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Evaluation of Thermal and Visual Comfort in University Classrooms: The Cases of Two LEED Silver Certified Buildings

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ABSTRACT

Thermal and visual comfort are often listed by occupants as the most important requirements for indoor environmental quality. Leadership in energy and environmental design (LEED), as an internationally recognized rating system for sustainable buildings, defines credits for the indoor environmental quality including thermal and visual comfort qualities. New designs, pursuing daylighting credits, draw on high window to wall ratios in order to provide natural light, which has also caused glare, closing the blinds, and consequently using artificial lighting during daytime. The high window/wall ratio increases the heat loss, resulting in cold spaces, and increases solar gains, resulting in overheated spaces during the hot seasons. The actual performance of LEED buildings should be assessed in order to define the gap between designed and actual levels of performance. This study, through questionnaire survey and onsite measurement, evaluates the visual and thermal comfort in four classrooms of different window sizes, locations, and orientations in two LEED buildings on the campus of Texas A & M University. The students' actual perceptions are compared through measurements and simulations with metrics proposed in LEED v2, v3, and v4, showing satisfaction wih the thermal, though not the visual environment. The results have been discussed for improving the quality of visual environment in university classrooms.

INTRODUCTION

The effect of Indoor Environmental Quality (IEQ) on health and productivity has been studied vastly in educational and office buildings. A few studies have concentrated on the IEQ in LEED certified buildings. IEQ of green buildings is generally assumed to be better than conventional buildings. There are many reasons to make this assumption, such as improved ventilation, increased personal control, removed indoor pollutants, more usage of daylighting, task lights, and green materials(Öz and Ergönül 2016). However, literature review gives confounding results about perceived IEQ and occupant satisfaction in green buildings compared with conventional buildings. These studies have reported differences between actual and predicted performance of LEED-certified buildings, resulting from inexact simulation models, differences in operational practices and schedules, changes occurred during construction, occupancy patterns and densities, and other issues not anticipated in the modeling process(Walker 2015). Altomonte and Schiavon(2013) concluded that there is not a significant influence of LEED certification on occupant satisfaction with indoor environmental quality, although the analysis of mean votes of satisfaction reveals that occupants of LEED buildings tend to be slightly more satisfied with air quality, and slightly more dissatisfied with

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the amount of light(Altomonte and Schiavon 2013). In a post-occupancy study of the visual environment in a laboratory building on a university campus (Gold certified), Hua et al. (2011) put a spotlight on the building's occupants. They examined the effectiveness of the daylighting design and system integration in creating a visual environment to support occupant comfort and satisfaction while reducing artificial lighting demand. Results generally show high satisfaction with daylit work environment and positive effect of the horizontal shading strategy. Overall review of the survey literature yields little evidence that green buildings offer superior perceived IEQ over conventional buildings(Thatcher and Milner 2016). This may be partly due to the fact that LEED focuses on reducing energy consumption rather than providing a high-level of occupants' satisfaction(Montazami, Ahmed et al. 2013).

However, these studies have more evaluated the overall satisfaction of occupants and less focused on visual and thermal comfort evaluations in LEED certified buildings through subjective and objective measurements (i.e. through both field survey and simulation). The aim of this study is to compare student's responses in terms of visual and thermal comfort over LEED daylight and thermal comfort metrics. Toward this end, we will pursue two objectives: first assessing the compatibility of LEED v2 case studies with LEED v3 and v4 requirements in terms of daylight and thermal comfort credits; and second assessing the success or failure of LEED buildings in providing occupant satisfactions in classrooms.

VISUAL AND THERMAL COMFORT LEED CREDITS

Daylighting is a valuable strategy for energy savings and gaining LEED credits. Beyond energy savings, careful use of daylighting can contribute to occupant well-being and productivity. Consequently, architects and engineers are encouraged to improve the application of daylighting strategies for building design solutions.

In the primary LEED (version 2)(USBGC 2005), EQ Credit 8.1 has been associated to daylight and views. 1 point is achieved when 75% of the space is daylit which can be defined by three methods/options:

1. Calculation
2. Simulations
3. Measurement

A minimum glazing factor of 2% in a minimum of 75% of all regularly occupied areas should be achieved in order to gain 1-point credit. In the second method, simulation by approved daylighting software, a minimum daylight illumination level of 25 foot candles (fc) should be achieved in a minimum of 75% of all regularly occupied areas at noon, on the equinox, at 30 inches (0.76 meter) above the floor in a clear sky condition. In the third method, this minimum could be also defined by measuring the level of illumination on a 10-foot grid (3 meter) for all occupied spaces and recording the data on floor plans. In version 3 of LEED (USBGC 2008), compared to LEED v2, an upper threshold (500 fc) has been considered and the evaluation time has been changed from two hour in the whole year (12 pm equinox) to four hours (9 am and 3 pm, September 21 and March 21). The lower threshold has been decreased to 10 fc in LEED v3 (2009).

In the latest version of LEED (v4, 2013) there are a few fundamental changes. First, the illuminance units have been switched from the English unit "footcandles" (fc) to the SI-unit "lux." Second, the acceptable illuminance value range has been narrowed to 300-3000 lux (approximately 28 fc to 280 fc). Another important change is the removal of "Option 2. Prescriptive" as a choice for the verification of daylighting values. This option has been replaced by a new simulation called "Spatial Daylight Autonomy (sDA) and Annual Sunlight Exposure (ASE)." SDA is a standard requiring 50% of occupied hours during a year a certain space be adequately daylit (between 300-3000 lux). ASE is the percentage of the square footage in a regularly occupied space that has direct sunlight, and is considered as a controlling criterion. The space's ASE should be less than 1000 lux in no more than 250 occupied hours in no more than 10% of the occupied floor area during a year. Occupied hours are defined typically between 8 a.m. and 6 p.m. Two points can be achieved if the sDA value is reachable in 55% of a regularly occupied space, and three points if the sDA value is achievable in 75% of the occupied space. In addition to the two methods that are defined by simulations, the points for the third option (measurement) is increased from 1 to 2 points. Table 1 presents a summary of daylight credits in different LEED versions(USBGC 2016).

Table 1. LEED Dayligh Credits

Version	Threshold	Time	Points
LEED v2 2005	75% area minimum 25 fc/270 lux	12 pm equinox	1
LEED v3 2009	75% between 10<space<500	9 a.m. and 3 p.m. equinox	1
LEED v4 2013	sDA 300 ASE 1000	Annual	2-3
	75% 300 and 3000 lux	9 a.m. and 3 p.m. equinox	1
	90% 300 and 3000 lux		2

Thermal comfort, the condition of mind that expresses satisfaction with the thermal environment, receives high significance in building performance as the main cause of energy consumption. Additionally, thermal comfort directly affects occupant's health, wellbeing, and productivity in offices and educational buildings. The LEED thermal comfort credits in version 2 and 3 include: 6.1. Controllability of systems, 7.1. Thermal comfort design, and 7.2. Thermal comfort verification, with one point for each credit. The aim is to design heating, ventilating, air conditioning (HVAC) systems, and the building envelopes that meet the requirements of ASHRAE Standard 55 (one point) and provide individual comfort controls for 50% (minimum) of the building occupants to enable adjustments to meet individual needs and preferences (one point). An extra credit could be achieved if a thermal comfort survey of building occupants is conducted within 6 to 18 months after occupancy and can lead to developing a plan for corrective actions--if more than 20% of respondent occupants are dissatisfied with their thermal environment. In version 4, thermal comfort verification has been removed and one point is considered for both thermal comfort design and control. In this version the baseline standards include ISO 7730(2005) and EN 15251(2007) in addition to AHRAE 55(2010). Table 2 presents the LEED criteria and points for thermal comfort.

Table 2. Thermal Comfort Criteria in LEED Rating System

version	criteria	threshold	point
LEED v2 2005/ v3 2009	Thermal comfort design	ASHRAE Standard 55 2004	3
	Thermal comfort control	ASHRAE Standard 55 2004	
	Thermal comfort verification		3
LEED v4 2013	Thermal comfort and control 50% of individual occupant spaces	ASHRAE standard 55-2010 ISO 7730: 2005 CEN standard EN 15251: 2007	1

METHODOLOGY

The methodology of the research is built upon case study. Texas A & M University in College station, Texas, was selected for this study. The university aims to become a sustainable campus by implementing and adopting several specific sustainable policies and practices in current buildings. These efforts provide an opportunity to measure the level of achievements through implemented policies and practices. According to ASHRAE, the climate zone of College Station is 2A defined as hot and humid with 6300 < CDD (Cooling Degree Days) 50ºF ≤ 9000 (3500 < CDD10ºC ≤ 5000). The local climate is subtropical and temperate and winters are mild with periods of low temperatures usually lasting less than two months. Snow and ice are extremely rare. Summers are warm and hot with occasional showers. The average drybulb temperature is 68°F (19.9°C) in a typical meteriological year.

Two LEED certified buildings on the campus were selected for this study. The Emerging Technology Building (ETB) as a LEED Silver Certified building (v2.2) with 36 out of 69 points and the Agriculture Life Science Building (AGLS) as a LEED Silver Certified building (v2.2) with 33 points out of 69. Two classrooms in each building, as shown in Figures 1, of almost the same size, material, and window properties, although different orientations, were selected for the visual and thermal comfort evaluations. Table 3 presents the features of the evaluated spaces.

a) b)

Figure 1 (a) AGSL classroom 1 and 2 in order from left, and (b) ETB classroom 1 and 2 in order from left

Table 3. The Features of the Studied Spaces

CLASS	Area(Sqm)	Capacity (People)	WWR	Orientation	Shading
ETB2	140	78	0.58	SE	N/A
ETB 1	84	46	0.52	NE	N/A
AGSL1	196	40	0.62	SW	Overhang 60 cm
AGSL 2	180	60	0.46	SW	Overhang 60 cm

DATA COLLECTION METHOD

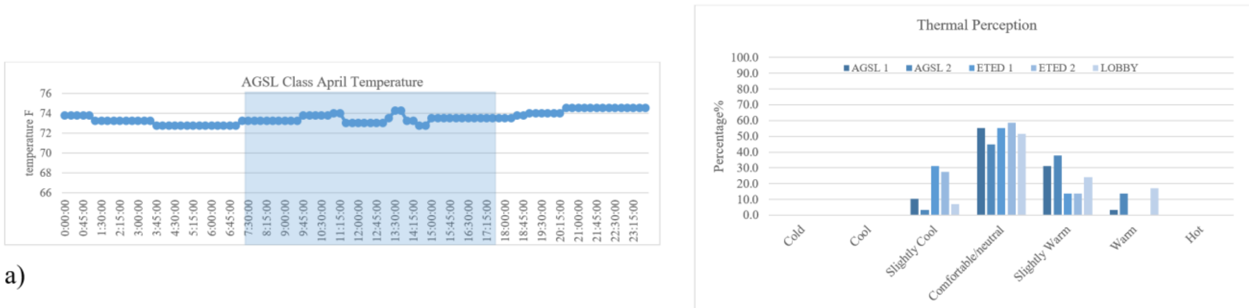
Occupant comfort surveys can provide invaluabe information for improving the performance of buildings. Surveys allow us to measure the responsiveness of building services and appropriateness of design features from views other than designers' subjective minds. Surveys can prioritize the required steps in improving occupants' satisfaction and workplace productivity. In the current study, authors used a questionnaire survey in accordance with new dynamic daylighting metrics and ASHRAE's standard thermal comfort questionnaire to assess the visual and thermal comfort of a number of subjects over different times throughout a year. The visual comfort questionnaire was devised based on several sources (Ne'eman, Craddock et al. 1976, Ne'Eman 1977, Kilic and Hasirci 2011, Othman and Mazli 2012, Jakubiec and Reinhart 2013, Kim, Hong et al. 2014) . The survey was carried out throughout February, March, and April in the four mentioned classes between 10 am and 12 am. A total of 250 useful responses were collected.

Recording daylight levels onsite would be cost-prohibitive and time-consuming. Thus, researchers relied on simulation results to analyze daylight availability in the selected classrooms. 3D models were created in Rhinoceros 3D software with approximate resemblance to the real condition, and simulations were run using Radiance through DIVA version 3 interface. The DIVA environment supports a series of performance evaluations by using validated tools including Radiance (Jakubiec and Reinhart 2011).

RESULTS

Students' Thermal Perceptions

The number of filled questionnaires in each space varied, therefore the results are presented based on the percentage of votes, rather than number, in order to be comparable with each other. According to the questionnaires' results, students felt more thermally comfortable/neutral in the ETB classrooms. Here, the temperature was 2.7°F-4.5°F (1.5-2.5°C) lower than the AGSL classrooms. Students felt slightly warm in the southeast classrooms and the lobby area; however, students in ETB classrooms felt slightly cool. In terms of air movement and humidity, while students felt the air slightly still, the majority of students felt comfortable. In all the studied cases more than 50% of the students preferred no changes in the thermal environment. About 40% preferred lower temperature in the south facing AGSL classroom 2. Students reported thermal discomfort due to hot/cold vented air, little or too much air movment, and inaccessibility of the thermostat in the classrooms. Figure 2 shows the results.



a)

b)

Figure 2 (a) An example of the recorded temperature in AGSL class in April and (b) thermal perception of the students in the studied spaces in April. ETB classrooms are shown as ETED in the graph.

Students' Visual Perceptions

Students' perception of the visual environment has been assessed through the questionnaires and the results are shown in Figure 3. According to the overall results, students feel more comfortable visually (over 50% of students) in the AGSL classrooms. However, 42% of students feel perceptible visual discomfort in the ETB classroom1, which only receives daylight from the backside of the classroom. Also in the ETB's classroom 2, which is daylit from both sides (back and side), 52% of students reported a neutral feeling. Students were asked to rate the degree of glare they experienced when looking toward the window in classrooms. The results indicate that students in the ETB classroom 1 experienced the highest amount of glare, while students in the AGSL classrooms reported no glare or perceptible glare. Students in the ETB classroom 1 sit backward to the windows, therefore they do not experience glare during class time as they are looking toward the instructor in the front. Although glare is not an issue for students, the instructors in the ETB classroom 1 reported intolerable glare when facing students and windows. As a result, to prevent glare, blinds are always down to block the daylight in the ETB classroom 1.

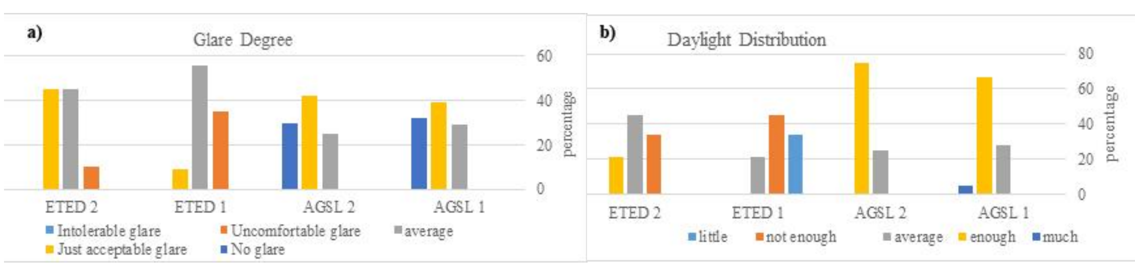


Figure 3 (a) Glare percentage and (b) daylight distribution in the studied spaces. ETB classrooms are shown as ETED in the graph

Daylight Simulations

Daylight availability in each studied space has been simulated and LEED v2, v3, and v4 credits have been defined. Table 4 shows the results, where more than 75% of the ETB's lobby and AGSL classrrom 2 receive more than 25 fc daylight at 12 pm on September 21 and are compatible with LEED v2 credits. Only the AGSL classroom 2 passed the LEED v3, which requires 75% of the space to receive between 10 and 500 fc daylight at 9 am and 3 pm on September 21. The studied spaces could not pass LEED v4, which requires sDA more than 55% and ASE less than 10%. The results show better daylight distribution in AGSL classrooms facing the southeast direction. However, 62.1

% of the ETB classroom 2, which is daylit from the northeast and northwest, receives between 10 and 500 fc at 9 am and 3 pm on September 21. The AGSL classroom 2 passes the sDA requirement of LEED 4, although the high level of ASE prevents passing the daylight credit in LEED 4. The low sDA in ETB classrooms, shown in Figure 4, has caused artificial lighting to be used all the times in these spaces.

Table 4. LEED Daylight Metrics for the Studied Spaces

LEED Version	ETB-1	ETB-2	AGSL-1	AGLS-2
v 2	32%	48%	45.2%	98.1%
Point	0	0	0	1
v 3: 9 am	30.4%	62.1%	73,5%	79.3%
v 3: 3pm	24.7%	62.1%	43.8%	79.3%
Point	0	0	0	1
v 4: sDA	10.2	30.2	46.9	95
v 4: ASE	2.8	6.5	22.6	35
Point	0	0	0	0

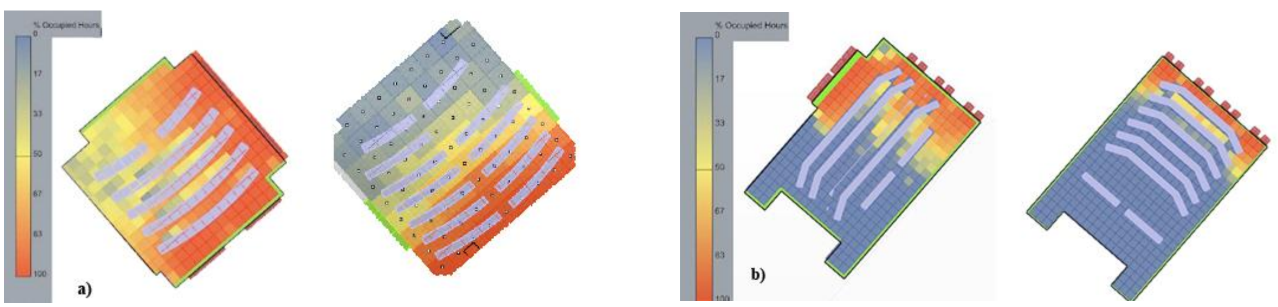


Figure 4 (a) sDA in AGSL classroom 1 and 2 in order from left, and (b) sDA in ETB classroom 1 and 2 in order from left

Discussion

Proper daylighting design strategies, integration of daylighting with design and operation of other building systems, and a careful consideration of occupants' perception and behavior are all necessary in order to realize the potential energy savings from daylighting and to support the comfort, health, and performance of building occupants. It is a constant challenge for architects, building researchers, building operators, and facility managers to design a building to make full use of daylight, as a dynamic light source, to meet the diverse needs of occupants. However, daylight has immense power which is easy to lose control of. Even in some of the highest-profile green buildings glare, overheating, and loss of productivity are reported. Blinds are always down and lights are always on. Re-learning how to use natural light in our buildings may be more difficult than we anticipate; not only because a modern daylighting system must integrate seamlessly with electric lights and mechanical systems, but also because our "desktops" are now computer screens and our classrooms are now multimedia learning spaces. Paradoxically, more efficient building envelopes may also work against the goal, trapping solar gain from daylight and increasing cooling loads.

With these in mind, some remarking issues from this study include: both buildings have received the LEED scores for thermal comfort with separate credits for design and control.; temperatures are in comfort zone during the class times; conditions were perceived to be on the hot side in March and April; and no significant difference was found between occupant thermal sensations during the three months. Questionnaires, observations, and measurements indicate that the temperature and air quality factors of these buildings are better, on average, than conventional classrooms on campus, which are mostly windowless. More attention must be given to design and operation, especially in terms of internal and external shadings and thermostat control. The ETB building had received the LEED v2.2 Daylight Credit; however, daylight performance is better in AGSL classrooms. More than 55% and 65% of students ranked the AGSL as comfortable with enough daylight distribution and acceptable levels of glare; however, according to simulations LEED v2 daylight credits are not achieved in the AGSL classroom 1.

Except for AGSL classroom 2, LEED v3 and LEED v4 credits are not achieved in any of the studied spaces. Questionnaires' results, compared with the simulation results, show a wider range of visual comfort in classrooms facing southeast and northeast. According to these results, LEED credits would not necessarily define visual comfort/discomfort, and other factors (e.g., view, expectations, and region) can change the degree of comfort experienced in each space. Students' impression about glare in south facing classrooms is more positive and optimistic than the results of simulations and measurements. Additionally, outside view can significantly affect students' impression and feelings about the space.

CONCLUSION

Post occupancy studies in education buildings should be carried out to identify solutions to further improve the visual environment quality and to generate guidelines for effective daylighting design for classrooms. Daylight has immense power that's easy to lose control of. LEED focuses more on reducing energy consumption rather than providing a high-level of occupants' satisfaction. Overlooking occupants' dynamic behaviors and reducing their needs to a couple of parameters required by standards (e.g. temperature set points and luminance thresholds) can cause a decline in satisfaction of the building performance and energy efficiency in buildings, including the LEED cases. Integration between daylighting and electric lighting systems and the level of occupant control should be identified for improving the effectiveness of daylighting and enhancing the quality of the visual environment in the studied buildings. Designing external shadings to use natural daylight and to avoid blocking the views is an effective strategy for providing better daylight quality.

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Altomonte, S. and S. Schiavon (2013). "Occupant satisfaction in LEED and non-LEED certified buildings." Building and Environment **68**: 66-76.
Jakubiec, J. A. and C. F. Reinhart (2011). DIVA 2.0: Integrating daylight and thermal simulations using Rhinoceros 3D, Daysim and EnergyPlus. Building Simulation-12th Conference of International Building Performance Simulation Association.
Jakubiec, J. A. and C. F. Reinhart (2013). Predicting visual comfort conditions in a large daylit space based on long-term occupant evaluations: a field study. Proceedings of the 13th International Conference of the International Building Performance Simulation Association; Aix-les-Bains, France. International Building Performance Simulation Association, UK. p.
Kilic, D. K. and D. Hasirci (2011). "Daylighting concepts for university libraries and their influences on users' satisfaction." The Journal of Academic Librarianship **37**(6): 471-479.
Kim, T.-w., W.-h. Hong and H.-t. Kim (2014). "Daylight evaluation for educational facilities established in high-rise housing complexes in Daegu, South Korea." Building and Environment **78**: 137-144.
Montazami, A., A. Ahmed and A. D. Al-Eisawi (2013). THE RELATIONSHIP BETWEEN PEOPLES' SATISFACTION AND LEED BUILDING RATING IN JORDANIAN OFFICE BUILDINGS. Sustainable Building Conference 2013, Coventry University, UK.
Ne'Eman, E. (1977). "Sunlight requirements in buildings—II. Visits of an assessment team and experiments in a controlled room." Building and Environment **12**(3): 147-157.
Ne'eman, E., J. Craddock and R. Hopkinson (1976). "Sunlight requirements in buildings—I. Social survey." Building and Environment **11**(4): 217-238.
Othman, A. R. and M. A. M. Mazli (2012). "Influences of Daylighting towards Readers' Satisfaction at Raja Tun Uda Public Library, Shah Alam." Procedia-Social and Behavioral Sciences **68**: 244-257.

Öz, A. M. and S. Ergönül (2016). "Improving Occupant's Satisfaction and Productivity in Sustainable Building Design." Journal of Sustainable Architecture and Civil Engineering **13**(4).
Thatcher, A. and K. Milner (2016). "Is a green building really better for building occupants? A longitudinal evaluation." Building and Environment **108**: 194-206.
USBGC (2005). "LEED® for New Construction & Major Renovations."
USBGC (2008). "LEED for New Construction and Major Renovations Rating System."
USBGC (2016). "LEED v4 for BUILDING DESIGN AND CONSTRUCTION."
Walker, K. (2015). Indoor environment quality in LEED buildings: Understanding conditions affecting performance, UC Berkeley.