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## Indoor Environmental Quality (IEQ)

### Title

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# Occupant Satisfaction with Indoor Environmental Quality in Green Buildings

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**Summary:** *This paper summarizes the results of a large indoor environmental quality survey in office buildings, comparing green with non-green buildings. On average, occupants in green buildings were more satisfied with thermal comfort and air quality in their workspace. However, the average satisfaction scores in green buildings for lighting and acoustic quality were comparable to the non-green average. Comparing complaint profiles of those dissatisfied with lighting and acoustic quality, a higher percentage of occupants were dissatisfied with light levels and sound privacy in green buildings. Our results suggest a need for improvements in controllability of lighting, and innovative strategies to accommodate sound privacy needs in open plan or cubicle office layouts in both comparison groups.*

**Keywords:** *green buildings, indoor environmental quality, post occupancy evaluation, occupant survey*  
**Category:** *Design and operation of healthy buildings*

## 1 Introduction

For more than four decades, Post Occupancy Evaluations (POE) have been used to evaluate the degree to which buildings enable users to fulfill their intended goals [1]. A comprehensive POE method, one that includes assessments of occupant well-being and productivity, completes the feedback loop that is essential for the successful future development and improvement of building design and practices.

The United States Green Building Council (USGBC) defines green buildings as ones that have significantly reduced or eliminated negative impacts on the environment and the occupants [2]. In 2000, USGBC launched the first formal framework for rating green buildings in the US; Leadership in Energy and Environmental Design (LEED). The rating system's structure consists of five categories: sustainable sites, water efficiency, energy & atmosphere, materials & resources, and indoor environmental quality (IEQ) [3].

The LEED rating system has been adopted widely in the US by federal agencies, state and local governments, and private companies as the standard for sustainable building. While it has brought green design and construction practices into the mainstream, systematic assessments of how these buildings affect the occupants are rarely done. Most POE studies of green buildings have focused on more easily quantifiable criteria such as energy use and physical measurements of environmental conditions, which at best give an indirect assessment of how the building is affecting the occupants.

In this paper, we look at occupant satisfaction in green buildings in comparison to non-green buildings, asking the occupants directly about satisfaction with IEQ in their workspace. As improved IEQ is a stated goal of sustainable design, we question how green buildings are in fact performing in comparison to non-green buildings from the occupants' perspective. If they are performing better, this indicates that the goal is being achieved. If not, we look into what is contributing to a negative outcome of a mostly positive effort.

## 2 Methods and data

For the past several years, the Center for the Built Environment (CBE) at the University of California, Berkeley, has been conducting a survey that assesses indoor environmental quality in office buildings. The survey measures occupant satisfaction and self-reported productivity in nine IEQ categories in an anonymous, invite-style web-based questionnaire [4].

The data collected by the CBE survey can be divided up into subjective and objective variables. The objective variables measured include gender, age group, type of work, office type, proximity to windows and exterior walls, and various types of control over workspace environment, such as window blinds. The subjective variables measured include occupant satisfaction (Figure 1) and self-reported productivity with the following IEQ categories: office layout, office furnishings, thermal comfort, air quality, lighting, acoustics, cleaning and maintenance, overall satisfaction with building and overall satisfaction with workspace. In

satisfaction and self-reported productivity questions we use a 7-point semantic differential scale with endpoints “very dissatisfied” and “very satisfied.” For the purposes of comparison, we assume the scale is roughly linear, and assign ordinal values to each of the points along the scale, from -3 (very dissatisfied) to +3 (very satisfied) with 0 as the neutral midpoint. In the event that respondents indicate dissatisfaction with a survey topic, they are taken to a follow-up page containing drill-down questions about the source of the dissatisfaction, and a text box for open-ended comments.

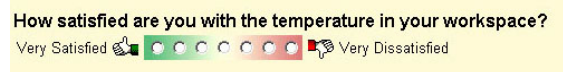


Figure 1 – Typical 7-point satisfaction scale in survey

Of the 215 buildings surveyed so far, 90% are located in the United States, the remainder in Canada and Finland. About 80% of the buildings are owned or leased (and primarily occupied) by some government entity (federal, state or local). As for building type, all are office buildings, with 22% providing some additional functionality, such as courthouse, bank, educational, or laboratory.

Occupants in each building are invited to take the survey through an invitation Email including the URL that links to the survey. Survey duration is usually two weeks. The survey has been conducted across seasons, but the majority of responses belong to the summer season. The refined<sup>1</sup> CBE survey database as of September 27<sup>th</sup> 2005 contains 181 buildings and 33,285 respondents. The average response rate was 46%.

Among these buildings, 15 have been rated via the USGBC LEED rating system. Another 6 have been identified by their designer or owner as being “green” – designed and operated sustainably. These self-nominated green buildings have received national or local green building or energy efficiency awards. But because they have not gone through the formal rating system, we don’t have a formal method to determine how green they are in comparison to each other or to LEED-rated buildings. We have identified self-nominated green buildings (n=6), as a distinct group in our charts but grouped them with LEED-rated buildings (n=15) in our quantitative analysis. Together this group comprises one of the main comparison groups in this paper referred to as “LEED-rated/green buildings” (n=21) throughout this paper. The other main comparison group is made up of non-green buildings referred to as “the rest of the CBE database” (n=160).

This paper focuses on occupant satisfaction with thermal comfort, air quality, lighting, and acoustics. We mention but won’t explore in detail office

<sup>1</sup> Buildings with fewer than 15 respondents or less than 10% response rate are not included.

layout, furnishings, cleaning and maintenance, and overall satisfaction with workspace. Self-reported productivity scores follow the same pattern as those of satisfaction – productivity scores are high where satisfaction scores are high, and low where satisfaction scores are low. In a given building, the satisfaction score for an IEQ category is derived from the mean of all occupants’ votes on satisfaction questions in that category. Similarly, mean satisfaction scores in each group of buildings are computed through a “one building – one vote” method to give buildings of various occupant population number equal weight in the analysis. All relationships are statistically significant to  $p < 0.05$ , unless noted otherwise.

### 3 Indoor environmental quality in green buildings

Comparing the results of surveys in LEED-rated/green buildings with the rest of the buildings in our database, we found that on average occupants in LEED-rated/green buildings are more satisfied in the following areas: office furnishings, thermal comfort, air quality, cleaning and maintenance, and overall satisfaction with workspace and building (Table 1).

Mean satisfaction score	Database buildings: all (non-green)	Database buildings: age<15 (non-green)	LEED-rated / green buildings
Office Layout	0.95	1.03	0.94
Office Furnishings *	0.84	1.03	1.26
Thermal Comfort *	-0.16	0.17	0.36
Air Quality * ^	0.21	0.52	1.14
Lighting	1.12	1.16	1.08
Acoustics	-0.20	-0.01	-0.27
Cleaning and Maint...*	0.91	1.15	1.48
Overall Workspace *	0.84	1.03	1.13
Overall Building *	0.93	1.14	1.47
Number of buildings	160	35	21

\* Difference b/w LEED-rated/green and the rest of CBE database is statistically significant.  
 ^ Difference b/w LEED-rated/green and new buildings in the rest of CBE database (age<15) is statistically significant.

Table 1 - Mean satisfaction score comparison across all CBE survey categories among three groups: database buildings, new database buildings, and LEED-rated/green buildings

Figure 2 shows a percentile rank chart of buildings in the CBE database based on their mean satisfaction score with building overall. Percentile ranks are calculated by ranking all of the buildings in order of their mean satisfaction score with a particular IEQ category. The 50th percentile in the percentile rank chart is the median of all buildings in the CBE database: half of all buildings in the database have lower and half have higher mean satisfaction scores than the median.

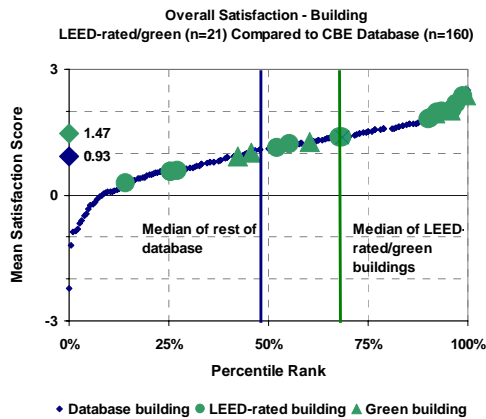


Figure 2 - Median and mean overall building satisfaction scores in LEED-rated/green buildings and the rest of the CBE database

The mean occupant votes for the two main comparison groups are shown on the y-axis. The medians of the two main comparison groups are marked by the vertical lines. As shown in Figure 2, the mean satisfaction score in LEED-rated/green buildings (1.47) is significantly higher than the mean satisfaction score for the rest of the CBE database (0.93). So on average occupants in LEED-rated/green buildings are more satisfied with their building overall than occupants in the rest of CBE survey database. The gap between the median lines for two groups also marks this difference.

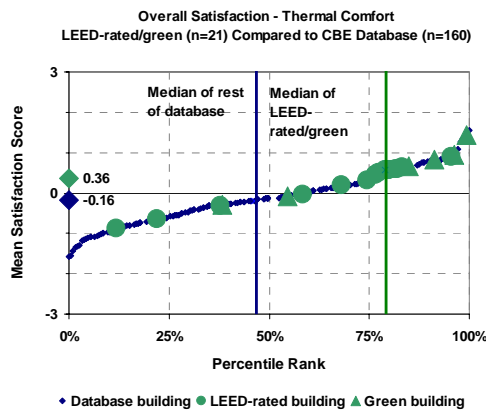


Figure 3 – Median and mean thermal comfort satisfaction scores in LEED-rated/green buildings and the rest of the CBE database

Figure 3 shows that occupants in LEED-rated/green buildings are on average more satisfied with their thermal comfort than occupants in the rest of the CBE database (compare 0.36 with -0.16). Unlike the other buildings in the database, LEED-rated/green building scores tend to be on the positive side (i.e. the “satisfied” side) of our 7-point scale for thermal comfort.

Figure 4 shows that occupants in LEED-rated/green buildings are on average more satisfied with the air quality in their workspace than occupants in the rest

of the CBE database (compare 1.14 with 0.21). The mean satisfaction scores in both groups have positive signs, which means that on average air quality in both groups is satisfactory.

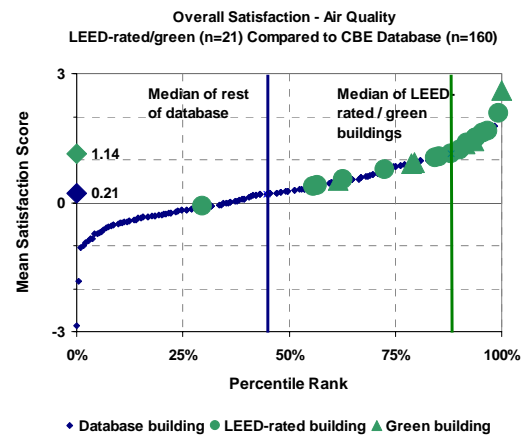


Figure 4 – Median and mean air quality satisfaction scores in LEED-rated/green buildings and the rest of the CBE database

Given the fact that LEED-rated/green buildings in CBE database are all new buildings, it is important to check for age as a confounding factor in our analysis. Figure 5 shows that even when considering only buildings newer than 15 years, the mean satisfaction score with air quality is significantly higher for LEED-rated/green buildings (1.14) than the rest of the CBE database (0.52). Interestingly, we do see the effect of age on air quality satisfaction by comparing scores in newer non-green buildings (0.52) to the all-age-inclusive non-green CBE database (0.21).

As shown previously in Table 1, when including only buildings newer than 15 years old in our analysis, aside from air quality satisfaction, no statistically significant relationship can be found between LEED-rated/green buildings and new non-green buildings in the CBE database in other IEQ categories of the survey.

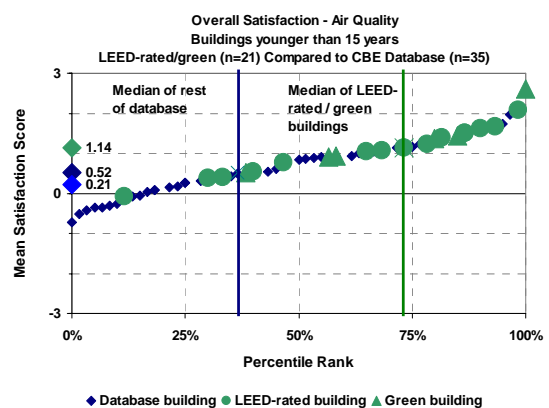


Figure 5 - Median and mean air quality satisfaction scores in LEED-rated/green buildings and the rest of the CBE database, for new buildings only

Coming back to the all-age-inclusive analysis of the database we see that on average, the difference between mean occupant satisfaction votes in LEED-rated/green buildings and the rest of CBE database is small and not statistically significant for the following categories: office layout, lighting, and acoustic quality. Figure 6 shows percentile rank chart of buildings in CBE database based on their mean satisfaction score with lighting. The median for LEED-rated/green buildings is slightly higher, but the average scores of the two groups are very close together. There are three distinct clusters; the LEED-rated/green buildings have grouped together in the top, middle and bottom of the database.

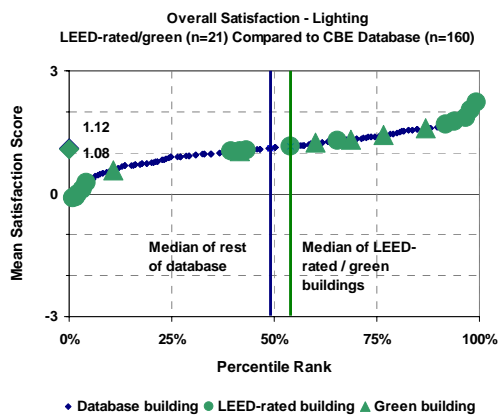


Figure 6 - Median and mean lighting satisfaction scores in LEED-rated/green buildings and the rest of the CBE database

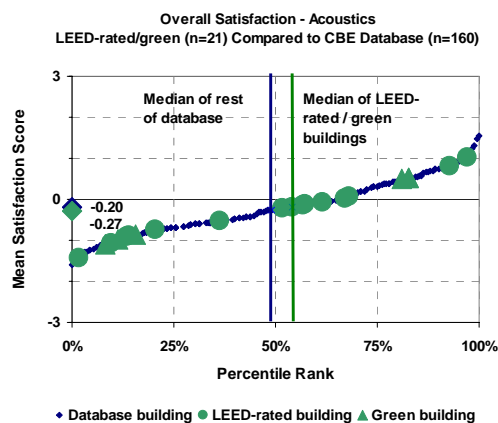


Figure 7 - Median and mean acoustics satisfaction scores in LEED-rated/green buildings and the rest of the CBE database

Figure 7 shows the acoustics comparison. The median is slightly higher for LEED-rated/green buildings but the mean score is slightly worse than the rest of CBE database. It is interesting to see that in contrast to the pattern visible in overall building, thermal comfort, and air quality, here we don't see a grouping of LEED-rated/green buildings in the top of the percentile rank chart. In fact in acoustics, as with lighting, we observe a grouping of LEED-rated/green buildings in the bottom of the percentile

rank charts. Assuming that there has been a deliberate effort to improve IEQ in LEED-rated/green buildings: why aren't occupants in these buildings indicating higher satisfaction with lighting and acoustics?

#### 4 Complaints and controls in lighting and acoustics

When occupants express dissatisfaction with a survey category, they branch to a follow-up page where they can check-all-that-apply from a list of possible sources of dissatisfaction. By analyzing responses from the branching pages, and comparing the distribution of controls and complaints in the two groups we get a detailed view of what is contributing to occupants' dissatisfaction with lighting and acoustics. It is important to note that when comparing the LEED-rated/green group with the other CBE database buildings, only those who were dissatisfied with the category saw the page. If the percentage of complaints are consistently higher in one group, it doesn't mean that on average that group would have scored lower in the IEQ category in question. It means that *among those dissatisfied*, a higher percentage in one group had complaints in certain areas than the other group.

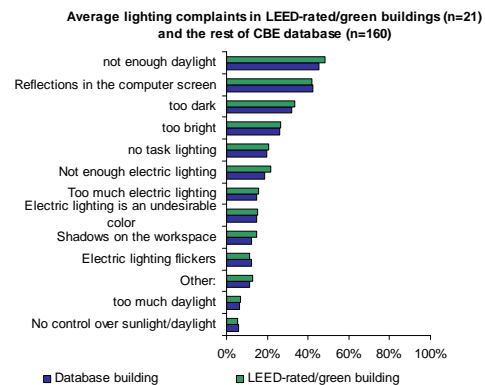


Figure 8 - Mean percentage of lighting complaints in LEED-rated/green buildings and the rest of the CBE database

Figure 8 shows the average distribution of lighting complaints in the two main comparison groups. The chart shows that major lighting complaint areas in LEED-rated/green buildings and the rest of the CBE database are, in descending order, "not enough daylight", "reflections in the computer screen", and "too dark". It is interesting to note that the frequency of complaints follow the same order in both groups. This suggests that the amount of lighting is a problem in both groups. We have not analyzed the content of the open-ended text entered by respondents who chose "other".

A common strategy in green buildings is to rely on lower levels of ambient electric lighting to save energy and provide occupants with task lighting to

compensate for it. It is also common to use daylighting for energy efficiency and to enhance the quality of the indoor environment. These strategies rely mainly on occupant control over their environment to be effective. Whereas daylighting enhances the quality of light indoors, and decreases reliance on electric lighting, it can also be a source of glare and thermal gain. Figure 9 shows the lighting control profiles in the two comparison groups. Control items where the difference between the two main comparison groups is statistically significant are circled on the chart. Contrary to what we would expect to see in terms of a higher degree of controllability in LEED-rated/green buildings, we see that these buildings on average have a significantly lower percentage of people who have control over “light switch”, and “window blinds or shades”. LEED-rated/green buildings also have a higher percentage of people who have voted they have control over “none of the above”, i.e. no control over the lighting in their workspace.

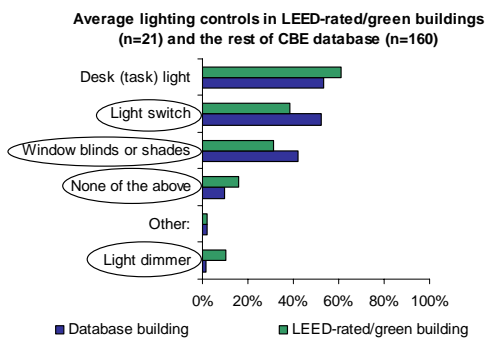


Figure 9 - Mean percentage of lighting controls in LEED-rated/green buildings and the rest of the CBE database

Figure 10 shows the acoustic complaints profile in the two main comparison groups. We can see that occupants in LEED-rated/green buildings associate the source of their dissatisfaction with acoustic quality most often with, in descending order: “people talking in neighboring areas”, “people overhearing my private conversations”, “people talking on the phone”, and “telephones ringing”.

Comparing the two groups, a higher percentage of people in LEED-rated/green buildings have occupants complaining about “people overhearing my private conversations”, “people talking on the phone”, and “telephones ringing”. Yet similar to lighting complaint profiles, the frequency of acoustic complaints follows the same order in both of our comparison groups. The top three complaints in both groups are related to a lack of speech privacy, and distractions from hearing others’ intelligible speech, rather than excessive distractions with noise; a consequence of open plan and cubicle office layouts [5].

We checked for the distribution of office types in LEED-rated/green buildings and the rest of the

CBE database. Figure 11 shows the comparison where LEED-rated/green buildings have a higher percentage of people in “cubicles with low partitions”, and “workspace in open plan office with no partition (just desks)”. LEED-rated/green buildings have a significantly lower percentage of people in private offices.

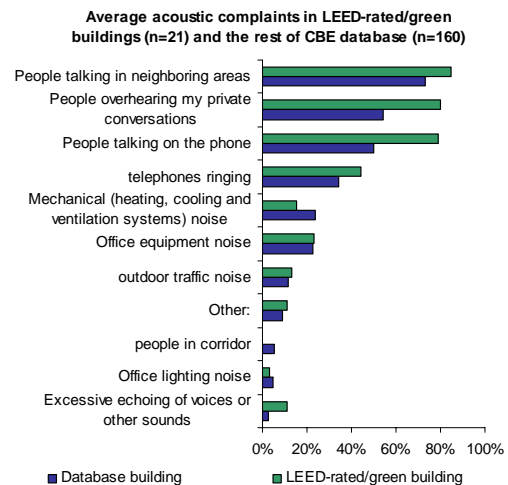


Figure 10 - Mean percentage of acoustic complaints in LEED-rated/green buildings and the rest of the CBE database

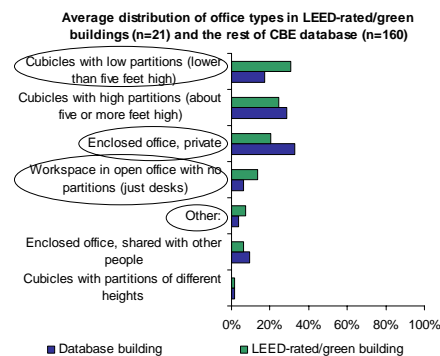


Figure 11 - Mean percentage of office types in LEED-rated/green buildings and the rest of the CBE database

## 5 Conclusion

What’s different in green buildings that leads to higher satisfaction with certain IEQ categories in comparison to non-green buildings? There are certain design decisions and operation practices that are generally known to affect IEQ and are commonly used in green buildings. These strategies include (but are not limited to): improving ventilation, removing indoor pollutants, using green materials, giving occupants personal control over operable windows, task air-conditioning, or underfloor air distribution systems, employing daylight, and reducing ambient light levels by using task lighting.

We observed that occupants in green buildings are on average more satisfied with their air quality and thermal comfort. Although we still see some green buildings in the lower quartiles of the CBE database, our results suggest that on average the strategies commonly employed in green buildings have been effective in improving occupant satisfaction with air quality and thermal comfort. Conversely, we see that lighting and acoustic quality in green buildings do not show a significant improvement in comparison to non-green buildings. Complaint profiles of those dissatisfied with their lighting point to problems with daylighting and electric lighting levels – at its source this could be due to inadequate provision of controls over lighting.

Common strategies to maximize daylight, views, ambient lighting opportunity, personal control, flexibility, and equality of workspace allocation in green offices prefer the spatial layout of open or partitioned floor plans to enclosed private offices. Our data supports this speculation and we showed that a higher percentage of people in green buildings work in cubicles with low or no partitions. But the controls have to be available and functioning properly for lighting to be effective.

In addition, a natural tension exists between the benefits provided by open spaces, and the need for speech privacy to concentrate or perform confidential tasks. Complaint profiles of those dissatisfied with the acoustic quality in their workspace point to problems with sound privacy, and distracting noise from people's conversation and telephone rings. While it is unrealistic and counter to lighting and air quality goals to provide every occupant with a private office, these results suggest that there is need for innovative strategies that provide optional spaces where quiet and privacy can be obtained when required.

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*See also:*

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