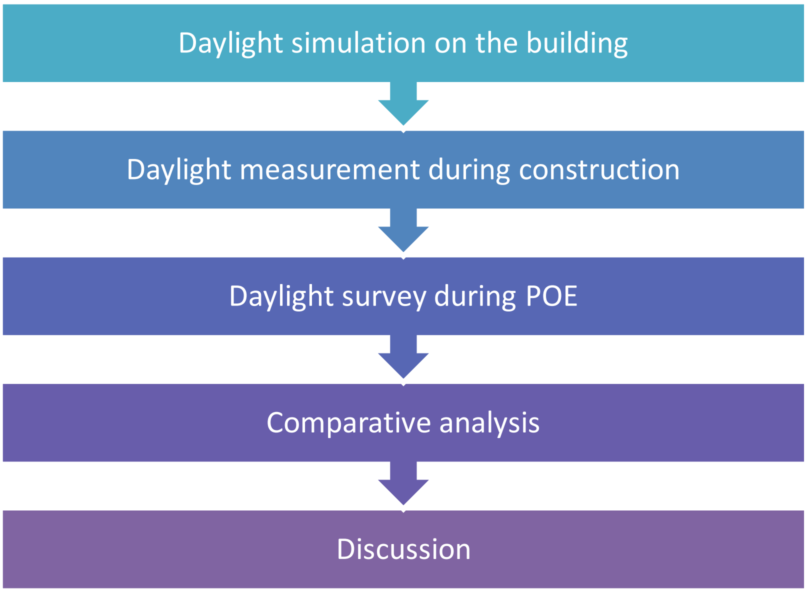

Fig. 2. Study conceptual framework.

3. Case study description

The current project is located at New Cairo in Egypt, it is a mid-size office building with a total of 6,600 square meters; the area includes seven floors of office spaces above the ground level, and two floors of underground parking garage. The project achieved LEED Gold certificate in June 2018, under LEED V3. The current case is from the building's second floor, Fig. 3, which represents the building's typical floor.

The building performance was well verified related to all aspects, since that enhanced Commissioning (Cx) process was applied. Most of the systems, assemblies, and components are interfaced through the Building Management System (BMS), including the building's daylight harvest system.

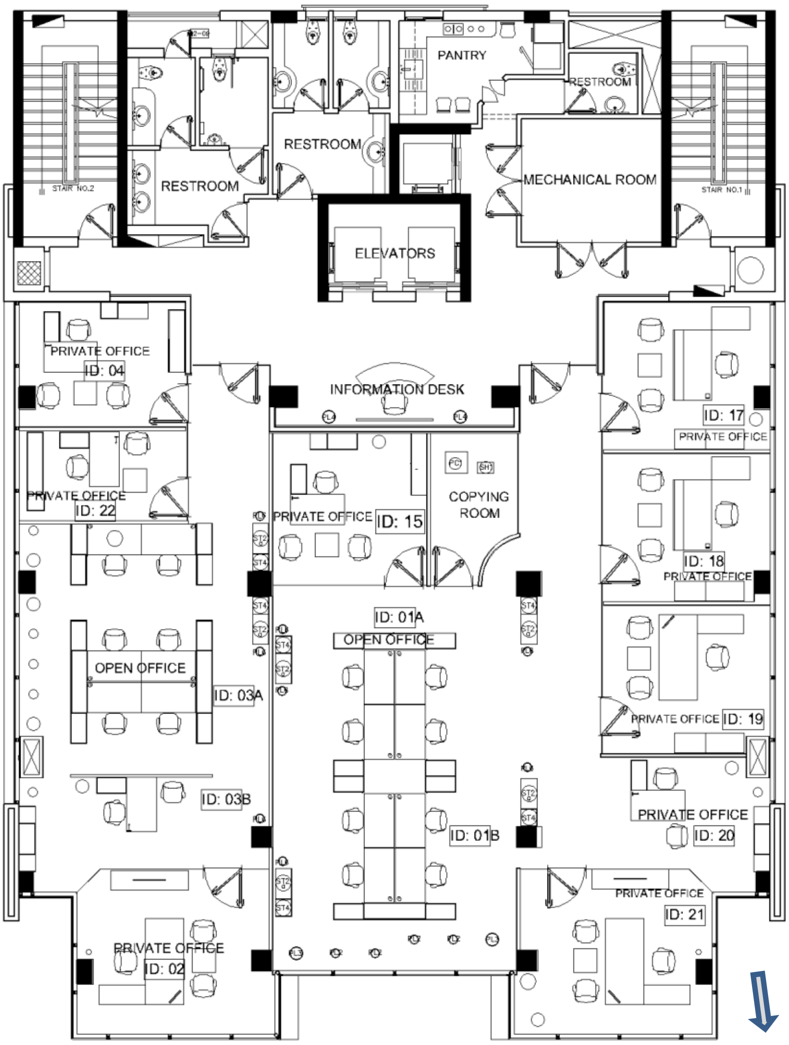

Fig. 3. Second floor (typical) floor plan.

The building's main façade is North oriented, and the building's north, east and west facades are constructed of curtain wall, with glass visible transmittance of 37%, which was selected for energy efficiency considerations.

The daylight harvest system is implemented by installing exterior light shelves, a daylight sensor, and dimmable LED lighting panels in each office space. Both, sensor and panel light are interfaced with the BMS, so that the lighting panel is able to dim as per daylight reading. Fig. 4 shows office space interior.

Fig. 4. Office space interior.

4. Daylight simulation

Simulation is done using Ladybug tools [15] within Grasshopper software [16]. Simulation is run on the same date and time on which daylight measurements were taken (December 8th, 1:00 PM). Results are also plotted on building plans with nearly the same spacing (1.4 meters) which was considered during measurements, and with the same constructed curtain wall glazing's luminous specifications, which is 37% visible transmittance, and with the same interior surfaces' reflectivity (90%); hence, the simulation is the closest as it can be to the actual building case. Fig. 5 shows daylight simulation results.

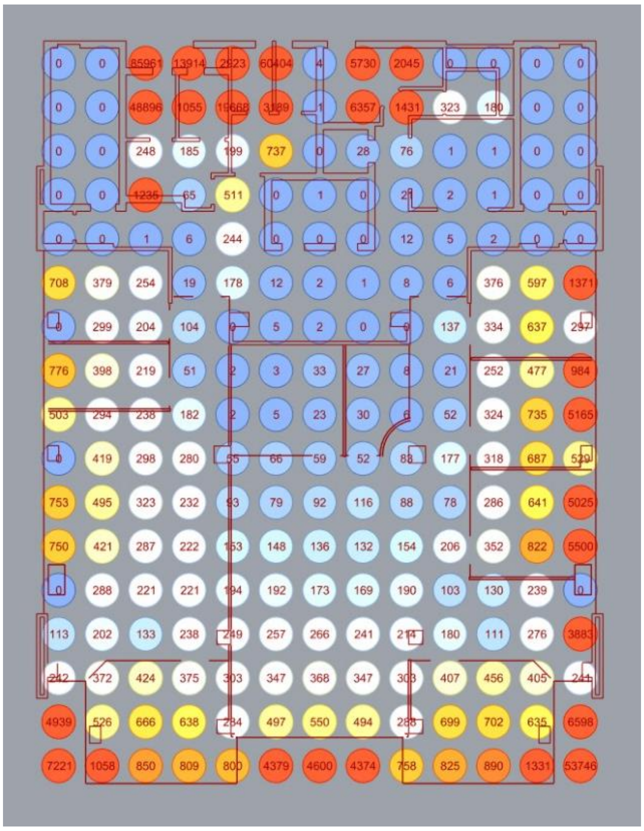

Fig. 5. 2nd floor Daylight simulation results (in Lux)

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5. Daylight measurement

Daylight measurements followed LEED requirements, and achieved LEED daylight 2 credit points, by fulfilling illuminance levels between 107 and 5380 Lux.

The measurements were conducted using recently calibrated lux meter, model: Testo-540. Measurements were conducted on December 8th, at 12:44 PM. Fig. 6 shows daylight measurement results on the 2nd floor (typical floor).

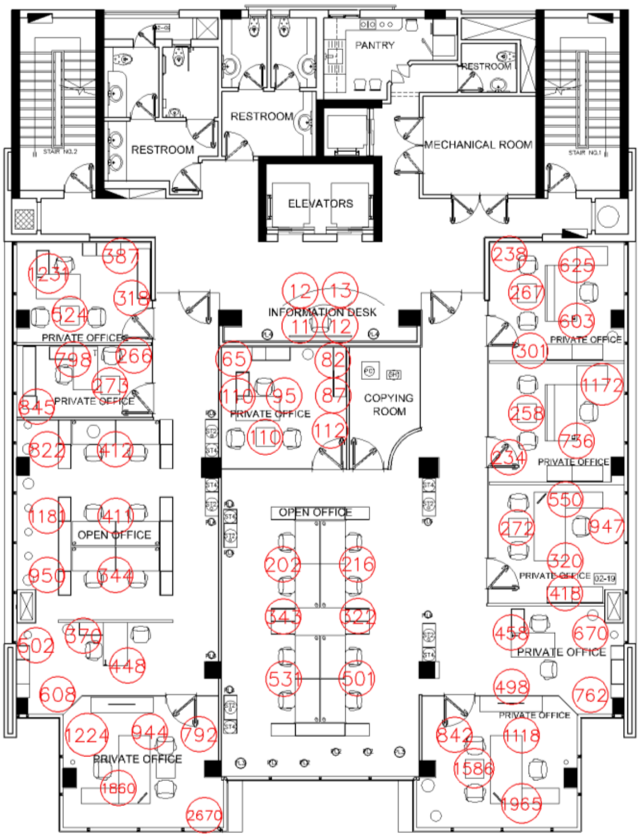

Fig. 6. 2nd floor Daylight levels (in Lux)

6. Building survey

Post Occupancy Evaluation (POE) was conducted after 9 month of building occupancy. The distributed survey evaluated several green building aspects, including satisfaction with daylight levels among building occupants. Total number of survey respondents is 59 occupants, out of the building's 90 occupants.

The survey showed that 42% of the occupants reported full satisfaction of daylight level; as shown in Fig. 7 and 8.

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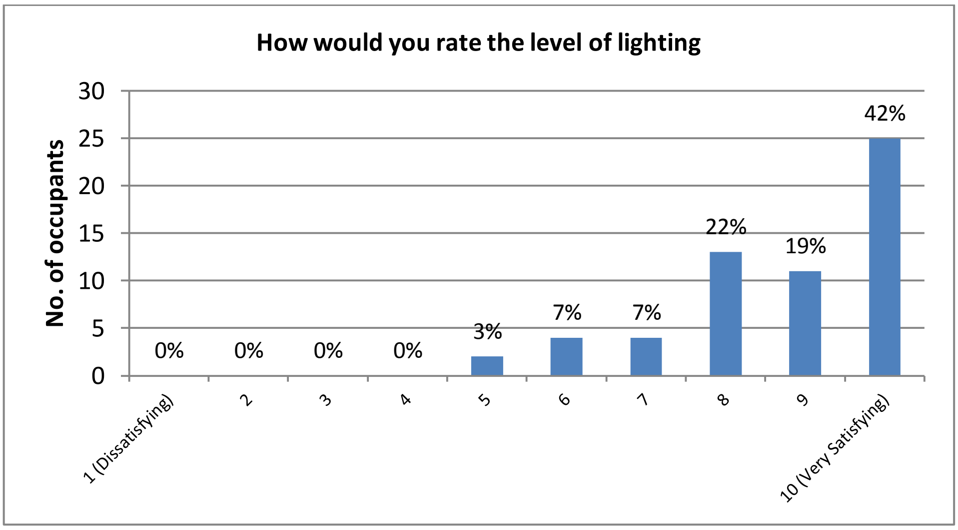

Fig.7 . Building survey results

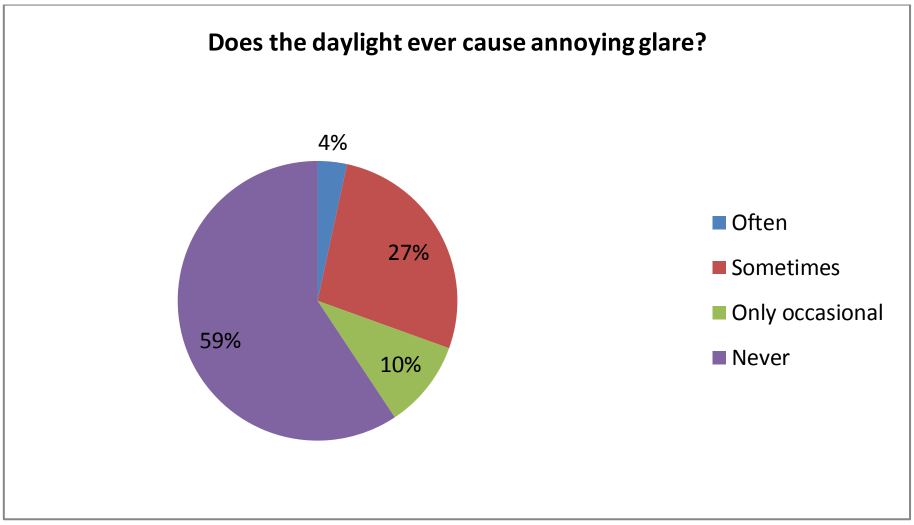

Fig. 8. Occupants feedback regarding glare

The survey results represent satisfaction with daylight for the whole building, while Fig. 9. shows occupants satisfaction on separate zones' level, showing how occupants feedback can relate to the measured daylight level on the same zone:

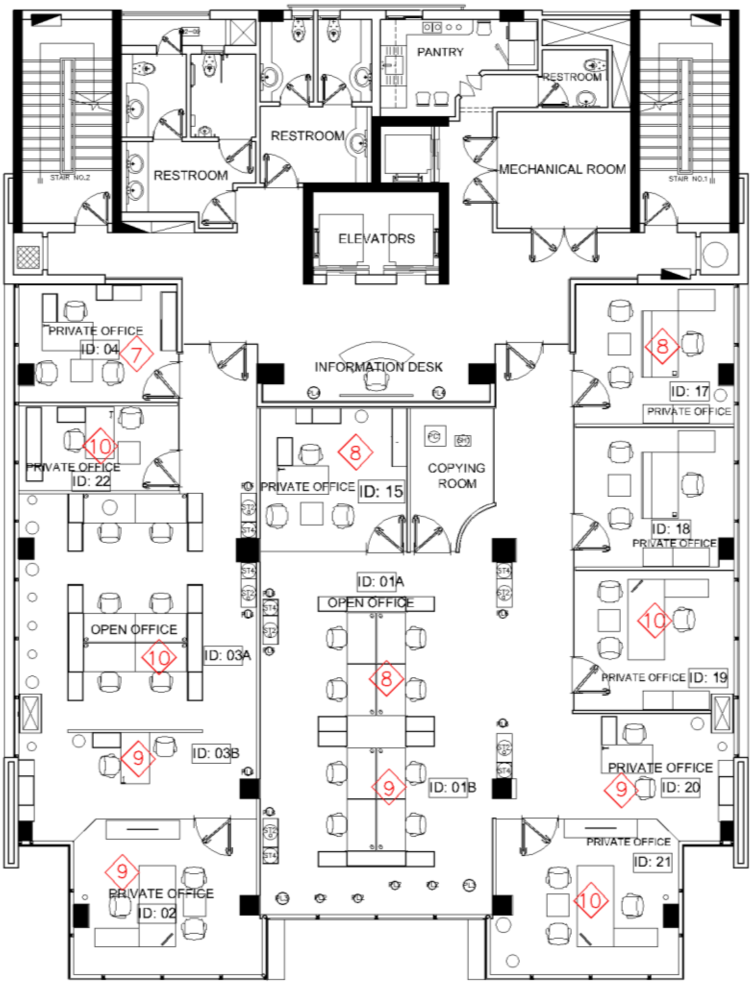

Fig. 9. Plan drawing showing Occupants' feedback on a 1 (dissatisfied) to 10 (very satisfied) scale, from the 2nd (typical) floor.

7. Assumptions and Limitations

The daylight measurement was conducted on a furnished office floor, directly before occupancy; hence, the measurement grid size of 1.4 meters wasn't accurately implemented, especially that the measurements were taken on working plan height.

8. Conclusion

Results show dramatic variation between simulation and measurement, proving simulation's uncertainty.

Based on occupants' perception; the studied LEED building case showed that a LEED building in an arid climate can fulfill satisfactory daylight levels, in terms of daylight quality and quantity.

Fig. 10 shows the numerical variation between simulation, measurement, and occupants' perception.

Zone ID	Simulation (Avg Lux)	Measurement (Avg Lux)	Variation	Occupants' satisfaction	Daylight cause glare?
01A	139.0	209.0	-50%	8 / 10	Never
01B	374.1	424.3	-13%	9 / 10	Never
02	635.4	1,498.0	-136%	9 / 10	Never
03A	373.3	686.6	-84%	10 / 10	Never
03B	184.2	482.0	-162%	9 / 10	Never
04	307.3	615.0	-100%	7 / 10	Only occasional
15	24.6	94.4	-284%	8 / 10	Never
17	602.0	406.8	32%	8 / 10	Never
18	554.4	600.0	-8%	NA	Never
19	2,104.0	501.0	76%	10 / 10	Never
20	615.0	597.0	3%	9 / 10	Sometimes
21	710.8	1,377.0	-94%	10 / 10	Sometimes
22	464.3	545.0	-17%	10 / 10	Never

Fig. 10. Results Summary

The study showed that simulation in this specific case underestimates illuminance levels of nearly all zones, (indicated with negative values), and only overestimates the three zones on the western façade, (indicated with positive values).

Despite the discrepancy between daylight measurement and simulation, this study proved the reliability of both methods in achieving the set lighting quality and criteria; both methods showed that the lighting levels are anticipated to be satisfactory to building occupants, which is the actual case, as all occupants reported high satisfaction levels with daylight.

In a nutshell, both methods; simulation and measurement, were reliable to demonstrate achieving the lower Lux boundary, 107 Lux, but for glare evaluation, simulation isn't expected to be reliable, as it showed high error levels when compared to measurements.

This study was limited for only one measurement, while it is recommended for future research to apply measurements on different days and times, and apply statistics to quantify the gap between simulation and measurement.

References

[1] T. Roberts, "We Spend 90% of Our Time Indoors. Says Who?," BuildingGreen, 15-Dec-2016. [Online]. Available: https://www.buildinggreen.com/blog/we-spend-90-our-time-indoors-says-who. [Accessed: 22-May-2019].

[2] M. Boubekri, Daylighting, Architecture and Health. Taylor & Francis, 2008.

[3] Ahmad Eltaweel and Yuehong Su, "Evaluation of Suitability of a Parametrically Controlled Louvers for Various Orientations throughout a Year Comparing to an Existing Case," Buildings, vol. 7, no. 4, Nov. 2017.

[4] Coralie Cauwerts, "Influence of presentation modes on visual perceptions of daylit spaces," Université Catholique de Louvain (UCL), Belgium, 2013.

[5] The world bank group, "Global Solar Atlas," 2016. [Online]. Available: https://globalsolaratlas.info/?c=9.275622,23.90625,2. [Accessed: 06-May-2019].

[6] USGBC, LEED reference guide for green building design and construction. U.S. Green Building Council, 2009.

[7] John Mardaljevic, "Daylight simulation: validation, sky models and daylight coefficients," De Montfort University, 2000.

[8] L. Bellia, A. Pedace, and F. Fragliasso, "Dynamic daylight simulations: Impact of weather file's choice," Solar Energy, vol. 117, pp. 224–235, 7.

[9] G. Chinazzo, J. Wienold, and M. Andersen, "Combined effects of daylight transmitted through coloured glazing and indoor temperature on thermal responses and overall comfort," Building

and Environment, vol. 144, pp. 583–597, Aug. 2018.
[10] O. Mansour, "Enhancing Green Building Performance: A Human Experiential Approach," PhD, University of Calgary, Calgary, Alberta, 2015.
[11] C. Tian, T. Chen, and T. Chung, "Experimental and simulating examination of computer tools, Radlink and DOE2, for daylighting and energy simulation with venetian blinds," Applied Energy, vol. 124, pp. 130–139, Jul. 2014.
[12] I. L. Wong, "A review of daylighting design and implementation in buildings," Renewable and Sustainable Energy Reviews, vol. 74, no. Supplement C, pp. 959–968, Jul. 2017.
[13] G. Yun and K. S. Kim, "An empirical validation of lighting energy consumption using the integrated simulation method," Energy and Buildings, vol. 57, pp. 144–154, Feb. 2013.
[14] C. F.Reinhart and OliverWalkenhorst, "Validation of dynamic RADIANCE-based daylight simulations for a test office with external blinds," Energy and Buildings, vol. 33, no. 7, pp. 683–697, Sep. 2001.
[15] M. S. R. Roudsari, "Ladybug Analysis Tools," grasshopper3d.com. [Online]. Available: http://www.grasshopper3d.com/groups/group/show?groupUrl=ladybug. [Accessed: 02-Jan-2017].
[16] R. M. & Associates, "Rhinoceros," Rhino 5, 2017. [Online]. Available: https://www.rhino3d.com/.