LIGHTING QUALITY AND ACOUSTIC QUALITY IN LEED-CERTIFIED BUILDINGS USING OCCUPANT EVALUATION

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ABSTRACT

Lighting quality and acoustic quality are often not well addressed in the current green building practice, including the Leadership in Energy and Environmental Design (LEED) Green Building Rating System in the US. While the level of LEED certification indicates the level of sustainability, it is not clear if a higher level of LEED certification also implies a more comfortable and productive work environment. The study intended to find the relationship between the level of LEED certification and the level of worker satisfaction and perceived job performance regarding lighting quality and acoustic quality from fifteen LEED-certified buildings. The findings indicate that the LEED Platinum building group tended to provide better lighting quality than the other lower certification groups, while the LEED Gold building group showed lower lighting quality and acoustic quality than the rest of the groups. Workplace designers and organizations should be mindful of the importance of lighting and acoustic qualities in promoting better comfort and productivity as it is easy to overlook these criteria when complying with LEED IEQ guidelines.

KEYWORDS

lighting quality, acoustics quality, IEQ, LEED

INTRODUCTION

There has been increased interest and extensive discourse on green building performance and evaluation in the US. As green buildings become the norm of society and standard practice in the architectural, engineering, and construction industry, the issue of the performance of green buildings and the quality of occupant's life inside green buildings has become important as well. To address this issue, some studies have recently been conducted to measure the performance of green buildings with various evaluation criteria. While some studies focused on one aspect and used a simpler method, other studies attempted to analyze green building performance with multiple aspects in a more complex manner. Assessing the quality of occupant's life inside green buildings has been an important evaluation criterion for the issue of the performance of green buildings. Especially, the effect of indoor environmental quality (IEQ)

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of green buildings on occupants has been of great interest in workplace because it has a direct relationship with worker satisfaction and productivity (Paul and Taylor 2008).

In the US, the largest segment of commercial projects that pursue a certification of the Leadership in Energy and Environmental Design (LEED) Green Building Rating System™ is offices (USGBC 2006). LEED was established in the early 2000s in the marketplace by the US Green building Council (USGBC) and was rapidly adopted to the building industry. It is now a nationally accepted rating system as well as a guideline for green buildings in the US. LEED measures the level of performance of buildings regarding five key areas of sustainability, including sustainable site development, water savings, energy efficiency, materials selection, and IEQ (USGBC 2010). As a larger number of organizations are interested in achieving a LEED certification for their work environment, assessing the performance of the IEQ of LEED-certified buildings on workers in office environments has become critical.

LEED includes only such criteria as indoor air quality (IAQ), chemical and pollutant source control, controllability of systems, thermal comfort, and daylight and views under the IEQ area of LEED New Construction and Major Renovation (NC) and LEED Commercial Interiors (CI), where most office buildings apply for a LEED certification. IAQ consists of the majority of the points available in the LEED IEQ area. However, general IEQ criteria used to evaluate work environment encompass such criteria as lighting, acoustics, furnishings, etc in addition to the LEED IEQ criteria.

Some studies have shown lower occupant satisfaction and perceived performance regarding lighting quality and acoustic quality in LEED-certified buildings. These findings might have indicated some problems in LEED-certified buildings as lighting and acoustic criteria are minimally addressed in LEED standards. LEED includes only credits for daylight and controllability of lighting system regarding lighting quality. Acoustic quality is not addressed in LEED NC and LEED CI, and is minimally addressed in the IEQ Credit 2.1 of the LEED Existing Buildings and in the new LEED Healthcare and LEED Schools. Thus, there is a concern with an insufficient quality of lighting and acoustics in the workplace of LEED-certified buildings. In addition, an emphasis given to other design criteria, such as IAQ and daylight and views in LEED, can conflict with design strategies to achieve better acoustic quality and improve overall lighting quality. Bradley and Wang pointed out that the design strategy of lowering partitions to increase daylight penetrations and the amount of views available to occupants can create a negative impact on acoustic quality (as cited in Birt and Newsham 2009). They also addressed that such design strategies as using hard ceiling and floor materials to increase IAQ for LEED certification can contribute to creating an acoustically problematic environment. Lighting problems in green buildings have also been reported. For instance, providing too many windows to maximize daylight into interiors can cause glare problems (Brown 2008). Focusing too much on providing daylight and views without considering the overall balance with artificial lighting in the work environment can hinder work productivity, too.

Despite such a concern, there has been little research done to define the current state of lighting quality and acoustic quality in LEED-certified buildings. Especially, there have been no studies done regarding whether the buildings with a higher level of LEED certification paid more attention to lighting quality and acoustic quality than the buildings with a lower certification in order to create a productive and comfortable work environment. In the LEED rating system, there are four certification levels available, based on the range of the total points that a building earns: Platinum (highest level), Gold, Silver, and Certified (lowest level). While the certification level indicates the level of sustainability achieved, it is not clear whether a

higher level of LEED certification also contributes to a higher level of worker satisfaction and performance. When organizations' commitment to a higher level of LEED certification consequently generates a more productive workplace, their commitment is not only rewarded but also truly creates a sustainable environment.

This study examined the relationship between the level of LEED certification and the level of worker's perceived lighting quality and acoustic quality in the workplace of LEED-certified buildings. As LEED minimally addresses lighting quality and acoustic quality, if at all, it is important to understand the current state of practice in lighting and acoustic qualities in four different levels of LEED certification. The findings will shed light on the issues of lighting and acoustic qualities in LEED-certified buildings; and help the design community and organizations complying with LEED make wiser decisions in promoting comfort and productivity in their work environments.

LITERATURE REVIEW

Studies have consistently found problems in occupant satisfaction with lighting quality and acoustic quality in workspaces of green buildings including LEED-certified buildings. In a study done by the Center for the Built Environment (CBE) at the University of Berkeley, California, worker satisfaction was compared between green buildings and conventional buildings in the US. The study found that the workers in the green buildings were less satisfied with lighting quality and acoustic quality than those in conventional buildings (Abbaszadeh et al. 2006). The green buildings included LEED-certified buildings as well as other buildings identified as green buildings. The main reasons for dissatisfaction with lighting quality in the green buildings were insufficient daylight, reflections on computer screens, and overly dark workspaces. The major complaints regarding acoustic quality centered on distractions created by people talking in neighboring areas, people overhearing private conversations, and people talking on the phone.

Turner (2006) found that occupant satisfaction with acoustic quality was the lowest among the six IEQ criteria in a study with six LEED-certified buildings in the northern west coast of the US. The levels of satisfaction with two acoustic quality measures: noise level and sound privacy were the only mean scores below zero in the study. However, lighting quality was satisfactory.

Lee and Kim (2008) conducted a study comparing IEQ between LEED-certified buildings and non-LEED certified buildings in the US. The study found that occupant's satisfaction and perceived job performance with regard to lighting quality and acoustic quality in personal workspaces were lower in LEED-certified buildings than in non LEED-certified buildings. The differences in lighting quality between the two groups were second highest among the seven IEQ criteria. In the study, occupants in LEED-certified buildings were mainly dissatisfied with lighting quality due to insufficient workspace lighting, reflections on the computer screen, and the absence of both adequate daylight and adequate electric lighting. The reasons for dissatisfaction with acoustic quality included people overhearing private conversations, people talking in neighboring areas, and people talking on the phone.

In an acoustic evaluation study for six green office buildings, Hodgson (2008) measured noise level, reverberation time, speech intelligibility index, and noise isolation between those green buildings. The study found that noise levels were excessively high in areas near exterior walls; reverberation times were excessively high in large areas and areas with insufficient sound absorption; and speech privacy was not adequate in shared and open-plan offices.

The US General Services Administration (GSA) conducted a post-occupancy evaluation of their own buildings in a total of twelve sustainable buildings, including seven LEED-certified buildings. In the study, occupant satisfaction with IEQ was surveyed and compared to the average performance of US commercial buildings (Fowler and Rauch 2008). Worker satisfaction with acoustic quality was higher in those twelve buildings than the national average. However, more than half of the workers were dissatisfied with acoustic quality, indicating some acoustic problems. Worker satisfaction with lighting quality was similar between those groups. The results might have been unique since these GSA buildings were governmental buildings under a different financial structure from commercial buildings. This is indicated in the study stating that the occupant satisfaction ratings in all items from these GSA buildings were higher than those of LEED-certified buildings in the private sector.

Recently, the Chicago Chapter of USGBC surveyed the occupants in eleven LEED-certified buildings in Illinois. It found that occupant satisfaction with lighting quality was one of the highest while satisfaction with acoustic quality one of the lowest among the total six questions in the survey (USGBC Chicago Chapter 2009).

Overall, the findings on occupant's evaluation of acoustic quality in green and LEED-certified buildings consistently indicate that there are some problems, while the findings regarding lighting quality are somewhat mixed. For this reason, the need to improve acoustic quality in green and LEED-certified buildings has constantly been emphasized in the literature (Hodgson 2008).

METHOD

Questionnaire and Data

The need of integrating post-occupancy evaluation to green building assessment has been emphasized by many building professionals as the current literature has shown a gap between the performance of IEQ and occupant's satisfaction and performance in green office buildings. Post-occupancy evaluation is a useful method to facilitate the improvement of green buildings as well as the rating systems (Newsham, 2009). This study used a survey that utilized a post-occupancy evaluation with office occupants.

The data came from the database of the Occupant Indoor IEQ Survey™ developed by the Center for the Built Environment (CBE) at the University of Berkeley, California. The CBE survey is a standardized web survey that is supported by the building industry nationwide. There were more than 51,000 participants from over 450 buildings by October 2009 (CBE 2010a). The on-going survey was initially developed to measure the performance of IEQ in office buildings for benchmarking building quality and trend analysis (Huizenga, Laeser, & Arens, 2002). More specifically, it was to provide a standardized on-line survey to the building industry for effective design intervention, benchmarking facility performance, and new guidelines for future practice, thus filling the gap in the building research field where surveys were often too project-specific and could not be applicable in examining overall trends. Such characteristics of the survey were suitable for the purpose of this study examining the trend of lighting and acoustics quality in LEED-certified buildings. The original survey included two sections: occupant's evaluation of IEQ and background information. The occupant's evaluation of IEQ measured various aspects of IEQ of work environment, from layout to acoustics, by the level of occupant's environmental satisfaction and perceived job performance. Additional follow-up questions were asked when participants were dissatisfied with

the IEQ criteria. The background information asked workers about the characteristics of their personal workspaces. The survey was based on self-assessment and administered online. The Center focused on the analysis of the IEQ performance of green buildings and LEED-certified buildings, as measured by occupant satisfaction, using the database of the Occupant Indoor IEQ Survey in 2007. There were 35,000 participants from over 200 office buildings including 15 LEED-certified buildings in 2007 in the CBE's database (CEB 2010b).

This study selected data relevant to only lighting quality and acoustics quality of those 15 LEED-certified buildings from the CEB's database, and reorganized them for the purpose of the study. The environmental satisfaction with lighting quality measured worker satisfaction with the amount of light and visual comfort in their personal workspaces in the original survey. The perceived job performance regarding lighting quality was measured by the level of perceived enhancement or interference with work performance affected by lighting quality in their personal workspaces. The environmental satisfaction with acoustic quality measured worker satisfaction with the noise level and sound privacy in their personal workspaces. The perceived job performance of workers was measured by the level of professed enhancement or interference with work performance affected by acoustic quality in their personal workspaces. In addition, overall worker satisfaction with personal workspace was included in the study to compare the pattern of worker's perceptions of the lighting and acoustic qualities and their overall satisfaction with personal workspaces. Worker's environmental satisfaction was measured using a Likert-type scale with seven choices from "very satisfied (+3)" to "very dissatisfied (–3)." Their perceived job performance was measured by a semantic differential scale with seven choices from "enhances (+3)" to "interferes (–3)." Table 1 shows the questions and the measurements for lighting quality and acoustic quality in the study.

TABLE 1. Questions and Measurement.

		Questions	Measurement
1	Lighting Quality	How satisfied are you with the amount of light in your workspace?	from very satisfied (+3) to very dissatisfied (–3)
2		How satisfied are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?	from very satisfied (+3) to very dissatisfied (–3)
3		Does the lighting quality enhance or interfere with your ability to get your job done?	from enhances (+3) to interferes (–3)
4	Acoustic Quality	How satisfied are you with the noise level in your workspace?	from very satisfied (+3) to very dissatisfied (–3)
5		How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbors overhearing and vice versa?)	from very satisfied (+3) to very dissatisfied (–3)
6		Does the acoustic quality in your workspace enhance or interfere with your ability to get job done?	from enhances (+3) to interferes (–3)
7	Overall Personal Workspace	All things considered, how satisfied are you with your personal workspace?	from very satisfied (+3) to very dissatisfied (–3)

The study also included the characteristics of personal workspaces relevant to lighting and acoustics issues to explain the findings by comparing the differences and similarities of the characteristics of their personal workspaces between the four levels of the LEED-certified buildings. The questions regarding the characteristics of personal workspaces consisted of personal workspace location in the building, direction of the closest windows to personal workspace, proximity to a window within 15 feet, proximity to an exterior wall within 15 feet, type of personal workspace, and available lighting control in workspace. These questions were measured by a categorical scale.

The data included a total of fifteen LEED-certified buildings whose occupants finished participating in the survey by the time of data gathering in March 2007. There were four LEED Platinum (highest level), five LEED Gold, three LEED Silver, and three LEED Certified (lowest level) buildings. The total numbers of respondents were 242 from the LEED Platinum building group, 2670 from the LEED Gold building group, 635 from LEED Silver building group, and 158 from LEED Certified building group.

Analysis and Limitations

The study employed descriptive statistics and analysis of variance (ANOVA) to analyze the data. The Center for Statistical Training and Consulting at Michigan State University was hired to conduct the statistical analysis. Mean scores were calculated by the level of certification in each IEQ question and percentages were calculated between answers in each question for the characteristics of personal workspaces. ANOVA-F tests determined the statistical significance of differences in occupants' responses between the four levels of LEED-certified building groups. Once a statistical significance was found from the ANOVA F-tests, post-hoc multiple comparison tests followed to identify which certification groups were significantly different from the other groups. The post-hoc multiple comparison tests were conducted at the 95% confidence interval, which is the common standard in practice (Snedecor and Cochran 1989).

The study proceeded without the adjustment of the uneven numbers of the sample sizes between the building groups. This is because the assumption of homogeneity of variance required for ANOVA tests were met and no further action was needed. Homogeneity of variance concerns the variability of the sample score between groups and is required for ANOVA tests to ensure that the samples between different groups all have the same variance whether their means are equal or not (Gall, Gall, and Borg 2003). When the assumption of homogeneity of variance is met, the populations from which the data are sampled are considered identical.

The main limitations of the study came from the use of the secondary data. There was not enough flexibility in the research design for the purpose of the study including the scope of available questions and the organization of data. Because all possible variables to explain the results of the study were not included in the original questionnaire, some of the causal explanations of the results might have been limited. In addition, even though the total number of respondents was 3705, the sample size could be considered relatively small since the unit of the study was the number of buildings.

However, the study focused on explaining the results within the possible variables directly affecting occupant's satisfaction and performance in the personal workspaces regarding lighting and acoustic qualities, producing meaningful discussions for the purpose of the study.

As the study aimed to examine the trend of lighting and acoustic practice in LEED-certified buildings, the results of the study will contribute to the body of green building research as an overview of the current practice, filling the gap in the current green building literature. In addition, the study followed appropriate procedure and statistical analysis. Therefore, a reasonable conclusion can be drawn.

RESULTS

Descriptive Analysis

The characteristics of personal workspaces of respondents between the four levels of LEED-certified buildings presented many similarities and some differences. However, particular patterns regarding the level of certification were not observed in the distributions of responses between the four groups. The most frequent location of personal workspaces in the building was north across the four levels of building groups (29% in LEED Platinum, 38% in LEED Gold, 25% in LEED Silver, and 33% in LEED Certified). While workspaces occupied were dispersed all around the buildings in all four levels of building groups, the LEED Platinum group had much less workspaces occupied in the core area (1%) compared to the other three groups (11% in LEED Gold, 10% in LEED Silver, and 6% in LEED Certified).

The two most frequent directions of the closest windows to personal workspaces were south and north in the LEED Platinum, Gold, and Certified building groups, while they were west and north in the LEED Silver group. The LEED Silver group also had as much as 20% of personal workspaces without windows, while the other groups had no more than 5%. The majority of the workers across the four building groups had a window within 15 feet of their workspace. The same pattern was observed for the proximity to an exterior wall within 15 feet. The workers in the Platinum and the Certified building groups had a higher number of people next to a window and an exterior wall within 15 feet than the ones in the Gold and Silver building groups.

The two most frequent types of personal workspaces across the four building groups were cubicles with low partitions and cubicles with high partitions. However, the LEED Gold group had a much lower number of enclosed private offices (7%) and a higher number of cubicles with higher partitions (70%) compared to the other building groups. The most frequently available lighting control across the four building groups was desk light. The second frequently available lighting control was window blinds or shades in the other three building groups, while it was light switches in the LEED Silver group. Table 2 shows the distribution of responses with regard to office characteristics between the four buildings groups.

The responses to the lighting quality and acoustic quality questions between the four building groups revealed many similar patterns. The LEED Platinum group showed the highest mean scores, while the LEED Gold group exhibited the lowest mean scores in all six questions. In the follow-up questions with those who expressed dissatisfaction with lighting quality in the LEED Gold building group, the main reasons of dissatisfaction were too dark workspace (35%), absence of sufficient electric lighting (29%), and reflections on the computer screen (27%). The most prevalent problems with lighting quality across all four groups were too dark workspace, reflections on the computer screen, absence of enough electric lighting, and absence of enough daylight, but in a different order in each building group.

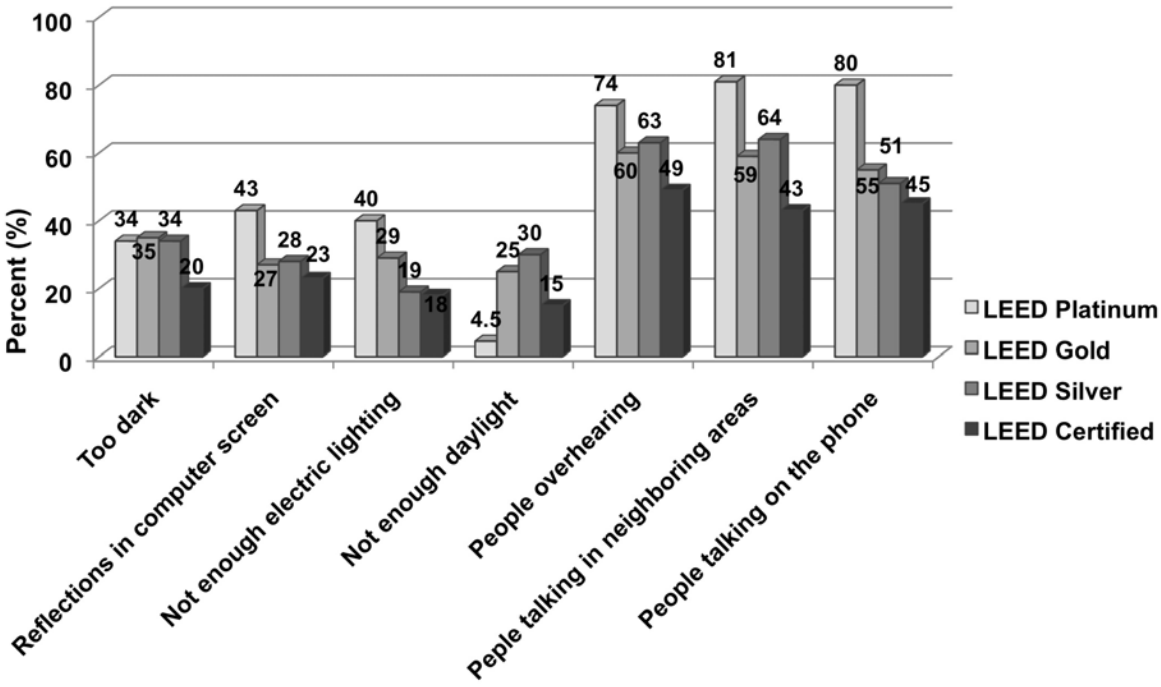
TABLE 2. Responses for Characteristics of Personal Workspaces.

Question	Answer	LEED Platinum Buildings (BN=4) (%)	LEED Gold Buildings (BN=5) (%)	LEED Silver Buildings (BN=3) (%)	LEED Certified Buildings (BN=3) (%)
Personal workspace location in building	North	29	38	25	33
	East	23	10	23	22
	South	20	28	13	15
	West	19	9	24	12
	Core	1	11	10	6
	Don't know	8	5	4	12
Direction of the closest windows to personal workspace	North	29	34	24	39
	East	17	12	12	11
	South	37	27	15	25
	West	10	19	25	9
	No windows	4	2	20	5
	Don't know	3	6	4	11
Proximity to a window within 15′	Yes	78	56	61	78
	No	22	44	39	22
Proximity to an exterior wall within 15′	Yes	76	55	62	76
	No	24	45	38	24
Type of personal workspace	Enclosed private office	20	7	23	20
	Enclosed but shared	10	2	14	3
	Cubicles with high partitions	33	70	31	23
	Cubicles with low partitions	25	16	22	46
	Workspace in open office	8	2	7	5
	Other	5	2	3	3
Lighting control in personal workspace	Light switch	47	12	39	18
	Light dimmer	9	7	5	10
	Window blinds or shades	53	22	29	36
	Desk light	64	81	51	53

In the follow-up questions with those who were dissatisfied with acoustic quality in the LEED Gold group, the main reasons for dissatisfaction were people overhearing private conversations (60%), people talking in the neighboring areas (59%), and people talking on the phone (55%). These were also the same reasons for dissatisfaction with acoustic quality in the other building groups but in a different order in each building group. Figure 1 compares the percentages of the main reasons for dissatisfaction with lighting and acoustic qualities between the four building groups.

Overall, the mean scores in lighting quality questions were higher than those of the acoustic quality questions across the groups. This means that workers in LEED-certified buildings were more satisfied with lighting quality than acoustic quality. This was consistent with the findings of other studies. Additionally, the mean scores in the sound privacy question in this study were all below zero across the building groups, indicating that this is a common problem in many LEED-certified buildings.

FIGURE 1. Dissatisfaction Reasons for Lighting & Acoustic Qualities.



A similar distribution pattern was observed in worker satisfaction with overall personal workspace as in the other questions. The LEED Platinum group showed the highest mean score and the LEED Gold group the lowest mean score. Table 3 presents the mean scores and standard deviations in IEQ questions between the four buildings groups.

TABLE 3. Mean Scores and Standard Deviations in IEQ Questions.

		Question	Mean & Standard Deviation	LEED Platinum	LEED Gold	LEED Silver	LEED Certified
1	Lighting Quality	Amount of Light	Mean	1.74	0.37	1.14	1.14
			Std. Dev	1.4	1.98	1.72	1.75
2		Visual Comfort	Mean	1.24	0.30	0.81	0.91
			Std. Dev	1.58	1.81	1.73	1.67
3		Lighting Quality Enhancing Job Performance	Mean	1.25	0.22	0.81	0.67
			Std. Dev	1.59	1.81	1.67	1.70
4	Acoustic Quality	Noise Level	Mean	0.65	–0.60	0.35	0.15
			Std. Dev	1.66	1.80	1.75	1.71
5		Sound Privacy	Mean	–0.07	–1.01	–0.61	–0.60
			Std. Dev	1.76	1.81	1.88	1.85
6		Acoustic Quality Enhancing Job Performance	Mean	0.07	–0.96	–0.08	–0.14
			Std. Dev	1.57	1.63	1.65	1.67
7	Overall Personal Workspace		Mean	1.67	0.47	0.83	0.85
			Std. Dev	1.25	1.65	1.54	1.58

ANOVA analysis

There was statistical significance in all seven questions according to the ANOVA F-tests. The p-values in all seven questions were close to 0.0000 or -0.0000. The positive number indicates a positive relationship and the negative number a negative relationship. Table 4 shows the results of the ANOVA F-tests for the questions regarding lighting quality, acoustic quality, and overall personal workspace quality.

Post-hoc multiple comparison tests at 95 confidence intervals, following the ANOVA F-tests, revealed interesting results. In the three lighting questions, workers in the LEED Platinum group were significantly more satisfied with the amount of light and visual comfort and perceived higher job performance resulting from lighting quality than the workers in the Gold and Silver groups. The workers in both the LEED Silver and Certified groups showed significantly higher satisfaction and perceived job performance than the Gold group in all three lighting quality questions. Workers in the LEED Platinum group were also significantly more satisfied with the amount of light and perceived higher performance affected by the lighting quality than those in the Gold group. Thus, all three LEED building groups showed significantly higher satisfaction and perceived job performance in all three lighting questions than the Gold group. However, no significant difference was found between the Silver group and the Certified group in all three lighting questions, indicating the response differences in lighting quality questions between these groups were not statistically significant.

The results of the acoustic quality questions between the four LEED building groups were more complicated than the lighting quality questions. Workers in the LEED Platinum group had significantly higher satisfaction with noise level and perceived job performance affected by acoustic quality than the ones in the Gold group. The Platinum group also showed higher satisfaction with noise level than the Certified group. The Silver group presented significantly higher satisfaction and perceived job performance regarding all three acoustic quality questions than the Gold group. The Certified group was also significantly more satisfied with noise level and perceived higher job performance affected by acoustic quality than the Gold group. Thus, the Platinum, Silver, and Certified groups all had significantly higher satisfaction with noise level and perceived job performance affected by acoustic quality than the Gold group. The only significant difference found in sound privacy was between the Gold group and the Silver group. The workers in the Silver group were significantly more satisfied with sound privacy than the Gold group. There was no significant difference between the Silver group and the Certified group in all three acoustic quality questions. Thus, no statistically significant difference was found in the responses to both lighting quality and acoustic quality questions between the Silver and Certified groups. This also means any differences in the characteristics of personal workspaces, such as proximity to windows and exterior walls between these groups were not likely significant.

With regard to the satisfaction with overall personal workspace, workers in the Platinum group were significantly more satisfied with their personal workspaces than those in the other LEED buildings groups. The workers in the Silver and Certified groups were also significantly more satisfied with their personal workspaces than those in the Gold group. Thus, all three LEED building groups including the Platinum, Silver, and Certified groups were significantly more satisfied with their personal workspaces than the Gold building group. However, there was no significant difference between the LEED Silver group and the LEED Certified group. Table 5 shows statistical significance in each question between the building groups.

TABLE 4. Results of ANOVA F-tests.

	Question		Source	Sum of Squares	Degree of Freedom	Mean Squares	F value	P value
1	Lighting Quality	Amount of Light	Regression	665.7770	3	221.9257	61.3295	0.0000
			Residual	13309.1342	3678	3.6186		
			Total	13974.9111	3681			
2		Visual Comfort	Regression	279.9613	3	93.3204	29.4426	–0.0000
			Residual	11667.1856	3681	3.1696		
			Total	11947.1469	3684			
3		Lighting Quality Enhancing Job Performance	Regression	367.9842	3	122.6614	39.1315	0.0000
			Residual	11328.4394	3614	3.1346		
			Total	11696.4236	3617			
4	Acoustic Quality	Noise Level	Regression	763.9016	3	254.6339	80.1520	–0.0000
			Residual	11605.1629	3653	3.1769		
			Total	12369.0644	3656			
5		Sound Privacy	Regression	75.1057	3	25.0352	7.3506	0.0001
			Residual	5360.8318	1574	3.4059		
			Total	5435.9375	1577			
6		Acoustic Quality Enhancing Job Performance	Regression	608.4562	3	202.8187	75.8957	–0.0000
			Residual	9711.2588	3634	2.6723		
			Total	3637				
7	Overall Personal Workspace		Regression	351.7481	3	117.2494	45.0871	–0.0000
			Residual	9525.6500	3663	2.6005		
			Total	9877.3980	3666			

TABLE 5. Post-hoc Multiple Comparison Tests.

	IEQ Question		(I) EXP	(J) EXP	MD (I–J)	95% Confidence		t	Significant
						Lower Bound	Upper Bound		
1	Lighting Quality	Amount of Light	Platinum	Gold	+1.36	+1.02	+1.70	10.574	Yes
				Silver	+0.60	+0.22	+0.98	4.156	Yes
				Certified	+0.60	+0.08	+1.12	3.081	Yes
			Gold	Silver	–0.76	–0.98	–0.53	9.028	Yes
				Certified	–0.76	–1.17	–0.34	4.859	Yes
			Silver	Certified	+0.00	–0.44	+0.45	0.005	No
2		Visual Comfort	Platinum	Gold	+0.89	+0.57	+1.21	7.454	Yes
				Silver	+0.43	+0.07	+0.79	3.212	Yes
				Certified	+0.33	–0.14	+0.81	1.837	No
			Gold	Silver	–0.46	–0.67	–0.25	5.848	Yes
				Certified	–0.56	–0.94	–0.17	3.830	Yes
			Silver	Certified	–0.09	–0.51	+0.32	0.620	No
3		Lighting Quality Enhancing Job Performance	Platinum	Gold	+1.02	+0.70	+1.34	8.535	Yes
				Silver	+0.44	+0.08	+0.79	3.256	Yes
				Certified	+0.57	+0.09	+1.05	3.146	Yes
			Gold	Silver	–0.58	–0.79	–0.37	7.423	Yes
				Certified	–0.45	–0.83	–0.06	3.101	Yes
			Silver	Certified	+0.13	–0.28	+0.55	0.845	No
4	Acoustic Quality	Noise Level	Platinum	Gold	+1.25	+0.94	+1.57	10.455	Yes
				Silver	+0.29	–0.05	+0.65	2.202	No
				Certified	+0.49	+0.01	+0.97	2.706	Yes
			Gold	Silver	–0.96	–1.16	–0.75	12.145	Yes
				Certified	–0.76	–1.14	–0.37	5.236	Yes
			Silver	Certified	+0.19	–0.22	+0.61	1.238	No
5		Sound Privacy	Platinum	Gold	+0.93	–0.01	+1.89	2.591	No
				Silver	+0.54	–0.41	+1.50	1.498	No
				Certified	+0.52	–0.48	+1.54	1.376	No
			Gold	Silver	–0.39	–0.65	–0.13	3.955	Yes
				Certified	–0.40	–0.83	+0.02	2.496	No
			Silver	Certified	–0.01	–0.45	+0.42	0.083	No
6		Acoustic Quality Enhancing Job Performance	Platinum	Gold	+1.04	+0.74	+1.33	9.421	Yes
				Silver	+0.16	–0.16	+0.49	1.299	No
				Certified	+0.22	–0.21	+0.67	1.349	No
			Gold	Silver	–0.87	–1.07	–0.68	12.048	Yes
				Certified	–0.81	–1.16	–0.45	6.040	Yes
			Silver	Certified	+0.06	–0.32	+0.45	0.446	No
7	Overall Personal Workspace		Platinum	Gold	+1.19	+0.90	+1.48	10.880	Yes
				Silver	+0.83	+0.50	+1.16	6.753	Yes
				Certified	+0.81	+0.37	+1.26	4.864	Yes
			Gold	Silver	–0.36	–0.55	–0.17	5.026	Yes
				Certified	–0.37	–0.73	–0.02	2.810	Yes
			Silver	Certified	–0.01	–0.40	+0.36	0.119	No

DISCUSSIONS

The findings of the study indicate that the LEED Platinum building group tended to be in general more satisfied and perceived higher job performance as a result of lighting quality and acoustic quality than the other groups, while the LEED Gold group tended to be less satisfied and perceived lower job performance than the other groups. However, no positive relationships overall were found between the level of LEED certification and the level of worker satisfaction and perceived job performance regarding lighting quality and acoustic quality in the study. This means that the worker satisfaction and perceived job performance regarding lighting quality and acoustic quality did not increase as the certification level was elevated. Instead, the Platinum group in general was the highest and the Gold group the lowest in lighting quality and acoustic quality among the four LEED certification levels, even though this was not consistent across all questions. The study results might suggest that the level of sustainability implied by the level of LEED certification does not indicate the level of comfort and productivity in the workplace when it comes to lighting quality and acoustic quality. This inconsistency might be attributed to the LEED's insufficient addressing of the need for lighting quality and acoustics quality in creating sustainable work environments that support occupant's health and well-being. Furthermore, an emphasis given to IAQ and daylight and views in the LEED IEQ category can contribute to the creation of conflicting design decisions, which can work against the overall lighting quality and acoustic quality in order to achieve a LEED certificate. Compromising the amount of artificial lighting in work environments to achieve points for energy conservation and daylight and views in LEED may be a good example.

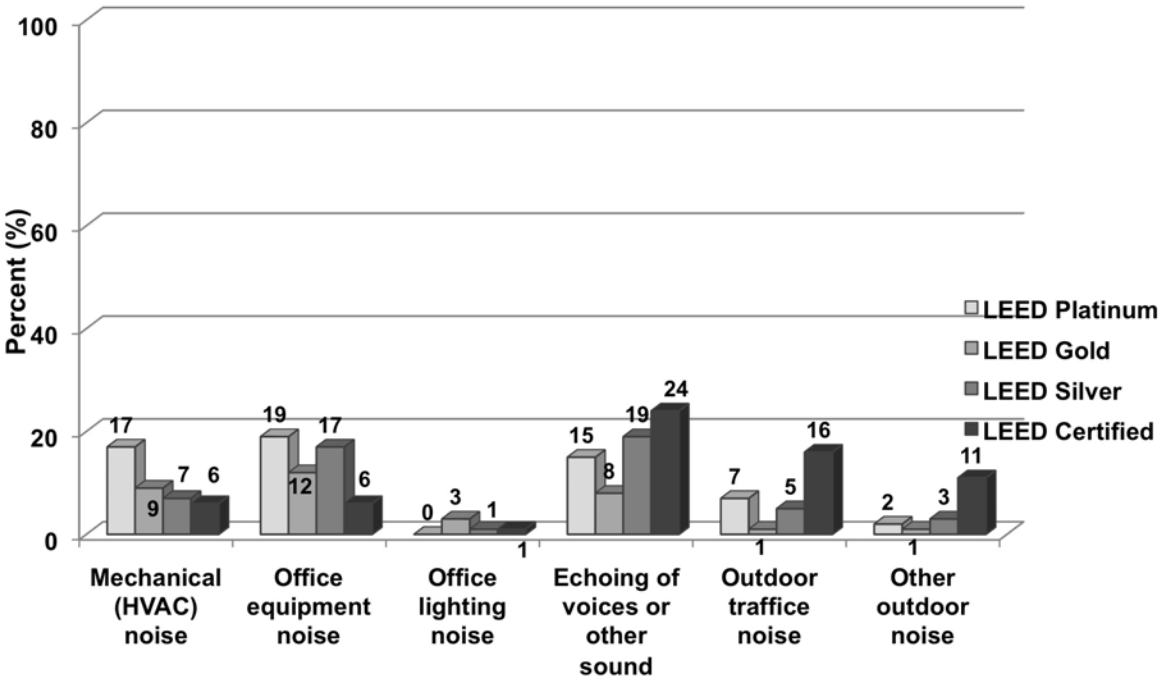
The results of the lighting quality questions showed some consistency among the four building groups of LEED certification levels. The Gold group showed significantly lower satisfaction and perceived job performance than the Silver and Certified groups in all three lighting quality questions, while there was no significant difference between the Silver group and the Certified group. However, the Silver group had the highest number of people (20%) without windows in their personal workspace compared to 2% in the Gold group and 5% in the Certified group. This might indicate that having windows in personal workspaces does not directly contribute to the overall lighting quality when such a design strategy is not considered conjointly with various factors affecting the overall lighting quality in work environments. Instead, lighting control types in personal workspaces might directly affect worker satisfaction with lighting quality and perceived job performance affected by lighting quality. The Gold group workers had a higher number of desk lights available in their personal workspaces (81%) compared to 51% in the Silver group and 53% the Certified group.

The results of the acoustic quality questions also showed some consistency between the four building groups. However, the pattern of the results was more complicated than the one of lighting quality questions. The three, Platinum, Silver, and Certified, groups showed significantly higher satisfaction and perceived job performance regarding noise level than the Gold group. However, only the Silver group showed significantly higher satisfaction with sound privacy than the Gold group. There were no other significant differences in noise level and sound privacy between the building groups. The results might imply that the office types alone do not directly contribute to the sound privacy problems. The Gold group had the highest number of high partitioned cubicles over 5 feet (70%), compared to 33% in the Platinum group, 31% in the Silver group, and 23% in the Certified group, but its satisfaction with sound privacy was only significantly lower than that of the Silver group and not the other groups. In addition,

higher partitions are known to contribute to better acoustic privacy (Newsham 2005). Thus, office types may have no direct relationship with sound privacy. Newsham (2005) points out that providing speech privacy is most important in solving acoustic problems, since two of the dominant tasks of office workers are doing individual work requiring concentration and conducting one-on-one conversations. This is also shown in the follow-up questions asking the reasons for dissatisfaction with the acoustic quality in personal workspace in this study. The majority of workers who were dissatisfied with acoustic quality identified that sound privacy issues were the major acoustic problems across the four groups. They chose people overhearing private conversations, people talking in the neighboring areas, and people talking on the phone as the top three acoustic problems. The problems with noise level were minor concerns as shown in Figure 2.

The different results between noise level and sound privacy in the study indicate that different approaches and strategies are required to tackle the problems concerning these issues. Indeed, sound privacy problems occur when background noise levels are very low but speech levels are comparatively high (Muehleisen 2010). This means that sound privacy problems exist without excessive noise level problems as shown in the study. Another interesting observation in the study is that the Platinum group showed no significantly higher satisfaction with noise level than both the Silver group and the Certified group, and no significantly higher satisfaction with sound privacy than any of the other groups. The work environments of the buildings with the highest level of LEED certification do not seem to create a better work environment when it comes to acoustic quality.

FIGURE 2. Minor Contributors to Noise Level Problems.



CONCLUSION

Achieving green buildings is an important goal to protect natural and built environment as well as occupant's health and well-being. While various approaches and strategies to achieving green buildings can be identified in practice, it is often forgotten that the ultimate goal of built environment is to provide a good environment that is balanced in all aspects. When the environment achieves a balance among various issues important to occupants without sacrificing any one particular issue, such an environment can truly be called a sustainable environment where occupants can sustain their lives harmoniously within their environment. While the study showed a limited portion of green building practice, utilizing a small sample size within the total number of LEED-certified buildings, the findings underpinned the prevailing concerns on lighting quality and acoustic quality in LEED-certified buildings.

The study suggests that design teams need a more thorough review of the various IEQ criteria in the workplace when complying with LEED. It is important that design teams maintain a balanced approach, including lighting and acoustic qualities, in addition to the LEED IEQ criteria. This will help them prevent making inappropriate decisions that will compromise lighting and acoustic qualities in order to obtain the points necessary for a LEED certificate. For instance, the use of interior glass partitions can provide more daylight and exterior views to interior occupants, but the use of too many hard materials can create acoustic problems (Muehleisen 2010).

Suggestions to improve lighting quality in the LEED-certified buildings include a provision for more light and considerations for the directions of both daylight and electric lighting. A provision for more light is necessary in personal workspaces as the main reasons for dissatisfaction with lighting quality included too dark workspace, insufficient electric lighting and insufficient daylight across the four groups. This indicates an overall lack of a sufficient amount of light in the work environment. In addition, the directions of daylight and electric lighting should be considered since many workers in the LEED-certified buildings had problems with reflectivity on computer screens. A balance needs to be struck between daylight and electric lighting for various tasks necessary to office workers. Natural light can help to reduce eyestrain but a provision for daylight alone might not be appropriate for activities focusing on close objects such as computer screens for a longer period (Brown 2008).

For acoustic quality in the LEED-certified buildings, technical solutions as well as the social aspect of work environment should be considered together. Work environment does not exist without occupants. Sound privacy problems can often be caused by occupants as the study results showed most problems in acoustic quality were people talking in neighboring area and people overhearing private conversations. It is important to address work etiquette while providing technical acoustic solutions, including sound absorbing materials, masking-noise systems, layout of workstations, and sizes of workstations (Newsham 2005)

Workplace designers and organizations should be mindful of the importance of lighting and acoustic qualities to promote better comfort and productivity when complying with LEED guidelines as it is easy to overlook these IEQ criteria, considering that the LEED guidelines minimally address these criteria. As the study showed no positive relationship between the level of LEED certification and the level of worker satisfaction and job performance regarding lighting and acoustic qualities, workspaces of LEED-certified buildings with a higher certification level may easily become less satisfactory and productive due to these issues, despite a higher financial commitment to achieving a higher level of certification. Thus, a thorough

review of design strategies is necessary to create a comfortable and productive work environment that does not sacrifice one IEQ criterion over another in achieving a green work environment.

In addition, expanding appropriate LEED credit requirements for lighting and acoustic qualities would certainly raise awareness of the critical role of these issues in the overall indoor environmental quality of workspaces, and help designers achieve a balanced work environment. For the quality of indoor lighting, illuminance and reflectance criteria need to be considered in the LEED IEQ requirements for occupant comfort and productivity (LEED User 2010). For acoustic quality, sound attenuation and acoustical privacy should be considered (Jensen et al. 2008).

Finally, valid instruments for sustainable buildings are essential to provide evidence of employee satisfaction and performance in the current sustainable building design practice (Guerin, Kim, and Brigham 2010). While assessing general conditions of lighting and acoustic qualities is the first step of providing evidence of the effectiveness of the design, further standardized, in-depth questionnaires need to be developed and widely used. This is necessary in order to diagnose specific effects of certain problems in lighting and acoustic qualities. For instance, separating glare, reflections, and contrast of lighting quality instead of combining all these different conditions into one question will result in more constructive discussions to rectify problems and a more in depth understanding of which physical properties of lighting quality are possible causes of the problems.

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