Indoor environment quality in LEED buildings: understanding conditions affecting performance

By

Kristine Walker

A thesis submitted in partial satisfaction of the

requirements for the degree of

Master of Science

in

Architecture

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Stefano Schiavon, Chair

Professor Gail Brager

Professor Duncan Callaway

Spring 2015

Table of Contents

List of Figures

List of Tables

Acknowledgements

The survey analysis was performed under funding provided by the Center for the Built Environment. The building assessments were supported, in part, by a scholarship award from the Eric Thor Andresen ASHRAE scholarship, Golden Gate Chapter.

I would like to thank Dr. Judith Heerwagen, Dr. Sergio Altomonte, Susan Ubbelohde, and Dr. Duncan Callaway for their direct contributions and valued guidance. Dr. Edward Arens, Dr. Hui Zhang, David Lehrer, Jessica Uhl, and all my colleagues and friends at the Center for the Built Environment who have shown constant support and encouragement along the way. The author is particularly grateful to Dr. Stefano Schiavon and Dr. Gail Brager for their incredible stewardship and instruction for this thesis work.

Many people and organizations across the building industry and academia supported this work as well with information, guidance, and coordination efforts. I will only name a few here: the HOK Group (sponsor of the focus group), Dr. Chris Pyke, Sean McMahon, Peter Rumsey, Eric Soladay, Henry Siegel, Lynn Simon, Margaret Pigman, Kit Elsworth, Sarah Salvini, Chris Detjen, and Joan Tionko. The depth of study would not have been possible without the flexibility and support of the building assessment participants.

There have also been many people who have been personally influential to me over the years. I am especially grateful to: Mark Cathcart, Ruth Cox, Astrid Haryati, Dr. Rebecca Kenney, Paige Loczi, Susana Mercado, and Beth Moore for providing counsel, support, and their belief that I could realize goals beyond what I thought possible.

Finally, my deep personal admiration and thanks goes to my sister Melissa. She has always been in my corner and never failed to provide loving guidance and a soft shoulder. I would not be the woman I am today without her.

1. Introduction and Background

We shape our buildings; therefore they shape us.
– Winston Churchill

At their fundamental level buildings are intended to provide shelter with spaces designed to support comfortable, productive environments for all manner of human activity. Currently many of our buildings are falling short of this basic intention. The Committee on the Effect of Climate Change on Indoor Air Quality and Public Health 2011 report provides that poor indoor environmental quality (IEQ) is creating health problems today and impairs the ability of occupants to work and learn and climate change may make existing IEQ worse and may also introduce new problems. But the report also offers that opportunities exist to improve public health while mitigating or adapting to alterations in IEQ induced by climate change (Institute of Medicine, 2011).

For the built environment, rating tools (such as LEED in the United States, BREAM in the United Kingdom, Green Mark in Singapore, etc.) are charting the way for the building industry to pursue sustainably-focused architecture and improved indoor environments. Arguably, the degree to which occupants are satisfied with their experience in these rated or "green" buildings is an essential aspect toward understanding and mapping improvements to indoor environment quality and our overall approach to buildings in general.

Figure 1 and Appendix A provide insight into how the cost of workers compares to other major office building costs. Workers are 1-2 fold the cost of other business expenses, thus supporting the office workspace as one of the primary building types where optimum satisfactory IEQ levels need to be achieved (Rocky Mountain Institute, 2014). Given that the perceptions of people who occupy these offices are at the core of understanding IEQ conditions, we use their level of satisfaction to guide this research and to help understand how the dynamic nature of designing, building, and operating buildings all contribute towards building performance.

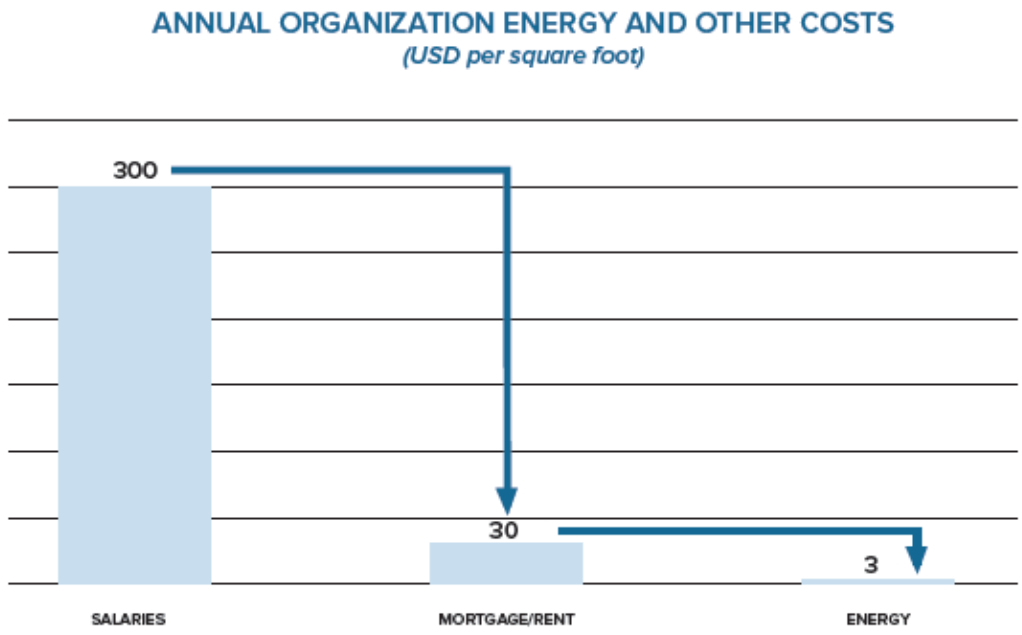


Figure 1 - Relative cost of workers verses other business expenses - Rocky Mountain Institute "Guide for building the case for Deep Retrofits", based on the original graph by Bill Browning, Rocky Mountain Institute 1994 and updated by Gurteken, Hartkopf, and Loftness for the Building Investment Decision Support (BIDS) Carnegie Mellon University Center for Building Performance and Diagnostics.

For this research, I have focused on a set of North American office buildings that are certified under the LEED rating system (described in Section 2.2) and surveyed using the Occupant Indoor Environment Quality (IEQ) Survey™ developed and administered by the Center for the Built Environment (described in Section 2.3).

1.1 The LEED program

LEED is currently the most widely used green building certification program in the United States and is administered by the US Green Building Council or USGBC. The USGBC website estimates over 22,900 LEED certifications have been awarded to commercial buildings. More than three billion square feet (27,870,913 square meters) of commercial space have received LEED certification and more than 4.3 million people occupy that space worldwide (U.S. Green Building Council, b). Further their website reports; “Every day, 1.7 million square feet of space is certified using LEED. More than 58,000 commercial and institutional projects are currently participating in LEED, comprising 10.7 billion square feet of construction space in more than 140 countries and territories. In addition, more than 50,000 residential units have been certified under the LEED for Homes rating system.”

The USGBC defines ‘green buildings’ as follows: “Green building is a holistic concept that starts with the understanding that the built environment can have profound effects, both positive and

negative, on the natural environment, as well as the people who inhabit buildings every day. Green building is an effort to amplify the positive and mitigate the negative of these effects throughout the entire life cycle of a building." (U.S. Green Building Council, c) From their definition it can be deduced that one of the objectives of LEED is *to amplify the positive and mitigate the negative* effect of the built environment on occupant satisfaction. Further they provide that the structure of LEED is "…a voluntary, consensus-based, market--driven program that provides third-party verification of green buildings" and has consistently evolved since its inception with many releases or "versions" following the initial pilot in March 2000.

The LEED rating system uses a credit-based structure through which points can be achieved in six categories: Sustainable Sites, Energy and Atmosphere, Water Efficiency, Materials and Resources, Indoor Environment Quality, and Innovation in Design (note that in LEED v4, which went into effect after the data collected in this study, some of the points in Sustainable Sites were separated into a new category called Location & Transportation). Currently LEED certification is awarded according to the following scale: Certified (40-49 points), Silver (50-59 points), Gold (60-79 points), Platinum (80 points and above). It's worth noting this scale has varied across the version releases. Within each of the LEED credit categories, projects must satisfy prerequisites and can earn points (up to 110 with the latest versions), which differ based on the LEED product and version under which the certification is sought. Two bonus credit categories are available for the Innovation in Design or Innovation in Operations credit (six additional points), addressing sustainable building expertise or design measures not covered under other credit categories; and Regional Priority (4 additional points), addressing environmental priorities for buildings in different geographic regions (U.S. Green Building Council, a).

Levels of certification vary across a subset of rating systems or "products" tailored to various types of projects. Each of these products has different credits available and prerequisites within each of the categories. All of the projects contained in this study fall under the following product types: 1) LEED for New Constructions & Major Renovations (NC); 2) LEED for Existing Buildings, Operation & Maintenance (EB and EBOM); and 3) LEED for Commercial Interiors (CI) (U.S. Green Building Council, 2015). For the purpose of this paper and given we are focusing on occupants of office space types, these primary LEED products (NC, EB, and CI) were considered to be the most relevant and were able to provide the most analytical opportunities. Only two projects where certified and published under the current version 4 (or v4) at the time the data was analyzed for this research and were not included in the study.

All versions preceding v4 were included in this study. LEED for New Construction (NC) v1.0 pilot was released in 2000 as the first official LEED rating system. It focuses on the construction of new commercial buildings and major renovations, including significant HVAC improvements, major envelope modifications, and interior rehabilitation. Following the initial version, several revisions of the rating tool have been released over the years, including; v2.0, v2.0/2.1, v2.1, v2.2, LEED for New Construction 2009 (or v3), and the aforementioned LEED v4 launched November 2013.

LEED v4 was made the primary version for certification in June 2014. LEED for Existing Buildings (LEED-EB) is applicable to building operations, processes, systems upgrades, and minor space use changes. Buildings can re-apply for EB certification even if they are previously certified under LEED for New Construction. Specifically, it addresses exterior building site maintenance programs, water and energy use, environmentally preferred products for cleaning and alterations, waste stream management, and credits related to ongoing indoor environmental quality. LEED for Existing Buildings, Operations & Maintenance (LEED-EBOM) is similar but also includes sustainable purchasing policies and waste stream management. The pilot version of LEED-EB was introduced in 2002, and version 2.0 – whose minor changes aimed mostly to clarify some requirements – was launched in 2004. LEED EB v2.0 was followed by further revised versions, up to the current LEED O+M v4. LEED for Commercial Interiors (LEED-CI) was initially launched in 2004 to certify interior tenant spaces (i.e., for users that lease their space or do not occupy the entire building). This rating system can be applied to a variety of commercial interiors including office, retail and hospitality spaces.

Within the Indoor Environment Quality (IEQ) category found in all the products and versions, LEED provides credits related to: air quality, thermal comfort, lighting, daylight and views, controllability of systems, and occupant surveying. This study focuses on the IEQ aspects of each building's LEED certification, CBE survey results, and directly investigated performance aspects.

1.2 The CBE Occupant Indoor Environmental Quality Survey

The web-based occupant survey developed by the Center for the Built Environment (CBE) at the University of California, Berkeley is a semi-standardized surveying tool that can be applied widely to evaluate performance of individual buildings, as well as systematically compare the performance of a group of buildings (Zagreus et al., 2004). The CBE survey can be used as a benchmarking tool to compare a building's performance against other buildings from the point of view of the occupant's satisfaction, it can also act as an effective diagnostic tool that can recognize specific problems and their sources (Huizenga et al., 2002). The main part of the survey is comprised of core IEQ-related modules with questions focused on acoustics, air quality, lighting, and thermal comfort, as well as non-IEQ questions about building cleanliness and maintenance, office furnishings, office layout, and general comments, as seen in Table 1. The resulting database of core questions and responses provides a unique opportunity to investigate several factors that drive satisfaction in the workplace from the perspective of the occupants. This can allow for many outcomes including facilitating decision making in the design of building projects and supporting related research (Huizenga et al., 2002, Wargocki et al., 2012, Brager and Baker, 2009, Kim et al., 2013, Frontczak et al., 2012a).

The survey can be applied to a variety of building types including commercial buildings (e.g. office, retail, etc.), healthcare facilities, laboratories, residential and educational buildings, prisons, and libraries. The full database currently includes more than 650 buildings and 70,000

individual occupant responses obtained over a period of ten years, mainly from commercial buildings in the United States, Canada, Europe and Australia. The survey has been widely recommended in the industry, including in ASHRAE Performance Measure Protocol for Commercial Buildings (ASHRAE, 2010).

The web-based CBE survey is composed of core and optional modules, which can be added based on the specific buildings' characteristics or the level of interest in particular features for the building or living conditions. The survey was independently assessed with an in-depth pre-testing method called "cognitive interviewing" to evaluate how well respondents were able to comprehend and accurately report answers to survey questions (Huizenga et al., 2003).

Along with core information found in Table 1, the survey also collects specific information about the survey participant, short of individually identifying them. This information includes gender, age group, type of work, office type, distance of workspace from the window, period of time since starting work in the current building and workstation, weekly working hours, etc. Information about the subject building is also collected and includes age of the building, location, size, number of floors and occupants, systems, shading devices and control mechanisms, LEED rating, energy use, cost of construction, and more.

The categories used in the CBE survey provide indicators of satisfaction and comfort either with indoor environmental quality or with the workspace in itself (Frontczak et al., 2012a). The survey uses a 7-point ordered scale ranging from "very satisfied" (+3) to "very dissatisfied" (-3), with a neutral midpoint (0). Although the core survey does not include some important parameters that can also affect occupant satisfaction, such as view to the outside, these factors were included in this overall research during the expert focus group and building assessment portions of the study (see Chapter 2, Methods).

Table 1.1 Categories included in the CBE Occupant Indoor Environmental Quality Survey

Acoustic Quality	Noise level in your workspace Sound privacy in your workspace (conversations without neighbors overhearing and vice versa)
Air Quality	Air quality in your workspace (i.e. stuffy/stale air, air cleanliness, odors)
Lighting	Amount of light in your workspace Visual comfort of the lighting (e.g., glare, reflections, contrast)
Thermal Comfort	Temperature in your workspace
Cleanliness and Maintenance	General cleanliness of the overall building General maintenance of the building
Office Furnishings	Comfort of office furnishings (chair, desk, computer, equipment, etc.) Ability to adjust furniture to meet your needs Colors and textures of flooring, furniture and surface finishes
Office Layout	Amount of space available for individual work and storage Level of visual privacy Ease of interaction with co-workers
General Comments	Your personal workspace Building overall

1.3 Related Studies

Although studies examining occupant satisfaction in buildings is increasing, due, in large part, to the CBE survey tool (see section 1.2), there have been few studies to date considering specific aspects of LEED buildings related to IEQ performance (Kim and de Dear, 2012). In 2013, Altomonte and Schiavon initiated their research by asking if LEED certified buildings lead to a higher, equal, or lower IEQ occupant satisfaction (measured with the CBE IEQ survey) than those surveyed in non-LEED buildings. They studied buildings that were comparable in age and size and were surveyed within one year or later of LEED certification. This resulted in a dataset of 10,129 respondents in 65 LEED-certified buildings and 11,348 respondents in 79 Non-LEED buildings. The results showed that occupants of LEED certified buildings verses non-LEED certified buildings have equal satisfaction with their workspace and building overall. The researchers concluded that there was no significant influence of LEED certification on occupant satisfaction (Altomonte and Schiavon, 2013). Based on the same database, Schiavon and Altomonte (2014) again investigated users' satisfaction in LEED and non-LEED certified buildings but this time focusing on factors unrelated to environmental quality, including consideration of office type, spatial layout, distance from window, building size, gender, age, type of work, time at workspace, and weekly working hours. Although there are specific cases which showed a tendency to be more effective in terms of satisfaction (some increased satisfaction with air quality and dissatisfaction with the amount of light for example), the overall results showed that the preceding list of factors had a statistically negligible effect on the level of satisfaction across the two types (LEED and non-LEED)

of buildings (Schiavon and Altomonte, 2014). While this previous research focused exclusively on CBE IEQ survey data, I felt that having additional insights from a focus group, expert interviews, and building visits might enhance the understanding of the results (see Chapter 2 Methods – quantitative and qualitative research).

A thorough review of other related research focused on occupant IEQ satisfaction in 'green' buildings can be found in (Altomonte and Schiavon, 2013, Schiavon and Altomonte, 2014). One review of note provided a literature survey of thermal, visual, acoustic, and olfactory factors and how they rank toward the contribution of comfort and how characteristics of the occupants (e.g. age, gender, etc.) and features of the workplace (e.g. occupant control, building type, etc.) affect occupant satisfaction (Frontczak and Wargocki, 2011). Additionally, selected investigations were highlighted in the aforementioned papers' literature reviews, given their provision of a more direct connection between green rating tools and occupant satisfaction. Since the Schiavon/Altomonte review, two studies of note were recently re-examined. Analyzing occupant satisfaction at the workstation level (open plan versus private office) in green versus conventional buildings, the researchers found that occupants of green buildings rated all environmental factors studied more highly than conventional buildings. As would be expected satisfaction with: acoustics and privacy was affected by office type and size, lighting with proximity to a window and glare conditions, and satisfaction with ventilation and temperature by pollutant concentration levels. They also examined job satisfaction and found it was most affected by pollutant concentration and office type (Leder et al., 2015, Newsham et al., 2012, Newsham et al., 2013). Other more recent studies reviewed have primarily featured research detailing specific aspects of IEQ-related satisfaction in LEED buildings, however, they contain relatively small samples sizes, specific climates, or building uses (i.e. university only buildings). (Deuble and de Dear, 2012, Collinge et al., 2012, El Asmar et al., 2014, Kim and de Dear, 2012, Tham et al., 2015, Hua et al., 2014).

No known research to date has used POE (Post Occupancy Evaluation) to study occupant IEQ satisfaction in LEED buildings at the individual rating, product, version and IEQ credit level and used large sample sizes. Further, currently available research has provided little additional contextual information about the conditions in the specific buildings to understand why they arrived at their findings.

1.4 Objectives

Practitioners in the building industry have wanted to better understand the connection between design strategies and occupant experience, particularly in green buildings where one of the goals is explicitly to enhance the IEQ. While there has been an underlying assumption that a LEED building will produce improved IEQ, there have been very few studies looking directly at the relationship between LEED certification and occupant satisfaction with IEQ. The objectives of this thesis are to explore:

1) To what extent do characteristics of LEED influence occupant satisfaction with IEQ?
2) What contextual factors in the design, construction, and operation of buildings affect are a factor in this relationship?

For this thesis, the LEED characteristics I investigated include product, version, certification level, and IEQ credits.

In addition to using the results of the CBE IEQ Survey, I investigated these questions in terms of the design intention of LEED-certified buildings, what IEQ-related building strategies were selected, how those strategies are performing in operation of the building (i.e., after LEED certification), and how those strategies impacted occupant satisfaction. I looked specifically at IEQ categories of air quality, thermal comfort, lighting, visual comfort and satisfaction with the building overall across several versions and products of LEED.

2. Methods

2.1 Overview

This research is founded on a quantitative analysis of occupant IEQ satisfaction in LEED-certified buildings using the CBE Occupant Indoor Environment Quality Survey (described in Chapter 1-Introduction). The study of these buildings has been further expanded using an industry focus group and a qualitative examination through individual building assessment (e.g. direct site visits). This research design is based on a mixed methodology approach of triangulation. Triangulation is explained as: "Multiple lines of sight in qualitative research providing the ability to triangulate and draw more solid conclusions….An important feature of triangulation is not the simple combination of different kinds of data but the attempt to relate them so as to counteract the threats of validity identified in each." (Berg et al., 2004). Triangulation is a method for increasing validity of findings, through deliberately seeking evidence from a wide range of sources and comparing findings from those difference sources. If they coincide, that strengthens our faith in having identified important issues (Patton 2005). Each method is intended to support the other by studying the relationship between LEED-supported IEQ factors and occupant satisfaction, providing direct examples of how green-rated buildings are performing, and laying a foundation for future study work. The use of the quantitative survey study, the focus group and the building assessments provides the framework for a *triangulated* study as seen in Figure 2. Specific to this research work, triangulation becomes important when considering the built environment from the occupant point of view and provides context to the complex design and construction process and the dynamic nature of building operations. Each of the three methods provides entirely different insights, and triangulation is a way to compare and related those insights to each other

Figure 2 - Primary triangulation of methods

Content analysis is used to bring the qualitative aspects of the focus group and building assessments into themes for analysis. The three classes of themes found in thematic networking – global, organizing, and basic – are then used to bring all three studies together. The use of thematic networks is a basic method of organization for analysis and seeks to uncover salient themes in the textual data and allow for cross-comparison and a common understanding across diverse data (Attride-Stirling, 2001).

Four primary categories emerged from the survey analysis and preparation for the focus group: indoor air quality, thermal comfort, lighting/visual comfort, and the building overall. Although other parings exist, these are the most directly applicable categories when examining the CBE IEQ survey and LEED credits and were used throughout this paper and study as the global themes. Within these categories, a series of paired LEED IEQ credits and CBE questions were developed from the IEQ survey analysis described in 5.2.2 and from recommendations by the focus group described in 2.3 (see also Appendix B and H). These parings provide the linkages between the IEQ survey, focus group, and building assessments. The selected LEED credits are therefore used as our organizing themes and the basic themes emerged from the content analysis of the focus group and building assessments, as well as, who they ultimately tie to survey analysis results.

2.2 IEQ Survey and LEED credit quantitative data analysis

2.2.1 Overview and description of the dataset

This research began with a quantitative analysis of levels of satisfaction found in LEED-certified buildings. The dataset is comprised of office buildings that have completed the LEED certification process (described in Chapter 1 - Introduction) and administered the CBE Occupant Indoor Environmental Quality Survey (described in Chapter 1 - Introduction) within 2 years of the LEED certification. The dataset for this research includes 11,243 survey respondents occupying 93 office buildings found throughout the US and Canada. The buildings were selected because they were primarily office-type activity and comprised the most complete sets of questions asked. Given that buildings may complete their LEED certification months or years after completing the work, buildings which had been surveyed using the CBE tool within 2 years of achieving LEED certification were also included. At the time of this analysis only two buildings certified using LEED version 4 were published by the USGBC, did not have credit level available, and therefore were not included in this dataset. All buildings used in this study have received certification using one of the following products: LEED for New Construction (NC), LEED for Existing Building (EB), and LEED for Commercial Interiors (CI), or, LEED for Existing Building Operations and Maintenance (EBOM). The distribution of buildings by rating, product, and version are all reported in Table 2.1 and 2.2. Table 2.1 provides study statistics at the building level and 2.2 provides statistics at the level of the number of respondents. The distribution of certification levels or rating (Certified, Silver, Gold, and Platinum) for the study buildings are predominantly certified under the higher “Gold” and “Platinum” products. This is disproportionate to the distribution of overall certified projects found in the USGBC project directory (USGBC, 2015). This means that the analyzed sample represent mainly the higher LEED certification levels. Along with

thirty nine newly certified buildings, credit level data was added to this study from the previous studies cited (Altomonte and Schiavon, 2013, Schiavon and Altomonte, 2014). The version used was also tracked with LEED 2, 2.1, and 2009 comprising the largest portion of the data. Table 2.2 provides a complete breakdown of numbers of respondents across the products at the levels of rating and version. If EB and EBOM are combined we see NC buildings have the highest percentage of respondents with EB and CI fairly comparable. With large portions or percentages of respondents in specific version and product combinations, later analysis was grouped to respond to these larger datasets.

Table 2.1 LEED-specific distribution - building level

Product	NC	CI	EB	EBOM	**Total**	USGBC % (US Green Building Council, 2015) as of July 2014
Rating						
Certified	5	4	0	0	9 (9.7%)	24%
Silver	8	6	1	1	16 (17.2%)	32%
Gold	29	7	4	3	44 (47.3%)	32%
Platinum	16	5	4	0	24 (25.8%)	12%
Version						
1.0 (or pilot)	2	5	1	0	8 (9%)	
Canada 1.0	1	2	0	0	3 (3%)	
Canada EBOM	0	0	0	3	3 (3%)	
2.0	15	9	2	0	26 (28%)	
2.1	10	0	0	0	10 (11%)	
2.1/2.2	6	0	0	0	6 (7%)	
2.2	21	0	0	0	21 (22%)	
2008	0	0	1	1	2 (2%)	
2009	3	6	5	0	14 (15%)	
Total	58 (62%)	22 (24%)	9 (10%)	4 (4%)	93 (100%)	

Table 2.2 Distribution of survey respondents in each LEED category

Product	CI	EB	NC	EBOM	**Total**
Rating					
Platinum	291 (10%)	848 (67%)	1186 (22%)	0	2325 (21%)
Gold	1746 (57%)	262 (21%)	3472 (65%)	1194 (75%)	6674 (59%)
Silver	425 (14%)	154 (12%)	524 (10%)	402 (25%)	1505 (13%)
Certified	591 (19%)	0	148 (3%)	0	739 (7%)
Total	3053 (27%)	1264 (11%)	5330 (48%)	1596 (14%)	11243 (100%)
Version					
1, 1.0 Pilot, and Canada 1.0	1602 (52%)	80 (7%)	284 (5%)	0	1966 (17%)
2.0	899 (30%)	164 (13%)	1371 (26%)	0	2434 (22%)
2.0/2.1	0	0	562 (11%)	0	562 (5%)
2.1	0	0	1551 (29%)	0	1551 (14%)
2.2	0	0	1410 (26%)	0	1410 (13%)
Canada EBOM	0	0	0	1123 (70%)	1123 (10%)
2008	0	18	0	473 (30%)	491 (4%)
2009	552 (18%)	1002 (80%)	152 (3%)	0	1706 (15%)
Total	3053 (27%)	1264 (11%)	5330 (48%)	1596 (14%)	11243 (100%)

Table 2.3 summarizes the building-related characteristics of the data set and demonstrates that the majority of buildings are designated as commercial use with the next largest set comprising government use buildings. Additionally 50% of the buildings are in the West of the United States, and located mainly in Cold, Marine and Hot-dry climates.

It is worth noting that all the spaces have been identified as office-related in terms of function. Table 2.4 summarizes the distribution of occupant-related data - the work types for the survey respondents are predominately licensed professional, managerial, and technical, with 23% in enclosed (private) offices. The mix of male and female is relatively even. The age range is predominately 31-50. Finally almost half of the respondents have been in their space for over one year. Of note, the designation of N/A in Table 4 constitutes no response provided by the individual surveyor or the survey itself did not include the question.

Table 2.3 Distribution of building-related data

Criteria	Count
Regional *	West US – 47 (50%) Midwest US – 13 (14%) Northeast US – 12 (13%) South US – 10 (11%) Alberta CA – 4 (5%) Ontario CA – 3 (3%) British Columbia CA – 3 (3%) Pacific US – 1 (1%)
Climate zone **	Cold – 28 (30%) Marine – 25 (26%) Hot-Dry – 18 (20%) Mixed-Humid – 14 (15%) Hot-Humid – 4 (5%) Very Cold – 4 (4%) Mixed-Dry – 0 Subarctic - 0
Space industry	Commercial - 61 (66%) Civic/government - 17 (18%) Education (office) - 15 (16%)

*(US Census Bureau, 2015)
** (US DOE, 2015)

Table 2.4 – Distribution of occupant-related data

	Responses
Office type	
Enclosed (private office)	2592 (23%)
Open space (low and high cubicle, and open)	7,597 (67.5%)
Other	329 (3%)
N/A (not answered)	725 (6.5%)
Spatial Layout	
Cubicles with low partitions	3258 (29%)
Cubicles with high partitions	3143 (28%)
Private office	2592 (23%)
Open with no or few partitions	735 (6.5%)
Shared office	461 (4%)
Other	329 (3%)
N/A	725 (6.5%)
Distance from Window	
Within 4.6 m (15 feet)	7324 (65.1%)
Further than 4.6 m (15 feet)	3011 (26.8%)
No response	908 (8.1%)
Gender	
Female	5221 (46.5%)
Male	3829 (34%)
N/A	2193 (19.5%)
Age	
30 or under	1810 (16.1%)
31-50	4006 (35.6%)
Over 50	2168 (19.3%)
N/A	3259 (29%)
Time in workspace	
Less than 3 months	645 (5.7%)
4 to 6 months	968 (8.6%)
7 to 12 months	1869 (16.6%)
More than 1 year	4942 (44%)
N/A	2819 (25.1%)
Weekly working hours	
10 or less	511 (4.5%)
11-30	1739 (15.5%)
More than 30	7076 (62.9%)
N/A	1917 (17.1%)
Work type	
Professional	2458 (21.9%)
Managerial/Supervisory	1595 (14.2%)
Technical/Professional	1746 (15.5%)
Administrative Support	993 (8.9%)
Administrative	498 (4.5%)
Other	677 (6%)
Staff/student	117 (1%)
Faculty	54 (.4%)
Administrator	15 (0.1%)
N/A	3090 (27.5%)

A subset of 17 of the questions found in the CBE Occupant IEQ Survey database has been used for this study and paper (see Appendix C). The selection was based on the ability to provide consistency, comparability of results, and relevance related to the LEED credits examined. The primary focus was on the survey's main core questions as described in Section 1.3, with brief descriptions of the types of questions found in Table 1 in Section 1.2 and a fuller listing of questions found in Appendix C. Specific to the personal workspace and building overall satisfaction questions, I found they are strongly correlated (see Chapter 3 Results) and therefore used only one, satisfaction with the building overall, to report throughout the majority of the analysis. For the purpose of this study, the CBE modules were organized by: general satisfaction (building and workspace overall), office layout, office furnishings, thermal comfort, air quality, lighting, acoustic quality, cleanliness and maintenance.

2.2.2 Statistical methods

Two main sets of survey data analysis were performed. First, the relationships between survey results and LEED rating, version, product, and total IEQ points achieved were investigated. Next, the relationship between survey results and individual LEED credits achieved were analyzed. The statistical analysis was performed using R software 3.1.2 (R Development Core Team, 2013).

With regard to analyzing the first set –summary statistics were calculated (1^{st}, 2^{nd} – median, 3^{rd} quartile and mean) using satisfaction with the 17 selected CBE survey questions (see Appendix C) and considering the four LEED characteristics (rating, version, product and total IEQ points). The relationship between "satisfaction with the building overall" and the total IEQ points achieved as a function of LEED product and version was investigated.

Also for this first set, the Spearman rank correlation (Rho, r) was used as effect size index to analysis rating level, version and total IEQ points achieved by CBE question (Ferguson, 2009, Schiavon and Altomonte, 2014). Using "Certified" as a base value the difference, percent change, and largest difference of mean values was examined. The mean differences between the three products and provided the range of differences for each of the 17 survey questions used was calculated. Also examined was the difference – calculated by dividing it by the 7 point scale satisfaction. This was used given it comprises the range of possible satisfaction responses (taking 0 or neutral out given answers can move in six levels or directions). The difference analysis provided the groundwork to examine each question at the rating level and allowed for the specific examination of Visual Privacy.

For all tests, the results were considered statistically significant when $p < 0.05$ (that is, the probability that a difference could have arisen by chance was below 5%). There are limitations to using null hypothesis significance testing (NIST) to determine the size or relative impact of the difference between two factors or sample groups. P-values can be influenced by the size of the effect and the size of the sample. For example if the sample size is very large a statistically significant result may be produced but this may be due more to its size than effect. Given the sample sizes for this study, the effect size is a better indicator of statistical significance and provides a more precise foundation for results and conclusions. As with the Schiavon and

Altomonte studies, the Spearman rank coefficient (rho, p) was used to estimate the standardized size of the mean differences in tested values.

The second set of analysis accounted for the individual IEQ credits achieved by each building as part of their LEED certification. For each credit again summary statistics were calculated (1st, 2nd – median, 3rd quartile and mean) for occupant satisfaction and compared with relevant IEQ credit score (from zero – not obtained – to max level of points for the studied credit). This was done only with the most relevant CBE survey questions associated with each credit. CBE expertise and the industry focus group, as described in Section 3.2, provided the insight to determine the relevancy of the study parings (CBE question and LEED IEQ credit). As with the first set of analysis, statistical significance was tested using difference of the mean and Spearman-rho was used as effect size. All the same criteria for testing analysis of the first set applies to this second set.

Finally once the building assessment sites were selected, the open-ended comments offered by the survey respondents in those buildings were analyzed using content analysis. Content analysis and the development of coding were employed to develop themes and patterns of satisfaction by building and provide a more detailed understanding of the patterns of satisfaction or dissatisfaction. The coding method was based, in part, on insights from the Phillip Merrill Environment Center study (Heerwagen and Zagreus, 2005) and the constant comparative method (Patton, 2005). Specifically, the assignments were made using the global themes (identified previously and in Appendix D) and the positive or negative intention of the comment. Number of occurrences of each was also determined. In some cases, the experience of the researchers was applied to determine the intent of the raw comments and special attention was given to the intensity and consistency of comments. For the final step, codes were then distilled into a series of actions possible during the building assessments. A basic code book (Appendix D) was developed summarizing each code word and description of the code, which provides insight into inclusion and exclusion criteria.

2.3 Expert feedback

2.3.1 Overview

Several sources of expert contribution where used to varying degrees for this research. It was important to use knowledge already in the field to bridge the quantitative IEQ survey analysis found in Section 2.2 and the approach and distillation of the building assessments found in Section 3.4. The expert contributions came from; literature reviews of existing research performed and methodologies used, direct conversations with professionals and researchers working in the field, and mostly the an industry-sponsored focus group.

HOK Architects sponsored a half day industry focus group comprised of 19 professionals were selected based on their direct experience developing, educating, or executing the LEED rating tool and their availability for the event day. It is important to note that the focus group discussions were probed for the sole purpose of collecting background information in order to

help us understand the patterns of our quantitative analysis (from previous survey database) and to inform the selection of the study sites. Using an inductive approach to arrive at this understanding, the group was tasked with 3 main objectives, to consider: 1) the relationships between selected IEQ LEED credits and occupant satisfaction questions from the survey, 2) the subsequent building assessments, and 3) the overall outcomes of the study.

For the first objective a portion of the completed occupant survey analysis described in Section 2.2 was used. The group was asked to consider six pairings of selected IEQ LEED credits in relation to corresponding occupant satisfaction questions (described in 2.2.2). Using an amended form of affinity diagramming[1] (originally developed as part of the KJ Technique[2]), groups of the attendees were picked at random (participants were asked to count off to 5 around the table to divide into 5 teams) to work in teams using a series of workout boards, each focused on one of the LEED IEQ credit and survey question pairings (Martin et al., 2012, Goodman et al., 2003). The teams cycled through the boards providing input through initialed post-it notes. There are several justifications to support using our amended approach to affinity diagramming. As discussed earlier, the intention of the focus group was to provide a method of collecting background information to better understand the patterns of the quantitative analysis, and also to inform the selection of study sites; it was not intended to be a systematic or quantitative study of the topic. Second, the *issue development* portion found early in the process of the KJ Technique was already a part of the earlier survey analysis and preliminary results. Therefore, the "in silence" portion of the KJ exercise, intended to lessen the possibility of group pressure, was not necessary in our case and a focus on the next level of affinity diagramming was more logical (Martin et al., 2012). Third, given the practical considerations such as the size of the focus group, the level of moderation, and the nature of how the participants generally work in collaborative teams in their industry, it was felt that a team approach was more effective for our intended use - to assist in tying the other aspects of study together in a triangulated approach.

The second and third objectives of the focus group were to suggest methods for subsequent building assessments, and to give general recommendations regarding what outcomes of the overall study they would find most useful. The participants were assembled together as one full group for these last two objectives. Particular attention was given to effective moderating (e.g., setting ground rules for the session, guiding the conversation rather than dominating it, drawing out quieter participants, maintaining a sense of pacing and variety of topics, using probing

[1] Affinity Diagramming: a process used to externalize and meaningfully cluster observations and insights from research while keeping teams grounded in data. Affinity diagramming helps designers capture research-backed insights, observations, concerns, or requirements on individual sticky notes so that design implication of each can be fully considered on its own. Notes are then clustered based on affinity, which form research-based themes. (Martin et al., 2012)

[2] KJ Technique: a consensus-building exercise that helps teams organize a complicated range of ideas and information. An effective way to externalize all the information that is in everyone's heads, and then organize and prioritize the data in a way that builds group consensus. (Martin et al., 2012)

techniques to encourage others to provide alternative viewpoints, and including a final pass around the table so all participants could provide their views.)

2.3.2 Analysis

Analysis of the focus group discussions began with transcribing the workout boards and the notes from the group interactions. The initials of the participants were initially used to track comments. Content analysis and coding provided the context to develop themes that could tie together the other two main methods (IEQ Survey Analysis and Building Assessments), as well as provide support for the study.

The content analysis began with selection of direct words used by participants (otherwise known as in vivo codes) where used as "keywords". The keywords were then grouped to begin to unify comments (Berg et al., 2004, Patton, 2005). Specifically, assignments of keywords into the common "codes" were determined using the exact word(s) used by the participant, positive or negative intention of the comment, and/or subject topic. In some cases, the experience of the researchers was used to determine the intent of the raw comments and special attention was given to the intensity and consistency of comments. For the final step codes were then distilled into categorical, or global, themes to provide insights for the balance of the study and for integration into the study results (Berg et al., 2004). A basic code book can be found in Appendix D and can be used to provide insight into inclusion and exclusion criteria (Berg et al., 2004, Tracy, 2012). No participant initials were carried through to the final coding and themes. I used them primarily to confirm that comments were fairly evenly distributed among focus group participants and there was no single individual(s) that unfairly dominated the discussion, and to ensure that coding process represented an equal representation of views.

In summary, by utilizing the KJ method the focus group achieved many benefits; specifically, "…the dynamic created by a small group of well-chosen people, when guided by a skilled moderator, can provide deep insight into themes, patterns, and trends." (Krueger, 2009)

2.4 Building assessments

2.4.1 Overview

Building assessments were comprised three direct site studies performed specifically for this thesis work. Given the time limitations of this study, the assessments focused on specifics of performance related to the four categories or global themes of air quality, thermal comfort, lighting/ visual comfort and the building overall. Vischer (2008) provides three recommended elements to the assessment of buildings and occupants, including systematic detailing of the user experience, defining the experience, and defining the built environment (see Appendix E). Some of these were considered in the evaluation. Many of these elements were assessed through interviews and walk-throughs of the sites, and evaluation of the published case studies. The main investigation included examination of both positive and negative aspects including: designed verses built strategies, strategic performance to date, current condition and operations, and occupant-related conditions, impacts, and current levels of satisfaction.

2.4.2 Site selection

The overall objective for the site assessments was to provide some insight into the relationships found in the analysis of occupant satisfaction and LEED characteristics, and a roadmap for future research. Buildings were prioritized for assessment based on 4 levels of review, illustrated in Figure 3.

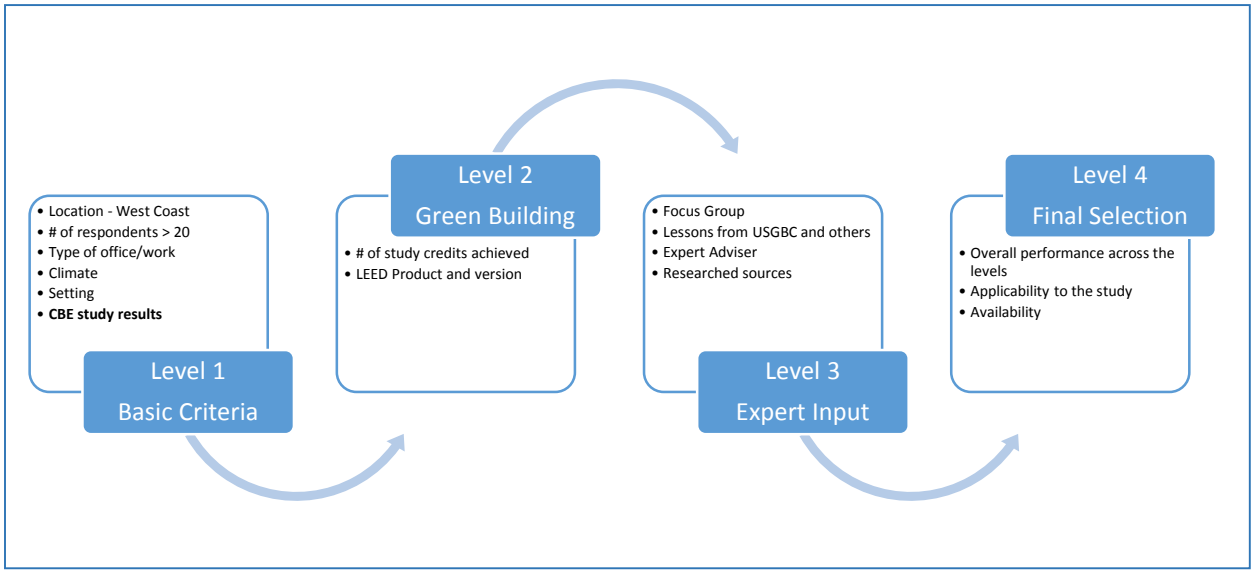


Figure 3 - Direct site assessment: prioritization and selection

Level 1 selection criteria had four different components. Given the pragmatic limitations of this study, the complete list of 93 buildings that had survey data was initially narrowed to those located on the West Coast. It is important to note that an analysis was performed examining the occupant satisfaction levels found in west coast buildings verses the study buildings in the other regions (Appendix F). We determined that west coast buildings, as a group, are representative of the larger study data set. Next, all study buildings were restricted to those whose occupants did not work within the building industry (i.e., architects, building engineers, etc.), and to those having over 20 occupants. Based on our research team experience, 20 or more occupants was determined to provide a large enough sample size and more generalizable results. Next, the percent of satisfaction for each of the 4 study categories was determined for each building within the new subset, and the high, medium, and low performers were identified.

In Level 2 selection criteria, the LEED specifics were used to select buildings - product and version and the mix of credits achieved (see Appendix G). Level 3 "Expert" criteria includes selection recommendations from the focus group, other studies, and industry and leading researchers (see Appendix H). Finally for level 4, a comprehensive consideration of performance across the 3 preceding levels, applicability to this study, and availability for access were utilized to select the final buildings for direct site assessment.

2.4.3 Fieldwork

Three buildings were analyzed to gain an understanding of the 3 LEED products (EB, NC, CI) and the high, medium, and low performers of surveyed occupant satisfaction, and four settings (urban, suburban, industrial) using the four global themes. A second use of the triangulation of methods was employed for these site visits (Berg et al., 2004). Each building was assessed using: interviews, measured and documented site conditions, and observations/walks. Each method is discussed in terms of the 3 phases of activity: pre-visit, visit, and post-visit.

Pre-visit activities included a building documentation/report review (see Appendix I for a listing) and an interview with the designer of record. Gathering this information prior to the visit provided insight into the intention for the project and current conditions, and, most importantly the foundation for a targeted guide for the direct (visit) assessments themselves. An interview guide was developed to maintain focus on the study objectives and adhere to the Committee for Protect of Human Subjects (CPHS) requirements (Appendix J). An introductory email was sent to occupants giving details of the study, including what they could expect for the upcoming visit, and contact information to respond if they would like to participate.

Visit activities were broken into operational and occupant examinations. Specific IEQ LEED credits achieved by the study building were selected as a guide for the field work and were narrowed based on the limited time of this study, the complication of studying a specific credit, and the credit's overall relevance to the post-occupancy evaluation. The operational examination included a walk-through of IEQ-related building systems and equipment strategies (related to the four global themes and interviews with the operators and building management).

Based on the approved CPHS process, all occupants were invited to participate and each participant was required to provide consent before being interviewed. Interviewees were assigned IDs in order of listing from a randomized list generated prior to the visit. No personally identifiable information was knowingly asked or tracked.

Occupant space study included: measurement of same day conditions (CO_2, operative temperature, temperature, RH, light, and glare), observational study (informal walks) of spaces and uses through photographic evidence, and occupant interviews modeled partially from the Phillip Merrill Environmental Study (Heerwagen and Zagreus, 2005). HDR photography was accomplished with a Canon Powershot A570IS Digital Camera with Opteka 52 mm lens using the Photosphere technique (Ward, 2015). Luminance readings were taken using Minolta Luminance Meter LS-100. Hobo data logger U12-012 were deployed for logging temperature, RH, and light over an approximate 2 week period per building. CO2 levels and operative temperature were also tracked for the 2 week period in some locations (depending on pre-visit investigation). Illuminance readings were taken using Minnesota Instruments LX802 light meter. Finally due to specific requests by a building (Urban Performance – see Section 3.3), limited acoustic readings were taken for 2 minute durations in 4 locations during the morning, early afternoon, and late afternoon with the Larson Davis Soundtrack LxT. Also some infrared imaging was performed using the Raytek PM Plus Infrared Gun Model RAYRPM30L3U.

All three aspects of study were tailored around the pre-visit documentation review and what was known about the building at that point. Post-visit activities were based on a distillation of the information collected to date, and included some additional follow up interviews with operations staff.

3. Results

3.1 IEQ Survey

The IEQ survey analysis focused on four aspects of the study buildings' LEED certification: rating, product, version, and individual IEQ credits. Total IEQ points achieved was also used to provide enhanced context to the analysis.

3.1.2 LEED Individual IEQ credits

The comparison of specific CBE survey questions to the most relevant IEQ LEED credits achieved in each building was the most direct way to assess the success of the intended IEQ design strategies. These relationships centered on aspects of indoor air quality, light (access to natural light and views), and thermal comfort with some analysis performed around visual comfort (e.g. glare), visual privacy, noise, and perceived impact on one's ability to get a job done.

The first set of comparisons, or pairings (see Appendix B), were determined using the experience of the research team and based on the direct relevance of one to the other. Furthermore, those initial pairings were used to facilitate much of the industry focus group who, in turn, recommended additional pairings to complete the analysis. All of the resulting graphs can be found in Appendix K. Among the 82 pairings we developed, some have more direct relationships than others, but all are included to provide the most complete picture of the analysis. (Note, graphs in Appendix K that have a relatively low sample size are highlighted in gray).The associated mean values, percent of change in the mean, and p or probability values are provided in the table found below each graph as ΔM, %ΔM, and effect size respectively. The associated mean values, percent of change in mean satisfaction, and p-values are provided in the table found below each graph as ΔM, %ΔM, and the effect size respectively.

Barring a few pairings with small sample sizes, supporting this is Appendix L table in which all pairings have a relatively small difference of means when examining number of respondents of buildings achieving the credit (shown as no point, 1 point, or 2 points) versus having not achieved the credit. All but one of the effect sizes are less than 0.2, therefore achieving the credit does not increase or decrease occupant satisfaction.

We expected to see a different result for a few notable pairings. Research suggests increased ventilation rates can affect specific aspects of worker/occupant performance, therefore, we expected a greater potential for positive satisfaction trends with use of improved ventilation strategies (Sundell et al., 2011). For our study we compared the surveyed satisfactions levels reported with air quality and the credit related to increased ventilation.

Figures 5A and 5B represent the two variations of LEED Credit 2 (Increased Ventilation graph A and Ventilation Effectiveness graph B) found in the majority of versions and product groupings (see Appendix L for full LEED credit groupings). The graphs were selected as a typical example based on our hypothesis that these credits were most likely to create an increase in satisfaction.

For this figure, occupant satisfaction with air quality is plotted versus LEED Credit 2. For Increased Ventilation, it is possible to earn up to 2 points and Ventilation Effectiveness can earn up to 1 point. Referring to the 7-point satisfaction scale, there is a 0.24 difference in mean satisfaction between achieving 0 and 1 point for Increased Ventilation, and a 0.32 difference between achieving 0 and 1 point for Ventilation Effectiveness. The effect size for both is under .20 (.07 and .1 respectively), therefore we concluded that achieving this credit is not related to occupant satisfaction with indoor air quality.

Similar to the reasoning for IEQ Credit 2, another two pairings of note is for Credit 1, Outdoor Air Delivery (Figure 4C) and CO_2 Monitoring (Figure 4D), and the survey question of satisfaction with air quality overall. The patterns are similar to what was found for Credit 2 in Figures 4A and 4B. However, this time for the CO_2 monitoring variation in Figure 4C, there is a reduction of mean vote of 0.59 corresponding to a reduction of 10%. For Outdoor Air Delivery Monitoring in Figure 4D, there is an increase of mean vote of 0.10 corresponding to an increase of 2%. For both, the effect size is less than 0.2, therefore we conclude there is not a significant effect of achieving these points on perceived air quality overall. It is important to consider that the LEED buildings in the "0 point" group have not achieved that specific credit, but are using other IEQ strategies, including pre-requisite requirements, to achieve certification which may also be contributing to occupant perception of air quality. These additional strategies were not considered in this study.

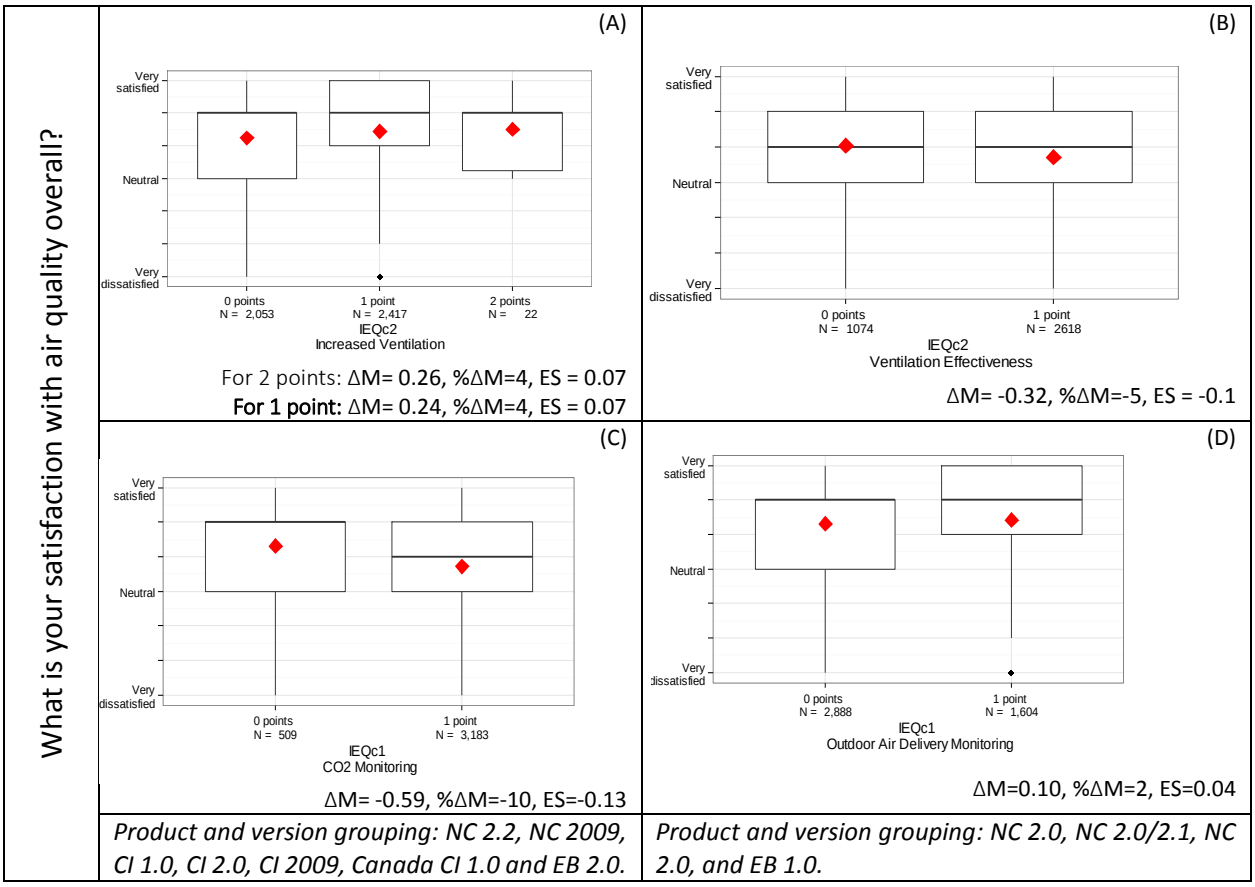


Figure 4 - LEED credit and IEQ survey question pairings

The pairing of credit 3.1 High Performance Green Cleaning Program and the survey question of satisfaction with air quality overall was found to result in a significant increase in satisfaction for LEED Existing Buildings (see Figure 5). For this credit, 1 point can be earned. The difference of the mean values is 1.29 and percentage of change in the mean values is 22%. The effect size is.30, is above .20, and, therefore we concluded there is a positive relationship in satisfaction and this green cleaning-related credit.

The other pairing results provided effect size values below .20 and, therefore not statistically significant relationships can be found for them.

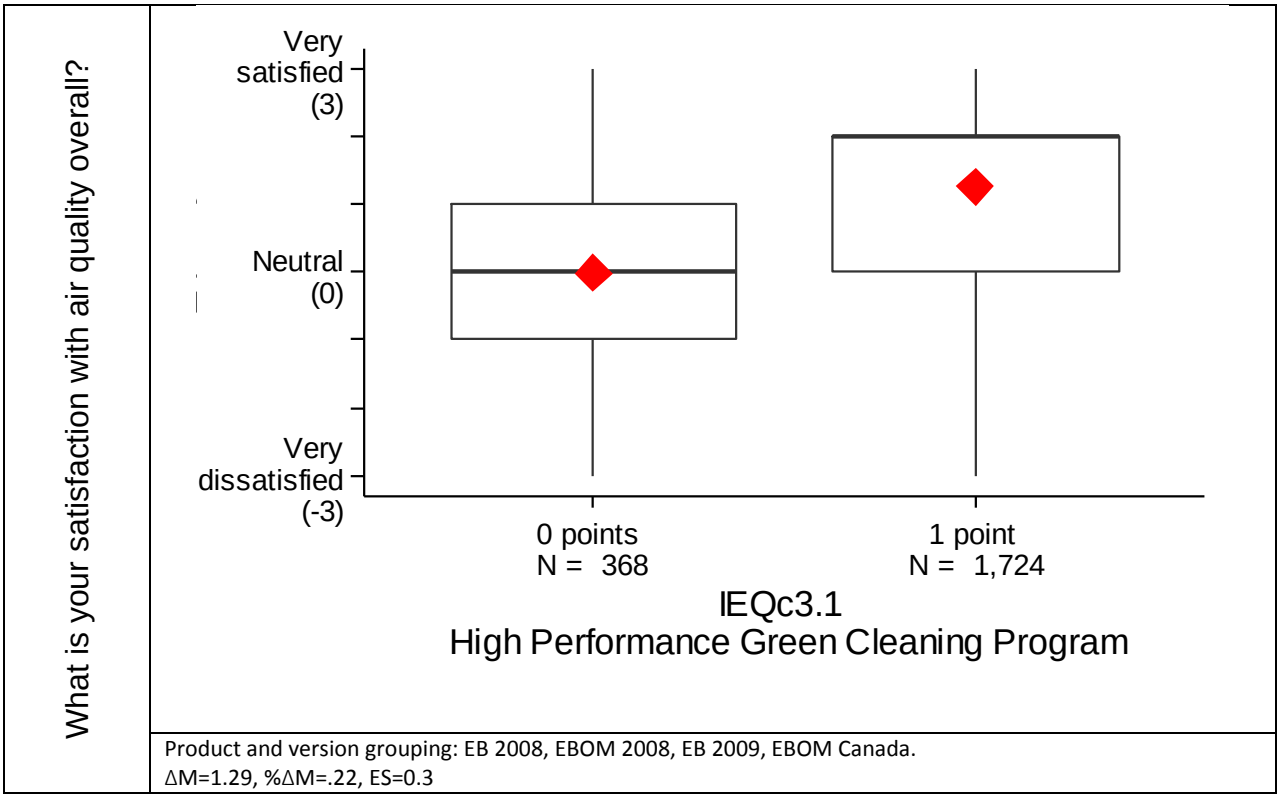


Figure 5 - IEQ credit 3.1 Green Cleaning versus satisfaction with air quality overall

3.1.3 LEED Version, Product and total points

Taking a broader view, variations of LEED product and version used throughout the study buildings were analyzed by comparing total number of IEQ points achieved and satisfaction with the building overall. The building overall was used because it summarizes all the aspects and it is difficult to assign a more specific IEQ satisfaction (e.g. air quality, thermal comfort, etc.) question to general certification aspects of a project (e.g. product, version, etc.) For each graph in Figure 6, total IEQ points achieved on the x axis range from 5 to 15 points – this is due to the low sample size of projects achieving the maximum of 16 points or below 5 points. The level of surveyed satisfaction with the building overall is found on the y axis. The colored lines within the graph are the linear regressions representing the different products or versions, with the gray areas around

the line providing the 95% confidence interval. For versions we used for the majority of study buildings (2, 2.1, 2.2, and 2009). It can be seen in Figure 6B that newer versions may perform slightly better than earlier versions in terms of overall satisfaction. We did not perform statistical testing and effect size calculations and, therefore, we cannot say with confidence if there is an effect. It should also be noted that new versions of LEED were likely being used for newer buildings, and so the age of the building could potentially be a confounding factor. This is more likely the case for LEED-NC, but not necessarily for EB or CI. Since we do not have consistently accurate information about the age of the buildings, or the date when significant renovations took place, this could not be accounted for statistically.

We also see that increasing total IEQ does not increase occupant satisfaction. For product (NC, EB, CI) in Figure 6C, we see some negligible negative and positive trends among the three products analyzed and again there is no significant impact as total points are increased. For CI the slope of the line = 0.07 and the R^2 = 0.01. For NC, the slope of the line = -0.03 and the R^2 = 0.00. For EB, the slope of the line = -0.06 and the R^2= 0.01. This can be seen as the satisfaction for CI certified buildings tends to increase, while the one for NC and EB tends to decrease, which is counter-intuitive and the reasons are unclear. A aggregated analysis of total IEQ points achieved and satisfaction with the building overall in Figure 6A simply confirms the other two analyses – increasing the total IEQ credit points does not have a relationship to occupant satisfaction.

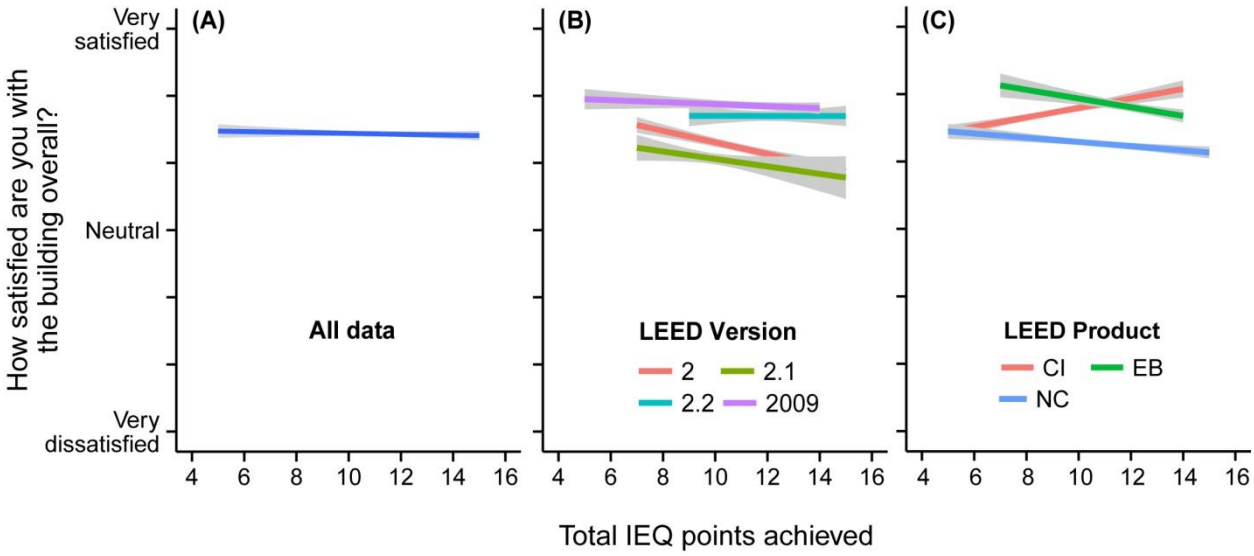


Figure 6 – Occupant satisfaction versus LEED Total IEQ points achieved for (a) all the data; (b) the main versions in the dataset (2, 2.1, 2.2, 2009); and (c) the main products (New Construction, Existing Buildings and Commercial Interiors). The grey lines represent the 95% confidence intervals.

Across the 17 survey questions used in this study (see Appendix C), a table is provided in Appendix M and uses Spearman-rho (effect size) and p values for all combinations of questions about the three LEED characteristics (Note that LEED rating, version, and total points are ordinal values; product is categorical and needs to be examined separately). All the effect size values are less

than 0.2, proving that there is no relationship between the variables. Also provided in Figure 7 is a heat map version of the results found in Appendix M.

Both the Appendix M table and Figure 7 show that increases in total points achieved have no effect on the satisfaction level with individual questions. Satisfaction does improve slightly as new versions are used – this follows Figure 6B and the upward graduation of the different version lines plotted. The graph found in Figure 6C for product follows a similar result to the other two (version and all data). In Appendix N, the differences between satisfaction with the three products was calculated in two different ways. "Difference" refers to the range of difference in satisfaction between the three products, and "Scale Difference" is the "difference" divided by the 7 point scale. The questions addressing visual privacy and sound privacy have the highest values for both "Difference" (68% and 62% respectively across the products) and "Scale Difference" (11% and 10% respectively across the scaled responses). Focusing on visual privacy we see a significant decline in satisfaction with Commercial Interiors projects. A potential argument for this is that in Commercial Interior projects, people's layouts are often changing (private office to open plan) and this could have a significant associated adjustment period.

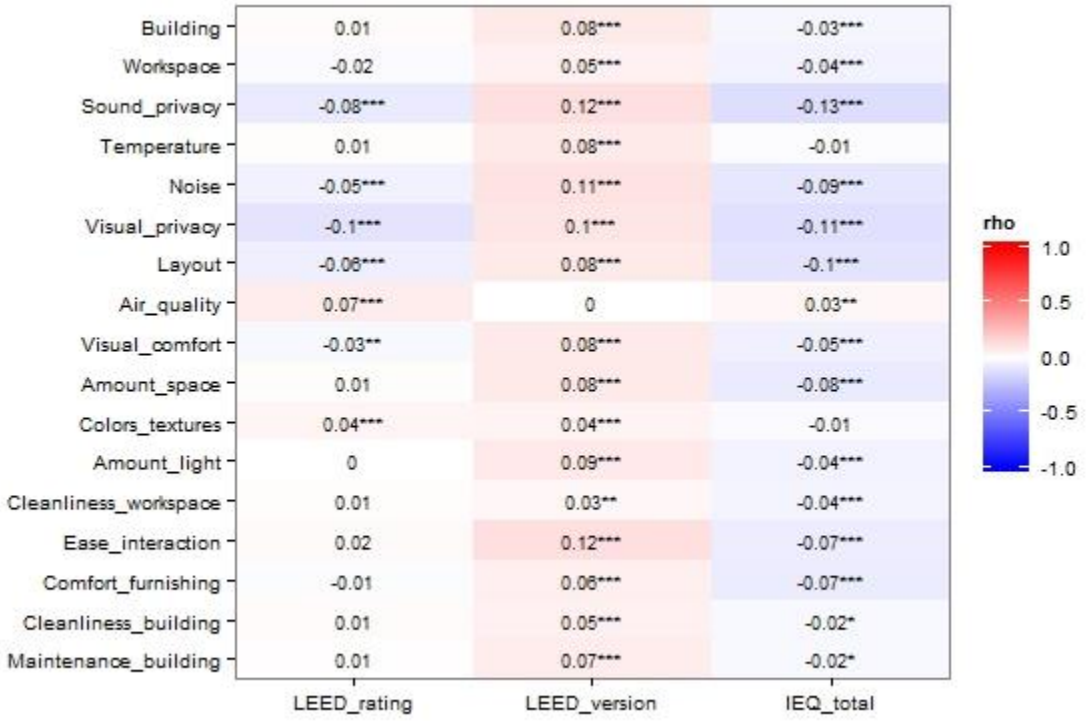


Figure 7 - Heat map of three ordinal value LEED conditions and 17 selected CBE questions

3.1.4 LEED Rating

Rating (Certified, Silver, Gold, and Platinum) is the easiest to understand but at the same time the most removed from the number of IEQ points achieved. The total rating is the result of credits in different areas (sustainable site, energy efficiency, etc.), and it has not changed over the evolution of the LEED program. The analysis is provided to complete the picture of all aspects of

LEED and demonstrate the variation among the survey questions. In Figure 8, the x axis shows the 7-point satisfaction scale and the y axis shows the 17 survey categories. Within the graph, the colored bars represent the 4 rating levels of LEED – each bar shows the full range of satisfaction responses, and the mean and median are represented by a diamond and line, respectively. Sound privacy, temperature, noise, and visual privacy all perform the lowest, as has been the case in the overall survey database for conventional buildings as well (Frontczak et al., 2012) It was surprising to see that mean satisfaction actually decreased for higher levels of rating for some of the survey questions – one explanation could be occupants of higher rated (and potentially more expensive) buildings may have higher expectations for these factors. The three largest variations were for sound privacy (from -.071 for Certified to -.037 for Platinum), noise (from 0.67 for Certified to .27 for Platinum), and visual privacy (from 1.24 for Certified to .36 for Platinum). Only in the case of colors and textures of furnishings did Platinum result in a slightly higher level of satisfaction. A heat map graph is also provided in Appendix O to give the mean level of satisfaction with each question as total points are increased.

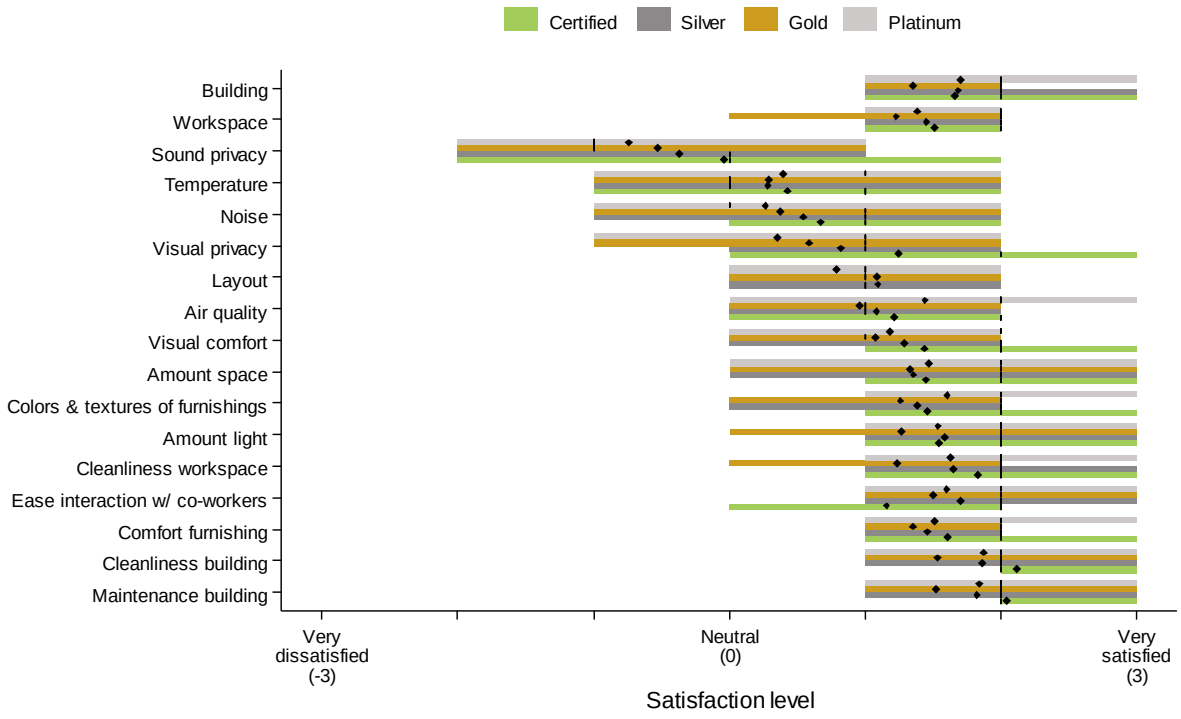


Figure 8 - LEED rating level of satisfaction with 17 selected survey questions

In Appendix P, the table shows the effect size for each of the selected 17 CBE survey questions and the level of LEED certification achieved using "Certified" as a base value. Only for visual privacy, ease of interaction, and sound privacy, the differences are considerably large. Increasing the certification level from Certified to Platinum, the occupant satisfaction with visual privacy was reduced of 0.88 (15%), with sound privacy of 0.67 (11%).

3.1.1 Air quality, thermal comfort, lighting, visual comfort and building overall

Figure 9 provides a heat map showing the mean satisfaction performance of each of the four primary survey categories (y axis), as total IEQ points are increased (x axis). Table 3.1 provides the sample sizes for each total IEQ point level achieved (this can also be used for later graphs analyzing). Total point values of five, fifteen, and sixteen points should be excluded for low sample sizes, but are provided to show the total range of points achieved for the study buildings. Mean satisfaction levels are neutral (white) to positive (green) for all of the categories, with none in the dissatisfied range (red). There is very little change in mean satisfaction levels for each question as points are increased. The question with the lowest level of mean satisfaction is temperature overall. The questions with the highest levels of satisfaction are amount of light and building overall.

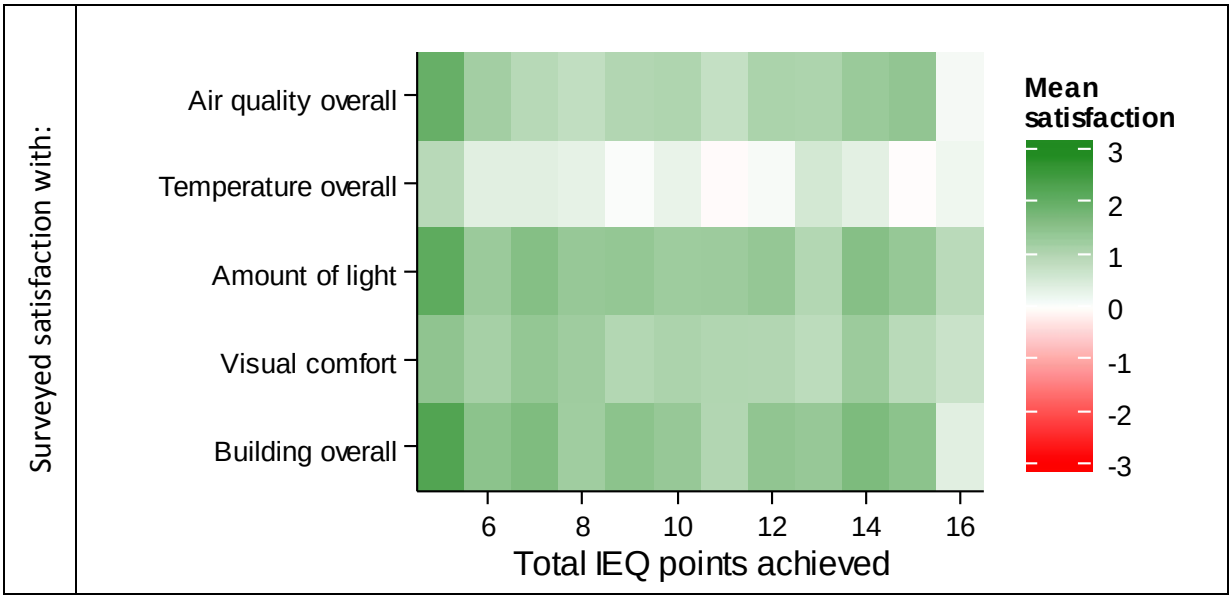


Figure 9 - Heat map of five primary thesis categories (questions) as total points are increased

Table 3.1: Sample sizes for total IEQ points achieved

# of total IEQ points	Number of buildings	Number of respondents
5	4	165
6	3	856
7	12	1537
8	8	916
9	9	746
10	12	2357
11	9	644
12	11	1208
13	9	1679
14	10	910
15	5	207
16	1	18

3.1.5 Buildings assessments

Three buildings were selected for direct site assessment based on criteria described in Section 2.4.2. They are identified as Urban Performance, Suburban Civic, and Industrial Mission. The names given are based on their setting, and the focus of the project that drove the design, such as wanting a building that was high-performing, had a civic function, or was focused on the company's mission.

Their levels of satisfaction across the four global themes are found in Table 3.2. The "Satisfaction" is the percent of occupants satisfied within a given building (above neutral) and the "CBE Percentile" represents where that building falls relative to other buildings in the database, for that satisfaction category. As part of the selection criteria the three buildings represent high, high/medium, and low performance. They will be discussed in more detail in Section 3.3.

Table 3.2 - Mean satisfaction and percentile in CBE database

Global Theme	Study Building	Satisfaction	CBE Percentile
Air Quality	Urban Performance	93%	95%
	Suburban Civic	57%	56%
	Industrial Mission	80%	91%
Thermal Comfort	Urban Performance	60%	85%
	Suburban Civic	27%	23%
	Industrial Mission	43%	51%
Lighting	Urban Performance	90%	89%
	Suburban Civic	63%	28%
	Industrial Mission	75%	76%
Building overall	Urban Performance	87%	87%
	Suburban Civic	55%	30%
	Industrial Mission	83%	78%

3.2 Focus group

The LEED IEQ credits and related survey question pairings discussed in 3.1.1 were used to outline three main questions for the focus group: 1) Why were we seeing little to no relationship in the pairings? 2) What where their specific experiences with the global themes around the questions: air quality, thermal comfort, lighting, and the building overall? 3) How should the study approach the building assessments to learn more? The first question related to pairing results is addressed in Section 3.4 Triangulation of Results. The second question asking for their experience is addressed in the next four sections. The third question can be found in Appendix H summarizing focus group recommendations.

3.2.1 Air quality

Even with indoor air quality standards, codes, and rating systems like LEED, the building industry struggles with many challenges and factors influencing performance in this area. The November 2014 focus group acknowledged that an occupant's ability to detect all types of air quality issues is limited, or to even understand what "satisfaction with air quality" might mean in the survey. Furthermore, over time people can become "desensitized" to associated odors or attribute any physical impacts experienced, like headaches, to other causes. Occupants' perceptions of indoor air may include odors that don't necessarily relate to more impactful health issues (e.g. food odors versus gas leak) and this may be a factor in fully understanding an occupant's surveyed assessment. With no way to tease these apart, focus group members felt it might be more difficult to make associations between the survey response and LEED credits for this are more than the others we have been examining in this study. Although the industry experts felt all potential contaminants are important to consider during design, they also felt contaminants should be prioritized in terms of their potential risk, and the overall design focus should be on aspects like proper air changes to reduce occurrences of sickness or point-in-time contaminations.

Off-the-shelf available technologies related to IEQ performance have struggled to keep up with the demand for green buildings. Specifically for air quality, occupants' perception of air quality and thermal issues are often confused, particularly in occupants' perceptions of draft, and this most frequently comes up in relation to the ventilation system. The discomfort from drafts can be caused by different air distribution strategies (mixing, displacement, UFAD, etc.) and by different HVAC controls (100% recirculated air, mixed air, 100% outside air). From a thermal comfort perspective, when people feel neutral or cool, air velocity and air temperature are the main parameters affecting the risk of draft. Air velocity depends on the total airflow rate and the diffuser selected. Air diffusers should be designed and operate in order to distribute the air as desired at all the possible designed air flow rates, for the purposes of both thermal conditioning and ventilation effectiveness, without creating discomfort (Zhang et al., 2010, Fang et al., 1998, Melikov and Kaczmarczy K, 2012). Inadequate software and sensors are a major issue leading to controls that commonly function far from intended performance. Focus group participants felt that in mid-sized office buildings, "green or innovative" technologies fair far worse as "canned" controls solutions don't mesh well with nonstandard approaches. This condition is supported by

focus group industry experts as well (Rumsey, 2011). The focus group suggested that too much or not enough air movement is a common complaint in the buildings they design, even with ASHRAE industry standards in place. It was offered that current systems don't do an effective job of delivering designed air flow at the room level and the physical locations of vents in a room play a role as the workstation layouts change over time. Even when the balance of air quality, thermal comfort, and energy performance seems to be achieved during the design stage, given the inadequacy of the software and sensors, operators can struggle to keep up with the demands of the buildings – including the occupant's needs within them (see section 4.1). Finally, the group suggested that outside air quality can sometimes be a significant factor in the ability to achieve good indoor air quality, and that this should be carefully considered on a site-by-site basis.

3.2.2 Thermal comfort

Cited as a common occurrence in their projects, occupant complaints about thermal comfort are the primary driver of actions during building operation, much more so than LEED or other design guidelines, standards, standard operating procedures, or proactive examination of systems and conditions. The second most common driver is cost savings related to energy. Neither condition – complaints as a driver for operational actions or the focus on energy savings - necessarily supports good performance or long term occupant satisfaction. And while these drivers are common to all four IEQ categories found in this section, the focus group felt they were most prevalent in thermal comfort-related operations. Very few buildings have a systematic method for handling complaint issues and there is little follow up. Specific to LEED, very few of the buildings the focus group members have been involved with performed the follow-up required in post-occupancy by LEED IEQ credit 7.2, for example. Further, most building's operations staff are not necessarily rewarded for finding better solutions, only for getting complaints resolved by whatever means necessary. This can fuel the long-term, steady decline of many systems.

From a design standpoint, there were two main issues cited – systems flexibility and controllability, as also discussed above in air quality section 3.2.1. Specifically, these comments referred to the components available in the market that are affordable for clients, and the proprietary and complex nature of building management systems. With these limitations, participants felt that it is very challenging to produce an optimized design that can meet the long-term energy performance and occupant thermal comfort goals that are the focus of building owners.

Finally, the group felt that occupants have little tolerance for the time it takes for their own body temperature to modulate upon entering the building or after activity. Additionally, many of the passive designs re-emerging in the green building industry require occupants give some time for the building to reach desired temperature and that they engage the building's features directly. Although we know occupants actually can prefer some variability in thermal conditions, the group's feeling was that generally occupants have little tolerance for minor ranges in temperature and become complacent in the building's operation.

3.2.3 Lighting and visual comfort

The dynamic nature of offices plays a heavy role in the long-term distribution of, and satisfaction with, light. Designing for flexibility is a main goal as individuals, workgroups, departments, and entire companies change layout configurations. It is not always possible to foresee and design for all possible conditions.

Technically, a good lighting design hinges on many nuanced factors. As found during commissioning, advanced lighting systems can have glitches in their algorithms. Although many are caught during installation, some persist and can worsen with improper operational amendments to "make something work for now". Also a technical issue directly related to achieving credits is the foot candle measurement used in LEED lighting; the focus group seemed to be in agreement that it is not a useful measure for achieving true light quality and levels. More specifically, it does not ensure light will get back into spaces (as is the main objective of LEED credit 8) or provide overall light quality critical to occupant satisfaction.

Designed elements, such as blinds, can play a significant role with satisfaction given its function to address frequent problems with glare; however, it was felt by the group LEED doesn't address this sufficiently (see section 4.1.2). Further they felt humans have an inclination to either leave shades or blinds in one position, therefore contributing to the challenge. Automated shade technology (exterior and interior) were cited as cost prohibitive for most clients, even with glare being a number one issue for some projects.

Finally, the site and possibilities for building orientation play a huge role in both lighting strategies and views. This is something that is somewhat prescribed for projects with pre-selected sites.

3.2.4 Building overall

There are common themes among the different IEQ categories that relate to the building overall: availability, flexibility, and affordability of off-the-shelf technologies; the occupant's role; the technical proficiency and focus of operations staff; the dynamic nature of companies; and limited adaptability of buildings in general.

The group felt that the building automation or management system can play a major role in occupant satisfaction and building performance but, many times, is designed and/or operated to be complicated, proprietary, and rarely works like the as-modeled design (see section 4.1). Enhanced commissioning is a way to mitigate some of these issues but is also rarely enlisted because of cost and inability for the building's design or operations teams to relate the effort to factors of satisfaction, performance, cost savings, and even productivity. Engaging facilities from design to operation and including designers in post-occupant evaluations are important goals for the building industry.

Finally, changing workplace demographics and specifically the age and gender of occupants was cited as a factor in occupants' overall satisfaction with the building. It was felt that discussing how LEED contributes to overall satisfaction with the building may be too diluted a comparison, given all the factors that can affect people's perceptions and impressions.

3.3 Building assessments

Three case study buildings were selected for site assessment as seen here in Figure 10:

			
Square feet: *Climate:* *LEED:*	*13,675* *Marine* *EB v4*	*13,600* *Hot Dry* *NC 2.1*	*74,500* *Marine* *CI 2009*
Setting: Project focus: Satisfaction: Space:	Urban Performance High 5% private, 95% open	Suburban Civic Low 50% private, 50% open	Industrial Mission/Employee Medium to high 10% private, 90% open

Figure 10 - Three assessed study buildings (Note selection criteria found in Chapter 2 - Methods)

The assessments of these buildings produced the detailed case studies in Appendix Q, which provide important information to understand the differences between the credits used, the approach to the building's design and operations, and a more in depth understanding of the occupants and their experience. The case studies are set up to comprehensively report method (interviews, measurements, and observations and walks) and specific LEED credit information. For all three buildings we observed behaviors of the occupants and their interaction with aspects of the building. The walks were formal (walk-throughs with operations staff) and informal (as we were taking measurements or observing behaviors) and were intended to uncover if the LEED-related strategies were installed as designed and how they were functioning. The collective findings from these three assessments are discussed here in relation to the four categories used throughout the study and paper (air quality, thermal comfort, lighting/visual comfort, and building overall).

Each building achieved slightly different LEED IEQ credits given the product and version used at the time. Specific LEED credits selected as a guide for the field studies were distributed among the four categories and were selected based on: the limited time frame of this study, the level of complication to study a given credit, and the credit's overall relevance to post-occupancy evaluation. The following sections will provide results related to each building. It is also worth noting all three building's technical operations are contracted out with only basic preventative maintenance functions being performed by a regular technician. The Industrial Mission building recently hired a contractor to update, streamline and train the property management staff on use and optimization of the building management system. None of the buildings reported having

dedicated policies in place or training programs to support green strategies with the occupants. Two of the buildings actively promoted support of green features by occupants and visitors. The Industrial Mission building includes a 20-minute tour and talk about the building as part of their new hire orientation, as well as a reference section about the building on their shared, internal company website.

3.3.1 Air quality

Only interviews (designer, operations, and occupants) and walking verification of associated strategies where enlisted for air quality. Together with the fact that IAQ testing can be complex and too time intensive for the scope of this study, measurements did not seem warranted based on our study approaches using the survey result information and the pre-assessment reviews of project and site documentation. The air-quality LEED credits used for this study deal with outside air delivery/CO_2 monitoring, increased ventilation/ventilation effectiveness, and indoor chemical and pollutant source control.

Designer interviews: the designers all felt IAQ was an important part of their building's design, but for different reasons. The setting was a key driver for all, such as aspects of carbon and exhaust in the urban environment, industrial/chemical emissions in the industrial environment, and allowing for maximum use of outside air in the hot/dry climate of the suburban environment. For the Industrial Mission building the designer was tasked with making the company's mission and high standard for its food products a priority, therefore she felt testing areas needed to have as high an IAQ as possible to allow for proper R&D lab conditions and taste testing. The designer for the Urban Performance building felt the bagging of HVAC equipment during the construction was a particularly effective LEED requirement as it led to a greater chance of occupant's first impressions of the building to be positive.

Occupant interviews: Across the three buildings there were a range of interview responses from positive to negative with most falling in neutral to positive response. One building demonstrated the importance of past events in an occupant's perception. The Industrial Mission building had a gas line leak two years earlier; even though the issue was resolved, occupants still remembered it and cited it during the interview. Also at the Industrial Mission building, hot and stuffy conditions were cited in telephone and conference rooms, but the use of plants and atriums was viewed as very positive. Another occupant interview for the Suburban Civic building revealed the interviewee's concern about the number of increasing upper respiratory issues her fellow employees had over the last year; but she also acknowledged that she felt it was due to general allergies and pollen, rather than a problem with the building. One interesting outcome of the study itself is the heightened awareness and participation of occupants that can occur due to study activities and overall re-engagement of occupants about their building. Yet another occupant of the Suburban Civic building said that, since he saw the study activity, he was using the ceiling fans more. The occupants of both buildings achieving the LEED ventilation credit 2 expressed more issues with air from vents being "too drafty" and affecting their thermal comfort. The potential confusion occupants have about perceived air quality (which should be directly

related to credit 2), and air movement, was discussed previously in Section 3.2.1. Occupants who did have access to windows cited being highly satisfied with being able to access “fresh air” and provide relief from thermal discomfort.

Operations interviews: Generally, for all three buildings, operations personnel described their satisfaction with air quality as “neutral” or “positive”. There were a few specific issues across the buildings. A pervasive issue in the Urban Civic building of sewer smells in the downstairs women’s restroom was mentioned both in the IEQ Survey responses and during the interviews. Interestingly, during the walkthrough, it was found they had a standard trap installed for the main floor drain with no drip system to keep the trap full, which would have prevented the smell entering the restroom from the main sewer line. Although it is a standard installation and is commonly part of regular maintenance to manually fill the traps, the building management is male and therefore are not directly experiencing the smells, so they do not know when water needs to manually be added to the drain unless notified by a female occupant. The female occupants shared they were tired of reporting it because it doesn’t seem to get fixed. Another issue described by operations personnel in both buildings with operable windows was a perception that lack of occupant use of the windows was a factor in IAQ and thermal comfort. For the Suburban Civic building, an advanced window notification system was installed but operations felt it was being ignored. All three buildings cited they had regular contracted cleaning services and monitored general cleanliness and their performance.

Observations and walks: During observations and walks, we found all LEED strategies related to IAQ were in place as reported. Building management system data for two of the buildings was ultimately not available to the study, and associated alarms and CO_2 levels that can be reported by those systems were not able to be varied. However, documentation from the mechanical design engineers verified strategies used and some commissioning reports verified installation and operation of mechanical equipment and performance. Occupants did not appear to be reacting to the window indicator lights at the Suburban Civic building when deciding to either open or close windows. Cleaning products in use at the Industrial Mission building were organically based. All buildings appeared clean and relatively dust-free – even the building with a dogs-at-work program. Areas around supply registers were clean. No air velocity issues that one might be able to observe were noticed (e.g. blown papers, many paper weights, etc.)

3.3.2 Thermal comfort

Interviews, observations and walks, and measurements were taken to study thermal comfort in all three buildings. The LEED credits used as a reference in this category include: *6.1 and 6.2 Controllability of Systems, Perimeter and Non-Perimeter Spaces, 6.1 Controllability of Systems for Thermal Comfort, 7.2 Thermal Comfort Design, and 7.2 Thermal Comfort Permanent Monitoring Systems*.

Designer interviews: The discussion of thermal opportunities and challenges varied, given the location and whether it was an existing building renovation or new construction. For example, although the Suburban Civic was new construction and therefore less complicated to design from

scratch, it had more challenges in using innovative passive technologies given its hot/dry climate. The Industrial Mission building was an existing building with in-place HVAC systems that the client did not want to replace and, therefore, had to be designed around. The goal of the Urban Performance building focused on providing an example of how to best design for new systems in an existing building with a relatively limited budget.

Particularly relevant to thermal comfort was the ownership status of the building and existing equipment. The Industrial Mission building is leased and had existing equipment that was cost prohibitive to replace and the lessor discouraged them to change it significantly. Only the conditioning zoning was somewhat flexible. Although she didn't offer specifics, the designer of this building also shared she would have liked to have been allowed to incorporate major envelope improvements, but these were also not permitted by the lessor. To mitigate the impacts of the existing envelope, she pulled the workstations away from the walls to increase access to shared light and, more importantly, provide a gap between occupants and the thermal mass of the walls. In the Urban Performance building, performance was a key driver for the design, but the building had to be built to the cost of a "standard" building, so the designer had to find "simple, elegant solutions". This designer said that in balancing comfort, cost, and performance, they didn't feel they achieved the highest comfort possible, but did meet the LEED standards and managed to provide relatively good thermal comfort. He felt that, in general, the architect must be closely involved and supportive of the mechanical engineer to fully integrate thermal systems into the design. Specifically, it was important that the architectural design support the elements needed to achieve distribution of conditioned air near the windows to provide good thermal comfort. For this project, the designer felt that careful integration of lighting and HVAC systems design (e.g. mechanically operated skylight locations) heightened benefits in terms of stack effect and reduction of heat gain. However, the client's needs to subsequently change use and layout of spaces has made meeting the thermal demand of certain areas more challenging. For the Suburban Civic building, the designer offered that there was a heightened tension between the daylighting aspect of the design (discussed in Section 3.3.3) and thermal comfort. His building has an east/west exposure and significant possibility for heat gain and glare. He felt that the occupants' lack of engagement with the operable windows (and associated indicator system) and the ceiling fans adds to the lower satisfaction. Finally he felt they pushed innovation by deciding not to use traditional air conditioning in a hot/dry climate and instead used an indirect/direct evaporative cooling system with 100% outside air and a recirculating high efficiency furnace. He offered that he felt it was great from an air quality standpoint by not always from a thermal comfort standpoint.

Operations interviews: All three buildings management representatives (operations) reported varying degrees of challenges with the building management systems related to thermal comfort, including: associated contractors not preforming and providing trend data, missing critical updates, and very slow overall systems due to alterations in programming and settings and outdated hardware. All three were impacted by these system challenges in terms of providing thermal comfort and were required to "strongly discourage" occupant control of thermostats. In

terms of zoning, all three also used words like “microclimates” and “pockets” to describe the challenges they feel they have with spaces throughout the building. They expressed to varying degrees that their buildings lacked an on-site person with a thorough technical understanding of the systems and strategies in place. This was attributed to the size and needs of the building, the cost of dedicated technical staff, and for one building a lack of understanding by financial decision makers. Management spoke about coping mechanisms (and challenges) for dealing with thermal comfort problems. The Industrial Mission and Urban Performance buildings both had unwritten policies prohibiting the use of floor heaters. The Suburban Civic building management resorts to using temporary measures, like cardboard on windows to help with heat gain and glare and manually shutting off valves. He also shared that the perimeter and non-perimeter spaces in the building varied greatly in terms of occupant thermal comfort and there were six to seven heaters currently in use by occupants while ceiling fans remain generally unused. In terms of fenestration, both the Suburban Civic and Urban Performance management expressed concern with occupant’s infrequent opening of windows, feeling that was detrimental to supporting better thermal comfort, and also with the length of time the main entry accessible doors remained open. The facilities manager of the Urban Performance building proactivity encouraged clothing adaptation (although based on observations, it appeared that occupants were doing this at all three buildings). He also felt the off-the-shelf technology used to achieve the energy performance they were after (e.g. thermafusers and package units), although not perfect, had contributed to achieving relatively good thermal comfort and energy performance. Boardrooms and conference rooms posed particular issues for the Urban Performance and Industrial Mission buildings, while the demand control strategy used at the Suburban Civic building was reported to have helped alleviate potential issues there.

Occupant interviews: Thermal comfort received the lowest ranking among all occupants interviewed in the three buildings, with responses typically ranging from “neutral” to “negative”. Occupants of all three buildings were discouraged from using thermostats directly. Many discussed the need to dress in layers, although occupants of the Industrial Mission location used positive language to describe the need to layer seeing it as “contributing to the building and larger planet”. To varying degrees, all the buildings’ occupants reported either hot or cold temperatures during specific times of the year or times during the day. Several of the interviewees at the Suburban Civic location discussed the difference between two distinct areas

found on the 2nd floor we will call the “hot” and “cold” suites. People felt that on the same day at the same time the two suites would experience extreme differences in temperature and comfort. Finally for occupants of the two buildings with operable windows, the majority interviewed said they did not open the window because it was a shared element and they didn’t feel they should change if for others, or that it was part of someone else’s specific workspace, or it was inaccessible to them. However for the occupants with access, they were highly satisfied with being able to access “fresh air” and change thermal conditions when needed. The Suburban Civic building’s window notification system (i.e., an “open window” light), was being ignored by all interviewees. Most said they just didn’t notice it anymore or they felt it inaccurately reflected the conditions (see Figure 11 – green lit “open window” light).

Figure 11 - "open window" indicator light – Suburban Civic building

Observations and walks: For the Industrial Mission building, as per the intentions described in the designer’s interview the layout provided a walkway between occupants and the exterior thermal mass walls. This building also has several rooms of glass punctuated throughout the building and a wide open (unshaded) glass wall at the northeast front façade. Although these spaces were commented on by the interviewees as important to their “connection to the outside”, the measurements discussed in the next section showed they can experience significant elevations in operative temperature during parts of the day. Having spent some time directly looking at the Suburban Civic building management system, there were significant issues with performing relatively simple diagnostic actions (e.g. adjusting set points and reading and clearing alarms, etc.), trending capabilities, and apparent re-programming of the system. All of these conditions have appeared to contribute to a significant increase in processing and response time. This building also had potential evidence of moisture issues with bubbled and swollen “seed” countertop material throughout the building. Only one building, the Industrial Mission, could provide trends. The Urban Performance building management thought trending was happening when it wasn’t. In the Suburban Civic building, during our walk we discovered the mechanical sky light in the “hot” suite was broken and appeared to not have been operating for some time. All buildings’ occupants were observed to dress in layers and change layering throughout the day.

Window operation didn't vary much across the relatively mild temperature days we conducted site visit. Two of the three buildings were required to make formal corrective action plans if occupant surveyed thermal satisfaction levels were below 80% (as found in LEED credit 7.2.) One building said they didn't think there was any follow up required from the survey or LEED post-occupancy. All LEED strategies related to thermal comfort were found to be in place, but operation varied as described above.

Measurements: The Urban Performance building average temperature was 71°F for the two-week study period and fell directly within the set point target. Operative temperature performed very similarly and followed the designer's theory about providing conditioned air distribution near the windows to more evenly distribute temperature. The greatest difference between zones was 3.5°F and, although just a one-time measurement, did not support the occupant's and operator's description of "pockets" within the building. The Suburban Civic building average temperature was also within the target set point at 71°F. High and low temperatures reached some extremes over the two-week study period at 81°F and 63°F, respectively, during logging of temperatures over operating and non-operating hours. Operative temperatures reached relatively high points at 85°F, supporting occupant's assessment of "pockets" in the building. Average relative humidity was 46% percent, however reached a high of 68% percent and a low of 28% percent during this wintertime testing; it's likely that the building could see even greater extremes of high temperature and humidity conditions in the summer, as described by occupants during the interviews. Further study of the readings and durations of temperature and relative humidity conditions would need to be performed throughout the seasons to make a definitive determination. Finally the Industrial Mission building experienced similar temperatures as the Suburban Civic in the main work areas, but were very different in the two all-glass conference rooms sharing a glass wall with an exterior atrium. These areas reached over 110°F during the spot measurements. Although the operative temperature readings were over 10 degrees less, they were still high and could be a significant contributing factor to the "microclimates" cited by operations and occupants. It is important to note as part of the specific report to the building it will be advised they retake these readings, as it seems implausible to reach such levels. We did

observe that even with very heavy use of the other conference rooms, these atrium-adjacent rooms were used mainly in the morning when temperatures were lower (See Figure 12).

Figure 12 - Conference room/atrium example - Urban Mission building

3.3.3 Lighting and visual comfort

Interviews, observations/walks, and measurements were taken to study lighting and visual comfort in all three buildings. The LEED credits used in this category include: 6.1 *Controllability of Systems, Lighting, 6.1 Controllability of Systems, Perimeter Spaces, Credit 6.2 Controllability of Systems, Non-Perimeter, Credit 8.1 Daylight and Views – daylight 75% of spaces, Credit 8.1 Daylight and View - daylight, and Credit 8.2 Daylight and Views – views of 90% of spaces.*

Designer interviews: All three designers said the strategies for daylighting and views were likely among the most positive in terms of occupant satisfaction, but that they also had to address one of the most challenging satisfaction issues – glare. The Urban Performance building was designed for low ambient light levels, mainly to be supplied by natural light, with task lights as a primary source. Existing skylights were expanded and reworked to provide overhead lighting – their design was based on past projects and historical knowledge of the design team (no modeling or light study was done). Although open on three sides, the existing building had virtually no windows. The new owners negotiated an easement on the east side of the building to prevent another structure to be built on the adjacent empty lot, which would potentially block daylight and views. This left all three of the open sides available to use large-scale windows and a generous window-to-wall ratio. In terms of skylight placement, an integrated system was used to design the daylighting, lighting, and HVAC systems to take advantage of things like stack effect (e.g. mechanically-operated skylights). Finally, the color and selection of the furnishings was an intentional effort related to lighting, views and overall livability and a 2nd architect was used to complete the selections. For the Suburban Civic building, the designer shared that the lighting and mechanical strategies were not as integrated or were “designs in tension”. Challenging east/west exposures were mitigated using exterior shades and interior blinds and light shelves. The designer also shared that the interior blind specifications have since been rethought for a

subsequent projects due to the performance reported by the building and its ineffectiveness to mitigate glare issues. In the Industrial Mission building, the designer said that lighting was a particularly challenging and "fun" aspect of the design. The building was originally three massive crane bays and the high saw tooth windows ran opposite of the desired orientation. Blinds are installed everywhere but the front, southeast-facing expansive window wall. She described how they looked at using skylights as a way to help with mitigating the "individual, tiny cubicle feel". Her big take away for lighting is that the blinds rarely get operated and automated blinds were cut from the budget – in hindsight she would have worked with the owners to find the budget for this feature. Although Under LEED 2009 used for this building 4 options are offered to meet the credit. Under "Simulation" option 1 the incorporation of view-preserving automated shades for glare control are required. This building used "Measurement" option 3 that only provides for daylight redirection and/or glare control devices to avoid high contrast situations and not specifically automated ones.

Operations interviews: All three operations personnel felt that, other than glare issues, lighting and views are the most liked and least complained about features of their buildings. All felt that there once lights were on during the day, the occupants rarely operated them (i.e., they wouldn't turn them off in high natural light conditions), and most people contacted the building manager to request changes in lights, given they were commonly shared. For the Urban Performance building, lighting is the most liked aspect of the building by occupants, and by visitors on tours. Although designed for low levels of general overhead light, with task lights available to each occupant, many occupants just work from the light of their computer screens and don't use the task lighting. The size of the windows was thought to be a significant contributing factor to the high occupant satisfaction with views, even though the views were simply of surrounding buildings. The operations personnel also felt that a good portion of the views were nicely framed by trees owned by neighboring property; when the neighbors were starting to cut them down, the building team negotiated for their neighbor to leave them in place. Bird strikes were mentioned as the only issue with the large windows given their size and low interior light levels. Site orientation was helpful in maximizing light levels and minimizing glare, however, they did add opaque blinds to strategic locations based on occupant complaints and they were being deployed. In the Suburban Civic building, the lighting is on a master on/off timer with occupancy sensors and on/off switches in individual spaces – other than lamps that burn out, the operations manager got very little complaints, with most feedback being positive. It was felt that the blinds are inadequate and people were not using them properly. The larger blinds were also becoming difficult to operate. The building manager for the Industrial Civic building said that although occupants generally don't change the artificial light during the day, everyone is happy because "everyone has a window".

Occupant interviews: Across all the interviews, occupants felt that this was the highest rated aspect of IEQ of the buildings and the most improved from buildings they occupied in the past, and they were almost unanimously positive overall. Glare was the only issue cited as a negative aspect related to lighting and views. In the Urban Performance building, occupants expressed concern with glare at the windows and main skylight, but to a much lesser degree than indicated in the survey. Added blinds have provided relief for affected occupants. Views of trees and sky

were cited as extremely positive by occupants. Artificial lighting was seen as somewhat inadequate by a few interviewees; however, interestingly, most said they do not use their task light. Lighting in the center 1st floor boardroom was a problem during most of the day. This is the only building where several of the occupants cited the materials, furnishings and color selections as having an overall impact on the comfort. At the Suburban Civic building, one interviewee said the lighting was annoying because they all came on together and other said that the lighting is tricky because it's sometimes "out" or not working properly, especially in conference rooms (scene controllers). The daylight was determined by all interviewees as excellent and very positive except for incidences of glare. The most common comment was that the blinds were inadequate and difficult to operate. The Industrial Mission building interviewees were the most positive about all aspects related to daylight and view, including comments like: the natural light is beautiful, I feel "connected" in the space, the space allows for us to be more "communal", the sounds of activity make me feel part of the work and culture, and we have a "shared community" in every way. Even though the interviewees said what is viewed directly through windows is not always pleasant, the size of the windows, view of the sky, and the dynamic street outside make it positive. Some interviewees reported "spot" occurrences of glare where they had to wear hats or sunglasses – the "roving sombrero" was part of the common culture. Most expressed an appreciation of the relationship to their culture and bringing the "outdoors in" through the atriums and many windows.

Observations and walks: All buildings had the LEED strategies in place and generally operational. All windows appeared to be clean. Task lighting was provided by all three buildings. For the Urban Performance building, little of the furniture-integrated task lighting was in use during this wintertime investigation and a few occupants had brought in their own fixtures. Select occupants changed the position of blinds during the time of our visits, mainly in areas with high light readings or in areas that had a high potential for glare. In Suburban Civic building, the operation of some of the larger blinds was poor, and wear was starting to show. More task lighting was in use in this building than the other two. Finally, for the Industrial Civic building, slices of direct sunlight were observed throughout the day and at different locations, see Figure 13. It was observed that only a few occupants controlled the overhead lights, and these lights were changed (on and off) in only a few areas throughout the day. Only blinds in the mezzanine area (windows directly adjacent to the desks) were changed.

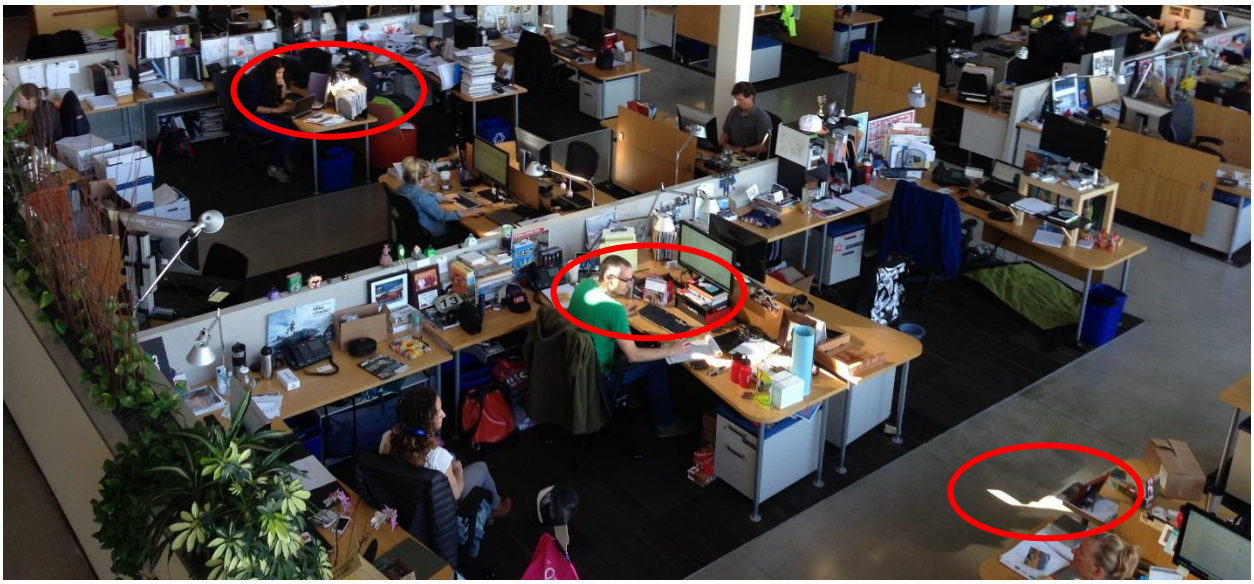


Figure 13 - Example glare spots - Industrial Mission building

Measurements: In the Urban Performance building, average foot candle readings at the desk top was 38 fc in the morning and 25 fc in the afternoon – this falls within acceptable OHSA standards. High contrast ratios (over 40:1) were measured for one office in the morning and afternoon and a large conference room in the morning (Occupational Health and Safety Administration, 1996, Ubbelohde, 2015). Average morning and afternoon light levels for the Industrial Mission building were also with standards as 25 and 28 fc, respectively. In the morning, three of 17 contrast ratio readings were above the 40:1 ratio and for the afternoon, one of 16 readings were above. The Suburban Civic building had the highest number of glare-related comments - average desktop readings were also within standards at 29 fc in the morning and 34 fc in the afternoon. In three out of 16 morning workstation readings, the contrast ratios were above the 40:1 acceptable ratio (with shades in the occupant's preferred deployment). There were a bank of offices with direct west-facing windows (on both the lower and upper levels) that had late afternoon readings far above the ratio with shades up (not deployed). However Figure 14 HDR photography provides addition verification of conditions in an upper level complainant's office. The left side provides images with blinds down (deployed) and the right side with blinds up (not deployed). Focusing on the desktop, glare is greatly reduced using the specified blinds. A second complaint on the lower level west side was also studied with similar results. During one of our walks, the research team noticed one additional west side workstation in which an occupant not part of the original complainants was using a poster board to block direct sun (see Figure 17). Again focusing on the desktop, end of work day HDR photos for this workstation provided in Figure 15 demonstrate greater evidence of glare than the other two, even with the blinds deployed. More thorough measurements were taken in these three specific west-facing offices as well. Contrast ratios for those areas far exceeded acceptable standards with the blinds up, and were much closer but still above standards with the blinds deployed. However for all these cases it is important to consider this condition exist primarily during one season (winter) and during the last 40 minutes of the standard work day.

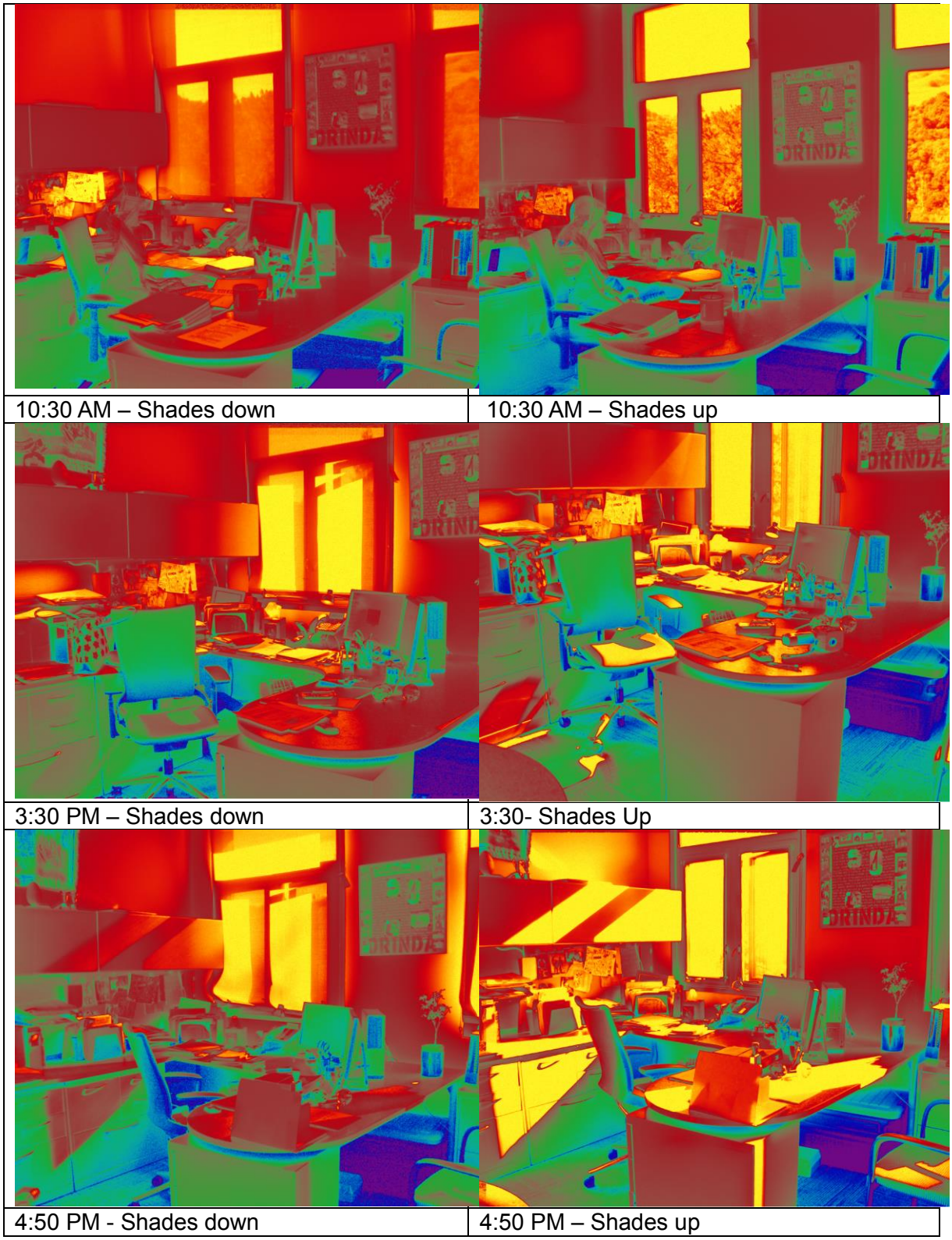
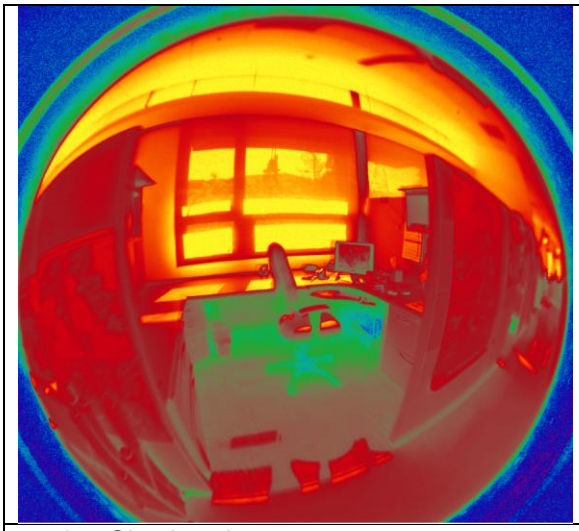


Figure 14 Complaint glare study: west-facing office #2 - Suburban Civic building



4:40 – Shades down	4:40 Shades up

Figure 15 - Added office glare study: west-facing office #3 - Suburban Civic building

3.3.4 Building overall

For this section, it is best to talk about each building in general rather than by the study methods, as used for the previous sections. All buildings had issues with the building automation systems, a lack of usable manuals and reference material, and no trending to proactively manage IEQ conditions and overall satisfaction. Building managers also had only an informal understanding of the status of occupant satisfaction and at times were out of sync with issues that were raised by the occupants in the surveys or interviews. None of the buildings kept complaint logs to better understand these issues related to a specific area of the building, individual, or time of day standpoint. In general, across the buildings, occupants expressed a pride regarding their green building and personal satisfaction with working in one.

Urban Performance – During interviews, the occupants were highly satisfied with the building as a whole. Their highest rated category was (natural) light and the lowest thermal comfort. The core intention of its design as a highly-performing, demonstration building is evident in many of the observed and measured aspects, as well as the occupant interviews. All occupant interviewees said their current building was better than their previous buildings they had worked in. The opportunity to completely start from scratch with all relevant systems and design elements on a building within a tight, high-activated urban setting has many advantages. The efforts of a specialized architect to carefully select colors and furnishings were recognized in the occupant interviews and was cited as a positive element enhancing their visual experience.

Suburban Civic – as the lowest performing building of the three case studies, in all four IEQ categories, there are more challenges to report. Their highest rated category was (natural) light and views and their lowest rated categories were thermal and visual comfort. It is important to state at this point that the building manager is relatively new and has the support of senior management to investigate and improve many aspects of the building. Given this, both

operations and building management are currently focused on critically analyzing all aspects of the building, including IEQ conditions. In general, there are many site factors (e.g. building orientation and variation in user needs from department to department) which are affecting the thermal and visual comfort performance, and consequently, the occupant satisfaction in this building. Although most said they were more satisfied with this building overall, and particularly compared to previous buildings they worked at (noting that their previous office space was a series of mobile offices or trailers, so this was probably quite easy to improve upon!). One of the main drivers for the dissatisfaction with thermal comfort and visual comfort has been a lack of continuity in the building management staff, which might be reflected in the poor performing building management system, the lack of occupant understanding and engagement, and the non-existent trending of things like preventative maintenance, BMS data, complaint logs and more. Occupants had very little working knowledge of the occupant-controlled features cited by the designer as a key aspect to optimized performance and satisfaction levels. They said they had received no formal training since the building opened and remember very little of how many of the aspects work, or have become admittedly complacent to them - as with the window indicator lights. Thermal issues are considered to be worse in the summer (not studied) given the high temperatures and humidity the area can experience. Finally there are very different thermal needs reported between two separate sections of the building ("hot" and "cold" suites). Temperature logging by zone showed elevated readings in the "hot" section and there is an observed issue with the mechanical skylight. This hot area also has personnel who are required to wear heavy clothing as part of a uniform, and they are generally more active than people in the "cold" section. Set points we were able to see on the building management system do indicate some are out of recommended range (based on the original engineer's commissioning report).

Industrial Mission – Generally the occupants were very satisfied with the building overall. Their highest level of satisfaction was with (natural) lighting, views and connection to the outdoors, and the general usability of the space. Their lowest level of satisfaction was with thermal comfort. The core intention of the design to relate to the company's mission is a driving factor in many aspects of its overall positive occupant satisfaction. Their mission includes provision for "…the kind of place we'd want to work…" and is reflected in the many aspects centered on increased employee satisfaction (for mission statement see Appendix Q, Case Study #3 "Considerations"). Not directly related to this study, the workplace has an on-site daycare, gym, laundry facilities, bike sharing, café, and many polices supporting increased satisfaction, such as a bring-your-dog-to-work policy. The common belief in the mission and culture seems to provide the groundwork for a more accepting workforce in this relatively larger and more open space. Building management has made consistent attempts to address complaints and improve conditions at the direction of the owners. They do discourage the use of thermostats due to past issues with the building management system. Floor heaters are also strongly discouraged. Occupant interviews showed the heavy management of these restrictions have spilled into their feeling around using other aspects of the building and what they are "allowed" or are permitted to do. Several said

they didn't operate the fans, blinds, lights, or thermostats because they did not want to cause issues with the building systems. Acceptance and individual accommodation (e.g. modulating voice levels and open collaboration) regarding the open space plan is more apparent and the open space scheme is felt by occupants to be positive by-in-large. There are several physical features that affect IEQ, such as sound insulation and clouds to help with noise, or the availability of many multi use spaces to provide relief from thermal discomfort, noise, and glare issues. However the occupants seem to focus more on positive terms when describing the space, such as – "communal", "inclusive", "collaborative", and "connected".

3.4 Triangulation and thematic networking

Across the three buildings, the one achieving the most IEQ LEED credits had occupants who were the least satisfied across the four categories. Many of the specific challenges pointed out in the focus group are relevant to understanding why this may be occurring. There were also many overlaps between the issues and conditions raised by the focus group, and the insights from the direct assessments point to issues about occupant satisfaction that are relevant not only to each of these three example buildings, but also to larger common issues in nearly any building, but that rating systems at the time didn't address.

Section 2.1 first introduced the idea of thematic networking as a way to tie the different approaches of this study together, and defined the following three types of themes in this method: 1) global (the IEQ categories that were from the survey), 2) organizing (the LEED credits), and 3) basic (the "codes" found in Appendix D). The first two have been talked about at length. The 3rd, the basic themes, were determined based on performing content analysis for the focus group and building assessments. Each basic theme is represented by a symbolic code or single word: behavior, condition, design, expertise, interpretation, method, and perception (the theme behind each of these codes is described in Appendix D).

These three themes are used to organize the discussion in this section. The subheadings that follow begin with the "global themes" (IEQ categories). Within each, I first summarize the patterns of occupant satisfaction with IEQ found from either the survey results (for all the study buildings), or from the interviews (from just the three building assessments). I then use the "organizing themes" (LEED credits), within which the most relevant codes representing the "basic themes" provide a framework for further analysis.

3.4.1 Air quality

<u>Occupant satisfaction findings</u>

Based on the survey of all the study buildings, occupant satisfaction with air quality primarily fell in the midrange of "satisfied" (see Figure 9, Section 3.1.1). Satisfaction in the assessed buildings was relatively high for two (90th percentiles) and low for the third (57th percentile). Interviews revealed mainly neutral to positive responses, with main issues around sewer gas smells in the restrooms. Overall, the interviews from all three assessments provided few negative ratings of air quality and most were neutral to positive (this was consistent with a lack of air quality-related comments in the survey results from two of the three buildings). When asked, interviewees generally said they didn't notice issues (but note that we are only talked about perceived air quality; we can't say anything about the actual physical characteristics of the air quality without measurement). One person offered, "…how would someone rank air quality as positive, it would only be negative if high (or the occupant would only be able to rank negative if noticed but it goes unnoticed otherwise)."

<u>LEED credit level</u>

Credit 1 addresses the percentage of outside air and CO_2 levels. The focus group and building assessments offered several explanations for the survey analysis results, which found no relationship between achieving this credit and occupant satisfaction with air quality. Using our codes, the focus group and building assessment explanations are outlined next.

- *Perception:* The focus group said there are issues with people's perception and ability to understand discrete differences in CO_2 levels. The building assessment interviews provided for very little dissatisfaction with air quality and the few issues cited were not related to CO_2.
- *Design*: Experts noted that available technology and accuracy issues with equipment, especially monitoring, leaves building management not always knowing their building's performance.
- *Condition:* Further exacerbating the design issue is a lack of operation's staff to engage proactively beyond responding to system alarms. Specific to this issue, experts shared that, many times, the programming of the system is set up so that operations staff must be focused on "putting out fires" and not proactive management. Technical skill can also play a role here with the need to use building management systems to monitor and diagnose potential issues. Specific use rooms with the potential to exceed occupancy demonstrated issues with "stuffiness".

Result

The ability to draw a relationship between the satisfaction with air quality overall to credit 1 is low. Surveyed comments or interview findings revealed very little negative or positive comments with regard to CO_2. The only reported condition ("stuffiness") occurred in heavily occupied conference rooms. Strategies like demand response systems are not required by the credit. Given that these conditions are found during point-in-time uses of conference/assembly rooms and are not specific to their day-to-day workstation conditions, they should not hold the same weight and should not be assessed as such.

Credit 2 addresses increased ventilation and effectiveness. Again, using the codes to connect ideas from the different phases of this study:

- *Design and Implementation*: The focus group revealed that a challenge for many designers and operators is trying to simultaneous achieve high performance in air quality (related to ventilation rate), energy efficiency, and thermal comfort. While air velocity is primarily a thermal comfort issue, there may also be a relationship with perceived air quality (Melikov and Kaczmarczy K, 2012, Fang et al., 1998, Zhang et al., 2010). Even LEED Credit 7.1 Thermal Comfort Design calls for the "integration and coordination" with Credit 2 with regard to air speed (see Thermal Comfort Section 3.4.2 for discussion of this issue). The qualitative building assessments did not observe any noticeable problems with perceived air quality that were directly related to the design and implementation of this credit. However, it should be noted that these assessments were not intended to be a rigorous investigation in that ventilation rates could not be provided from the building automation systems and no air velocity measurements were taken.

- *Behavior:* The focus group suggested that there are limitations to what people will report and confirmed that the balance of ventilation tends to be more of a thermal comfort issue than an air quality one. In the occupant interviews related to this credit, occupants' comments centered on the ventilation rates themselves and it the conversation evolved into an evaluation of thermal comfort rather than air quality (this will be addressed in thermal comfort 3.3.2). In the assessed building with the lowest surveyed air quality satisfaction (53% satisfied), the survey comments were limited to the inability to open windows if there were offensive odors or a smell in the restroom, which, according to interviews, had been solved subsequent to the survey. Interestingly, the building with the highest rating for air quality (93% satisfied) also had as the primary comment a sewer smell in the women's downstairs restroom. In the assessed buildings, occupants with access to windows saw them as a very positive feature providing access to "fresh air" and thermal relief when needed. This issue has not been permanently solved, as it came up again in interviews. When I asked the janitorial staff, they said given they are men and do not use that restroom they do not know when water in the trap for the main floor drain evaporates and allows gases to enter the room - it takes the women using it complain. The female interviews said they were "tired" of complaining as it doesn't seem to get fixed permanently.
- *Condition:* The focus group raised the point that pumping in "bad" outside air, in many cases, could be contributing to issues of indoor air quality. With the three building assessments, we saw no evidence this was an issue. Only one building manager had taken proactive steps in looking for the connection to outside air quality. Upon finding exterior patio furniture had a black, carbon build up appearing between cleanings, he increased the air filter changes and continued to monitor the filter conditions until he felt they were being changed at an acceptable level.

Result

Looking this this purely as ventilation intended to improve air quality (and not a thermal comfort issue) there were no direct interview comments that discussed associated issues, and no evidence of issues on walks performed. Therefore it is difficult to determine if occupants' ratings of air quality overall is related to this credit, conditions of another credit or something unrelated entirely. . Based on the assessments, this credit and satisfaction with air quality overall are not relatable.

Credit 5, Indoor Chemical and Pollutant Control, primarily addresses admittance of contaminants through main entry ways, and the confinement and proper disposal of chemicals used in the building.

- *Condition*: Although the focus group felt that methods used to achieve this credit were relatively straightforward and this was mainly an operational, post-occupancy issue, they also felt it was relatively less important in the total air quality picture. All three assessed buildings had all prescribed measures in place – little to no maintenance is required.

- *Perception*: No chemical smells or issues with dust and particulates in the building were reported in the surveys or interviews. The Industrial Mission building survey respondents commented on a gas leak right after the building opened. Interviews revealed that was solved within a few weeks. This is the only "smell" issue beyond the sewer smells discussed in credit 2, is a singular occurrence, and is not related to this credit. One interviewee said they were pleased that all organically-based products were being used for general cleaning.

Result

The feedback from occupants, the relative ease of meeting this requirement, and the observation that all measures provided in the credit were in place for all three buildings, collectively support there is a more direct relationship between satisfaction with air quality overall and credit 5.

3.4.2 Thermal comfort

Occupant satisfaction findings

Surveyed occupant satisfaction with thermal comfort fell primarily in the low range of "satisfied" (see Figure 9, Section 3.1.1). The assessed buildings' survey results were relatively high for one building (85th percentile) and low for the other two (51th and 23rd percentiles). Occupant interviews for the three assessed buildings revealed mainly neutral to negative responses and focused on seasonal temperature issues and "drafts". Most thermal comfort issues for these buildings were related to occupants feeling "cold" at the time of study. High diurnal and seasonal swings (both hot and cold) were generally reported for the Suburban Civic building.

LEED credit level

Although there are many conditions that can affect occupant thermal comfort, two primary design and operations related conditions were identified by the focus group as likely being most impactful. First, BMS, or building management (also automation) systems, have long played a role in the effective management of buildings. LEED credits are just beginning to address BMS issues in the new version 4), but this version was not part of this study, and this issue is not found in the credit analysis below. However, this is further discussed in Section 4.1, given that these systems affect the performance of thermal comfort and air quality strategies widely. The second challenge they identified is balancing air quality (i.e., particularly related to ventilation rates), energy efficiency, and thermal comfort. This aspect also came up repeatedly in the survey analysis and interviews in the form of "drafts" and issues near or around a vent – this is also discussed in Sections 3.2.1 and 3.4.1. The focus group believed that even when the design seems to balance these performance goals, many times the systems are not being installed to design specification or operated as intended. They felt that this wasn't necessarily a problem with LEED, but a problem with the design-construction-operation cycle that is a constant struggle. This issue is strongly tied to the first BMS condition. Credit 7.1 (Thermal Comfort, Design) addresses designed air temperature, radiant temperature, humidity, and air speed and is where this balance

is addressed. I will also discuss the aspects of controllability and monitoring found in credits achieved by the assessed buildings.

It is worth noting, credits 6.1, 6.2, 7.1, and 7.2 used in this study have undergone changes across version releases for the different products. Versions of credit 6.1 and 6.2 include lighting and thermal comfort control for perimeter and non-perimeter spaces (also discussed in Section 3.4.3 Lighting/Visual comfort). Related to thermal comfort, these credits mainly deal with four aspects of the building process: controllability, design, verification (or the assessment of thermal comfort over time in the form of a survey), and monitoring. I will break them up accordingly.

Controllability (credits 6.1 and 6.2 for study building version New Construction 2.1) credits aim to provide a high level of thermal comfort, ventilation, and lighting system control by individual occupants or specific groups in multi-occupant spaces.

- *Behavior:* The focus group questioned if people are inclined to make adjustments to the systems even when personal control is provided, and to what degree. Looking at interviews from our building assessments, occupants generally felt they wouldn't change thermal settings because "what I like may not be right for others" or "the building doesn't allow us to make changes". The building management substantiated this by saying they had unwritten policies that occupant control of thermostats was restricted and changes needed to be requested. They cited issues with the building management system and the number of complaints resulting from occupant set point adjustments as the main reasons for these restrictions. For buildings with operable windows and ceilings fans, many occupants interviewed also felt they could or should not operate these features. For interviewees without direct access to a window in their workstation, they felt windows were owned or managed by the people with direct adjacency to them. For the fans, several interviewees said that although they wished to have the fans on, others in the space thought it was "too drafty" or provided "too much air". In the building with the largest open space and highest ceiling, several occupants expressed they didn't pay attention to the fans and even forgot they were there. It is interesting to note that neither of the buildings with ceiling fans were using the winter nor summer settings and the operations staff was not aware those alternative settings might be available.
- *Condition:* Building management and occupants cited many reasons for lack of use of operable windows, including outside noise and, as just discussed, ownership of adjacent workstations. For those with access to windows, it was seen as a very positive feature providing access to "fresh air" and thermal relief when needed.

Result:

Based on the collective findings from the survey, focus group, and building assessments, the pairing of the controllability credits and thermal comfort satisfaction is not as strong as might have been expected, particularly if strategies are not being widely operated and used among occupants as intended. This may constitute a larger re-consideration of the credit and approach to occupant-controlled features overall.

Credit 7.1, Thermal Comfort – Design, requires that HVAC designs meet the requirements of ASHRAE Standard 55-2004. Specifically, this standard requires that project teams address air temperature, radiant temperature, humidity, and air speed. Earning this credit also sets the stage for one to earn credit 7.2, discussed next.

- *Design, Expertise, and Implementation*: As discussed in Air Quality 3.4.1, one aspect found to be a challenge is the overall balance of air quality (as related to ventilation), energy efficiency, and thermal comfort. Credit 7.1 calls for the "integration and coordination" with Credit 2 with regard to air speed (also see Thermal Comfort Section 3.4.2) The surveys and interviews both contained comments revealing drafts and proximity to vents as an issue yet very little had been done at the building to correct it. Building management felt adjustments to the system in response to only selected complaints can make the conditions of other areas worsen. One interviewee shared that the occupant next to him kept changing the direction of the blades of the supply register and he finally just gave up to get it corrected. The focus group also offered that many times installation is not to specification and can provide either far too much, or not enough, air in a space, those effecting the air velocity near the vents. They cited the consistency of issues found in post installation commissioning reports as proof. Unfortunately no measurement or testing of air velocity was undertaken as part of this study. The survey results, found in Figure 16, show a potential issue with the intent of the credit and the level of satisfaction. The number of buildings achieving the point is relatively high, however, this is not definitive and further examination is required given the relatively small sample size for "no point".

Result

Given that "vents" and "too much air" was a common complaint during occupant interviews, and the challenges cited by the focus group were evident in the assessed buildings, we can see some relationship between this credit and occupant satisfaction. However, this would need to be investigated more directly and fully, perhaps through a field study with physical measurements (see Section 6.2). Although not specifically related to thermal comfort, it's interesting to note, both of the assessed buildings that achieved the ventilation-related credit 2 found in Air Quality Section 3.4.1 resulted in surveys and interviews as having the preponderance of issues with drafts and thermal comfort.

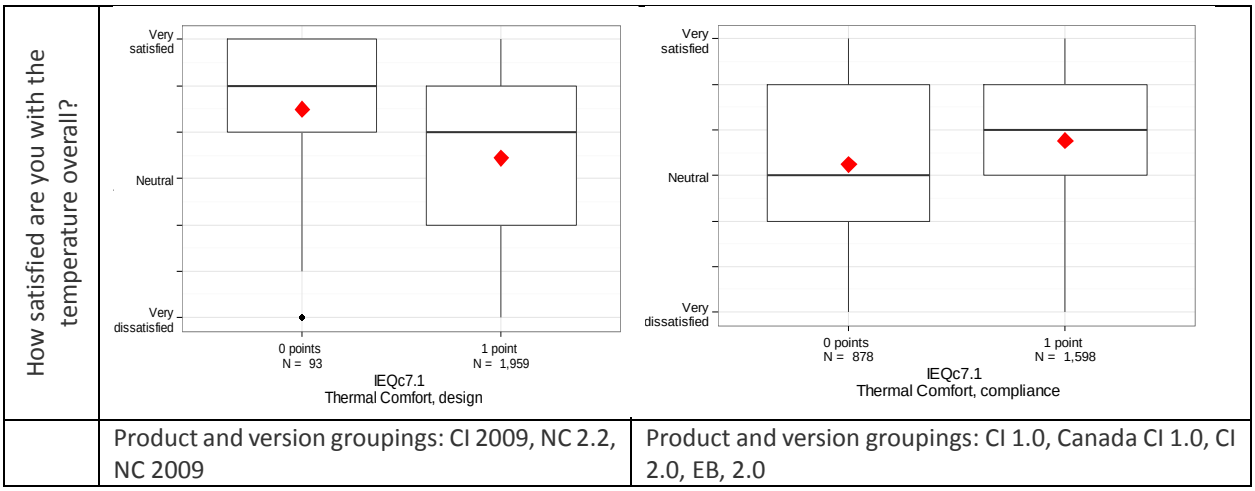


Figure 16 - LEED credit 7.1 and IEQ survey satisfaction with temperature

Credit 7.1, Thermal Comfort – Design, is intended to provide for the assessment of occupant comfort over time using post-occupancy evaluation surveys. For some versions, a resulting corrective action plan is also required. Although the focus group felt post-occupancy evaluation is critically important to an increased understanding of building performance by design professionals, they saw limitations in using only a survey to provide this understanding. Further, they felt that the information from the surveys was not being used to its fullest in building operations.

- *Conditions and Method*: The focus group felt that the complaints of a few were driving building operations, rather than more systematic surveys. The building assessments supported this view, as all three operators interviewed said that although they did not track complaints, it was the main driver of their operational activities and they had used survey results very little in their work. The measurements taken in the building generally refuted some of the "pockets" or "microclimates" occupants complained about, but the findings did support variation in conditions over the course of the day. Further, neither of the two buildings that had low percent thermal satisfaction made the required credit 7.2 post-survey corrective action plans. However, both had engaged in larger equipment and system upgrades to support better thermal comfort (verified with contractors) and one has undergone the EB re-certification process. This building manager felt achieving the requirements for EB were sufficient to meet their corrective action plan requirement. Also related to conditions, there were many confounding conditions affecting thermal comfort, ranging from the varied activity levels of occupants to individual preference.
- *Design and Expertise:* The limitations of building management systems to control thermal comfort were evidenced by limited use of two building's systems and the amount of overrides and long processing time observed at the third. All three felt they had limited to no access to the expertise needed to run them, and that the systems were too complicated and difficult to use. This, too, would need to be studied further; however, most areas of these three buildings had issues with thermal comfort based on the earlier survey, and to varying degrees

continue to have issues. Only one building has made equipment improvements and reported seeing a direct improvement in satisfaction. Occupant adaptation (mainly adjustment of clothing) was more prevalent at the other two buildings. One building manager said he resorted to using cardboard to cover windows and manually shutting heating and cooling valves to solve thermal comfort complaints.

- *Interpretation:* As had been suggested would be found by the expert focus group, the assessed buildings revealed a significant deficit in the tools to effectively interpret, manage, and optimize all the thermal comfort technologies and equipment. This included a lack of operations manuals, preventative maintenance programs, complaint tracking, trending, and more. One of the three buildings was able to provide trend data from the systems and all three, to varying degrees, described persistent issues with controllability, flexibility, and accuracy (based on "feels like" perceptions). In the recommendations section of this paper, we offer as a key topic the need for more easily usable and understandable versions of these tools and development of an overall method to bring them together for decision-making.

Result

In terms of surveyed satisfaction with thermal comfort (temperature) and credit 7.2 Thermal Comfort Design, we can see many field conditions which can affect this relationship, and suggests challenges for a rating system like LEED to address. Although the focus group all felt that post-occupancy evaluation was important for varying reasons and should be considered, we not did find operators directly using survey results in the operation of buildings, nor completing the required LEED follow up plans. They further lacked the technical expertise to make the required improvements to the systems and struggled to justify to upper management the costs of hiring a qualified contractor. Although an obvious relationship can be drawn between surveyed satisfaction and thermal comfort – the lack of follow up post-occupancy required by the rating system (at the time these buildings were certified) and the inability of building operators to make the technical changes needed to address levels of satisfaction remain an issue. Also potentially relevant is how the survey results are presented and specifically how operators can best understand the results so they can be bridged to direct actions in the buildings.

Monitoring is found in credit 7.2 for version NC 2.1 and provides for a permanent temperature and humidity systems to operate through the seasons and permit control of building zones. Again the focus group felt there were limitations to drawing a comparison of thermal comfort satisfaction and this credit – provided for in the following themes.

- *Design*: Here, too, the limitations of current technology (e.g. sensors and controllers) available was cited by the focus group as a factor. Only one assessed building achieved this credit and had the most significant issues with the innovative technology used and the lowest satisfaction.
- *Expertise and Behavior*: This condition was confounded by the inconsistency of the building management staff, lack of a champion to support building operations at a high-level, and

complacency among occupants for a building designed to have occupant-controlled features play a critical role in performance.

Result

Considering that the sense of the focus group, and our findings from the assessment, is that buildings that achieve this credit at the design phase rarely follow-up and actually conduct the post-occupancy evaluations, it is more difficult to draw any conclusions about the relationship of this credit with surveyed thermal comfort satisfaction. This would require further study of building that has actually conducted these assessments, rather than just looking at the buildings who had intended to, as this study did.

3.4.3 Lighting and visual comfort

Occupant satisfaction findings

Based on the surveys of all the study buildings, occupant satisfaction with lighting primarily fell in the mid of "satisfied" (see Figure 9, Section 3.1.1) and was where some of the highest levels of surveyed satisfaction were found. The assessed buildings' survey results were relatively high for two of the buildings (76^{th} and 89^{th} percentiles) and quite low for one (28^{th} percentile). Subsequent interviews at all three buildings revealed mainly positive comments for lighting and views. There were a few comments related to glare at the two higher performing buildings. The preponderance of negative interview comments was found at the lowest performing building, and these were all related to glare.

LEED credit level

Again for this category, two credits, 6.1 Controllability of Systems, and 6.2 Perimeter and Non-Perimeter, are related to both lighting/visual comfort and thermal comfort. This section discusses just the lighting and visual comfort aspects.

Credit 6.1 and 6.2 intend to provide lighting system control by individual occupants or specific groups in multi-occupant spaces.

- *Behavior:* Behavior was the main issue discussed by the focus group. Both in terms of shades and artificial lighting controls, the focus group believed humans become complacent about such features. In the case of blinds, they felt occupants are generally not inclined to change them. The assessed building managers confirmed this for their buildings, saying that unless it's something like excessive glare, occupants do not engage or even pay attention to the features. One building manager/operator suggested it "…becomes like doing the laundry". In the same building an occupant said, "It's like getting a new, hi-pro blender with 20 settings…ultimately you only end up using just one."
- *Condition:* Although universally, occupants were very positive about natural light in their space, glare was among the top issues found in both the surveyed comments and the interviews. At the building with the most glare issues, occupants expressed wanting better blinds as they "were not doing the job", larger ones were difficult to operate, and were poor quality.

- *Expertise:* It was felt by the focus group that when the lighting strategies are relatively simpler to understand and appreciate, occupants and operators may be able to more directly relate their satisfaction with it. The building assessments did show a relative ease on the part of both occupants and operators to relate and discuss aspects of lighting design to their working and building conditions. Occupants shared that they felt more connected to nature and happier with the natural light. These were not words used to describe any of the other three categories.
- *Method:* Although this is the category providing an overall higher level of satisfaction, the focus group felt that there were challenges in comparing questions about the amount of light and visual comfort related to this credit. Their opinion was the question related to the ability to adjust light is more direct and potentially linked to the credit. This pairing was subsequently analyzed and showed no relationship between ability to adjust lighting and the achievement of this credit (see Appendix K). However, only one 6.1 credit pairing was possible, given all the other combinations yielded insufficient sample sizes for analysis. This too may require further study.

Result

Provision of occupant control continues to be an area needing further examination by LEED and the industry. Although the negative comments about glare are directly related to control, the issues with the engagement of occupants and their behavior are important to the success of the building, but are beyond the scope of the credit. This makes it challenging to draw a relationship between these credits and occupant satisfaction. However, it's worth noting that version 4 has begun to address the issue of glare and is discussed in more detail in 4.1.2.

Credits 8.1 and 8.2 focus on with providing natural daylight and views to occupants. These are the two most positively rated aspects for our study buildings.

- *Design:* The focus group felt that the use of foot candle measurement at the desk top, and its inability to provide insight into the quality of light for working, was a challenge they felt directly impacted the ability of LEED credit 8.1 in influence occupant satisfaction.
- *Perception:* Even the building with the lowest satisfaction had specific survey comments about the importance of views, some saying it was their favorite part of the building design.
- *Condition*: Glare was cited by the focus group as a huge issue associated with this credit. Glare was not addressed by LEED (at the time these buildings were certified), and was discussed at the focus group as an industry-wide challenge. Building managers/operators and occupants in all three buildings talked about glare as an issue. Measurements of light levels in two of the assessed buildings, at locations identified by occupants as "glare spots", confirmed that glare was, indeed a challenge in these buildings. However, it appeared that the duration was very brief and occupants made accommodations. The building with the most glare issues is also the one with direct east/west exposure, and all of the complaints shared during the interviews were from occupants exposed to the afternoon west side of the building (Suburban Civic building case study, Appendix Q). The occupant featured in Figure 17 said she

would move a poster board along to block the sun rather than fully deploy the blinds and block her view. As found in Figure 15 there is reason to consider glare as an issue, however, the blinds do aid in the reduction of conditions. There was also evidence throughout the building of the blinds coming apart, and difficulty opening and closing them. In the late afternoon (after 4:30pm) all three workstations selected for special study had luminance readings well above the 40:1 acceptable ratio (Ubbelohde, 2015). With the exception of the Urban Performance building, observed conditions showed little use of blinds except in extreme glare conditions. To varying extents, all the building had glare complaints and none had automated systems; however, the Urban Performance building added opaque blinds to the workstations associated with complaint issues. These were reported to reduce complaints significantly and the blinds were observed to be in use. One interviewee who had the additional blind at her location said it made a significant difference in her visual comfort

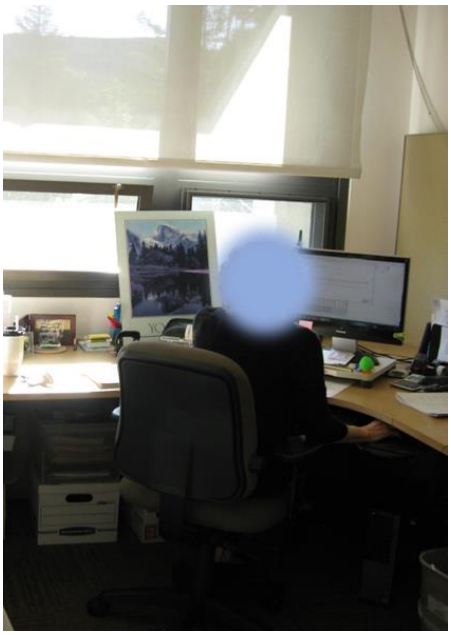


Figure 17 - Occupant adaptation - "poster board" vs glare

Result

Although this research shows that satisfaction with lighting is easily relatable to the credits addressing lighting, we can see there are challenges with the lighting credit themselves – both how they focus on the occupant and how they are measured. See Section 4.1.2 Glare for more specifics.

3.4.4 Building overall

Occupant Satisfaction

Surveys showed people generally rated their satisfaction with the building overall high.

- *Interpretation, Perception, Behavior, and Expertise*: Satisfaction with the building overall can best be described by some of the survey comments and interviews. Across the three buildings, almost all occupants said they were proud of their green building and it was an improvement from their previous work place. But does this relate to satisfaction? One occupant offered, “People can appreciate an advanced approach without knowing every detail or using every aspect.” In this appreciation, there is a relationship to satisfaction albeit indirect. One building had a dozen positive survey comments about their green building. Even the managers who were frustrated with some of the performance said they were proud to be managing a LEED-certified building.

Result

The focus group offered that it is difficult to associate any specific aspect of LEED design or credit to the question of satisfaction with the building overall. Buildings are too complex and dynamic to provide any relationship with these comparisons. As can be seen from the occupant comments and in the preceding three sections this is likely true. Important to this evolving understanding are the common conditions found in the assessed buildings (Section 4.1) and initial key themes that live across the surveyed and assessed buildings (Section 4.2).

4. Discussion

The built environment is dynamic and complex. This is reinforced by the number of research studies, journals, industry groups, conferences, and more, that focus on a wide variety of aspects of buildings, including IEQ performance. It's limiting to exclusively use quantitative or qualitative analysis to arrive at conclusions about it, yet it's also challenging to combine the findings from both methods. But it's exactly this challenge that this thesis took on in trying to answer two primary research questions:

1) To what extent do characteristics of LEED influence occupant satisfaction with IEQ?
2) What contextual factors in the design, construction, and operation of buildings affect are a factor in this relationship?

For this thesis, the LEED characteristics I investigated include product, version, certification level, and IEQ credits. Using our three methods of study we begin to bring together findings to provide conclusions and discussion to support them.

4.1 IEQ survey analysis

The main conclusion for all the IEQ survey analysis performed is there is little relationship between LEED certified buildings and IEQ occupant satisfaction as found in the CBE survey. Even at the individual IEQ credit level where patterns were expected, there is little to no difference in satisfaction between LEED certified buildings that achieved a particular credit verses buildings that did not. There are, however, some comparisons where positive relationships are found. Featured in Figure 5 we see the example of the green cleaning credit positively effecting occupant satisfaction - moving from neutral to somewhat satisfied - when the credit's point was earned. A similar, albeit less dramatic result, can be found for credit 2.3 Occupant Comfort – Thermal Comfort Monitoring and 7.1 Thermal comfort – Compliance. The analysis of the product, version, and rating levels are considered more removed than comparison to credit level but, as would be expected, by-in-large show a similar result. We found that as newer LEED versions were released, satisfaction improved (see Figure 6B). However, as total IEQ points were increased, satisfaction remain largely unchanged.

The survey results were used to build the foundation for the other methods (Expert/Focus Group and Building Assessments) and has helped shape their development and conclusions. The triangulation of these methods resulted in a more critically-focused analysis providing varying degrees of an improved understanding of the relationship between the credits and occupant survey questions (reviewed in Section 3.4) and cross-method conclusions found in Section 4.4.

<u>Limitations</u>

The survey analysis looks at the relationship between LEED (which occurs during the design phase) and occupant satisfaction (which of course takes place after the building is operational). There is much in between which can affect the performance and may not be intended or foreseen

by the designer, or rating tool. With energy modeling, modeled performance is rarely achieved, but generally the energy model is not blamed because we understand there are many factors which can affect performance between the design and its final state as a functioning building. Perhaps the same is true for tools like LEED.

As eluded to throughout the survey analysis sections of the paper, the credit level is where the research team felt we could learn the most. As the analysis gets farther from the specific strategies occupants are exposed to (e.g. certification level, rating, product, and version) it might be expected that it would become less related to their levels of satisfaction.

The wider intention of POEs is to evaluate building performance, provide feedback to designers and building management, and improve the building. The survey, whilst a useful tool to gather occupant satisfaction information, it can "…typically lack contextual information, continued feedback, and physical measurements of the building's indoor climate" and can "over-exaggerate" poor building performance (Deuble and de Dear, 2014). As one example in this study, we can see this is likely true with the severely low levels of surveyed satisfaction at the Civic Suburban building and the less severe impressions obtained in the interviews and measurements.

For this research, the survey results provided an excellent foundation and was used to inspire conversation, narrow points of investigation, and provide context to participants in the study.

4.2 Expert/focus group

The aim of the focus group was not to be conclusive about the study topic, but be more informative of it; however, some conclusions can still be derived from the discussions. Related to the findings of this this study, the group identified many potential challenges in the emerging green building industry associated with: the advancement of technology and keeping pace with the demand of innovative solutions, ongoing technical expertise available after the building is occupied, issues with creating a "one size fits all" rating system, and how to balance and relate quality post-occupancy evaluation. There are also many positive aspects of green buildings and the promise created by the building industry's desire to create better environments for occupants (also can be seen in the Sections 3.4.3 and 3.4.4 and in the Recommendations Chapter 6). As outlined in many of the citied works found in this paper and by our focus group, there is no single, simple approach to arrive at a high level of satisfaction given the dynamic nature of buildings and the complexity of understanding human satisfaction itself;.

<u>Limitations</u>

Although an open, collaborative exercise such as this study's KJ technique-inspired focus group can generate creative solutions and provide a framework for consensus, it is inherently based on opinion and professional judgement, not necessarily verified facts. Further, individual participation can be motivated by that person's specific set of specialized experiences, and not necessarily a broader understanding. And, although this is a common technique used in the building design community, working in a group can potentially bias some answers or be dominated by a few participants (see focus group methods).

This group was designed to best balance the ability to collaborate freely, given their experiences, and hear from each participant; however, not all of these objectives was likely fully accomplished. But because the results of this group was intended merely as a "tying" element for the other more structured aspects of study, it was appropriately designed for its use.

4.3 Building assessments

Even with the limited number of the assessed buildings in this study, we can see across their variation (particularly in the LEED approach used and the physical setting) that there are a great many possible factors affecting occupant satisfaction. As such, we feel that these three buildings truly served as good example case studies. For example, the assessed building with the relatively low level of IEQ satisfaction achieved the most IEQ points in LEED. By-in-large, LEED prescribed measures were found to be in place, however the lack of continuity in management has greatly diminished the efficient running of the systems, the responsiveness to occupants, the effective engagement with them (occupant control was a key part of the design), and the overall focus on the success of the building as a priority. It was found that people in all three buildings were very positive about having natural light and views, as well as the fact that they worked in a "green" building in general.

There were also many common conditions found in the next section at the assessed buildings which potentially have an effect on occupant satisfaction. They directly impact the ability of operations staff in the buildings to both reactively and proactively take actions and respond to the occupants.

Limitations

Given the time limitations of this part of the study, a relatively low number of buildings were assessed, and were all located in the San Francisco Bay Area. Not all the combinations of LEED products and versions are represented. The length of measurements and assessment of trended performance was limited to two weeks during the winter/early spring and could be expanded to capture more potential impacts and seasonal changes.

4.3.1 Common conditions

Guided by the focus group discussions, and using the three assessed buildings as the case study examples, I identified common conditions that might affect performance (Figure 18). It is hoped they can provide a better understanding which might help expand or improve green building approaches and standards like LEED (see Table 6.1).

	Common conditions affecting performance
Design & Use	BMS-related issues – complexity and serviceability
	Occupant-controlled features (ex: thermostats) - Policies, habitual use, and training
	"Champion" role
	Multi-use, flexible spaces
	Limited knowledge of occupants
	Glare and sun control
	General policies (ex: Space heater use)
	Early involvement of all stakeholders
Operations	Preventative maintenance to "proactive" maintenance
	SOP/O&M Manual – User-friendly guides
	Use of trend data and surveys
	Training, expertise, and consistency of operations
	Access to deeper technical expertise
	Following through on prescriptive actions – ex. Credit 7.2 corrective action plan

Figure 18 - Common conditions found in the assessed buildings

In this section, I chose three common conditions to elaborate on, based on their potential impact to improve today's occupant experience and their overall satisfaction. They are: BMS-related issues, glare, and multi-use spaces. (Also see Section 6.1 for summary recommendations for occupant-controlled features, developing a "Champion" role, and preventative to "proactive" maintenance)

4.3.1.1 BMS-related issues

BMS-related issues are perhaps among the most common and impactful conditions affecting green building performance today and can affect thermal, air quality, and for some buildings, even lighting performance. There are cross-over issues for these IEQ conditions (e.g. heat gain, and drafts) that can exacerbate issues between them and further challenge the effectiveness of systems. Although the degree of building management system issues varied among the 3 subject sites, the level of satisfaction was most impacted by the ability of the building managers to manage the thermal environment. Generally, the challenges were related to; proprietary issues, difficult to understand reference materials, little or no on-going training, technology that becomes outdated quickly, the gradual disintegration of programming and available parts, the lack of continuity with technically-savvy site operators, and the general complex nature of building operations. This all led to the building managers having limited ability to keep people thermally comfortable and satisfied.

Of course, solving several of these challenges would require a significant shift in the industry – something LEED and others have been doing successfully for some time. Leading sustainable design engineer, Peter Rumsey, offered that "…the industry needs a makeover." Particularly for "green or low-energy innovative" buildings, controls don't work well with non-standard approaches. Because of this and the resulting poor performance of pilot projects, it leaves building owners reluctant to try new techniques (Rumsey, 2011). Further, he offers that it is difficult to specifically identify where the problems lie, but building management systems' performance varies with the installer and programmer, who are typically trained in electrical and IT work, respectively, and not mechanical systems design. The quality of sensors and bad control loops compounds the issues as valves, dampers, fans, and pump performance cycle uncontrolled sometimes for years at a time. The faulty sensors which read this performance inaccurately or not at all further compound the issues. Rumsey calls for more user-friendly interfaces that support operations staff day-to-day needs, and minimize these issues. Moreover the systems themselves should be "self-healing", more reliable, and more accurate (Rumsey, 2011).

Standards should support these goals. Upon contacting Peter Rumsey directly, he offered that the focus of LEED committees could be on credits that support systems which are smarter and don't need commissioning. Further, user control is still a central strategy but it needs to be delivered in smarter ways that people will actually use, like personal comfort systems (Pasut et al., 2014).

4.3.1.2 Glare

Historically LEED has focused on how to get the most light into the greatest amount of floor space, and on not the quality of light, contrast/glare control, etc. But glare is often what occupants are responding to in terms of dissatisfaction. This is a case where the metric of the LEED point and the survey question may be misaligned and further examination is needed.

Just behind thermal comfort, the second most prevalent problem in the study buildings were issues related to glare. The technical approach to measuring visual comfort issues, and the level of effectiveness of the strategies used to address it, are emerging to be at the heart of our current glare-related challenges.

This study's building industry focus group said that it can be difficult to balance natural daylight and glare, and that it is not easily designed for. Further, they felt if not done correctly, it can often cause more problems than provide solutions. This important feedback may support that, even with the recent changes to LEED, we may be headed in the wrong direction. This position becomes even more evident in the examination of this study's building assessments and the pervasive issues found around glare. Next is some relevant history and context to that point.

LEED leadership and the technical advisory committees understood that focusing credits only on the illuminance levels needed to maximize natural daylight fell short of evaluating critical visual comfort performance. They began to address the issue starting with version 2009. Credit 8.1 Daylight and Views proved to be a good first attempt and it offered four options to achieve the

credit (simulation, prescriptive, measurement, and combination). The non-simulation options asked for provision of sunlight redirection and/or glare control devices, and refined the use of foot candle measurements. This methodology allow for designers to more easily and readily make proper design decisions and avoided the need for more complicated luminance readings and modeling through the use of several options. Overall these provisions were intended to find a balance between acceptable light levels and visual comfort, the variability among projects, and use tools and skills already in the market. Only the simulation option provided a specific type of shading be used - "view-preserving automated shades". A case in point to the pros and cons of this credit can be found with this study's Commercial Interiors v2009 assessed example – Industrial Mission building (see Appendix Q Case Studies). The designer said that although performing the calculations for credit 8.1 was one of the most valuable aspects of the LEED process, the post-occupancy issues with glare led her to the one thing she would change – finding the budget provision to include automated shade control. Credit option #3 *measurement* used for the project did not require it. Even with tinting added later, there are persistent issues with glare at this building today.

LEED version 4 requires a more technical examination of luminance levels that, short of hiring a qualified lighting designer, may actually exacerbate the issues the focus group discussed and eliminate the aspects for v2009 found valuable by the designer as described above. Further, LEED v4 does not require automated shading. This was a significant issue for all three assessed buildings. In the most problematic areas, one building (Urban Performance building) added opaque shades behind the originally installed version, thereby eliminating the views required by credit 8.2. Another (Industrial Mission building) added tinting, as previously discussed, but that did not completely solve their visual comfort issues. The third (Suburban Civic building) has done nothing and still receives a complaints with less than desirable occupant adaptions being observed (see Figures 13, 14, and 17).

What could be done? The industry is now in the process of validating emerging methods for the assessment of contrast conditions and glare (Ubbelohde, 2015). Therefore, this may not be the time for LEED to make the measurements more technically challenging and, instead, it may be optimal to wait until tools become more easily and readily available. Additionally, the type of shades and sun controls used are critical to solving visual comfort issues and, at a minimum, automated shades with manual overrides could be the way to go. Owner expense and budget were cited as the reason for cutting the automated version for the v2009 building, but no consideration to the potential energy savings from reduced heat gain or the potential increase in productivity resulting from a better balanced approach to daylight and visual comfort was considered. Both the methodology for measurement in design and the specification for strategies are fundamental to solving the issues.

4.3.1.3 Multi-use, flexible spaces

I will use the direct context to one of the study buildings as an excellent example to discuss *multi-use, flexible spaces*. The Industrial Mission building designers and owners gave careful

consideration to the effective design of multi-use and communal spaces. Occupant interviews revealed high levels of satisfaction with these spaces citing the ability to use them when thermal, lighting, and noise conditions were affecting their work, as stimulation when a different view was needed, and as places for formal and informal conversations. Along with the addition of acoustic clouds and careful consideration of team grouping and placement in the space (as described by the building manager based on their noise and activity levels), these multi-use spaces provided for significant relative reduction in noise levels, even with the associated bring-your-dog-to-work policy. The variety of spaces also offer a place for communal interactions that further re-enforce the company's culture and mission. In a study of the Philip Merrill Environmental Center, Judith Heerwagen discussed similar findings. She provided that "People respond positively to daylight, views, connection to nature, good ventilation, aesthetic pleasantness, and social features of the environment – all of which are readily transferable. In the end, philosophy may also play a major role in the realization of benefits. Designs that begin with a true focus on human health and well-being may, in the end, reap the biggest benefits from sustainable design." (Heerwagen and Zagreus, 2005) The designer of the Industrial Mission building shared that the company's mission was at the center of their design and has been carried through by the abiding stewardship of the owners, thus supporting Heerwagen's findings and the clever design of multi-use spaces.

4.4 Triangulation

Many factors play a role in occupant satisfaction, and a thorough understanding requires multiple methods of post-occupancy investigation. We found that for each of the four categories, or global themes, different factors affecting satisfaction performance can start to be developed and are important to talk about here. Here are our current findings by category.

4.4.1 Air quality

Satisfaction with air quality falls generally between neutral and satisfied in the survey, and also generated very positive interview comments (for example, related to the access to fresh air and operable windows.) Occupants tend not to notice indoor air quality unless there is an issue. Further, it generally requires a very proactive, attentive building operations staff to detect day-to-day issues and resolve them. Settings of buildings (i.e. urban, industrial, suburban, etc.) can also be a factor in achieving good indoor air quality. Current sensors and controls systems many times fall short of providing the level of accuracy and flexibility needed. And setting the bar for good indoor air quality is a difficult task for codes, standards, and rating systems such as LEED to accomplish. The related LEED credits appear to be making some head way toward improved air quality, but consideration for improvements should be made (see Section 6.1).

4.4.2 Thermal comfort

Thermal comfort was the lowest rated for occupant satisfaction among the four categories. It was also the top issue for the assessed building's operations staff and the inability for them to respond is eroding the confidence and satisfaction of occupants. Building management systems play a key role in this condition (see Section 4.3.1.1). Also the relative degree of integration of innovative green approaches and occupant-controlled features has proven to affect both positive and negative aspects of satisfaction performance. The balance of energy, thermal comfort, and air quality performance in building systems design is a main contributing factor (specific issues related to this can be found in Chapter 3 - Results). Even when designed in balance, the implementation and operation of related systems can lead to thermal comfort satisfaction issues. Further, systems can start off balanced and commissioned to design specifications but the performance can deteriorate over time, making enhanced commissioning and use of proper performance management protocols an important part of on-going operations (ASHRAE, 2012). This is probably the most significant category where LEED and other codes and standards could continue to refine to achieve better satisfaction (see Section 6.1).

4.4.3 Lighting/visual comfort

Lighting was the one of the most liked and positively-rated aspects studied (however, as noted earlier, when there was dissatisfaction, glare was most commonly noted as the source). All assessed buildings had documented use of LEED methodology to design for natural light penetration into the floor plates and provide views for as many occupants as possible. The findings for all three buildings generally showed average desktop readings within OSHA standards using relatively little to no artificial light in sunny conditions (Occupational Health and Safety Administration, 1996). The limitations with the LEED standards were mainly found with visual

comfort issues and specifically glare. The significant issue of glare, as also discussed by the focus group, undermines overall lighting satisfaction. Occupants' low propensity to use shades and other measures only exacerbate this issue. LEED is making progress and glare is addressed in the newest LEED version 4 glare, however, it is not clear we are moving in the best direction (see Chapter 4 Discussion, Section 4.3.1.2 Glare). To varying degrees, all the assessed buildings in this study had glare complaints and none had automated systems.

Although the IEQ survey does not ask directly about views in their base study, it was also a top-rated aspect for interviewees. Even in the urban setting people felt access to a view of the sky and trees was important (see Figure 19). The designer of the Urban Performance building shared that capturing views was one of the main focuses of the project, with the size of the windows and maximizing elevation differences as key considerations. We did see indication that previous work spaces played a role in satisfaction and the differences were mainly described in terms of the views from their old verses new buildings.

Figure 19 - View from Urban Performance building

For this same building, several of the occupants cited the materials, furnishings, and color selections as having an overall impact on the comfort. The designer provided that they brought in a 2nd architect specializing in color and material selection. Although not a conclusive finding, it is an example of the importance of future study work for this thesis and the overall confirmation that there are many, complex factors to be studied.

4.4.4 Building overall

Satisfaction with the building overall is rated positively across the study buildings. This is not surprising given larger studies using the CBE IEQ Occupant satisfaction survey (Frontczak and Wargocki, 2011). The focus group offered that it is difficult to associate any specific aspect of

LEED design or credit to the question of satisfaction with the building overall. Buildings are too complex and dynamic to provide any relationship with this comparisons. However, there were many common conditions found which could provide context to the building overall and provide a groundwork to consider improvements in the industry (Section 4.3.1.) Specific details are provided for two of the most impactful conditions found – BMS-related issues and glare (Sections 4.1.1 and 4.1.2). It is also evident from elements found in LEED version 4 that the USGBC and building industry are focusing on many of the conditions found in our study.

4.5 Implications

4.5.1 Perceptions of LEED

The designers, managers, and occupants of the three assessed study buildings all had something to share about LEED.

Designers felt the rating tool served three main purposes to: drive projects with stakeholders throughout the process, provide a means to increase the sustainable elements used in the project (i.e. "we can get gold if we add…"), and as a starting checklist to begin the conversation. One designer felt it was better to focus on the needs of the organization and the most sustainable project possible and then see how those elements fit into LEED. They all offered that LEED's higher value is to drive the market and to provide a high-recognizable brand with 3rd party certification which, in turn, provides a needed bridge to validate projects in the eyes of those with less knowledgeable. It was also felt the pool of construction professionals able to work with innovative technologies has been greatly increased by LEED. Finally, all three discussed the importance of a "champion" on the project and being able to use LEED to arm them with the knowledge needed (also see Section 6.1). In general LEED "…opens up valuable conversations to generate ideas."

The building managers' understandings of LEED and green building technology varied. One who had undergone two LEED certification processes under his watch was a bit more tactical in his assessment. He recommended the following criteria for building owners considering LEED: the building be over 20,000 square feet, have the ability to put professional management in place, provide leadership that has sustainability as an important part of the corporate strategy, and support an overall focus of the company to be fiscally and environmentally responsible.

Interestingly, one of the buildings was leased and there was a layer of property management that had to be worked through in the design and operation of their building. This company had a policy of renewing LEED certifications every five years. During the interview, the property manager said she saw it, at least in the San Francisco Bay Area market, as a necessary and valuable process. She did also say that, with recent changes in the system, she felt people could "buy" rather than earn their certifications and that this could diminish LEED's value in the market.

All the occupants interviewed felt that having a LEED building supported some aspect of their company's sustainable philosophy and that they were proud to work in a LEED certified building.

5. Conclusions

From this thesis work I conclude that:

- Overall, for the quantitative survey analysis we found that increasing the total number of IEQ credits or certification level not increase occupant overall building satisfaction. This result does not significantly change for the different LEED products used or release of versions.
- We tested how much obtaining an IEQ credit can affect surveyed occupant satisfaction with related questions. We tested 82 pairings. We found (with the exception described below) that obtaining the analyzed IEQ credits does not result in statistically significant differences in occupant satisfaction with related questions.
- Obtaining the LEED IEQ credit 3.1 (High Performance Green Cleaning Program) for EB certified buildings significantly increased (percentage increase 22%, effect size .30), therefore, we concluded there is a positive relationship in satisfaction and this green cleaning-related credit.
- LEED rating levels and all 17 IEQ survey questions used in the study were analyzed. Mean values by question generally did not vary as LEED rating levels (e.g. certified, silver, gold, platinum) were achieved. Some of the mean decreased for higher levels of rating with the three largest three largest variations in the differences between the mean: sound privacy (from -.71 for Certified to -.37 for Platinum); noise (from 0.67 for Certified to .27 for Platinum), and visual privacy (from 1.24 for Certified to .36 for Platinum).In one case, colors and textures of furnishings, platinum resulted in a slightly higher level of satisfaction.
- For LEED version although Figure 6B does appear to show a positive trend as versions are released, we do not know from this study if newer versions are performing better than older ones. Further analysis would be valuable and would need to consider confounding factors such as the age of the building or the date of major renovations.
- LEED Product (NC, EB, CI), as total IEQ points are increased we see some slight negative and positive trends among the three products analyzed again there is no significant impact as total points are increased. For CI the slope of the line = 0.07 and the R2 (or the fit of x to predict y) = 0.01. For NC, the slope of the line = -0.03 and the R2 (or the fit of x to predict y) = 0.00. For EB, the slope of the line = -0.06 and the R2 (or the fit of x to predict y) = 0.01. The satisfaction for CI certified buildings tends to increase, while the one for NC and EB tends to decrease. In analyzing the 17 selected survey questions visual privacy and sound privacy have the highest values for both percentage of mean difference (68% and 62% respectively across the products) the difference across the seven point satisfaction scale (11% and 10% respectively across the scaled responses). Focusing on visual privacy we see a significant decline in satisfaction with Commercial Interiors projects.
- The focus group brought to light that there are many challenges for designers in the emerging green building industry, including the advancement of technology and keeping pace with the demand of innovative solutions, technical expertise available after the

building is operational, issues with creating a "one size fits all" rating system, and how to balance and relate quality post-occupancy evaluation. However, many in the building industry are engaged to understand how they can make better buildings and what their roles can be to accomplish it.

- There are many possible factors affecting occupant satisfaction between the time a building is designed (and LEED certification is obtained), and during the construction and operation of the building (which is a challenge for the building industry, but they may not all be possible to address in a rating system). For our study buildings, these are outlined in Chapter 4 results.
- Using a triangulated approach we can begin to see where LEED is most and least effective and provide some clues for improvement.
    - Air quality – Air quality has many confounding factors in buildings, which may not all be adequately addressed in LEED. The CBE survey instrument is designed to assess perceived air quality, but in should be noted that some aspects of air quality are not perceivable by occupants. There are many pollutants that may affect occupant health, but cannot be perceived. Further, from the interviews and the focus group feedback, it appears that occupants are less clear about how to rate air quality compared to the other categories. These factors all suggest that there is not a clear relationship between satisfaction with air quality and LEED credits.
    - Thermal comfort – Although mean thermal satisfaction in the LEED buildings was generally positive, in the neutral to satisfied range (mean value of .31, or falling in the "somewhat satisfied" range on the 7 point scale), it was still the lowest rated of the categories studied. LEED addresses thermal comfort in terms of controllability, design, verification, and monitoring, and improvements can be made in all these areas. They credits primarily rely on existing codes and standards to drive good design and are not as aligned with moving the market and industry forward as found in other credit categories. Also, surveys and post occupancy evaluations showed weak links to affecting changes at the buildings.
    - Lighting, views, and visual comfort – Access to natural light and views are among the most liked aspects of the study buildings, but where problems exist they are primarily about glare. The negative residual of LEED's historic sole focus on quantity of natural light and views is seen in these problems of visual comfort, and the glare and contrast issues associated with them. Solutions are possible and are described in Section 4.3.1.2.
    - Building overall – Satisfaction with the building overall is positively rated in the surveys (mean rating is 1.49 or falling the "satisfied" range on the 7 point scale), and also in the comments of the surveys and during interviews from the selected building assessments. Collectively, this suggests that a value of green buildings may be in the pride and feeling of making a larger contribution by the people occupying them.

Overall, I believe that although there are challenges to providing foolproof guides and rating systems for the building industry, there are signs we are moving in positive directions and open, critical discussion is being undertaken. Although this study began as an investigation of the relationship between LEED and surveyed occupant satisfaction, it quickly became apparent that there were larger lessons to be learned about how to improve building design and operation, beyond what LEED alone can address. And since improving buildings is an important goal – whether or not they are LEED certified - it is hoped that these broader lessons learned will hone our understanding and ability to make effective changes to improve all the factors affecting occupant satisfaction.

6. Recommendations

People are hungry to know "how can we make better buildings". Certification is only part of the puzzle to achieve this goal. Given the momentum in the industry and the possibilities for impact, it is more important than ever that we think critically and thoughtfully consider improvements in the building industry, and a start is provided in Section 6.1. In the recommendations for future study in Section 6.2, you will see the call to continue to expand the research, both in methodology and in the numbers of buildings studied.

6.1 Buildings and Rating Systems

Table 6.1 summarizes the recommendations discovered through this research, related to either the LEED rating system, or the general building industry, and also for the CBE Survey tool. This is offered as a list of potential topics for discussion.

Table 6.1 Potential recommendations for LEED, Buildings, Designers, and the Building Industry

Category	Recommendation
Air quality	**LEED:** • Consider refining operations-related requirements - move from preventative to proactive maintenance programs (see below example). • Re-examine provisions for BMS to help drive the market to more user-friendly, accurate, and flexible systems. **Buildings:** • Consider developing an enhanced, building-specific preventative maintenance program (including regular monitoring of filter and cleaning schedules). • Use tracked trends/alarms, PM logs, complaint logs, and POE surveys to gain a complete picture of IAQ conditions. • Seek regular, enhanced commissioning and follow up on recommendations.
Thermal comfort	**LEED:** • Re-examine provisions for BMS to help drive the market to more user-friendly, accurate, and flexible systems. • Add more personal comfort-related technology. • Consider refining requirements addressing air velocity issues and help balance the goals of energy, thermal comfort, and air quality performance. **Buildings:** • Provide more occupant control and re-enforce culture of occupant involvement. • Enlist technical expertise where needed (BMS). • Proactively trend and monitor, particularly seasonally-focused.

	• Seek regular enhanced commissioning, follow up on recommendations, and include contract for training.
Lighting/ Visual comfort	**LEED:** • Re-visit glare-related credits. Specifically examine if manual blinds (v4) are sufficient to solve glare broadly. **POE/Survey (CBE):** • Consider questions related to views and connection to nature. **Buildings:** • In design phase, request clients consider future use and include space planning as part of larger company/business plan, particularly with overlaying lighting and furniture. • Provide more useable task lighting (ex: furniture integrated versus articulating). • Ensure blinds are operational and adequate. • Monitor seasonal conditions & track complaints by areas.
Building overall	**LEED:** • Consider integration/cross-platforming with other certification programs. • Continue to examine ease of use of LEED. • Link more directly across the 5 credit categories where possible, and encourage creative strategies around the linkages (ex: mechanical skylights). • Expand post-occupancy requirements (some actions already in process – LEED Dynamic Plaque). Use related research to understand gaps in performance and aspects of the program needing improvement. • Provide for a "champion" role and specific guidelines for continuity and effectiveness as people shift (see below example). • Consider less direct strategies like the inclusion of multi-use spaces which provide opportunity for alternate thermal comfort, lighting, etc. when needed. Also opportunities for communal/gathering spaces. • Re-examine all occupant-controlled credits to include a deeper understanding of what people are willing to use and how they engage. • Examine the positive aspects of LEED for Homes and consider for more broad application across the different rating systems (e.g. contractor training and verified on-site compliance). **Designers:** • Provide manuals suited for less technical user & easily updateable • Provide specific recommendations for on-going training. • Entrench the use of the Integrated Design Process (IDP) to consistently include stakeholders like facilities managers. Move IDP as a tool more solidly across the industry as a standard practice. • Provide future-use plan where possible.

	• Encourage multi-use space design were possible and include spaces that can provide relief for temporary conditions of glare, thermal comfort, different levels of light, and views to the outside. • Encourage clients to tie their mission to principles which support their green building and the occupants in them (where appropriate). • Carefully consider what levels of occupant engagement and control are practical for the client (see below). **POE/Survey (CBE):** • Add a guide to survey results that more directly bridge to action in the field. • Consider expansion of the semi-customized survey to specific aspects not covered in the standardized questions. For example questions that might be tied to emerging rating systems and more specific questions about thermal comfort and air quality where possible. **Building level:** • Enlist a "champion" in an on-going role. • Have a thoughtful plan for space use changes – incorporate design professional where possible. • Create polices that support green aspects in the building and provide occupant training and education where appropriate to increase engagement. • Develop more effective systems for addressing complaints and follow up and use the system to revise preventative maintenance plans were appropriate. • Consider smaller actions that may have a larger impact for occupants – example interviewee discussed "dead plants in random containers" at old office and plant serviced "healthy, beautiful plants" at new office changing the mood. Brainstorm this with occupants. • Update manuals as building improvements occur. • Follow through on current and emerging LEED post-occupancy requirements. • Set simple methods in place for legacy planning – training, providing cross over to new and leaving operations staff where possible, retain qualified technical support. **Industry:** • Move industry to include post-occupancy design team support. This could include changes in standard contract language and an expansion of the Integrated *Design* Process to an enhanced approach - the *"*Integrated *Building* Process*"*. Integrate building operators as a key part of the expansion. Make them a stronger part of the process and support training and education to provide them the tools needed. • Develop comprehensive, interactive method for building level diagnostics and legacy planning.

Next is a brief discussion of just a few selected recommendations offered in Table 6.1, to give examples of how strategies may be considered and developed.

Occupant control

Occupant controlled features were designed heavily into all three assessed buildings but were most integrated into the lowest satisfaction building. All interviewees expressed they had become complacent about many of the features. Quotes from some of the study participants give context to *why* this may be true – "becomes like doing the laundry" and "It's like getting a new, hi-pro blender with 20 settings…ultimately you only end up using just one." Research shows people with differing degrees of personal control had wide variation in thermal responses further supporting the need to include occupant control albeit considerately. There should be careful consideration of what people are actually likely to use, how we design for that use, and how we can better engage occupants overall.

Champion

The designers of all three projects provided that a champion was a key element to driving a more sustainably-focused effort and carrying through critical aspects of the design. The two higher performing buildings retained their champions while the lowest performing building did not. Perhaps it could be as simple as creating or elevating the role of the building manager/operations person to understand and drive the performance as a "champion" for occupants. It would be key for upper management/decision makers to support of this role in terms of funding and recognition for the work performed. Including provisions for this role directly in LEED could be more realistic as post-occupancy performance continues to emerge as the next focus of the standard.

Preventative maintenance

For all three buildings, preventative maintenance is contracted to an outside company. This is common, especially for small to mid-sized buildings. One of the buildings provides a simple example of how *preventative* maintenance can move to *proactive* maintenance. For the Urban Performance building, the manager noticed a buildup of carbon on the exterior patio and increased the rate of filter replacement. Abandoning the "every four month" filter replacement cycle, he continued to monitor the filters until he was satisfied with the condition of the filters and the resulting IAQ that remained unnoticed by the occupants. Although not measured or directly verifiable, using logical evaluation and analysis to take what seems a relatively simple action has likely improved air quality in the building. Providing buildings with a user-friendly guide that can help with such actions, as well as, on-going training and expert support could be a value editions by the industry.

6.2 Future Work

This study provided us with a starting point for better understanding the many factors affecting occupant satisfaction and how we can realize better buildings for them. But there is more work to be done.

It would be useful to dive deeper into the content analysis performed for the focus group and final triangulation of results, using the code book found in Appendix C. Future building assessments could also be expanded in terms of both depth and breadth, adding more variety to the buildings studied in terms of their size, location, and climate. This would allow one to better capture key themes across the various IEQ categories.

It would also be interesting to study the relationship of worker demographics and occupant satisfaction with different building features. A preliminary finding from the assessments was that the building with a younger population talked about their open space in terms of being "communal" and "connected", while the building with the older population commented more around negative aspects with the open space, such as glare, noise, and visual privacy. The focus group further supported this aspect of study offering that age can play a role in acceptance of features in a design. Analysis of the CBE Survey database based on age, or a series of focused field studies, may shed light on these potential age-related patterns in relationship to issues such as open-space design, glare, visual comfort, and views (including the interior colors and textures in relation to the views).

Although the survey analysis performed to date showed little relationship between the IEQ categories and LEED credits, there could be a deeper consideration of acoustics, visual privacy, and sound privacy. Also a deeper examination of satisfaction and LEED version releases is recommended as found in the conclusions.

Specific to the three assessed buildings (or to others that might be studied in similar ways), I recommend adding a follow up survey to better understand how things may have changed over time, such as: installed improvements, shifts in satisfaction performance, changes in staff, or degradation to the building. One might also do more detailed follow-up physical measurements to investigate specific problem areas found in each building. For example, air velocity testing could be useful for buildings with "draft" and "vent" issues. Additionally, some form of IAQ testing could be added. For all of these, I would recommend continuing the use of a customized plan or pre-assessment review for each building based on their design approach to LEED, analysis of survey results, and other available documentation (e.g. commissioning reports, design documents, complaint logs, and interviews with designers – see Appendix I). Along with the study of air velocity, I recommend looking at factors affecting designed balance of air quality and thermal comfort which could include: directed questioning of occupants regarding thermal comfort satisfaction (i.e. is it related to temperature, heat gain, vents and drafts, or somethings else), a review of compliant logs for trends or patterns related to thermal comfort, and specific

examination of commissioning reports for details related to temperature and air delivery. I would recommend this study's methodology be used to select any additional buildings for investigation (see Section 2.4.2).

Finally, given the interest from the assessed study buildings to improve their operations, individual reports are in development and are intended to provide recommendations specific to their facilities. This work required significant extra meetings and effort so I would recommend this only if there is time and resources in the study to do so.

APPENDIX

Appendix A – Rocky Mountain Institute, Deep Retrofit Value Guide

Deep Retrofit Value Report Summary: Engineering Co.

	Value Element	Leaders Taking Action	Supporting Analysis
1	Retrofit Development Costs	$831,000 development cost offset	Tax credits, grants, and avoided costs
2	Non-Energy Operating Costs	$105,400 reduction in annual operating costs	Improved space utilization, insurance discount, reduced maintenance costs
3	Retrofit Risk Mitigation	Best practice risk mitigation practices implemented well	Deep retrofits subject to construction-related risk as well as new products, systems, service providers which are mitigated well, putting outcomes within normal business risk parameters considered
4	Health Cost Savings	$275,000 reduction in annual health costs	Reduction in absenteeism
5	Employee Cost Savings	$137,500 to $1,787,500 in annual employee cost savings	Recruiting/retention cost savings; worker productivity (salary) cost savings
6	Promotions and Marketing Costs	$0 to $ 450,000 cost savings per year	Brand promotion cost reduction, reduced customer acquisition and closing costs
7	Customer Access and Sales	Increased annual sales of $0 to $1,125,000, or earnings of $0 to $112,500 annually	Conservative estimate based on potential limitations on customer access—which must be factored into enterprise risk analysis
8	Property Derived Revenues	Increased net present value of property $1,385,000	Assumed 4% sales price increase and sale in year 7
9	Enterprise Risk Mitigation	Increased company NPV of $867,500	Assumes slight increase in earnings multiple due to significant contribution to reducing key company business risks including competitive and stakeholder pressures, brand management, talent recruiting and retention, and future regulatory risk

Appendix B: LEED IEQ Credit and CBE question pairings

IEQ Survey Analysis/LEED Credit Paring Key:

Paring #	Survey Question	LEED Credit
A.1	Air Quality Overall	IEQ 1 - Co2 Monitoring and Outdoor Air Delivery
A.2	Air Quality Overall, Conditions Productivity	IEQ 1.1 & 1.2 – IAQ Best Management practices
A.3	Air Quality Overall	IEQ 1.3 & 1.4 – IAQ Best Management practices
B.1	Air Quality Overall	IEQ 2 - Increased Ventilation and Ventilation Effectiveness
B.2	Temperature and Acoustics	IEQ 2 - Increased Ventilation and Ventilation Effectiveness
B.3	Amount of Light	IEQc2.2 - Controllability of Systems - lighting
B.4	Visual Comfort, Temperature	IEQc2.3 - Occupant comfort - thermal comfort monitoring
B.5	Amount Light, Ability Light, Conditions Productivity	IEQc2.4 – Daylight and views
C.1	Air Quality Overall	IEQ 5 - Indoor Chemical and Pollutant Source Control
C.2	Odor and cleanliness	IEQ 5 – Indoor Chemical and Pollutant Source Control
D	Amount of Light, Visual Comfort, Temperature	IEQ 6.1 & 6.2 - Controllability of Systems
E.1	Temperature	IEQ 7.2 - Thermal comfort monitoring and verification
E.2	Air Quality Overall	IEQ 7.2 - Thermal comfort monitoring and verification
F.1	Amount of Light, Noise, Visual Privacy	IEQ 8.1 & 8.2 - Daylight and Views, Daylight
F.2	Light quality, overall air quality, visual comfort	IEQ 8.1 and 8.2 – Daylight and Views,

Appendix C: Occupant Indoor Environmental Quality (IEQ) Survey™ question key

Analysis code	Sample of typical question
Ability light	Overall, does the lighting quality enhance or interfere with your ability to get your job done?
Adjust furniture	How satisfied are you with the ability to adjust your furniture to meet your needs?
Age	What is your age?
Air quality	How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odors)?
Air quality - odor dissatisfaction	If there is an odor problem, which of the following contribute to this problem?
Amount light	How satisfied are you with the amount of light in your workspace?
Amount space	How satisfied are you with the amount of space available for individual work and storage? Or How satisfied are you with the amount of space available for individual work?
Amount space	You have said that you are dissatisfied with the amount of space available for individual work and storage. Which of the following contribute to your dissatisfaction?
Building	How satisfied are you with the building overall?
Cleanliness building	How satisfied are you with general cleanliness of the overall building? (or) How satisfied are you with the cleanliness and maintenance of the building?
Cleanliness workspace	How satisfied are you with cleaning service provided for your workspace?
Colors textures	How satisfied are you with the colors and textures of flooring, furniture and surface finishes?
Comfort furnishing	How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)?
Conditions productivity	Please estimate how your productivity is increased or decreased by the environmental conditions in this building (e.g. thermal, lighting, acoustics, cleanliness):
Ease interaction	How satisfied are you with ease of interaction with co-workers? 0r How satisfied are you with your ability to communicate with co-workers in person (face to face)?
Energy overall	Considering energy use, how efficiently is this building performing in your opinion?
Exterior wall	Are you near an exterior wall (within 15 feet/4.6 meters)?
Gender	What is your gender?
Hours week	In a typical week, how many hours do you spend in your workspace?
Layout	Overall, does the office layout enhance or interfere with your ability to get your job done?
Light dissatisfaction	You have said that you are dissatisfied with the lighting in your workspace. Which of the following contribute to your dissatisfaction?
Location area	In which area of the building is your workspace located?
Maintenance building	How satisfied are you with general maintenance of the building?
Noise	How satisfied are you with the noise level in your workspace?
Sound privacy	How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbors overhearing and vice versa)?
Temperature	How satisfied are you with the temperature in your workspace?
Time workspace	How long have you been working at your present workspace?
Type office	Which of the following best describes your personal workspace?
Type work	How would you describe the work you do?
Visual comfort	How satisfied are you with the visual comfort of the lighting (e.g. glare, reflections, contrast)?
Visual privacy	How satisfied are you with the level of visual privacy?
Window	Are you near a window (within 15 feet/4.6 meters)?
Window direction	To which direction do the windows closest to your workspace face?
Workspace	All things considered, how satisfied are you with your personal workspace?
Years building	How many years have you worked in this building?

Appendix D: Content Analysis Code Book for Focus Group Results

Code Book: Frame work & study definitions			
Codes	*Condition*		Physical situation or state that changes performance or perceived performance. This can include one dynamic feature of the building affecting another.
	Expertise		Ability to technically understand the intent of the credit and/or a technical aspect how something should perform
	Design		Limitation due to available tools, equipment or perception in the design industry. Also physical design.
	Interpretation		Variation or ability to understand an aspect of the survey questioning, LEED credit, or terminology. Also the tools needed to directly make this interpretations.
	Method		How a survey question is asked or a LEED credit is outlined. Also *pairing* mismatch.
	Perception		Variation across people's physical and intellectual rating of satisfaction and variation in what is successful in terms of strategy.
	Behavior		Use of a given technology or building feature by an occupant to adjust or enhance their environment and make it part of their day-to-day actions (activities?). This can include an occupants' ability or desire to use "occupant-controlled" aspects of a building. Also desire to report issues.
	Themes definition		Direct comments grouped by code and given in summary of why this credit may not lead increased occupant satisfaction (as surveyed). Attention paid to the intensity and consistency of themes.
	Thematic Networking	*Global*	Centralizing themes – Air quality, thermal comfort, lighting/visual comfort, building overall
		Organizing	LEED credits used
		Basic	Basic themes – for this study they are the codes found above
	Theory-building definition		General and more or less comprehensive set of statements or propositions that describe different aspects of some phenomenon. Interrelated ideas about various patterns, concepts, processes, relationships, or events. A system of logical statements or propositions that explain the relationship between two or more objects, concepts, phenomena, or characteristics of humans – what are sometimes called variables. Also might represent attempts to develop coherent narratives about reality or ways to classify and organize events, describe events, or even predict future events. Theories are explanations.

Appendix E: Vischer User-Centred Theory Excerpts (Vischer, 2008)

First defining elements of the user-centered theory

1. Systematic detailing of the user experience
    a. *Who are the users* (those answering the survey, to what degree are they invested in the space and what is appropriate for the given studied element(s)?

        Our study: Average work day. Atmosphere for collaboration. Is it formal or informal?

    b. *Moral priority of the users* – so who has the right to weigh in on a space? Who would have the most useful insight?

        Our study: For example, a worker that teleworks 90% of the time or someone spending 50 hours in the space?

    c. Has the *user group changed* (since certification)? In the case of dynamic work environments, is it appropriate to perform point-in-time surveys? "And if we agree to do so, then is the 'truth' of the user-built space relationship being falsified by finding an answer that only fits one point in time, thus fixing both user and environment and thereby rendering them artificial?

        Our study: Has there been a major hiring or layoff? Has there been a major restructuring? How has that impacted the space and satisfaction?

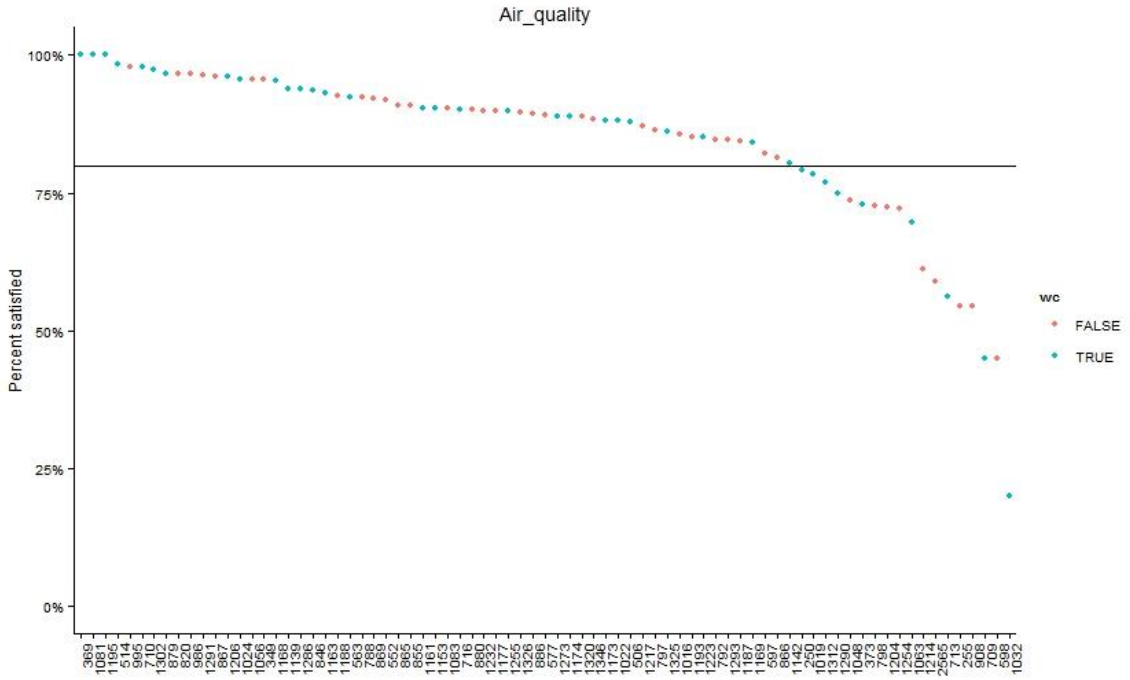
    d. Are there *heighten cycles of work* and how does this affect surveying performed?

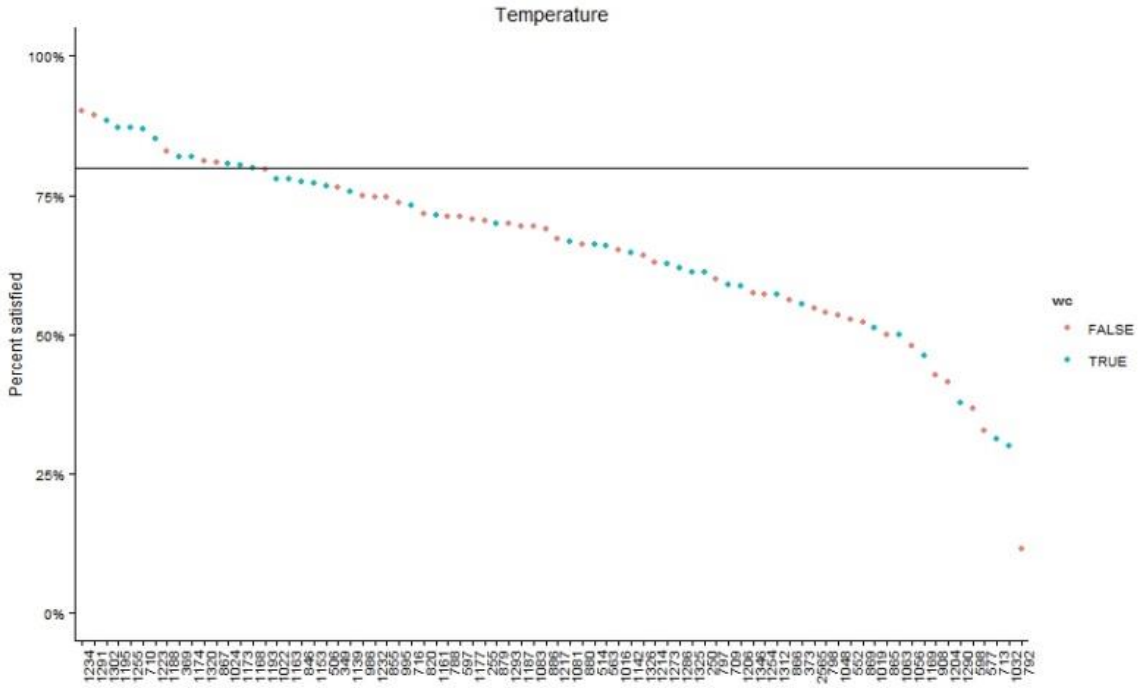
2. Define experience
    a. Missing *multi-sensory understanding* of a given element. "Are you satisfied with…?" is not enough alone. Subjective approach is the answer and she feels researchers are getting more accurate at reflecting user perception to facilitate action.
3. Define built environment
    a. *User part of environmental system of building*. Questions can separate this integration. Also other users are part of that system and affect perceptions.

        Our study: This can be direct or indirect. A direct example can be occupant control – how do they use it and how do they feel it makes a difference in the satisfaction? An indirect example – how do other people in the space affect the interviewed individual's satisfaction.

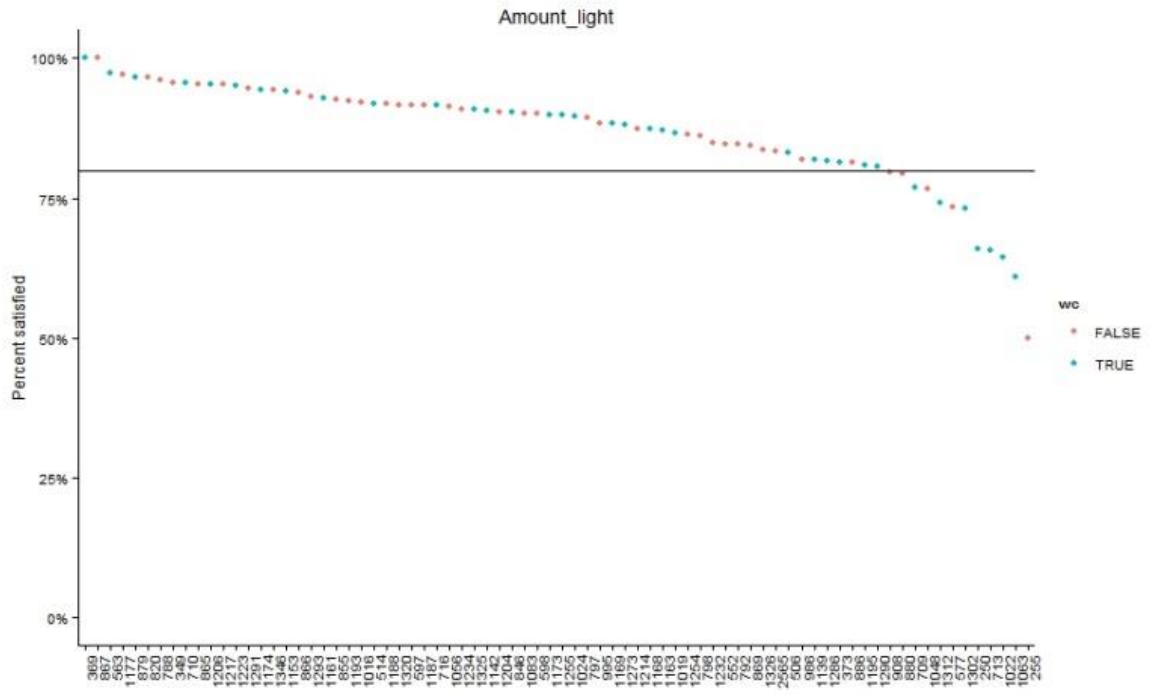
Vischer's case - "The user-centered approach must therefore address the complexity of the fact that the user-environment relation is dynamic and interactive. It is reciprocal: that is to say that part of the user's environmental experience includes the consequences of any user behavior that may occur. The user is not a passive receptacle experiencing the built environment statically, as input….Thus, the user's experience if the environment is itself transformed by the activities she is performing in that environment, is in fact a continuing process of transformation." *(She is using a more 'systems thinking' approach?)*

Appendix F: West Coast buildings (blue) verses other study buildings (red)





Appendix F: West Coast buildings (blue) verses other study buildings (red) - continued



Appendix G: Part one - Building selection table

	Survey*						
Location	**High**	**Medium**	**Low**	**Prioritized**	**# Occ.**	**Date Surveyed**	**Date LEED Certified**
Orinda			temp, light, aq	1	24	10/24/2009	5/18/2009
Sacramento			light, aq, temp	2	617	10/26/2007	1/10/2003
San Francisco		light	aq, temp	3	80	2/26/2007	5/21/2009
Los Angeles	temp, aq, light			4	327	5/25/2009	2/9/2009
Emeryville	light, aq		temp	5	135	8/1/2011	4/19/2012
Los Altos	aq, temp	light		6	79	4/28/2013	1/11/2013
Menlo Park	aq	temp		7	64	12/9/2005	9/12/2002
Oakland	light, aq	temp		8	30	4/16/2008	12/7/2007
Tacoma	light, aq, temp			9	85	10/18/2010	8/31/2010
Sacramento		light	temp, aq	10	37	2/19/2013	8/19/2011
Monterey Park	light, aq, temp	vis privacy		11	47	6/22/2007	6/28/2007
Davis	light, aq	temp		12	131	10/29/2010	10/18/2011
San Francisco		light, aq	temp	13	50	11/9/2012	5/7/2010
Tacoma		aq	temp	14	96	12/20/2010	5/8/2012
Eugene			temp, aq	15	49	7/8/2009	11/10/2006
Chino			aq, temp	16	92	3/31/2005	3/31/2004
Seattle				17	84	11/12/2010	7/16/2009
San Francisco	temp			18	56	3/17/2011	3/1/2011
Sacramento				19	118	12/21/2010	12/22/2010
Stanford				20	118	11/19/2012	7/31/2013
Pasadena					20	6/28/2010	3/23/2010
West Sacramento	temp				514	2/28/2011	10/14/2011
Agoura					36	8/19/2013	6/20/2013
Portland					133	6/21/2013	9/8/2010
Forest Grove, OR					122	5/10/2011	7/20/2009
Portland					32	10/26/2007	8/1/2006
Davis					71	10/29/2010	6/21/2012
Merced					22	4/28/2010	5/18/2009

(Continued on next page)

Appendix G (continued): Part two - Building selection table

LEED											
Date LEED Certified	IEQc1	EB only IEQc1.1-1.5	IEQc2	EB only IEQc2.1-	IEQc5	IEQc6.1	IEQc6.2	IEQc7.2	IEQc8.1	IEQc8.2	LEED combo
5/18/2009	1		1		1	1	1	1	1	1	NC 2.1
1/10/2003	1		1		1	0	1	1	0	1	NC 2.0
5/21/2009	0	0	1	0	0	1	0	0	0	0	EB 2.0
2/9/2009	0		0		0	0	0	1	0	0	CI 2.0
4/19/2012	0		1		1	1	0	1	1	0	CI 2009
1/11/2013	1		1		0	1	1	1	1	1	NC 2009
9/12/2002	1		1		1	1	1	1	1	1	NC 2.0
12/7/2007	1		0		1	1	1	1	1	1	NC 2.2
8/31/2010	1		1		1	1	1	1	0	1	NC 2.2
8/19/2011	0		0		0	1	0	0	0	0	CI 2009
6/28/2007	1		1		0	1	0	1	1	1	CI 2.0
10/18/2011	1		1		1	1	1	1	1	0	NC 2.2
5/7/2010	0	3	0	5	0	0	0	0	0	0	EB 2009
5/8/2012	1		1		1	1	1	1	1	1	NC 2.2
11/10/2006	1		1		0	0	0	1	0	0	NC 2.1
3/31/2004	1		0		1	0	0	0	1	0	NC 2.0
7/16/2009	0	0	1	0	0	0	1	0	1	1	EB 2.0
3/1/2011	1		1		0	1	1	1	1	1	NC 2.2
12/22/2010	0		0		0	1	1	1	1	1	NC 2.2
7/31/2013	0	3	0	5	0	0	0	0	0	0	EB 2009
3/23/2010	0		1		1	1	0	1	0	0	NC 2.2
10/14/2011	0	4	0	5	0	0	0	0	0	0	EB 2009
6/20/2013	1		1		0	1	1	1	2	1	NC 2009
9/8/2010	1		1		0	0	0	0	0	0	CI 2009
7/20/2009	0		1		1	1	1	1	1	1	NC 2.2
8/1/2006	1		1		1	0	0	1	0	0	NC 2.0
6/21/2012	0		1		1	1	0	1	0	0	NC 2.2
5/18/2009	0		0		0	0	0	0	0	0	NC 2.1

Appendix H: Expert summary building selection criteria

Summary of Expert Recommendation for Building Selections	
Industry and leading researchers :	**Focus Group:**
High/Low performers	High/low satisfaction performers
Small and large occupancy	Active BMS
Specialize function - office	Simple vs Complex buildings
Look at different products and versions	Dedicated operations
Ability to spend time in working space - multi-sensory understanding (general temp, light, glare, noise, acoustic measured levels)	Commissioning performed
Ability to interview variety of occupants	Good LEED documentation
Ability to triangulate - get thorough understanding across 3 types of investigation: measurements, interviews, observations and walks.	Complete interviews with Designer, Operations, Owner, and Occupants
Follow up CBE survey possible	Know specifics of design, implementation and operation
Ability to inspire future research	(Case Study research)
Already available case studies	Focus on Existing buildings
References: (Berg et al., 2004, Patton, 2005, Martin et al., 2012, Tracy, 2012, Heerwagen et al., 2004, Heerwagen and Zagreus, 2005, Vischer, 2008) Additional direct conversations with researcher and expert Judith Heerwagen used.	Reference: Content analysis of direct results from the Focus Group as described in Section 5.2 Expert/focus Group.

Appendix I: Building assessment desired documentation

Direct Building Assessment: Pre-visit documentation		
Design	**Construction**	**Occupancy**
Design drawings	As-Built Drawings	Trend analysis - points based on LEED strategies
Design specifications	As-Built Specifications	Operating hours and occupancy
Design equipment list	As-Built Equipment list	Service call logs
LEED Packet	Final LEED submission	O&M service records
	RFIs	Cleaning service type and schedule
	M&V Reports	List of recent repairs and rebuilds
	Cx Reports	Service contracts
	Testing performed	Any other surveys taken
		RCx reports
		Operations manual(s) and training guides
		Occupant-related policies

Appendix J: Building Assessment Interview Guide - sample

Occupant(s)

ID #:	Date:	
Question	Answer	N/A
1. Do you consider your space and work environment: informal, formal, causal or something else? Does this level of formality complement the work you do?		
2. Do you consider your position: Administrative support, Executive, Management, General Staff, other?		
3. What is your average day like? Time in office, desk work, meetings, team work, etc.? Do you have a preferred area to work (can be at home)? Why?		
4. What were your first impressions of the building and how do you feel about it now?		
5. How long have you worked in your current space and has there been any shifts of work group locations?		
6. Does you work fall into cycles and is there a time this is most prevalent? Does your perception of indoor environment quality may change with the cycle?		
7. What is it like to work here compared to how the space was before, previous building, etc.? (ask them to use multi-sensory descriptions) Would you say you're more, same or less satisfied?		
8. Do you feel you've been properly informed on the green features of the building? Trained?		
9. What is your experience (positive, neutral or negative) with the lighting? Natural and artificial.		
10. Views? (why)		
11. Visual comfort?		
12. Thermal comfort?		
13. Air quality?		
14. Favorite aspects of the building? Of your space?		
15. Less favorite aspects of the building? Of your space?		
16. If applicable, how do you use the occupant-controlled aspects of your space and does this affect your satisfaction? Were you trained to use these?		
17. What would you change about your building?		
18. Have you experience significant issues with the building? Branching question: If so how did you handle them?		
19. How does the space, if at all, impact your work? How do others in your space have an impact?		
20. If and how does the space related to the mission of your organization, group, etc.?		
21. Your building rated high with regard to pride in having a green building but low with a lack of understanding. What makes you proud? Do you think it's important to know about the green features and do you feel it's a priority for you personally to participate in reaching building performance goals?		
22. Is there a case you would rank a space you've been in as highly satisfied with IEQ? If so, what was it?		

Appendix J (continued): Building Assessment Interview Guide - sample

Building operations/management staff

ID #:	Date:	
Question	Answer	N/A
1. How long have you been in building operations/management?		
2. How long have you been working at this building?		
3. What types of duties do you perform?		
4. How are the day-to-day operational functions handled?		
5. Discuss and record findings from pre-visit documentation. (see site plan) a. Air Quality b. Thermal Comfort c. Lighting d. Visual Comfort		
6. Do you have an operation manual(s)? How effective are they and do you ever use them?		
7. Did you receive training when you started at this building? Branching question: If so what training did you receive?		
8. Was the training provided affective? Is it on-going?		
9. Are there any systems of the building which are particularly challenging? Branching question: if so, what do you feel is a factor related to this and how significantly do you feel it affects building performance?		
10. What systems are on the BMS? How is lighting controlled?		
11. What are you finding are the best-operating aspects of the building?		
12. What types of activities demand most of your attention?		
13. Have there been pervasive issues with the building (e.g. past water damage, etc.)?		
14. Have you experienced significant issues with the building? Branching question: If so how did you handle them?		
15. What are any "work-arounds" you had to use for systems or operational aspects of the building?		
16. What have you replaced? (e.g. systems, components, etc.)		
17. There was a time gap between LEED cert and occupant survey – when did they move in and were there any pervasive issues that were corrected?		
18. How do occupants of the building feel about it?		
19. How are occupants engaged? (e.g. complaint process, tenant meetings, regular surveys, etc.)? Are you given this information in a way you can use to support operating the building?		
20. How do you feel about the building?		
21. What was your favorite building that you've worked in? If not this one, what about it is not as good?		
22. Are you familiar with all the "green building" features of this building and how do you track performance of them?		
23. Specifically for Indoor Environment Quality (e.g. comfort, space, light, acoustics, etc.) what do you feel are the challenges and successes for this building?		
24. Why do you think satisfaction levels surveyed:		

Category	% satisfied	Percentile
Acoustic Quality	47%	68%
Air Quality	80%	91%
Lighting	75%	76%
Thermal Comfort	43%	51%
General Building	93%	92%
Workplace	83%	78%

Appendix J (continued): Building Assessment Interview Guide - sample

Building owner/management:

Building Name:	Date:	
Question	Answer	N/A
1. Have there been any major changes in staffing? Major restructuring: hiring, layoffs, furlows, work group moves, tenant changes?		
2. Are there major cycles of work for the study group areas? If so when and would on or off this cycle give us the truest sense of satisfaction levels?		
3. Does this building meet your intended purpose?		
4. Why did you go for LEED?		
5. How difficult was it to stay committed to LEED certification?		
6. Do you feel LEED helped or hurt the overall quality of the building?		
7. Do you feel LEED adds value to the property?		
8. Are there any other green building features outside of LEED you considered or installed and how are they performing?		
9. What was your motivation for building a sustainably (green) focused building?		
10. What polices or programs do you have in place to support the green performance of the building?		
11. Do you have ways to track organizational performance? Employee productivity, work goals, etc.		
12. Do the metrics for the building performance and its IEQ complement or are part of the overall performance metrics?		
13. How do occupants of the building feel about the building?		
14. How are occupants engaged? (e.g. complaint process, tenant meetings, regular surveys, etc.)? How is this information used?		
15. How do you feel in general about the building in its operating state?		
16. What metric or tool, if any, was or is used to evaluate operational performance? Branching question: same question for occupant satisfaction?		
17. Branching question: what did you expect to see, and what specifically was measured?		
18. What is your favorite building that you've been involved with or occupied, and if not this one, what about it is different?		
25. Why do you think satisfaction levels surveyed: Acoustic – 30% satisfied/ 12% percentile Air Quality – 57% satisfied/ 56% percentile Lighting – 63% satisfied/ 28% percentile Thermal Comfort – 27% satisfied/ 23% percentile		

General thoughts on Intention to Building/Construction to Operation:

- Air Quality
- Thermal Comfort
- Lighting
- Visual Comfort

Appendix J (continued): Building Assessment Interview Guide - sample

Building designer

Firm and Project Name:	Date:	
Question	Answer	N/A
1. What/who drove the design intentions?		
2. What specific IEQ strategies did you use in our subject building? a. Air Quality b. Thermal Comfort c. Lighting d. Visual Comfort (+ specifically approach to views?) e. Visual Privacy		
3. Did you hold a design charrette and if so who attended?		
4. How difficult was it to match the intentions to LEED criteria?		
5. How did you development and define them specific to IEQ-related goals?		
6. How do you feel about the final product in relation to the intent?		
7. Are there any other relevant issues you faced meeting LEED?		
8. What has since been added or amended from the original design?		
9. What are your best and least-liked aspects of LEED elements used? Branching question: What are your best and least-liked elements of green building strategies used in general for this building?		
10. Did you try a design element that you hadn't used in previous projects? Branching question: if so, how successful was it and under what conditions would you use it again?		
11. How do occupants of the building feel about the building?		
12. How do you feel about the building in its operating state?		
13. What metric, if any, was used in the building to evaluate that performance and for what duration was the building evaluated? Branching question: If so, what evaluation methodology was used?		
14. What did you expect to see, and what specifically was measured?		
15. What is your favorite building that you've designed, and if not this one, what about it is different?		
16. Why do you think satisfaction levels surveyed: Acoustic – 47% satisfied/ 68% percentile Air Quality – 80% satisfied/ 91% percentile Lighting – 75% satisfied/ 76% percentile Thermal Comfort – 43% satisfied/ 51% percentile General Building – 93% satisfied/92% percentile Workspace – 83% satisfied/78% percentile		

General thoughts on Intention to Building/Construction to Operation:

- Air Quality
- Thermal Comfort
- Lighting
- Visual Comfort

Additional Notes

CPHS reference outline

Focus group use: The discussions at the focus group initiated by HOK were probed for the sole purpose of colleting background information in order to help us understand the patterns of our quantitative analysis (from previous survey database) and to inform the selection of the study sites.

General Interviews:

- Interviews will be open-ended and additional questions maybe asked related to topics found in the interview guide questions.
- No exclusions other than area of the study building(s) will be used to select participants. Selected at random from area (or who consents). 18 years or older.
- Conducted by Dr. Gail Brager or Kristine Walker.
- Audio recordings maybe used. Captured via digital recorder and stored on GSR password protected computer.
- Audio recordings – listened to by direct researchers and erased once transcribed (within 1 week of visit).
- Still photos taken with permission. No photos with individuals recognizable unless written permission obtained.
- Media release and consent form needed. 18 years or older.
- All interviews (written, recorded, and transcribed) managed via assigned IDs and only available to the direct researchers.
- Consideration of any individually identifiable comments will be considered and remain unpublished.
- Transcripts will be deleted from the personal computer of the GSR and all information stored on the CBE Y:drive for a minimum of 3 years.

Occupant interviews:

- Randomized – with specific areas (floors or zones) targeted based on previously surveyed information
- In person
- IDs determined prior to arrival at site using excel – assigned in numerical order
- All interviews (written, recorded, and transcribed) managed via assigned IDs and only available to the direct researchers.
- IDs will be limited to the locations within the building and not directly identifiable information about the participant.
- Introductory email sent – sent to building representative and then they sent to occupants – occupants are asked to contact researchers directly if they are interested in participating. The email must go to all people in the study area.
- 15 to 20 minutes

Appendix J (continued): Building Assessment Interview Guide – additional notes

Designers:

- 30 to 45 minutes per interview
- Pre–visit
- Found via website search - contacted directly phone and/or email.
- Phone or in person interview
- Follow-up as needed questions may be asked. 5 to 30 minutes.

Building Operators:

- Introductory email sent to the building representative authorizing the study and they will forward to operators. The operators are asked in the email to contact researchers directly if they are interested in participating.
- 30 to 45 minutes
- Follow-up as needed questions may be asked. 5 to 30 minutes.

Building Management/Owner:

- Found via web search - contacted directly phone and/or email.
- Phone or in person interview
- Follow-up as needed questions may be asked. 5 to 30 minutes.

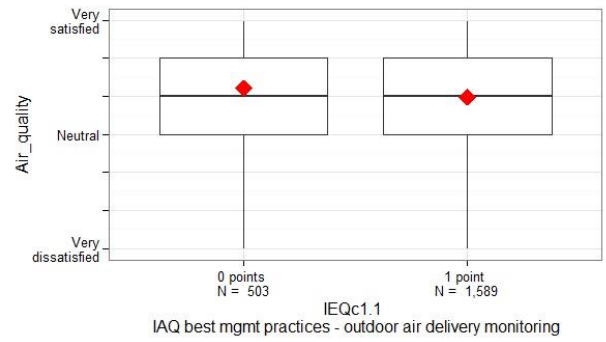
Post-visit occupant follow up CBE survey:

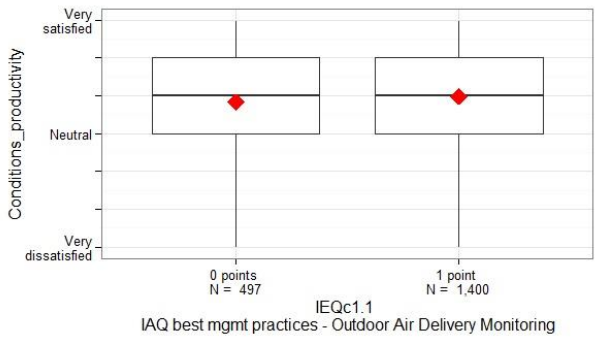
- 15 to 30 minutes
- Same format as original survey

Appendix K: LEED credit/CBE survey question pairings

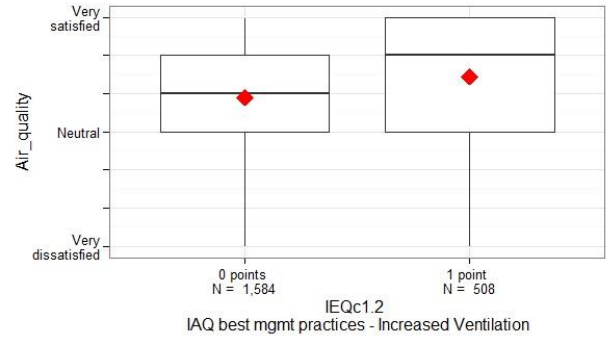
Note: For all the Appendix K graphs, the paired credit is found on the x axis, the level of surveyed satisfaction is found on the y axis, the red diamonds are the mean values. Also results for credits labeled "2 points possible" (highlighted) use the maximum difference the maximum difference of satisfaction from 0 to 2 points and therefore, is not directly comparable to other pairings.

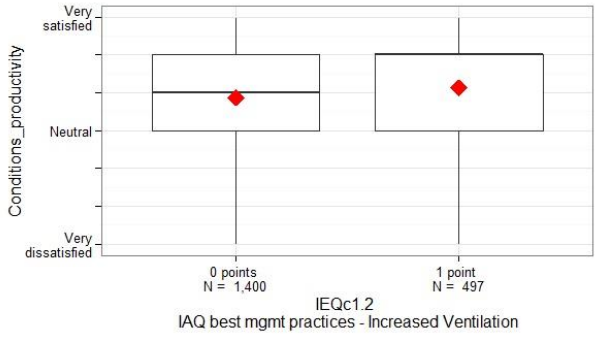
Credit 1 (also see Figure 4)



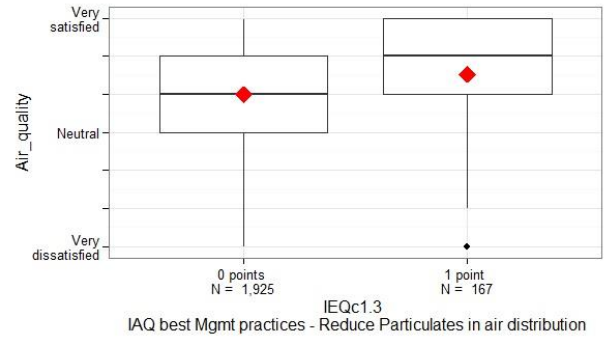


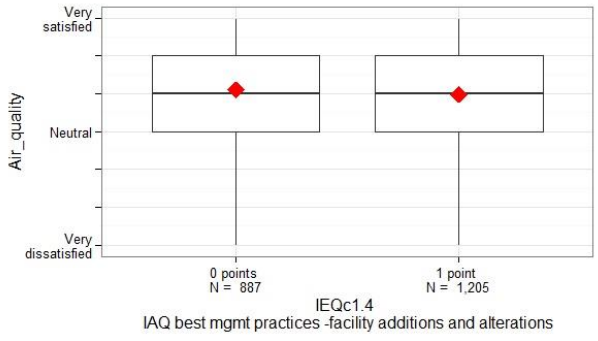
ΔM = -0.24 %ΔM = -4 ES (effect size) = -0.05	Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada	ΔM = 0.15 %ΔM = 3 ES =0.05	Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada





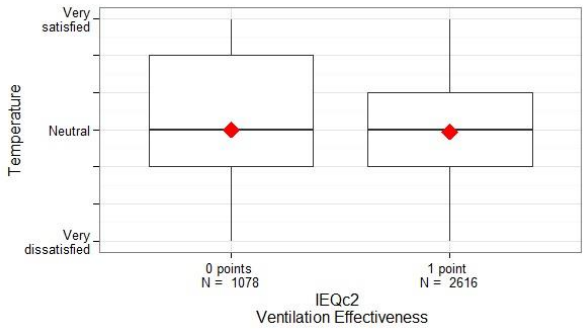
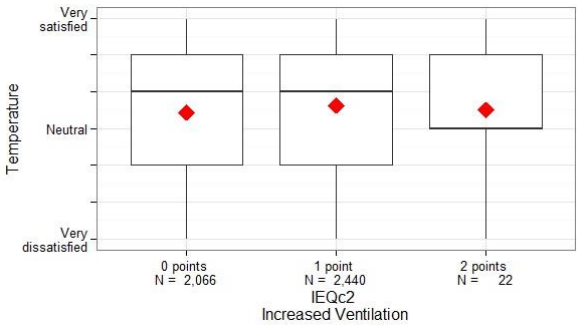
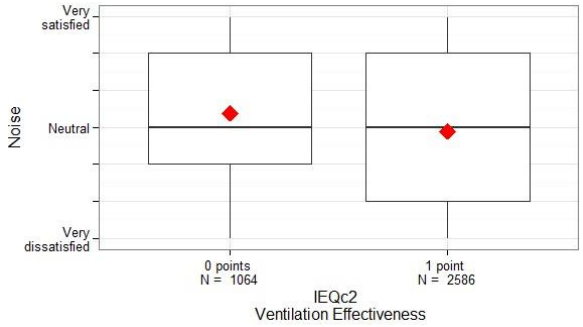
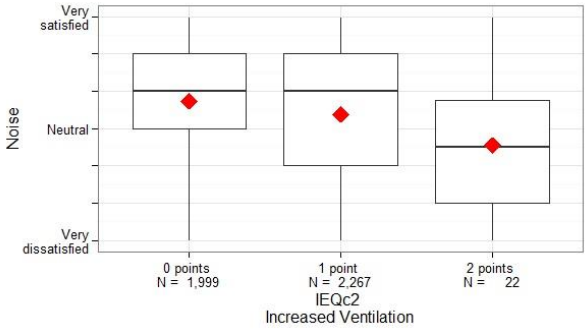
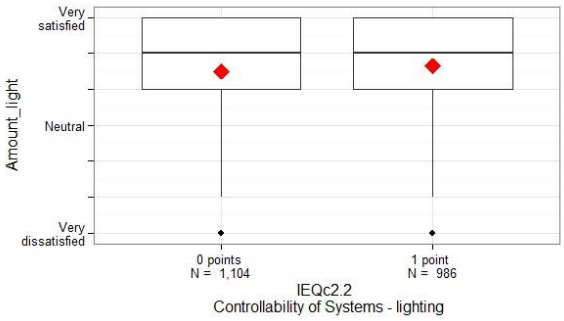
ΔM = 0.54 %ΔM = 9 ES = .16	Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada	ΔM = 0.25 %ΔM = 4 ES= 0.07	Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada



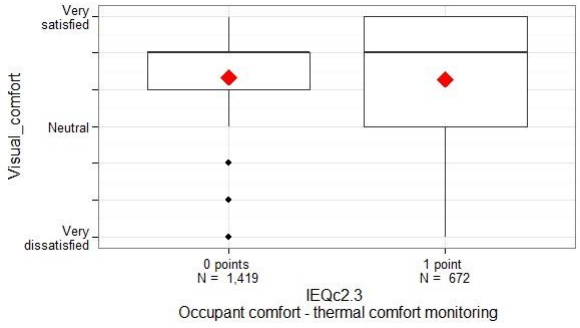


ΔM = 0.54 %ΔM = 9 ES = 0.1	Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada	ΔM =- 0.12 %ΔM = -2 ES= -0.02	Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada

Appendix K: LEED credit/CBE survey question pairings (continued)

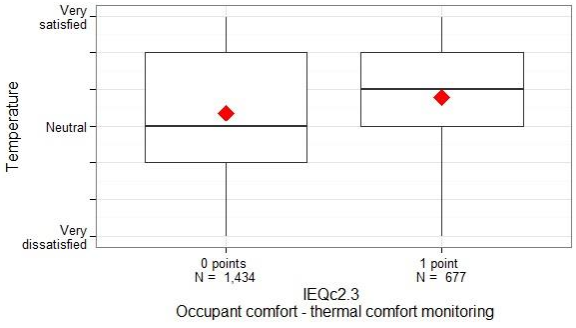
<table>
<tr><td colspan="4">Credit 2 (also see Figure 4)</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = -0.06
%ΔM = -1
ES = -.01</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, EB 1.0</td><td>ΔM = 0.18
%ΔM = 3
ES = .05</td><td>Grouping: NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, Canada CI 1.0 and EB 2.0.</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = -0.51
%ΔM = -9
ES = -.12</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, EB 1.0</td><td>ΔM = -1.18
%ΔM = -20
ES = -.09</td><td>Grouping: NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, Canada CI 1.0 and EB 2.0.</td></tr>
<tr><td colspan="2">Credit 2.1 Occupant survey – not analzyed</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM =
%ΔM =
ES =</td><td>Groupings:</td><td>ΔM = 0.16
%ΔM = 3
ES= .09</td><td>Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada</td></tr>
</table>

Credit 2 (continued)



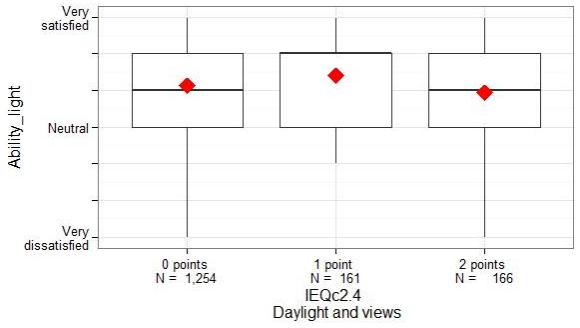
ΔM = 0.05
%ΔM = 1
ES = 0.01

Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada

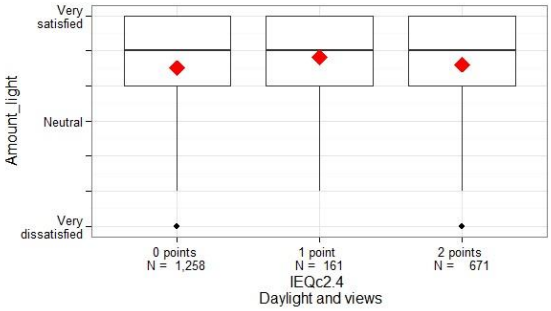


ΔM = 0.42
%ΔM = 7
ES= 0.12

Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada

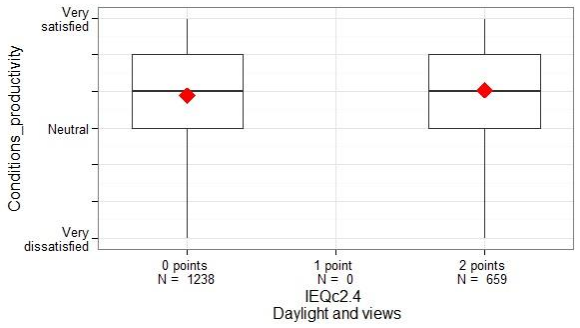


Note: relatively low sample size
ΔM =
%ΔM =
ES =



ΔM = .29
%ΔM = 5
ES = 0.07

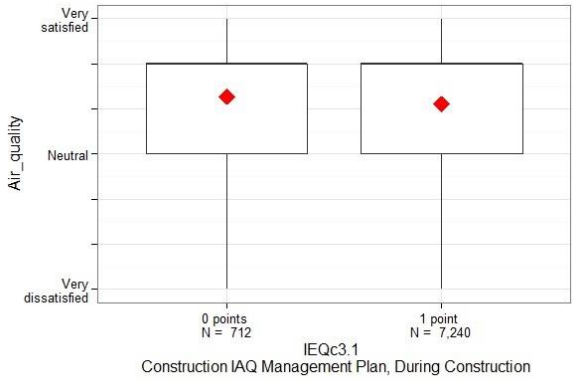
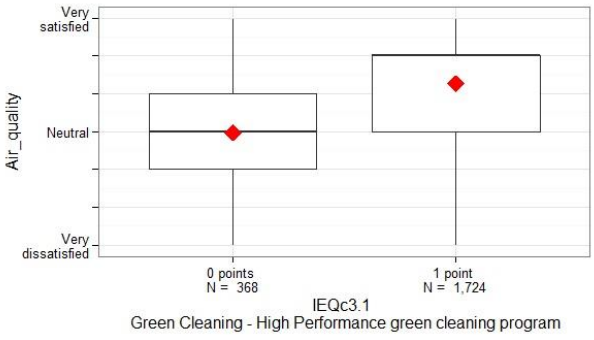
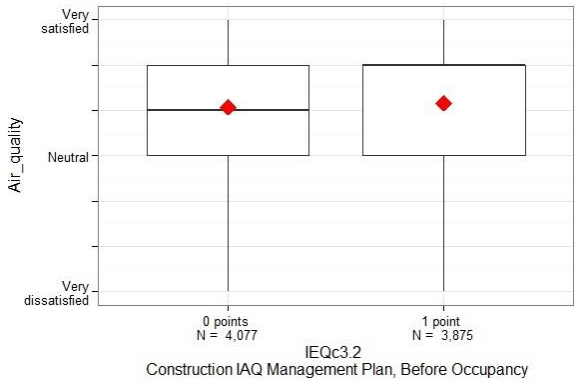
Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada



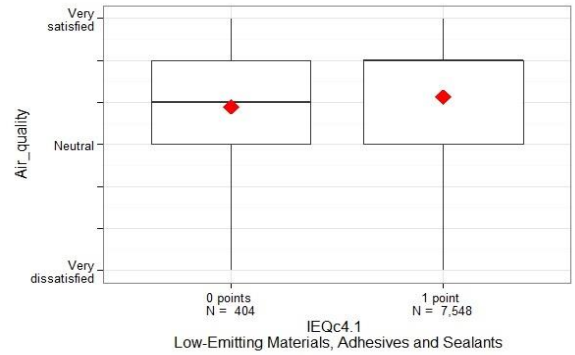
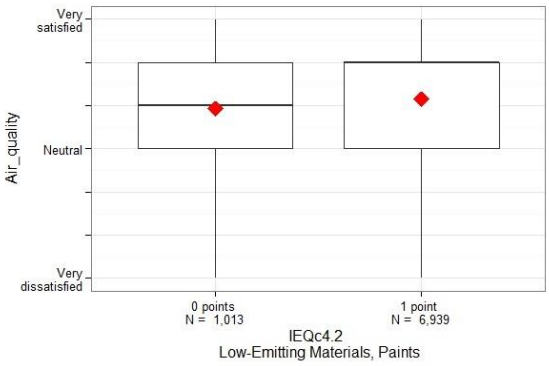
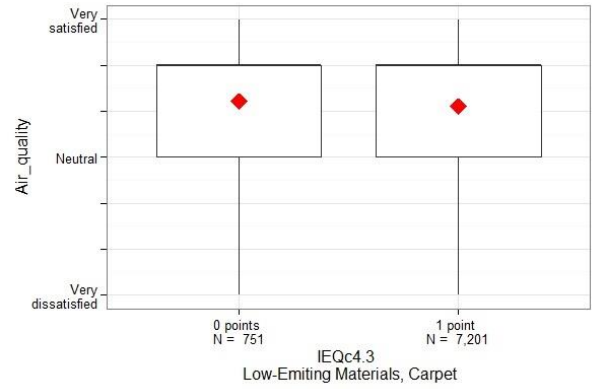
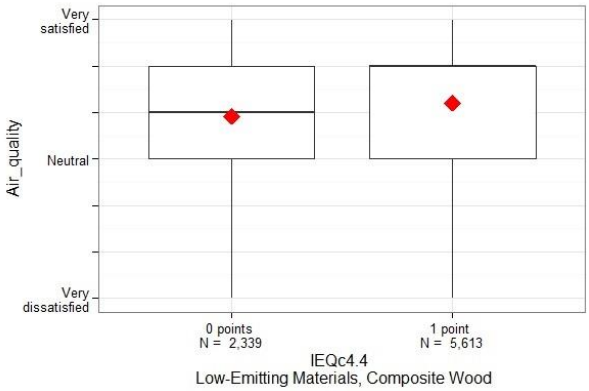
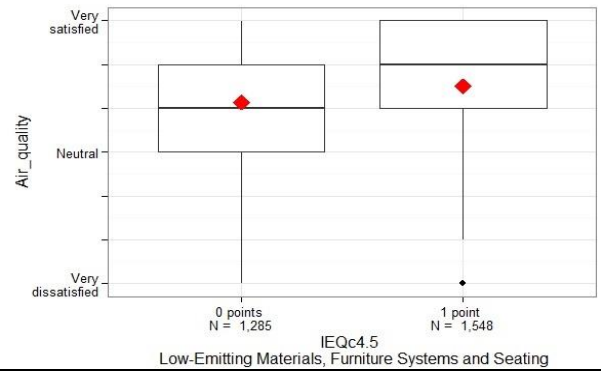
Note: All projects 0 or 2 points
ΔM = 0.14
%ΔM = 2
ES=0.05

Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada

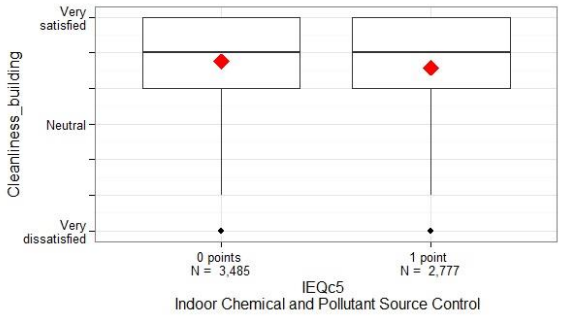
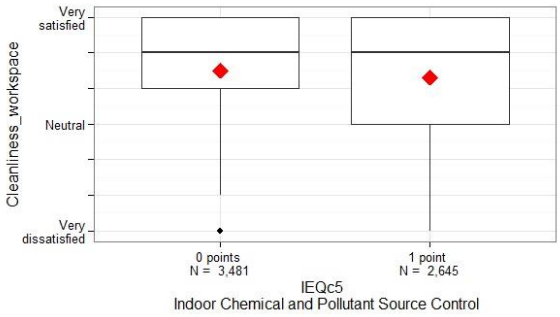
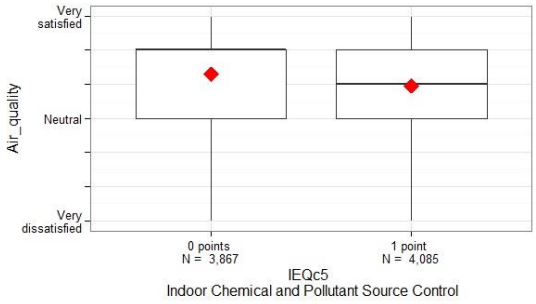
Appendix K: LEED credit/CBE survey question pairings (continued)

<table>
<tr><th colspan="4">Credit 3</th></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = -0.019
%ΔM = -3
ES = -0.03</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td><td>ΔM = 1.29
%ΔM = 22
ES= 0.3</td><td>Grouping: EB 2008, EBOM 2008, EB 2009, EBOM Canada</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"></td></tr>
<tr><td>ΔM = 0.08
%ΔM = 1
ES = 0.02</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td><td colspan="2"></td></tr>
</table>

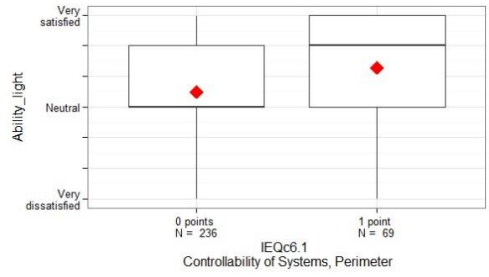
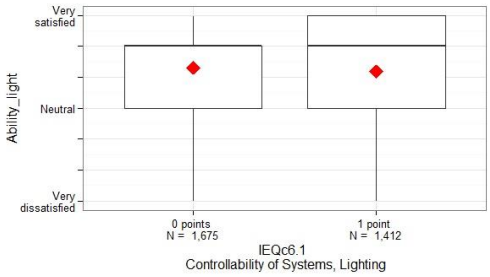
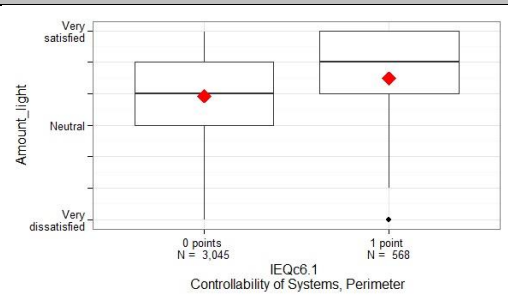
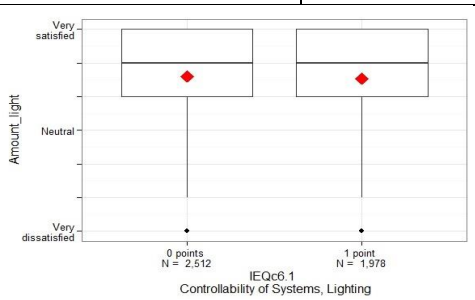
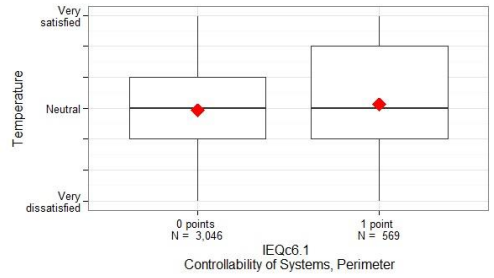
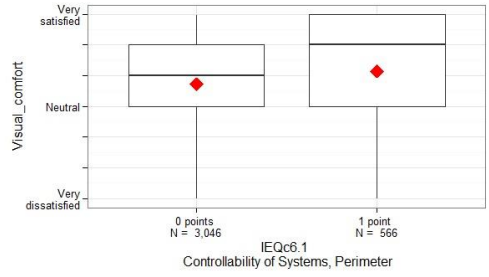
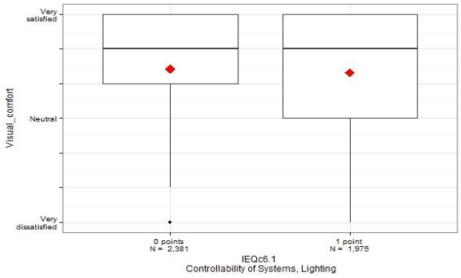
Appendix K: LEED credit/CBE survey question pairings (continued)

<table>
<tr><th colspan="4">Credit 4</th></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = 0.23
%ΔM = 4
ES = 0.04</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td><td>ΔM = .023
%ΔM = 4
ES = 0.05</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = - 0.11
%ΔM = -2
ES = -0.01</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td><td>ΔM = 0.29
%ΔM = 5
ES = 0.08</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"></td></tr>
<tr><td>ΔM = 0.47
%ΔM = 8
ES = 0.012</td><td>Grouping: CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td><td></td><td></td></tr>
</table>

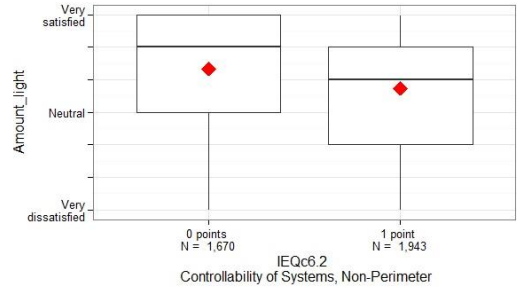
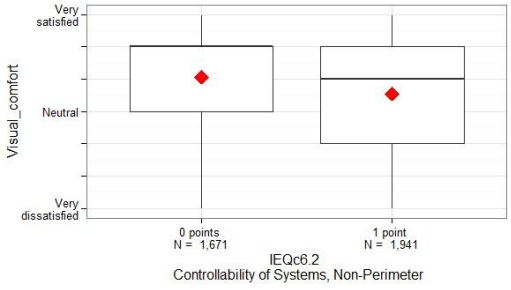
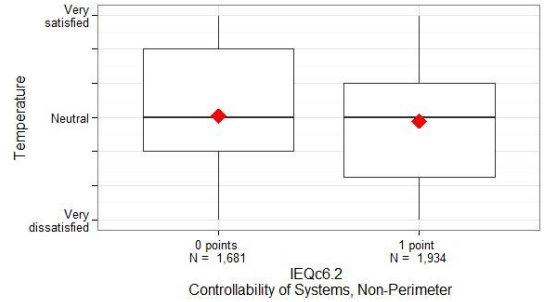
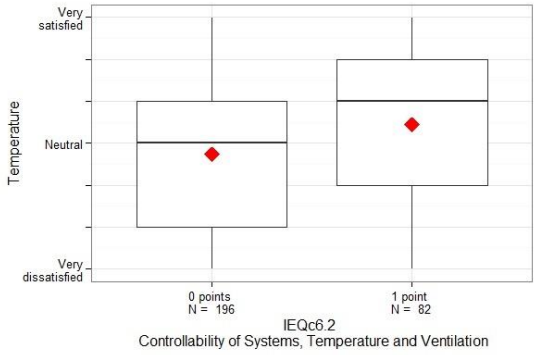
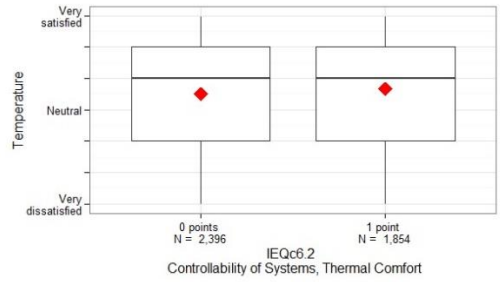
Appendix K: LEED credit/CBE survey question pairings (continued)

<table>
<tr><th colspan="4">Credit 5</th></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = -0.17
%ΔM = -3
ES = -0.05</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td><td>ΔM = -0.19
%ΔM = -3
ES = -0.05</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"></td></tr>
<tr><td>ΔM = -0.33
%ΔM =-6
ES = -0.1</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, and Canada CI 1.0.</td><td colspan="2"></td></tr>
</table>

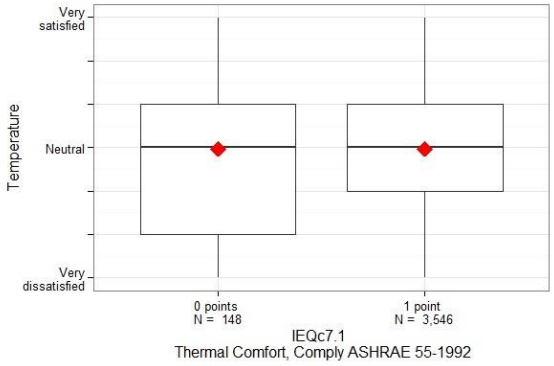
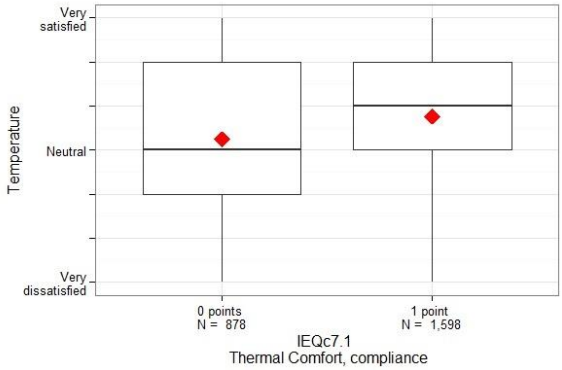
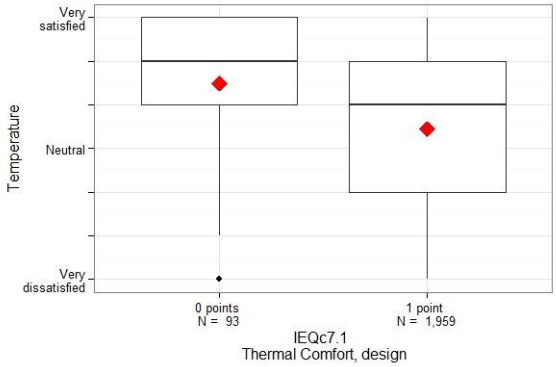
Appendix K: LEED credit/CBE survey question pairings (continued)

<table>
<tr><td colspan="4">Credit 6</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td colspan="2">Note: relatively low sample size</td><td>ΔM = -0.13
%ΔM = -2
ES = -0.02</td><td>Grouping: NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, Canada CI 1.0 and EB 2.0.</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = 0.53
%ΔM = 9
ES = 0.12</td><td>Grouping: NC 2.0, NC 2.0/2.1, and NC 2.1</td><td>ΔM = -0.07
%ΔM = -1
ES = 0</td><td>Grouping: NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, Canada CI 1.0 and EB 2.0.</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"></td></tr>
<tr><td>ΔM = 0.18
%ΔM = 3
ES = 0.03</td><td>Grouping: NC 2.0, NC 2.0/2.1, and NC 2.1</td><td></td><td></td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = 0.38
%ΔM = 6
ES = 0.09</td><td>Grouping: NC 2.0, NC 2.0/2.1, and NC 2.1</td><td>ΔM = -0.11
%ΔM = -2
ES = -0.03</td><td>Grouping: NC 2.2, NC 2009, CI 1.0, CI 2.0, CI 2009, Canada CI 1.0 and EB 2.0.</td></tr>
</table>

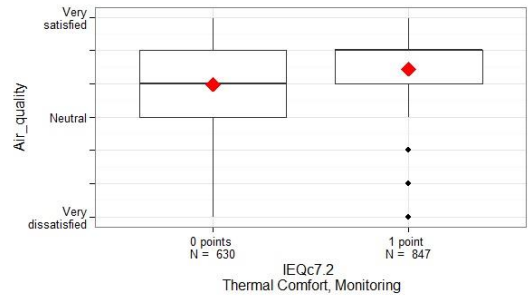
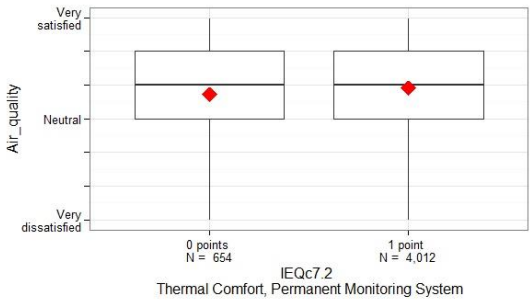
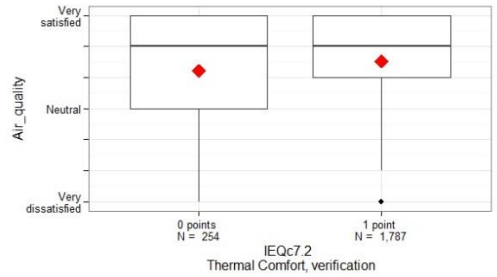
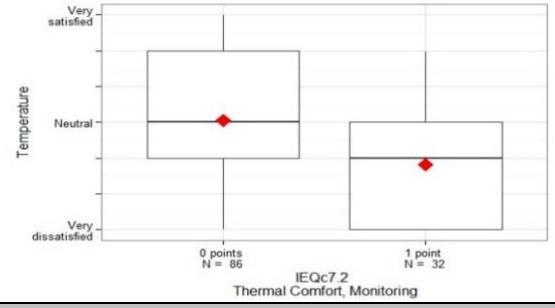
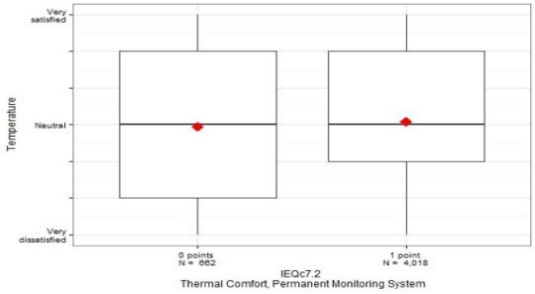
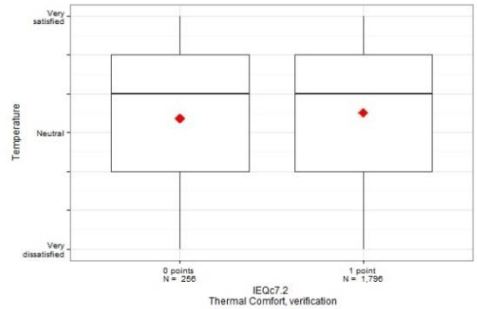
Appendix K: LEED credit/CBE survey question pairings (continued)

<table>
<tr><th colspan="4">Credit 6.2</th></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = -0.63
%ΔM = -11
ES = -0.18</td><td>Grouping: NC 2.0, NC 2.0/2.1, and NC 2.1</td><td>ΔM = -0.55
%ΔM = -9
ES = -0.16</td><td>Grouping: NC 2.0, NC 2.0/2.1, and NC 2.1</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = -0.16
%ΔM = -3
ES = -0.04</td><td>Grouping: NC 2.0, NC 2.0/2.1, and NC 2.1</td><td colspan="2">Note: Relatively low sample size</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"></td></tr>
<tr><td>ΔM = 0.16
%ΔM = 3
ES = 0.05</td><td>Grouping: NC 2.2, NC 2009, CI 2.0, CI 2009, Canada CI 1.0.</td><td colspan="2"></td></tr>
</table>

Appendix K: LEED credit/CBE survey question pairings (continued)

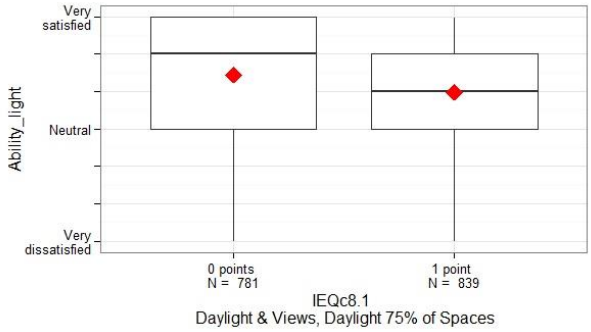
<table>
<tr><th colspan="3">Credit 7.1</th></tr>
<tr><td> 
</td><td colspan="2"> 
</td></tr>
<tr><td>Note: Relatively low sample size (0 points)</td><td>ΔM = 0.36
%ΔM = 6
ES = 0.09</td><td>Grouping: CI 1.0, CI 2.0, Canada CI 1.0, and EB 2.0.</td></tr>
<tr><td> 
</td><td colspan="2"></td></tr>
<tr><td>Note: Relatively low sample size (0 points)</td><td colspan="2"></td></tr>
</table>

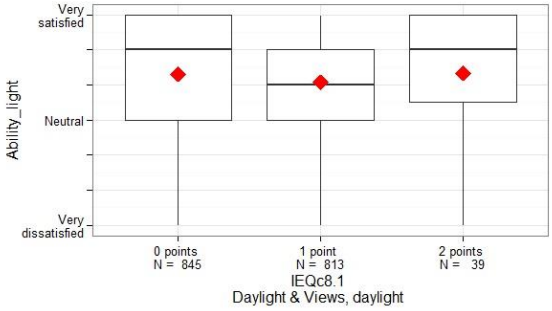
Appendix K: LEED credit/CBE survey question pairings (continued)

<table>
<tr><th colspan="4">Credit 7.2</th></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td>ΔM = 0.48
%ΔM = .8
ES = 0.16</td><td>Grouping: CI 1.0 and Canada CI 1.0.</td><td>ΔM = 0.33
%ΔM = 6
ES = 0.06</td><td>Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 2.0, EB 1.0, and EB 2.0.</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"></td></tr>
<tr><td>ΔM = 0.32
%ΔM = 5
ES = 0.06</td><td>Grouping: NC 2.2, NC 2009, and CI 2009.</td><td colspan="2"></td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"> 
</td></tr>
<tr><td colspan="2">Note: Relatively low sample sizes</td><td>ΔM = 0.19
%ΔM = 3
ES = 0.03</td><td>Grouping: CI 1.0 and Canada CI 1.0.</td></tr>
<tr><td colspan="2"> 
</td><td colspan="2"></td></tr>
<tr><td>ΔM = 0.15
%ΔM = 3
ES = 0.03</td><td>Grouping: NC 2.2, NC 2009, and CI 2009.</td><td colspan="2"></td></tr>
</table>

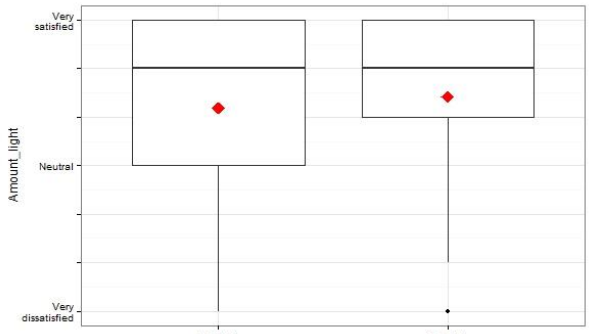
Appendix K: LEED credit/CBE survey question pairings (continued)

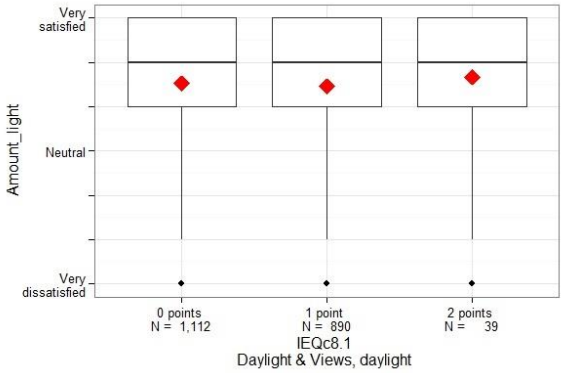
Credit 8.1



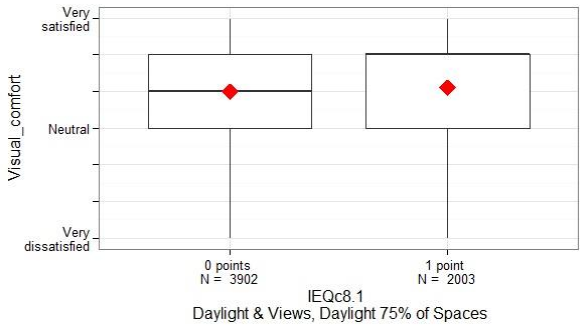


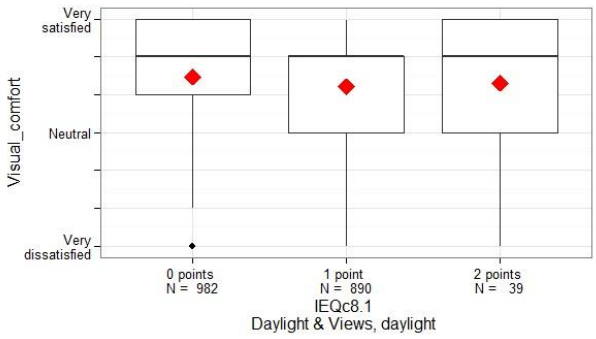
ΔM = -0.39 %ΔM = -7 ES = -0.14	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	Note: Relatively low 2 points sample size ΔM = -0.25 %ΔM = -4 ES = -0.07	Grouping: NC 2.2, NC 2009, and CI 2009.





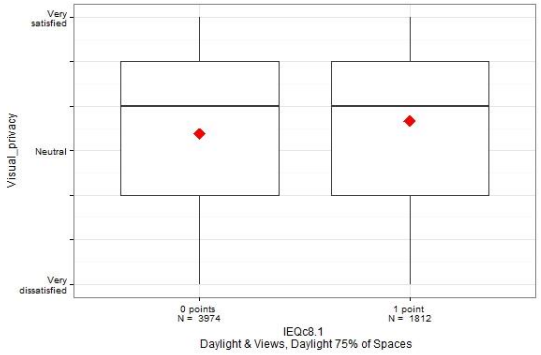
ΔM = 0.14 %ΔM = 2 ES = 0.03	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	Note: Relatively low 2 points sample size ΔM = -0.22 %ΔM = -4 ES = -0.03	Grouping: NC 2.2, NC 2009, and CI 2009.

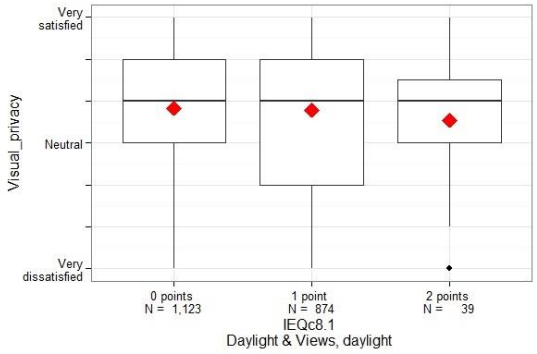




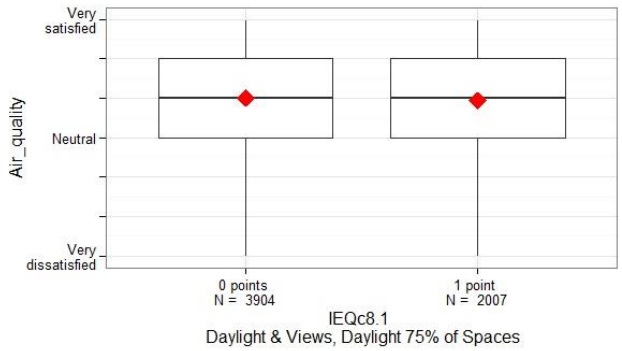
ΔM = 0.04 %ΔM = 1 ES = -0	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	Note: Relatively low 2 points sample size ΔM = -0.25 %ΔM = -4 ES= -0.07	Grouping: NC 2.2, NC 2009, and CI 2009.

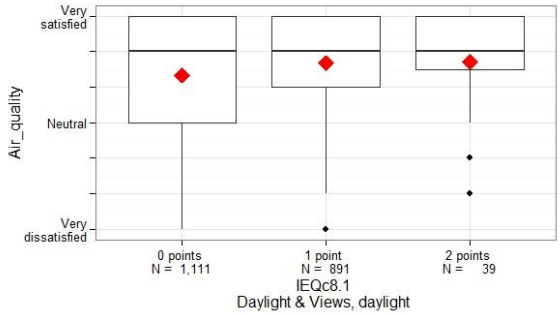
8.1 (continued)



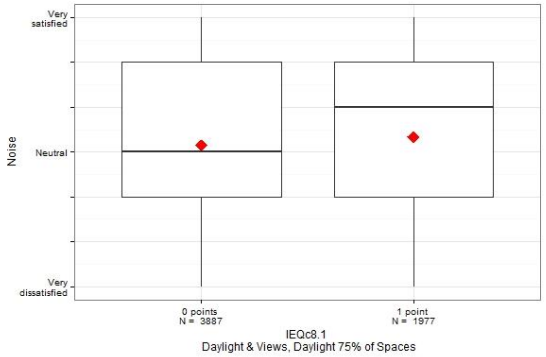


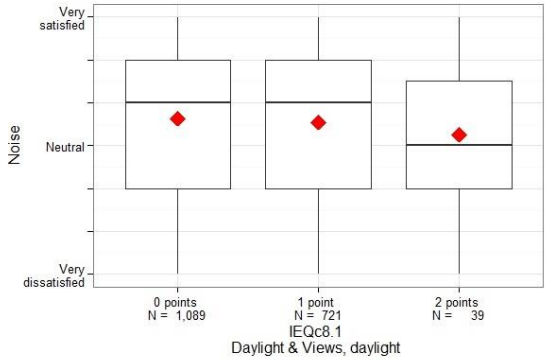
ΔM = 0.32 %ΔM = 5 ES = 0.08	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	Note: Relatively low 2 points sample size ΔM = -0 .28 %ΔM = -5 ES = -0.02	Grouping: NC 2.2, NC 2009, and CI 2009.





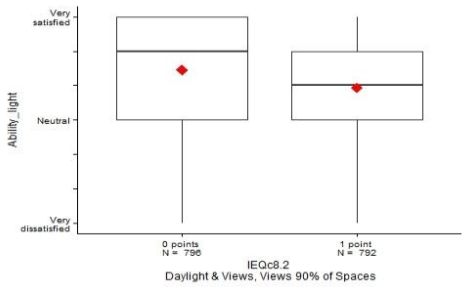
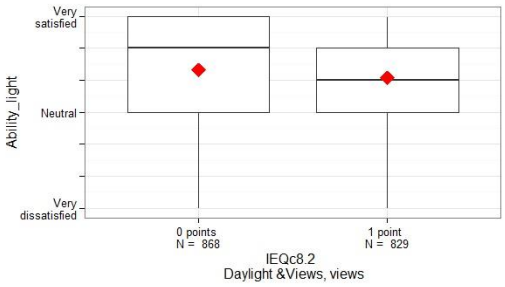
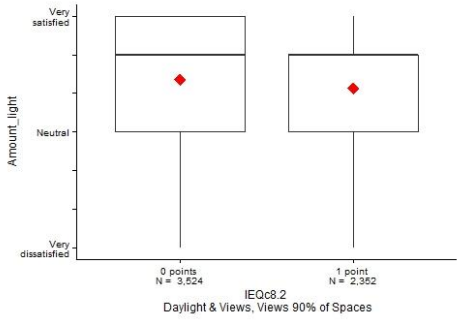
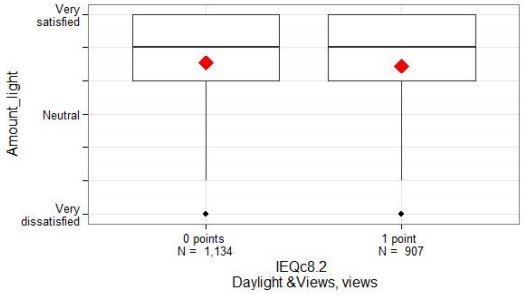
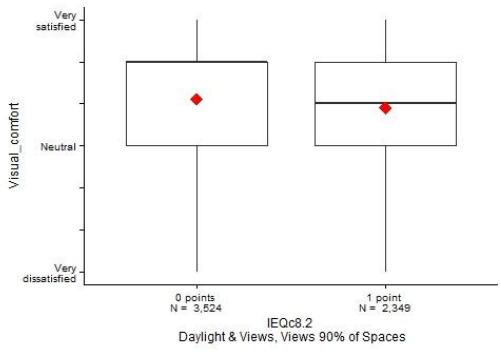
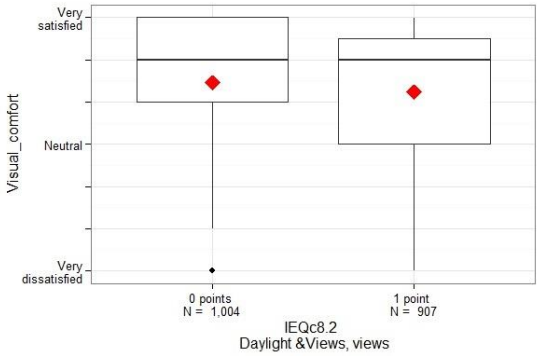
ΔM = 0.09 %ΔM = 2 ES = 0.03	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	Note: Relatively low 2 points sample size ΔM = 0.38 %ΔM = 6 ES = 0.1	Grouping: NC 2.2, NC 2009, and CI 2009.



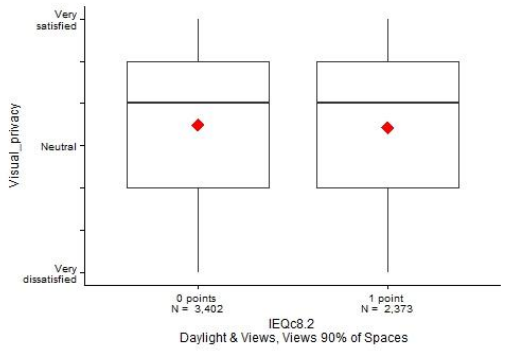
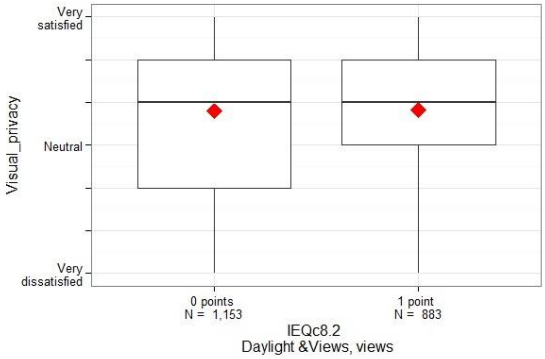
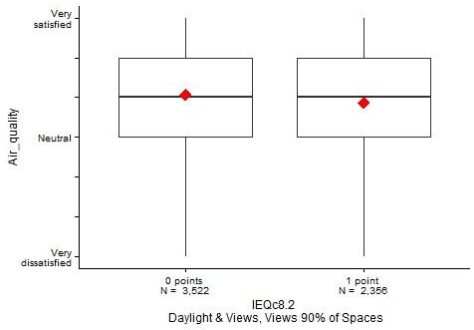
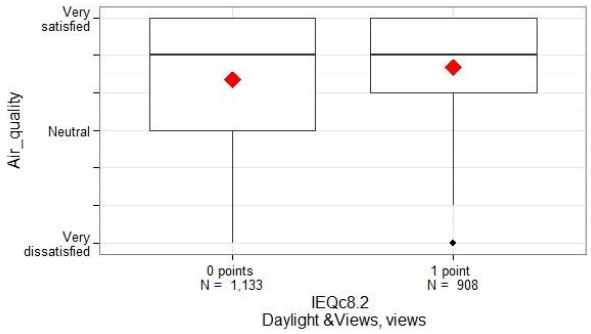
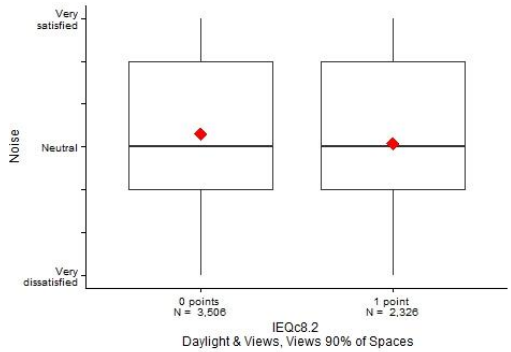
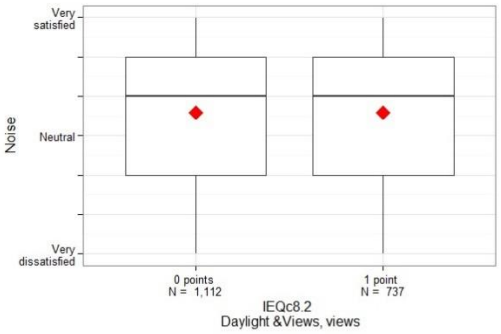


ΔM = 0.14 %ΔM = 2 ES = 0.03	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	Note: Relatively low 2 points sample size ΔM = -0.37 %ΔM = -6 ES = -0.03	Grouping: NC 2.2, NC 2009, and CI 2009.

Appendix K: LEED credit/CBE survey question pairings (continued)

8.2			
			
ΔM = -0.42 %ΔM = -7 ES = -0.15	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	ΔM = -0.24 %ΔM = -4 ES = -0.08	Grouping: NC 2.2, NC 2009, and CI 2009.
			
ΔM = -0.22 %ΔM = -4 ES = -0.04	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	ΔM = -0.10 %ΔM = -2 ES = -0.04	Grouping: NC 2.2, NC 2009, and CI 2009.
			
ΔM = -0.22 %ΔM = -4 ES = -0.07	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	ΔM = -0.23 %ΔM = -4 ES = -0.07	Grouping: NC 2.2, NC 2009, and CI 2009.

Appendix K: LEED credit/CBE survey question pairings (continued)

8.2 (continued)			
			
ΔM = -0 .05 %ΔM = -1 ES = -0.01	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	ΔM = -0.02 %ΔM = 0 ES = -0.01	Grouping: NC 2.2, NC 2009, and CI 2009.
			
ΔM = -0.07 %ΔM = -1 ES = -0.04	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	ΔM = 0.33 %ΔM = 6 ES = 0.08	Grouping: NC 2.2, NC 2009, and CI 2009.
			
ΔM = -0.19 %ΔM = -3 ES = -0.0	Grouping: NC 2.0, NC 2.0/2.1, NC 2.1, CI 1.0, CI 2.0, Canada CI 1.0	ΔM = -0.01 %ΔM = 0 ES = -0.01	Grouping: NC 2.2, NC 2009, and CI 2009.

Appendix L – Individual IEQ Credit and Survey Question pairing testing

credit	name	group	survey question	ΔM	%ΔM	Effect Size
IEQc1	CO2 Monitoring	B, E	Air quality	-0.59	-10	-0.13
IEQc1	Outdoor Air Delivery Monitoring	C, C.1, C.2, C.3, C.4, F	Air quality	0.1	2	0.04
IEQc1.1	IAQ best management practices - outdoor air delivery monitoring	G, G.1	Air quality	-0.24	-4	-0.05
IEQc1.1	IAQ best management practices - outdoor air delivery monitoring	G, G.1	Conditions productivity	0.15	3	0.05
IEQc1.2	IAQ best management practices - increased ventilation	G, G.1	Air quality	0.54	9	0.16
IEQc1.2	IAQ best management practices - increased ventilation	G, G.1	Conditions productivity	0.25	4	0.07
IEQc1.3	IAQ best management practices - reduce particulates in air distribution	G, G.1	Air quality	0.54	9	0.1
IEQc1.4	IAQ best management practices - facility additions and alterations	G, G.1	Air quality	-0.12	-2	-0.02
IEQc2	Ventilation Effectiveness	B, E	Air quality	-0.32	-5	-0.1
IEQc2	Increased Ventilation (2 points possible)	C, C.1, C.2, C.3, C.4, F	Air quality	0.26	4	0.07
IEQc2	Ventilation Effectiveness	B, E	Noise	-0.51	-9	-0.12
IEQc2	Increased Ventilation (2 points possible)	C, C.1, C.2, C.3, C.4, F	Noise	-1.18	-20	-0.09
IEQc2	Ventilation Effectiveness	B, E	Temperature	-0.06	-1	-0.01
IEQc2	Increased Ventilation (2 points possible)	C, C.1, C.2, C.3, C.4, F	Temperature	0.18	3	0.05
IEQc2.2	Controllability of Systems - lighting	G, G.1	Amount light	0.16	3	0.09
IEQc2.3	Occupant comfort - thermal comfort monitoring	G, G.1	Visual comfort	0.05	1	0.01
IEQc2.3	Occupant comfort - thermal comfort monitoring	G, G.1	Temperature	0.42	7	0.12
IEQc2.4	Daylight and views(2 points possible)	G, G.1	Amount light	0.29	5	0.07
IEQc2.4	Daylight and views(2 points possible)	G, G.1	Ability light	0.46	8	0.01
IEQc2.4	Daylight and views(Only achieved 0 or 2 points)	G, G.1	Conditions productivity	0.14	2	0.05
IEQc3.1	Construction IAQ Management Plan, During Construction	B, C, C.1, C.2, C.3, C.4	Air quality	-0.19	-3	-0.03
IEQc3.1	Green Cleaning - High Performance green cleaning program	G, G.1	Air quality	1.29	22	0.3
IEQc3.2	Construction IAQ Management Plan, Before Occupancy	B, C, C.1, C.2, C.3, C.4	Air quality	0.08	1	0.02
IEQc4.1	Low-Emitting Materials, Adhesives and Sealants	B, C, C.1, C.2, C.3, C.4	Air quality	0.23	4	0.04
IEQc4.2	Low-Emitting Materials, Paints	B, C, C.1, C.2, C.3, C.4	Air quality	0.23	4	0.05
IEQc4.3	Low-Emiting Materials, Carpet	B, C, C.1, C.2, C.3, C.4	Air quality	-0.11	-2	-0.01
IEQc4.4	Low-Emitting Materials, Composite Wood	B, C, C.1, C.2, C.3, C.4	Air quality	0.29	5	0.08
IEQc4.5	Low-Emitting Materials, Furniture Systems and Seating	B, C.1, C.2, C.3, C.4	Air quality	0.47	8	0.12
IEQc5	Indoor Chemical and Pollutant Source Control	B, C, C.1, C.2, C.3, C.4	Air quality	-0.33	-6	-0.1
IEQc5	Indoor Chemical and Pollutant Source Control	B, C, C.1, C.2, C.3, C.4	Cleanliness building	-0.17	-3	-0.05
IEQc5	Indoor Chemical and Pollutant Source Control	B, C, C.1, C.2, C.3, C.4	Cleanliness workspace	-0.19	-3	-0.05
IEQc6.1	Controllability of Systems, Perimeter	B	Conditions productivity	0.49	8	0.1
IEQc6.1	Controllability of Systems, Perimeter	B	Amount light	0.53	9	0.12
IEQc6.1	Controllability of Systems, Perimeter	B	Visual comfort	0.38	6	0.09
IEQc6.1	Controllability of Systems, Perimeter	B	Temperature	0.18	3	0.03
IEQc6.1	Controllability of Systems, Lighting	C, C.1, C.2, C.3, C.4, F	Ability light	-0.13	-2	-0.02
IEQc6.1	Controllability of Systems, Lighting	C, C.1, C.2, C.3, C.4, F	Visual comfort	-0.11	-2	-0.03

Appendix L – Individual IEQ Credit and Survey Question pairing testing continued

IEQc6.2	Controllability of Systems, Non-Perimeter	B	Amount light	-0.63	-11	-0.18
IEQc6.2	Controllability of Systems, Non-Perimeter	B	Visual comfort	-0.55	-9	-0.16
IEQc6.2	Controllability of Systems, Non-Perimeter	B	Temperature	-0.16	-3	-0.04
IEQc6.2	Controllability of Systems, Thermal Comfort	C, C.1, C.2, C.3	Temperature	0.16	3	0.05
IEQc7.1	Thermal Comfort, compliance	C.1, C.3, C.4, F	Temperature	0.36	6	0.09
IEQc7.2	Thermal Comfort, Permanent Monitoring System	B, C.1, E, F	Temperature	0.19	3	0.03
IEQc7.2	Thermal Comfort, Verification	C, C.2	Temperature	0.15	3	0.02
IEQc7.2	Thermal Comfort, Permanent Monitoring System	B, C.1, E, F	Air quality	0.33	6	0.06
IEQc7.2	Thermal Comfort, Verification	C, C.2	Air quality	0.32	5	0.06
IEQc7.2	Thermal Comfort Monitoring	C.3, C.4	Air quality	0.48	8	0.16
IEQc8.1	Daylight & Views, Daylight 75% of Spaces	B, C.1, C.3	Noise	0.14	2	0.03
IEQc8.1	Daylight & Views, daylight (2 points possible)	C, C.2	Noise	-0.37	-6	-0.03
IEQc8.1	Daylight & Views, Daylight 75% of Spaces	B, C.1, C.3	Amount light	0.14	2	0.03
IEQc8.1	Daylight & Views, daylight (2 points possible)	C, C.2	Amount light	-0.22	-4	-0.03
IEQc8.1	Daylight & Views, Daylight 75% of Spaces	B, C.1, C.3	Visual privacy	0.32	5	0.08
IEQc8.1	Daylight & Views, daylight (2 points possible)	C, C.2	Visual privacy	-0.28	-5	-0.02
IEQc8.1	Daylight & Views, Daylight 75% of Spaces	B, C.1, C.3	Visual comfort	0.04	1	0
IEQc8.1	Daylight & Views, daylight (2 points possible)	C, C.2	Visual comfort	-0.25	-4	-0.08
IEQc8.1	Daylight & Views, Daylight 75% of Spaces	B, C.1, C.3	Ability light	-0.39	-7	-0.14
IEQc8.1	Daylight & Views, daylight (2 points possible)	C, C.2	Ability light	-0.25	-4	-0.07
IEQc8.1	Daylight & Views, Daylight 75% of Spaces	B, C.1, C.3	Air quality	0.09	2	0.03
IEQc8.1	Daylight & Views, daylight (2 points possible)	C, C.2	Air quality	0.38	6	0.1
IEQc8.2	Daylight & Views, View 90% of Spaces	B, C.1, C.3	Noise	-0.19	-3	-0.05
IEQc8.2	Daylight & Views, views	C, C.2	Noise	-0.01	0	-0.01
IEQc8.2	Daylight & Views, Views 90% of Spaces	B, C.1, C.3	Visual comfort	-0.22	-4	-0.07
IEQc8.2	Daylight & Views, views	C, C.2	Visual comfort	-0.23	-4	-0.07
IEQc8.2	Daylight & Views, Views 90% of Spaces	B, C.1, C.3	Visual privacy	-0.05	-1	-0.01
IEQc8.2	Daylight & Views, views	C, C.2	Visual privacy	-0.02	0	-0.01
IEQc8.2	Daylight & Views Views 90% of Spaces	B, C.1, C.3	Ability light	-0.42	-7	-0.15
IEQc8.2	Daylight & Views, views	C, C.2	Ability light	-0.24	-4	-0.08
IEQc8.2	Daylight & Views, Views 90% of Spaces	B, C.1, C.3	Air quality	-0.07	-1	-0.04
IEQc8.2	Daylight & Views, views	C, C.2	Air quality	0.33	6	0.08
IEQc8.2	Daylight & Views, Views 90% of Spaces	B, C.1, C.3	Amount light	-0.22	-4	-0.07
IEQc8.2	Daylight & Views, views	C, C.2	Amount light	-0.1	-2	-0.04

Group Key	
A	NC 1.0
B	NC 2.0, 2.0/2.1, 2.1
C	NC 2.2, 2009
C.1	CI 2.0
C.2	CI 2009
C.3	Canada CI 1.0
C.4	CI 1.0
E	EB 1.0
F	EB 2.0
G	EBOM 2008
G.1	EBOM Canada

Important note: Results for credits labeled "2 points possible" use the maximum difference of satisfaction from 0 to 2 points and, therefore is not directly comparable. Effect size should be used for evaluation.

Appendix M: Spearman analysis for Total IEQ Points, Rating and Version.

x	y	rho	p
IEQ total	Air quality	0.03	0.005
LEED rating	Air quality	0.07	<0.001
LEED version	Air quality	0.00	0.969
IEQ total	Amount light	-0.04	<0.001
LEED rating	Amount light	0.00	0.878
LEED version	Amount light	0.09	<0.001
IEQ total	Amount space	-0.08	<0.001
LEED rating	Amount space	0.01	0.390
LEED version	Amount space	0.08	<0.001
IEQ total	Building	-0.03	0.001
LEED rating	Building	0.01	0.195
LEED version	Building	0.08	<0.001
IEQ total	Cleanliness building	-0.02	0.027
LEED rating	Cleanliness building	0.01	0.335
LEED version	Cleanliness building	0.05	<0.001
IEQ total	Cleanliness workspace	-0.04	<0.001
LEED rating	Cleanliness workspace	0.01	0.402
LEED version	Cleanliness workspace	0.03	0.008
IEQ total	Colors textures	-0.01	0.213
LEED rating	Colors textures	0.04	0.001
LEE _version	Colors textures	0.04	<0.001
IEQ total	Comfort furnishing	-0.07	<0.001
LEED rating	Comfort furnishing	-0.01	0.534
LEED version	Comfort furnishing	0.06	<0.001
IEQ total	Ease interaction	-0.07	<0.001
LEED rating	Ease interaction	0.02	0.080
LEED version	Ease interaction	0.12	<0.001

x	y	rho	p
IEQ total	Layout	-0.10	<0.001
LEED rating	Layout	-0.06	<0.001
LEED version	Layout	0.08	<0.001
IEQ total	Maintenance building	-0.02	0.021
LEED rating	Maintenance building	0.01	0.581
LEED version	Maintenance building	0.07	<0.001
IEQ total	Noise	-0.09	<0.001
LEED rating	Noise	-0.05	<0.001
LEED version	Noise	0.11	<0.001
IEQ total	Sound privacy	-0.13	<0.001
LEED rating	Sound privacy	-0.08	<0.001
LEED version	Sound privacy	0.12	<0.001
IEQ total	Temperature	-0.01	0.523
LEED rating	Temperature	0.01	0.324
LEED version	Temperature	0.08	<0.001
IEQ total	Visual comfort	-0.05	<0.001
LEED rating	Visual comfort	-0.03	0.008
LEED version	Visual comfort	0.08	<0.001
IEQ total	Visual privacy	-0.11	<0.001
LEED rating	Visual privacy	-0.10	<0.001
LEED version	Visual privacy	0.10	<0.001
IEQ total	Workspace	-0.04	<0.001
LEED rating	Workspace	-0.02	0.119
LEED version	Workspace	0.05	<0.001

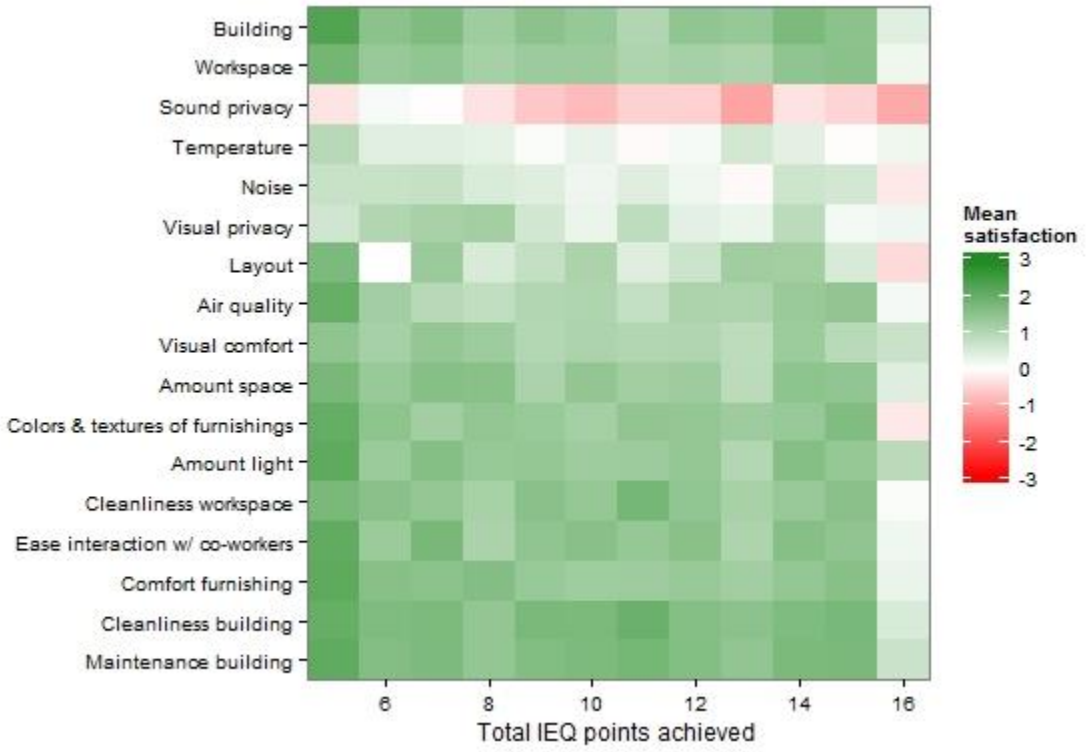
Appendix N: LEED product versus 17 survey questions

Difference between the 3 main products analyzed (NC, EB, CI) and scale difference, or divided across the 7 point scale as surveyed.

CBE Question	Difference (%)	Scale Difference (%)
Maintenance building	55	7.5
Cleanliness building	43	7.2
Comfort furnishing	27	4.6
Ease interaction	37	6.2
Cleanliness workspace	54	8.9
Amount light	46	7.6
Colors textures	37	6.2
Amount space	40	6.7
Visual comfort	46	7.7
Air quality	55	9.1
Layout	43	7.2
Visual privacy	68	11.3
Noise	56	9.3
Temperature	46	7.6
Sound privacy	62	10.3
Workspace	35	5.9
Building	54	9.0

Appendix O: Heat map – Total points achieved versus 17 survey questions

Mean satisfaction levels by survey question as total IEQ points are increased. (see Table 3.1 for sample sizes)



Appendix P: LEED rating levels and 17 selected CBE questions

variable	LEED rating	Mean	Difference from Certified	Percent Change from certified	Largest Difference	Percent change largest difference
Air quality	Certified	1.22	0		0.49	8%
Air quality	Silver	1.08	-0.13	-2%		
Air quality	Gold	0.96	-0.26	-4%		
Air quality	Platinum	1.44	0.23	4%		
Amount light	Certified	1.54	0	0%	0.31	5%
Amount light	Silver	1.58	0.04	1%		
Amount light	Gold	1.27	-0.27	-5%		
Amount light	Platinum	1.54	0	0%		
Amount space	Certified	1.45	0	0%	0.14	2%
Amount space	Silver	1.36	-0.09	-2%		
Amount space	Gold	1.33	-0.12	-2%		
Amount space	Platinum	1.47	0.02	0%		
Building	Certified	1.66	0	0%	0.35	6%
Building	Silver	1.69	0.03	1%		
Building	Gold	1.35	-0.31	-5%		
Building	Platinum	1.7	0.04	1%		
Cleanliness building	Certified	2.12	0	0%	0.58	10%
Cleanliness building	Silver	1.86	-0.26	-4%		
Cleanliness building	Gold	1.53	-0.58	-10%		
Cleanliness building	Platinum	1.88	-0.24	-4%		
Cleanliness workspace	Certified	1.83	0	0%	0.60	10%
Cleanliness workspace	Silver	1.65	-0.18	-3%		
Cleanliness workspace	Gold	1.23	-0.6	-10%		
Cleanliness workspace	Platinum	1.63	-0.2	-3%		
Colors textures	Certified	1.46	0	0%	0.35	6%
Colors textures	Silver	1.38	-0.07	-1%		
Colors textures	Gold	1.26	-0.2	-3%		
Colors textures	Platinum	1.6	0.15	3%		
Comfort furnishing	Certified	1.61	0	0%	0.26	4%
Comfort furnishing	Silver	1.46	-0.15	-3%		
Comfort furnishing	Gold	1.35	-0.26	-4%		
Comfort furnishing	Platinum	1.51	-0.1	-2%		
Ease interaction	Certified	1.16	0	0%	0.55	9%
Ease interaction	Silver	1.71	0.55	9%		
Ease interaction	Gold	1.5	0.35	6%		
Ease interaction	Platinum	1.6	0.45	8%		

Appendix P (continued) Effect size analysis – LEED rating levels and 17 selected CBE questions

variable	LEED rating	Mean	Difference from Certified	Percent Change from certified	Largest Difference	Percent change largest difference
Layout	Certified	NA	NA	NA	NA	NA
Layout	Silver	1.09	NA	NA		
Layout	Gold	1.08	NA	NA		
Layout	Platinum	0.79	NA	NA		
Maintenance building	Certified	2.04	0	0%	0.52	9%
Maintenance building	Silver	1.82	-0.22	-4%		
Maintenance building	Gold	1.52	-0.52	-9%		
Maintenance building	Platinum	1.84	-0.2	-3%		
Noise	Certified	0.67	0	0%	0.41	7%
Noise	Silver	0.54	-0.13	-2%		
Noise	Gold	0.38	-0.29	-5%		
Noise	Platinum	0.26	-0.41	-7%		
Sound privacy	Certified	-0.04	0	0%	0.70	12%
Sound privacy	Silver	-0.37	-0.32	-5%		
Sound privacy	Gold	-0.53	-0.49	-8%		
Sound privacy	Platinum	-0.74	-0.7	-12%		
Temperature	Certified	0.43	0	0%	0.14	2%
Temperature	Silver	0.28	-0.14	-2%		
Temperature	Gold	0.29	-0.14	-2%		
Temperature	Platinum	0.4	-0.03	-1%		
Visual comfort	Certified	1.44	0	0%	0.36	6%
Visual comfort	Silver	1.29	-0.15	-3%		
Visual comfort	Gold	1.08	-0.36	-6%		
Visual comfort	Platinum	1.18	-0.26	-4%		
Visual privacy	Certified	1.24	0	0%	0.89	15%
Visual privacy	Silver	0.82	-0.42	-7%		
Visual privacy	Gold	0.59	-0.66	-11%		
Visual privacy	Platinum	0.36	-0.89	-15%		
Workspace	Certified	1.51	0	0%	0.28	5%
Workspace	Silver	1.45	-0.06	-1%		
Workspace	Gold	1.23	-0.28	-5%		
Workspace	Platinum	1.38	-0.12	-2%		

Appendix Q: Building Assessment Case Studies

Case Study #1: Urban, Performance

Quasi-governmental building. Public use and demonstration.

"….we took a rundown structure built in 1927 and transformed it into a beautiful, environmentally responsible and healthy workplace." --- Company website

General

Setting:	Urban/City
Focus:	Performance – Showcase building
Use:	Office
Space:	5% private, 95% open (approximately)
Region:	West
Climate:	Marine
Gross square feet:	13675
Orientation:	North (west)
Current Occupancy:	40
Building:	Owned
LEED Certification:	12/7/2007
LEED Product:	NC (original) EB (recently)
LEED Version:	2.1 (NC) and v4 (EB)
LEED Rating:	Platinum
LEED ID:	10002744
Total points achieved:	54
Points available:	69
IEQ points achieved:	13
IEQ points available:	15

Considerations:

- Demonstration building used for community engagement.
- Dense, urban area in transition.
- No trending, complaint log, or preventative maintenance tracking.
- Trending and tracking about to begin resulting from EB process and desire to institute occupant engagement computer-based program. Original contract for tracking not followed by contractor.
- Operations manuals not used by building.
- Occupant control – occupants discouraged from using thermostats. Lighting, blinds, windows are all open to be used.
- No open design charrette – specific aspects mocked up and reviewed by some employees.
- All LEED strategies in place. No formal follow up of corrective action plan (per credit 7.2) developed. However, many actions taken and continuing to be taken to improve thermal comfort.
- Occupants rated environment as casual, supporting their work.

Case Study #1 - Project Information

(pairing table in Appendix B)

Pairing	LEED IEQ Credit	LEED IEQ intent	Strategy Used
A – Air Quality Overall	LEED Credit 1: Outdoor Air Delivery Monitoring	Provide capacity for ventilation system monitoring to help sustain occupant comfort and well-being	2 methods – temp o/s air and return air then 100% o/s air supplied. Sensed CO_2 in buildings greater than required, o/s air increased until falls to acceptable level. 2nd floor conference room (25 people for 1000 square feet) has dedicated CO_2 sensor, 4 more sensors – one in conference rooms on each floor, one in board room, one 2nd floor open space. ASHRAE allowable is considered in the range of 500 to 650 ppm above outside levels – design allows for an assumed 400 ppm outside level and 500 ppm from the range total 900ppm. Package unit integrated direct measurement outdoor monitoring device.
Not pursued	LEED Credit 2	Not pursued	
C- Air Quality overall, Odors, Cleanliness	LEED Credit 5: Indoor Chemical & Pollutant Source Control	Minimize exposure of building occupants to potentially hazardous particulates and chemical pollutants.	1. Permanent entryway systems installed at all regular entry points to the building. Aluminum alloy frame with roll up type with tread rails – 6feet in the direction of travel (in and outside). Pedimat. 2. All areas where hazardous gases and/or chemicals to be fully sealed from adjacent spaces and have been provided with an exhaust system that provides sufficient negative pressure within the room to prevent cross-contamination to adjacent spaces. Janitor's closet rooms 119 and 211 and Mail and Copy room 105 – deck to deck partition, self-closer on door. 
D – Amount of light, Ability Light, Visual comfort, Temperatur e	LEED Credit 6.1: Controllability of Systems, Lighting	Provide a high level of lighting system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and well-being of building occupants.	38 workstations, 37 thermal comfort controls provided. Board Room/Training Room, combo of accessible operable windows and one t-stat is designed as comfort controls in the space. Conference room 2nd level – accessible operable windows designed for comfort. Conference room 1st level – T stat to modify comfort. Comfort control strategy includes: t stats, operable windows, thermafuser diffusers. Windows counted where occupants within 20 feet of exterior wall and 10 feet either side of window.

Case Study #1 LEED Information (continued)

Pairing	LEED IEQ Credit	LEED IEQ intent	Strategy Used
D – Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.2: Controllability of Systems, Thermal Comfort	Provide a high level of thermal comfort system control by individual occupants or by specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and well-being of building occupants.	38 workstations, 37 thermal comfort controls provided. Board Room/Training Room, combo of accessible operable windows and one t-stat is designed as comfort controls in the space. Conference room 2nd level – accessible operable windows designed for comfort. Conference room 1st level – T stat to modify comfort. Comfort control strategy includes: t stats, operable windows, thermafuser diffusers. Windows counted where occupants within 20 feet of exterior wall and 10 feet either side of window.
E – Temperature, Air Quality	LEED Credit 7.1: Thermal Comfort, Design	Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.	Design HVAC systems and the building envelope to meet the requirements of ASHRAE Standard 55-2004, Thermal Comfort Conditions for Human Occupancy. Demonstrate design compliance in accordance with the Section 6.1.1 Documentation. Establish comfort criteria per ASHRAE Standard 55-2004 that support the desired quality and occupant satisfaction with building performance. Design building envelope and systems with the capability to deliver performance to the comfort criteria under expected environmental and use conditions. Evaluate air temperature, radiant temperature, air speed, and relative humidity in an integrated fashion and coordinate these criteria with EQ Prerequisite 1, EQ Credit 1, and EQ Credit 2.
E – Temperature, Air Quality	LEED Credit 7.2: Thermal Comfort, Verification	To provide for the assessment of occupant thermal comfort over time.	Between 6 and 18 months post-occupancy – conduct anonymous survey about the thermal comfort of the building. This will included overall satisfaction with the thermal performance and id of thermal comfort related problems. Corrective action plan will be developed should more than 20% of the occupants be dissatisfied with the thermal comfort. Any corrective measures will be timed with Cx review, so that all changes will be made at the same time.

F – Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.1: Daylight & Views, daylight 75% of spaces	Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.	Option 1 used Glazing factor calculation. Occupied space estimate – 8485 square feet. Regularly occupied space with min 2% glazing factor – 7453 square feet. Percent – 87.84%.
F – Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.2: Daylight & Views, views 90% of spaces	Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.	Regularly occupied space 8485 square feet with access to views 8322 square feet or 98.08% of occupied space has views.

Case study #1 – Content Analysis
LEED Credit/Question Pairing Tables

The content analysis is the combination of themes gathered from the satisfaction survey, expert feedback (including the focus group and publications and direct guidance from subject matter experts), and the assessment of the studied building across the 4 studied categories: Air Quality, Thermal Comfort, Lighting/Visual Comfort, and Building overall. A sub table is used to give more specific content analysis for the interviews, observations, and measurements taken during the building assessment.

Urban Table 2 **Air Quality** - *Summary*

Survey Question (table xx)	LEED Credit	Survey	Expert	Building Assessment
Air Quality Overall	LEED Credit 1: Outdoor Air Delivery Monitoring	Questions Air Quality:	➢ Limitations of a one size fits all design.	➢ Interviews – Generally positive

Not Pursued	LEED Credit 2	**93% satisfied**/ 95% percentile Comments Inability and infrequency of window operation. Restroom smell.	➢ Outside air quality can be bad – must design for. ➢ Implementation not performed to specification - potential too much air blowing. (Note: industry standard - ASHRAE). ➢ Too subtle or get used to - people stop reporting.	➢ Measurements – none taken – no BMS data available ➢ Observations – no evidence of poor IAQ. Survey report of carbon residue on outside patio furniture.
Air Quality overall, Cleanliness	LEED Credit 5: Indoor Chemical & Pollutant Source Control		➢ Mainly janitorial and operations ➢ Below human ability to perceive ➢ Associated odors common and may not relate to true AQ issues.	➢ Interviews – Positive to neutral ➢ Measurements – none taken ➢ Observations – all measures (mats and sealed rooms) in place

Urban Sub table 1.1 **Air Quality** - *Interviews*

Credits	Designer	Operations/Management	Occupant (7 interviews)
Credit 1	➢ Design -focused on proper ventilation and exhaust.	➢ No alarms at building. No complaints. ➢ Operable windows enhance occupant controllability for some not all. Urban noise a factor in opening of windows. Street repairs common in downtown Oakland due to age of city and infrastructure.	➢ Nothing noticed or Good
Credit 2			
Credit 5	➢ Best and least liked IEQ LEED aspects - simple things -bagging and making sure debris doesn't get into the HVAC system. ➢ Printers/copy - office function but did go through the process. ➢ AQ - tight urban environment wonderful views and good AQ.	➢ NO problems with mats or sealed rooms. ➢ In terms of air quality, signs air quality at their urban site lead the management to pay close attention to air quality. Filters were monitored and the replacement of filters increased from 6 to 4 months. Also stepped up cleaning. ➢ Green cleaning is part of contract and recently changed to contractor with more green cleaning experience.	➢ Nothing noticed or Good

		➢ Increased air changes – good air quality bad for thermal and drafts.	

Urban Sub table 1.2 **Air Quality** – *Measurements and Observations*	
Measurements	**Observations**
None taken	Credit 1: NEED TREND data. For urban environment, 2.5 days observed and no issues.
	Credit 2: not pursued
	Credit 5: All strategies in place and operational. Extended mat application inside building as part of EB cert.
	Credit 5: No cleaning materials on site – brought in by contractor. Appeared clean. Do not notice or perceive air movement issues. Future study could be recommended.

Urban Table 2 - **Lighting/Visual Comfort** - *Summary*				
Survey Question (table xx)	**LEED Credit**	**Survey**	**Expert**	**Building Assessment**
Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.1: Controllability of Systems, Lighting	Questions Lighting: **90% satisfied**/ 89% percentile Comments ➢ Great natural light ➢ Glare ➢ Direct sun from skylight ➢ Ability to adjust blinds – not in my area ➢ Furnishings color complement to views and light ➢ Views good	➢ Human inclination to shades down or up. ➢ Many other factors affecting - nuanced issue. ➢ Glare not addressed. ➢ Foot candle measurement not useful and light not actually getting into space based on LEED spec.	➢ Interviews – Positive. Natural light good and additional blinds for specific glare improved. ➢ Measurements – Morning average foot candle – 28. Afternoon average foot candle – 58. Some dark and bright areas. 1 desk had high contrast ratios throughout the day and one conference room in the morning. ➢ Observations – Blinds being used by people in potential glare areas. Furnishings are particularly complimentary. Dark and light areas – one
Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.1: Daylight & Views, daylight 75% of spaces			
Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.2: Daylight & Views, daylight 90% of spaces			

				long wall with no windows. Windows in place, large and clean.

Urban Industrial Table 3.1 **Lighting/Visual Comfort -** *Interviews*			
	Designer	**Operations/Management**	**Occupant (7 interviews)**
Credit 6.1	➢ Integrated systems and goals - With windows and lighting strategy also wanted to also incorporate to create stack effect.	➢ Lighting is great – intention low ambient light with integrated task lights provided. ➢ Low ambient light – light levels observed were low in overcast conditions, not many people used their task lights however. Many on computer and work lit by screen.	➢ Old building view of parking lot and dark, tinted windows. ➢ Don't change. Some task used. ➢ Lighting in boardroom problem. Controls difficult and no occupancy sensor. ➢ Blinds generally used and added to help with glare - effective. ➢ Task lights occasionally used.
Credit 8.1 Credit 8.2	➢ Original building - no windows on most - covered over. ➢ Good because blank slate and could focus on lighting. Started with one side up against neighbor. Other side negotiated easement for property line windows on property side that has opening to garage. All functions that don't require human habitation on the one side - light deep in the building. ➢ Small light well existing - save and expand - current stairwell. ➢ Second stair - only ladder to roof - wanted green roof and had to make future plan. Hole	➢ Many positive comments for daylight and views of building. ➢ Size of windows and open plan excellent for natural light but contributes to some thermal issues and some glare in the winter. ➢ Low ambient light – light levels observed were low in overcast conditions, not many people used their task lights however. Many on computer and work lit by screen. ➢ Size of windows (more than view itself) significant aspect of high satisfaction with views. Some tree tops visible even with walls of buildings at most eye-level views. ➢ Bird strikes more recent issue – window size and low artificial light factors. ➢ Site orientation and interior layout maximizes light and minimizes glare.	➢ Very positive. ➢ Light from above good. ➢ View of trees and sky extremely positive. ➢ Glare but corrected with additional blinds. ➢ Artificial light somewhat inadequate. ➢ Don't generally use task light.

	for elevator 2nd skylight. Didn't do light study modeled computer. Had historical and experience.	➢ Much glare avoided by orientation of site (east to west) and use of combination of sheer and opaque blinds where needed.	

Urban Sub table 3.2 **Lighting/Visual Comfort** – *Measurements and Observations*	
Measurements*	**Observations**
<u>Illuminance</u> Morning (pre-occupancy) : Average: 38, High: 210, Low: .5 (*Foot candle*)	All in place and working except Boardroom - occupancy controls missing. Limited use of blinds - specific desks have control and size of windows affects many - reluctant to change. Ambient light rarely changed. Some task lighting used. Very specific desks with potential glare issues - opaque blinds added.
Morning (post-occupancy) : Average: 58, High: 145, Low: 11 (Foot candle)	Daylight - natural lighting penetrates space and is relatively even. Skylight provides signif shaft/stairwell of building. Also highlights use of stairs over elevator. Dark and light a windows. Windows in place, large and clean.
<u>Illuminance</u> Afternoon: Average: 29, High: 221, Low: 6 (*Foot candle*)	Views - see photos. Some surrounding buildings not so attractive, but large windows, trees and sky provide enhanced views and connection to nature. 
<u>Luminance</u> ▪ Morning: 3 of 6 readings above 40:1 ratio ▪ Afternoon: 1 of 6 readings above 40:1 ratio	Colors and finishes well selected - appealing to many and balanced (also found in designer's account of time spent on material selection).
* Readings taken on 2/27/15 and 3/13/15	

Urban Table 3 - **Thermal Comfort** - *Summary*				
Survey Question (table xx)	**LEED Credit**	**Survey**	**Expert**	**Building Assessment**
D – Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.2: Controllability of Systems, Thermal Comfort	Questions Thermal Comfort: **60% satisfied**/ 85% percentile Comments: Cold. Inability to use windows – access & noise. Different area to area and time of day.	➢ Difficult to achieve 80% satisfaction with current technology and client budgets, even with standards. System flexibility and controllability main issues. ➢ Survey not always performed as required. ➢ Survey rarely followed up on with physical actions – addressing issues. Credit does not require. ➢ Required plan rarely done post cert – no one checks. ➢ System management driven by complaints of a few and not conditions. ➢ Little relation to LEED credit ➢ Rarely any occupant follow up. Occupants give up.	➢ Interviews – neutral to negative. Unwritten policy to engage building to change. ➢ Measurements – Average temperature 71 directly within set point. Operative temperature very similar. Greatest difference between zones – 3.5 degrees. ➢ Observations – clothing adaption evident
E- Temperature, Air Quality	LEED Credit 7.1: Thermal Comfort, Design And LEED Credit 7.2: Thermal Comfort, Verification	Questions Thermal Comfort: **60% satisfied**/ 85% percentile Comments: Cold. Inability to use windows – access & noise. Different area to area and time of day.		

Urban Sub table 3.1 **Thermal Comfort** - *Interviews*			
Credit	**Designer**	**Operations /Management**	**Occupant (7 interviews)**
Credit 6.2	➢ Use of the building has shifted - increased significantly for amount of space.	➢ Encourage occupants to contact building facilities person if temperature set points need to be changed. Equity and economy (not setting to extreme) were cited. Set	➢ Discouraged from using thermostats - told to notify building. ➢ Limited feeling of appropriateness for all in building to open windows the

		point changes are temporary and go back to design set points after a short period of time. ➢ Discourage use of personal heaters. Encourage personal clothing adaptation and to contact building facilities for alternate solutions. ➢ Challenging BMS ➢ Operable windows enhance occupant controllability for some not all. Urban noise a factor in opening of windows. Street repairs common in downtown Oakland due to age of city and infrastructure.	windows are part of a specific person's direct space – noise and comfort factors.
Credit 7.1 & 7.2	➢ Basic principle of good thermal design - Always makes sense to distribute by the windows - not easiest thing but better. Look for the best possible place - where losing it. ➢ Simple, elegant solutions. Looked at many options but not economically feasible. Efficient system - works overall - although not perfect. Cost effective and light years better than most.	➢ Approach - Good thermal with off the shelf technology and simplicity of system. ➢ Challenging BMS ➢ Pockets of temp issues reported. ➢ Issues with server room – would consider differently for future natural vent/mixed mode projects. ➢ Boardroom fluctuation in occupancy requires attention, more difficult with simple, efficiency driven design. ➢ About the same time as survey, we found a problem with the gear - fixed and improved performance and comfort. Also rebalanced the thermal-fusers. We're always tweaking things. ➢ With 30% dissatisfied no formal corrective action plan was developed and no follow up by USGBC. We're planning for EB and felt that was adequate for plan.	➢ Zone issues - "pockets" of temperatures. Time of day and location an issue. Not consistent issue. ➢ Front windows hot - open windows, noisy - 2 private offices and large conference room.

Urban Sub table 3.2 **Thermal Comfort**– *Measurements and Observations*	
Measurements*	**Observations**
Temperature: ▪ Avg 71.6 ▪ High 77.6 ▪ Low 67.63	Thermal mass modulation evident - prior to morning system start up – slightly colder in morning - but much more moderate than outside. Systems seemed adequate to balance. Thermal imaging showed no air intrusion and very minimal thermal bridging issues. Noted insulation only ½ way up the wall.
RH: ▪ Avg 44.75 ▪ High 55.49 ▪ Low 32.76	No issues with humidity reported or observed.
Operative Temperature: ▪ Avg 71.2 ▪ High 74.86 ▪ Low 68.52	Some variation across zones but didn't experience as severe as occupant and management reported. Evident of perimeter focused heating and cooling to balance space. (as outlined by designer)
*(17 zones, 15 loggers) Duration 3/18/15 to 4/1/15	A few floor heaters. Laying of clothing. Many variations of layered clothing. Predominately coats or sweaters. Much activity and movement.
	One person heads all operations for the building and it's 50% of his time. Most interaction is reactive to complaints however going through a more recent EB process has allowed for more proactive engagement with staff. They plan to install a LEED Dynamic Plaque which they feel will improve the connection of the occupants to the building.

Urban Table 4 **Building Overall** - *Summary*				
Survey Question (table xx)	**General LEED insights**	**Survey**	**Expert**	**Building Assessment**
Building Overall	➢ All interviewed parties knew about LEED and understood the	Building overall: **87% satisfied**/87% percentile	➢ BMS – is it working ➢ Complexity verses simplicity – application and short	➢ Demonstration building ➢ Complete gut and rebuild

	context to this building.		and long term investment matter ➢ Engaged facilities operator – design to occupancy ➢ Enhanced commissioning and planned operations	➢ Window placement and size important – light in an originally dark and unpleasant space. ➢ Heighten concentration on finish colors, textures, usability, and utility. ➢ EB v4 obtained subsequently – consistent upgrades and changes to the building ➢ Challenges with adding staff – spaces "put together" and not re-planned as a whole.

Urban Table 4.1 **Building Overall -** *Interviews*		
Designer	**Operations/Management**	**Occupant (7 interviews)**
General: ➢ Best and least liked IEQ LEED aspects - simple things -bagging and making sure debris doesn't get into the HVAC system. Hardest for contractors - not IEQ. Waste tracking. Central to client. ➢ Simple, elegant solutions can be best. ➢ IEQ - affected by a lot of different things. Finishes huge. Color is tricky can be highly individualistic. Special architect focused - spent a lot of time on color. Specifically to complement views, provide visual comfort, and	General: ➢ We are very responsive to occupant needs - no logs maintained. Overall building runs well. Only 1 to 2 complaints or requests a month. Most prevalent complaint – cold and draft. ➢ BMS slow and not easy to use. ➢ Engineer exceeded air change per hour. Good for air quality and flow – bad for drafts and perception of cold. Designed to work with "energy sipping" systems that demand less heating and cooling. ➢ Systems are well designed given economy and performance but can be challenging to operate. ➢ Overall with simple, off the shelf available HVAC technology used, achieving relatively	General: Positive. Natural light. Aesthetically pleasing. Warm - good environment. Some movement and changes. Spaces made to work rather than planned or thought out to work. Ability to collaborate/share. Also little space for private meetings or conversations. Some spaces not being used as designed. More open and airy. Less institutional. Lack of private meeting space. Lack of communal space. Noise No formal training. Ability to find out. Should know more.

still reach across all for what is pleasing. Carpet - random pattern of carpet squares - allows for not only replacement & acoustic properties - but better color design, fun and satisfaction. It's an art more than science. Gives a sense of place. ➢ *Why do you get involved in post-occupancy*? No pay. If client is going to do post occupancy evaluation - not typical - so important for us to know. ➢ Important for architects to be very involved with mechanical and other trades. This project: ➢ Wanted to make sure it looked nothing like it did. Gut it. 50's drastically altered - no historical issue - open slate ➢ Use of the building has shifted - increased significantly for amount of space. We did in place mock-up of recommended typical workspace - showed how partitions to reps that would afford the most privacy but focused on light. ➢ No specific design charrette. ➢ Client focus - most green building possible for the $. Core Mission as semi-public agency – use standard project of	very good results. Can result from pockets of hot and cold events during extreme outdoor conditions and some drafts from Thermafuser use. Mostly at the ends of duct runs. Short of more expensive UFAD we feel we are getting the most from our system. Also use no reheat – energy efficiency has some trade off. ➢ Surprisingly very little occupant adaptation. ➢ Difficult to maintain with changing workforce – similar core number of employees but added interns and contract help. Rework cubicles and spaces takes consideration. ➢ Boardroom most complaints – extreme changes in occupancy leads to swings in feels like temperature and there is no occupancy sensor for lighting. ➢ Negotiated with neighbor property to keep trees ➢ Size of building an ability to have dedicated staff an issue. Have a plan. ➢ Proper training is challenging as personnel changes. ➢ Must stay dedicated and have leadership behind the mission. ➢ Policies or recommendations by the organization supporting the strategies are important. ➢ Survey taken soon after occupancy – good and bad. Would look at timing of survey.	Aesthetics - materials and colors. Balance of simplicity and beauty.

its type same cost. Also demonstration building - minimum LEED silver as county required. Tied to mission - reduced, reuse recycle - rarest point and got it.		
General LEED: ➢ We did not focus on LEED but on good sustainable design. We used LEED to go from Gold to platinum – easy to show we were very close. Used "LEED game" to persuade board. ➢ If trying to set an example - pushed harder and calculated 3% of total budget to reach platinum. ➢ What was value of LEED program for this project – highly-recognized. Bridges people's understanding of how sustainable a building is designed - even with little knowledge. ➢ Being a 3rd party is value. ➢ Aspect of LEED - driving engagement and contractor's ability perform. Pushes for more construction education. A lot of clients don't want to pay for LEED - but want to build to standard. What does that mean? Makes it easier for contractor to carry project to project with experience. ➢ Architects not as involved in ops as HVAC. We looked for the team with the most LEED AP's for mechanical. ➢ Champion - project manager. Left but current building management picked up.	General LEED: ➢ I definitely think going for LEED is a great idea, especially for building owners that: 1) have buildings over 20,000 square feet, 2) have buildings that are professionally managed, 3) have sustainability as part of their leadership/corporate reporting strategy, 4) have the need for being fiscally and environmentally responsible (like public sector). It's a great way to analyze one's situation and explore ways to improve processes for managing buildings; which is beyond just getting the label. There is a cost involved, and a process that needs to be put in place, but the result is a better managed and measured building. ➢ Pursuing a process that renews the commitment, like EB, important to longer term performance. ➢ Initially for this building started at silver and moved up to platinum. Now understand value and would recommend pushing for highest level possible. ➢ Beyond LEED, established innovative sustainable landscape, much more robust than sustainable sites. Also we are experimenting with Energy Chickens to "gamify" engagement of occupants and looking to try other innovations with the installation of the LEED Dynamic Plaque.	General LEED: ▪ View of trees, sky and plants inside. Connection to nature. ▪ Sewer smell in lower restrooms. (persistent from beginning – mainly women's and male building manager doesn't use – doesn't know until extreme that water needs to be put in the trap to stop sewer gas – retro drip difficult to install) ▪ Yes - directly related to mission ▪ Highest score not norm. Can always improve.

Case Study #2: Suburban, Civic

Government building. Multiple city departments and functions.

"It's a social experiment…it requires users to interact more with a building than usual." --- Lead Designer

General

Setting:	Suburban
Focus:	Civic
Use:	Office
Space:	50% private, 50% open
Region:	West
Climate:	Hot-Dry
Gross square feet:	13600 (approximately)
Orientation:	West (south)
Current Occupancy:	40
Building:	Owned
LEED Certification:	5/18/2009
LEED Product:	NC
LEED Version:	2.1
LEED Rating:	Gold
LEED ID:	10001732
Total points achieved:	43
Points available:	69
IEQ points achieved:	15
IEQ points available:	15

Considerations:

- Site on steep slope. About 80 percent of the building faces southwest, while the remainder faces west, overlooking a creek and the buildings below.
- Occupant interaction/engagement key aspect of design.
- No formal design charrette – members of the staff engaged.
- Dual duct 100% outside air direct/indirect evaporative cooling. High efficiency recirculating furnace for heating.
- Exterior shades and interior light shelves. Window indicator signs and operative windows.
- Occupant control – occupants discouraged from using thermostats. Lighting, blinds, ceiling fans, and windows are all available to be used.
- Several personnel changes in building management. No training or legacy planning. No trending, complaint log, or preventative maintenance tracking.
- Operations manuals (many) – unused by building management – too difficult to relate.
- All LEED strategies in place. No formal follow up of corrective action plan (per credit 7.2) developed. However, many actions taken and continuing to be taken to improve thermal comfort.
- Occupants rated environment as informal.

Case Study #2 - Project Information

(pairing table in Appendix B)

Pairing	LEED IEQ Credit	LEED IEQ intent	Strategy Used
A – Air Quality Overall	LEED Credit 1: CO_2 Monitoring	Provide capacity for indoor air quality (IAQ) monitoring to help sustain long-term occupant comfort and well-being.	Dual duct air handling system. The cold duct is supplied by 100% outside air indirect-direct evaporative cooling and the hot duct is supplied by 100 % recirculating furnace. Ventilation air is supplied on the cold duct. Each zone has a VAV box with an airflow sensor at the cold duct inlet that makes sure that the zone minimum ventilation rate is maintained. In heating mode, when zone minimum flows are lower, the building control system sums up the total outdoor air flow rate for the building to maintain a building wide minimum outdoor airflow of 1800 cfm. The building control system is an Automated Logic Controls system with a web-based remote interface and alarming capability. All densely occupied spaces (greater than 25 people per 100 sq ft) have demand controlled based have CO_2 control and a floor plan with CO_2 sensors. There are fully operable windows with system integrated indicator lights.
B - Air Quality Overall, Temperature and acoustics	LEED Credit 2: Ventilation Effectiveness	Provide for the effective delivery and mixing of fresh air to support the safety, comfort and well-being of building occupants.	The required outdoor airflow rate based on these calculations is 1124 CFM. The Orinda City Hall minimum outdoor air ventilation rate is 1800 CFM so it exceeds the standard 62.1 minimum required 60%.
C- Air Quality overall, Odors, Cleanliness	LEED Credit 5: Indoor Chemical & Pollutant Source Control	Avoid exposure of building occupants to potentially hazardous chemicals that adversely impact air quality.	Permanent Entryway systems in high volume. Chemical use and copy rooms physically separated deck to deck with exhaust vent. Spaces where chemical concentrate mixing occurs drains plumbed environmentally for disposal of waste.
D – Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.1: Controllability of Systems, Perimeter spaces	Provide a high level of thermal, ventilation and lighting system control by individual occupants or specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and wellbeing of building occupants.	Thermostats, lighting controls, ceiling fans, blinds, operable windows and system-tied indicator lights.

Case Study #2 LEED Information (continued)

Pairing	LEED IEQ Credit	LEED IEQ intent	Strategy Used
D – Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.2: Controllability of Systems, Non-Perimeter	Provide a high level of thermal, ventilation and lighting system control by individual occupants or specific groups in multi-occupant spaces (i.e. classrooms or conference areas) to promote the productivity, comfort and wellbeing of building occupants.	T-stats, lighting controls, ceiling fans
E – Temperature, Air Quality	LEED Credit 7.1: Thermal Comfort: Compliance with ASHRAE 55-1992	Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.	Comply with ASHRAE Standard 55-1992, Addenda 1995, for thermal comfort standards including humidity control within established ranges per climate zone. For naturally ventilated buildings, utilize the adaptive comfort temperature boundaries, using the 90% acceptability limits as defined in the California High Performance Schools (CHPS) Best Practices Manual, Appendix C – A Field Based Thermal Comfort Standard for Naturally Ventilated Buildings, Figure 2. Establish temperature and humidity comfort ranges and design the building envelope and HVAC system to maintain these comfort ranges.
E – Temperature, Air Quality	LEED Credit 7.2: Thermal Comfort, Permanent Monitoring System	Provide a thermally comfortable environment that supports the productivity and well-being of building occupants.	A permanent temperature and humidity monitoring system will operate throughout all seasons to permit control of building zones within the thermal comfort ranges defined in ASHRAE 55-1992.

F – Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.1: Daylight & Views, daylight 75% of spaces	Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.	Calculations tabulated in a spreadsheet and drawings that define the daylight zone and prediction calculations or daylight simulation results to demonstrate a minimum Daylight factor of 2% in 75% of all space occupied for critical visual tasks.
F – Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.2: Daylight & Views, views 90% of spaces	Provide for the building occupants a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the building.	90% of occupants within regularly occupied spaces will have direct sight lines - calculations tabulated in a spreadsheet and drawings highlighting direct line of sight zones.

Case study #1 – Content Analysis
LEED Credit/Question Pairing Tables

The content analysis is the combination of themes gathered from the satisfaction survey, expert feedback (including the focus group and publications and direct guidance from subject matter experts), and the assessment of the studied building across the 4 studied categories: Air Quality, Thermal Comfort, Lighting/Visual Comfort, and Building overall. A sub table is used to give more specific content analysis for the interviews, observations, and measurements taken during the building assessment.

Suburban Table 1 **Air Quality** - *Summary*

Survey Question (table xx)	LEED Credit	Survey	Expert	Building Assessment
Air Quality Overall	LEED Credit 1: CO_2 Monitoring	Questions Air Quality: **57% satisfied**/ 56% percentile	➢ Limitations of a one size fits all design.	➢ Interviews – Generally positive

Air Quality Overall, Temperature and acoustics	LEED Credit 2 : Ventilation Effectiveness	Comments ➢ Indicators for windows not predominate ➢ Windows not accessible to all ➢ Outside equipment loud – reluctant to open window ➢ Ceiling fans too strong ➢ Humid in summer	➢ Outside air quality can be bad – must design for. ➢ Implementation not performed to specification - potential too much air blowing. (Note: industry standard - ASHRAE). ➢ Too subtle or get used to - people stop reporting.	➢ Measurements – none taken – no BMS data available ➢ Observations – Some evidence of humidity/moisture issues – "seed" table tops bubbling and warping.
Air Quality overall, Cleanliness	LEED Credit 5: Indoor Chemical & Pollutant Source Control		➢ Mainly janitorial and operations ➢ Below human ability to perceive ➢ Associated odors common and may not relate to true AQ issues.	➢ Interviews – Positive to neutral ➢ Measurements – none taken ➢ Observations – all measures (mats and sealed rooms) in place

Suburban Sub table 1.1 **Air Quality** - *Interviews*

Credits	Designer	Operations/Management	Occupant (5 Interviews)
Credit 1	➢ 100% outside air so great from an air quality standpoint ➢ Other strategies, like radiant, not as good for OSA.	➢ No complaints. ➢ Operable windows are not being used as they should. ➢	➢ No complaints. Better.
Credit 2	➢ Needs to have occupant open windows, use thermostats, shades, ceiling fans.	Negatives – cold air blowing, people issues	➢ Study made me realize good to use fans.
Credit 5	➢ No comments	➢ No problems with mats or sealed rooms. ➢ Green cleaning is part of contract - no cleaning supplies stored on site.	➢ Good ➢ Increased upper respiratory issues

Suburban Sub table 1.2 **Air Quality** – *Measurements and Observations*

Measurements	Observations
None taken	Credit 1: NEED TREND data.

	Credit 2: Fans not good for everyone – one person shared during walks.
	Credit 5: All strategies in place and operational.
	Credit 5: No cleaning materials on site – brought in by contractor. Appeared clean. Do not notice or perceive air movement issues.

Suburban Table 2 - **Lighting/Visual Comfort** - *Summary*

Survey Question (table xx)	LEED Credit	Survey	Expert	Building Assessment
Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.1: Controllability of Systems, Perimeter	Questions Lighting: **63% satisfied**/ 28% percentile Comments ➢ Glare issues even with blinds deployed ➢ Operability and quality of blinds poor ➢ Access to change blinds limited ➢ Lighting controls don't work - ask operations, look for obvious signs with lighting on/off and levels if photocells	➢ Human inclination to shades down or up. ➢ Many other factors affecting - nuanced issue. ➢ Glare not addressed. ➢ Foot candle measurement not useful and light not actually getting into space based on LEED spec.	➢ Interviews – Positive. Blinds an issue. 2 people glare. ➢ Measurements – Morning average foot candle – 29. Afternoon average foot candle – 34. Luminance - Lower front desk constant high ratios all day. SW upper in the late morning/midday and lower level west in the late afternoon/early evening had high contrast ratios. ➢ Observations – Blinds being used by people in potential glare areas. Windows clean.
Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.2: Controllability of Systems, Non-Perimeter			
Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.1: Daylight & Views, daylight 75% of spaces			
Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.2: Daylight & Views, views 90% of spaces			

Suburban Table 3.1 **Lighting/Visual Comfort -** *Interviews*

	Designer	Operations/Management	Occupant (5 interviews)
Credit 6.1 Credit 6.2	➢ Daylighting on separate track not as integrated, tension between daylight and heat gain so shading pushing and	➢ Lighting is separate sensor on/off, dimmable.	➢ Lighting annoying because all on together ➢ Lighting - tricky - sometimes out and not working properly

	pulling in various ways to make sure enough light without too much heat gain.	➢ Blinds – automated would have been better. People not using properly – also inadequate.	➢ Lighting - on and off by themselves.
Credit 8.1 Credit 8.2	➢ Challenging exposure mostly west facing – address with shading, light shelves, operable window shading which hasn't been as successful.	➢ Light levels generally good – no complaints. ➢ Always positive about the views.	➢ Daylight - Excellent. Very Positive. ➢ Glare an issue for some. ➢ Blinds inadequate and difficult to operate. ➢ Views #1 favorite aspect. ➢ Don't want to feel blocked in. Poster board to block small section as sun moves. ➢ Seems worse in winter

Suburban Sub table 3.2 **Lighting/Visual Comfort** – *Measurements and Observations*	
Measurements*	**Observations**
<u>Illuminance</u> Morning: Average: 29, High: 78, Low: 6.4 (Foot candle)	All in place and working
<u>Illuminance</u> Afternoon: Average: 34, High: 71.5, Low: 8.5 (*Foot candle*)	Daylight - natural lighting penetrates space and is relatively even. Translucent panels as part cubicles pointed out by occupant and allow for good penetration of light into non-window wall cubicles. Pendant Lights provide good ambient and task. 
<u>Luminance</u> ▪ Late morning: 3 (desk and SW) readings of 16 over 1:40 ratio	Exceptional views. Hillside with trees and hills.

▪ Afternoon: 2 (desk and W) of 13 readings over 1: 40 ratio ▪ Notes: Lower front desk constant glare issues all day. SW upper in the late morning/midday and Lower level west in the late afternoon/early evening	
* Readings taken on 3/11/15 and 3/25/15	

Suburban Table 3 - **Thermal Comfort** – *Summary*

Survey Question (table xx)	LEED Credit	Survey	Expert	Building Assessment
D – Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.2: Controllability of Systems, Non-Perimeter	Questions Thermal Comfort: **27% satisfied**/ 23% percentile Comments: ➢ Too cold in winter/too hot in summer ➢ Humid ➢ One part of building opposite thermally	➢ Difficult to achieve 80% satisfaction with current technology and client budgets, even with standards. System flexibility and controllability main issues. ➢ Survey not always performed as required. ➢ Survey rarely followed up on with physical actions – addressing issues. Credit does not require. ➢ Required plan rarely done post cert – no one checks. ➢ System management driven by complaints of a few and not conditions. ➢ Little relation to LEED credit ➢ Rarely any occupant follow up. Occupants give up.	➢ Interviews –Neutral to negative ➢ Measurements – n/a ➢ Observations – clothing adaption evident
E- Temperature, Air Quality	LEED Credit 7.1: Thermal Comfort: Compliance with ASHRAE 55-1992 And LEED Credit 7.2: Thermal Comfort, Permanent Monitoring System	Questions Thermal Comfort: **27% satisfied**/ 23% percentile Comments: ➢ Too cold in winter/too hot in summer ➢ Humid ➢ One part of building opposite thermally		➢ Interviews – Neutral to negative ➢ Measurements – Average temperature within range. High and low somewhat extreme. Operative temperature high. RH slightly high. ➢ Observations – clothing adaption evident

Suburban Sub table 3.1 **Thermal Comfort** - *Interviews*			
Credit	**Designer**	**Operations /Management**	**Occupant (5 interviews)**
Credit 6.2	➢ Daylighting on separate track not as integrated, tension between daylight and heat gain so shading pushing and pulling in various ways to make sure enough light without too much heat gain. ➢ Occupant controlled aspects important to comfort.	➢ Numerous serious issues with BMS ➢ *Doing* many work arounds – cardboard on windows, manually shutting off water values. ➢ More complaints at the perimeter than non-perimeter - much different side to side of the building (east to west). ➢ Mechanical Skylight in "hot" area has been broken for some time.	➢ T-stats don't have authority to change. Temporary fixes to issues. Told will make system issues worse. ➢ We used to be able to control the thermostat. Was told the swamp cooler was using too much water - ability to control to bring people to comfortable level now takes hours. ➢ Don't notice window indicator lights. ➢ Window indicator lights seem to be inaccurate with temperature and activation.
Credit 7.1 & 7.2	➢ Used innovative system for the climate ➢ Innovative thermal strategy for area – Starting question: Could we do a building in this climate without ac – thermally needed cooling needed but indirect/direct – 100% osa so great from an air quality standpoint. Tension between daylight and heat gain - shading in various ways to make sure enough light without too much heat gain. Challenging exposure mostly west facing – address with shading, light shelves, operable window shading which hasn't been as successful. ➢ Experience of 8 or 10 years since project - look at whole different heating/cooling. Radiant and then what about fresh air. Tried new – mixed mode– bigger dead band on reasonably	➢ Didn't know humidity was part of the system or could be tracked. ➢ Bay area - dress in layers. ➢ Doors long operation. ➢ Ceiling fans and windows don't get used as designed. ➢ The BMS system is very difficult to operate so very hard to allow occupants to use t-stats. ➢ 6 or 7 floor heaters.	➢ Worst is summer – hot and humid ➢ Cold most of winter ➢ Very different thermal needs for one section of the building. ➢ Executive interviewee explained they wanted to shift work space to include another department in the building. Ultimately they were told the HVAC system could not support a major redesign of the space.

	moderate days. Would still explore for other projects – technology improved, smaller units.		

Suburban Sub table 3.2 **Thermal Comfort**– *Measurements and Observations*	
Measurements*	**Observations**
Temperature: ▪ Avg 71 ▪ High 82 ▪ Low 63	Automated skylight issue – not operational.
RH: ▪ Avg 46.24 ▪ High 68.72 ▪ Low 28.47	Several occasions - particularly in PD, window indicator light off, window open, cooling on
Operative Temperature: ▪ Avg 72 ▪ High 85 ▪ Low 63	Layered clothing - several heavier jackets in the morning.
*(27 loggers) Duration 3/18/15 to 4/1/15	Little observed use of windows and blinds beyond the same few people. Indicator lights completely ignored.1:20 on 3/25 - indicator lights on both floors, some windows on upper level already open, all windows lower level closed and not opened for the rest of the day with light on. Second observed condition – set point 78 degrees, windows open and indicator light off.
	Thermal imaging showed not air intrusion or thermal bridging issues.

Suburban Table 4 **Building Overall** - *Summary*				
Survey Question (table xx)	**General LEED insights**	**Survey**	**Expert**	**Building Assessment**
Building Overall	➢ Less understanding of LEED by building interviewees.	Building overall:	➢ BMS – is it working ➢ Complexity verses simplicity –	➢ Lack of continuity in building management and champion for performance.

		55% satisfied/30% percentile	application and short and long term investment matter ➢ Engaged facilities operator – design to occupancy ➢ Enhanced commissioning and planned operations	➢ No on-going training or re-enforcement ➢ Slow and inefficient BMS – little ability to control building properly ➢ All the elements of what could be a much higher performing building in place ➢ Evidence of moisture/humidity issues ➢ No tracking of preventative maintenance, complaints, or trends. ➢ Little occupant engagement – blaming design. ➢ Building manager relatively new and wants to make major improvements.

Suburban Table 4.1 **Building Overall -** *Interviews*		
Designer	**Operations/Management**	**Occupant (5 interviews)**
General: ➢ "Passive buildings require active occupants " ➢ People have different perception of home verses work – they just want the workspace to be right This project: ➢ Training need and on-going ➢ Champion left before project complete – little support since. ➢ Not a lot of consensus building from the beginning. Did a charrette with team not with workers. Did understand population but changes in staffing and policy, but leadership told staff we are going to do it this way and you need to get on board.	General: ➢ Positives – Beautiful, Parking, access to trail, views ➢ No real manual (box of individual manual for the system) tried none user friendly, especially BMS. With all the turnover, many changes and overrides to the system. No consistent method for management. ➢ BMS incredibly challenging – 10 year older system in adjacent building much more intuitive and easier to manage. Also very slow – takes many minutes for screens to fully come up and more to make adjustments. Time is limited to work	General: Positive. Natural light. Aesthetically pleasing. Warm - good environment. Some movement and changes. Spaces made to work rather than planned or thought out to work. Ability to collaborate/share. Also little space for private meetings or conversations. Some spaces not being used as designed. More open and airy. Less institutional. Lack of private meeting space. Lack of communal space. Noise No formal training. Ability to find out. Should know more.

➢ Wish building had active champion now. ➢ Satisfaction levels frustrating. Could so easily be different.	through because no cell signal in room and I'm the primary contact person. ➢ No training ➢ Swamp cooler loud. Good strategy for Oakland but not in hotter climate.	Aesthetics - materials and colors. Balance of simplicity and beauty.
General LEED: ➢ Asked for silver, gave gold. Good for making sure you've not missed anything. ➢ The main role here –council wanted it and helped weather budget and political issues. Timing – demand huge for green building at the time – contractor added huge cost to bid and had to accept. Steel and materials also super expensive 2005/2006. Council didn't let go because of LEED. ➢ Champion very important. Left before finished and building has suffered. Wish the building had an active occupant champion now.	General LEED: ➢ Don't know a lot about LEED. Hope to learn from this study. ➢ Workarounds – use cardboard to block vents and windows. Manually shutting off heating pipes when necessary. HVAC maintenance contractor only source of technical expertise and not really equipped to provide long term solutions. ➢ Occupants email when there is an issue, no log is kept. Do send guys or myself immediately and follow up. ➢ Would like integrated management system for civic buildings in the area. ➢ Maintenance subcontracted and quarterly. Nothing proactively checked otherwise. ➢ Glare and Thermal primary issues.	General LEED: ▪ View of trees, sky and plants inside. Connection to nature. ▪ Sewer smell in lower restrooms. (persistent from beginning – mainly women's and male building manager doesn't use – doesn't know until extreme that water needs to be put in the trap to stop sewer gas – retro drip difficult to install) ▪ Yes - directly related to mission ▪ Highest score not norm. Can always improve.

Case Study #3: Industrial, Mission

Industrial Mission
CI

Corporate headquarters for health/food-related company.

"….of our ongoing efforts to run a different kind of company: the kind of place we'd want to work – that makes the kind of food we'd like to eat, and that strives for a healthier, more sustainable world – the kind of world we'd like to pass on to our children." --- Company Owner

General

Setting:	Industrial
Focus:	Mission of company
Use:	Office
Space:	90% open space - 10% private office (approximately)
Region:	West
Climate:	Marine
Gross square feet:	74,508
Orientation:	North (west)
Current Occupancy:	320
Building:	Leased
LEED Certification:	4/19/2012
LEED Product:	Commercial Interiors
LEED Version:	2009
LEED Rating:	Platinum
LEED ID:	1000002427
Total points achieved:	80
Points available:	110
IEQ points achieved:	12
IEQ points available:	17

Considerations:

- Strong tie to company mission and employees. The mission is built around the five aspirations (spokes of a wheel) including; business, brands, people, community, and the planet. Mission includes providing "people" with an exceptional working environment. All in support of a culture around the outdoor/sports related food they produce.
- Many additional factors – pets at work (air quality), on-site day care (noise and use), café and gym (moisture). Several strategies in place – all have positive impact on IEQ.
- No trending, complaint log, or preventative maintenance tracking.
- Trending and tracking by contractor about to begin.
- Many operations manuals – main ones organized by contractor and not system. No SOP or "guide" style manual. Took management 2 hours to look up a lighting lense replacement for example.
- Occupant control of specific aspects of the building discouraged.
- All LEED strategies in place. No formal follow up of corrective action plan (per credit 7.2) developed. However, many actions taken and continuing to be taken to improve thermal comfort.
- Occupants rated environment as casual, supporting their work.
- Many options of multi-use spaces assists with supporting individual satisfaction with the building.

Case Study #3 - Project Information

(pairing table in Appendix B)

Pairing	LEED IEQ Credit	LEED IEQ intent	Strategy Used
Not pursued	LEED Credit 1: Outdoor air delivery	not pursued	
B – Air Quality overall, Temperature, Acoustics	LEED Credit 2: Increased ventilation	To provide additional air ventilation To improve indoor air quality for improved occupant comfort, well-being and productivity.	NOTE PROJECT SPECIFIC _ FROM LEED. Recommendations from LEED - For mechanically ventilated spaces: Design ventilation systems to provide breathing zone ventilation rates at least 30% larger than the minimum rates prescribed by the referenced standard. CASE 1. Mechanically Ventilated Spaces - Increase breathing zone outdoor air ventilation rates to all occupied spaces by at least 30% above the minimum rates required by ASHRAE 62.1-2007 (with errata but without addenda1) as determined by IEQ Prerequisite 1: Minimum Indoor Air Quality Performance.
C- Air Quality overall, Odors, Cleanliness	LEED Credit 5: Indoor Chemical & Pollutant Source Control	To minimize building occupant exposure to potentially hazardous particulates biological contaminants and chemical pollutants that degrade air and water quality.	LEED Recommended strategy - Design separate exhaust and plumbing systems for rooms with contaminants to achieve physical isolation from the rest of the building. Where appropriate, install permanent architectural entryway systems such as grills or grates to prevent occupant-borne contaminants from entering the space.
D – Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.1: Controllability of Systems, Lighting	To provide a high level of lighting system control for individual occupants or groups in multi-occupant spaces (e.g. classrooms and conference areas) and promote their productivity, comfort and well-being.	Design the tenant space with occupant controls for lighting. Strategies to consider include lighting controls and task lighting. Integrate lighting systems controllability into the overall lighting design, providing ambient and task lighting while managing the overall energy use of the building.
Not pursued	LEED Credit 6.2: Controllability of Systems, Thermal Comfort	not pursued	
E – Temperature, Air Quality	LEED Credit 7.1: Thermal Comfort, Design	To provide a comfortable thermal environment that promotes occupant productivity and well-being	EQc7.1 requires that HVAC designs meet the requirements of ASHRAE Standard 55-2004, which deals with thermal comfort of building occupants. Specifically, ASHRAE 55 requires project teams to address air temperature, radiant temperature, humidity, and air speed.

Case Study #3 LEED Information (continued)

Pairing	LEED IEQ Credit	LEED IEQ intent	Strategy Used
E – Temperature, Air Quality	LEED Credit 7.2: Thermal Comfort, Verification	To provide for the assessment of occupant thermal comfort over time.	LEED Requirement: Provide a permanent monitoring system and process for corrective action to ensure that building performance meets the desired comfort criteria as determined by IEQ Credit 7.1: Thermal Comfort—Design. Agree to conduct a thermal comfort survey of tenant space occupants within 6 to 18 months after occupancy. This survey should collect anonymous responses about thermal comfort in the tenant space including an assessment of overall satisfaction with thermal performance and identification of thermal comfort problems. Agree to develop a plan for corrective action if the survey results indicate that more than 20% of occupants are dissatisfied with thermal comfort in the tenant space. This plan should include measurement of relevant environmental variables in problem areas in accordance with ASHRAE Standard 55-2004 (with errata but without addenda1).
F – Amount Light, Ability Light, Visual Comfort, Visual Privacy, Noise, Air Quality	LEED Credit 8.1: Daylight & Views, Daylight	To provide occupants with a connection between indoor spaces and the outdoors through the introduction of daylight and views into the regularly occupied areas of the tenant space.	LEED potential strategies: Design the tenant space to maximize interior daylighting. Strategies to consider include lower partition heights, interior shading devices, interior glazing and high ceiling reflectance values; additionally, automatic photocell-based controls can help reduce energy use. Predict daylight factors via manual calculations or model daylighting strategies with a physical or computer model to assess foot-candle levels and daylight factors achieved.
Not pursued	LEED Credit 8.2: Daylight & Views, views from seated spaces	To provide the building occupants a connection to the outdoors through the introduction of daylight and views into the regularly occupied areas of the tenant space.	not pursued

Case study #3 – Content Analysis
LEED Credit/Question Pairing Tables

The content analysis is the combination of themes gathered from the satisfaction survey, expert feedback (including the focus group and publications and direct guidance from subject matter experts), and the assessment of the studied building across the 4 studied categories: Air Quality, Thermal Comfort, Lighting/Visual Comfort, and Building overall. A sub table is used to give more specific content analysis for the interviews, observations, and measurements taken during the building assessment.

Industrial Table 1 **Air Quality** - *Summary*

Survey Question (table xx)	**LEED Credit**	**Survey**	**Expert**	**Building Assessment**
Air Quality overall	LEED Credit 2: Increased ventilation	<u>Questions</u> Air Quality: **80% satisfied**/ 91% percentile <u>Comments</u> Odor (gas issue), stuffy conf. rooms. Air velocity/circulation too much.	➢ Limitations of a one size fits all design. ➢ Outside air quality can be bad – must design for. ➢ Implementation not performed to specification - potential too much air blowing. (Note: industry standard - ASHRAE). ➢ Too subtle or get used to - people stop reporting.	➢ Interviews –Neutral to negative. Issues with being below, between vents. Without vent issues – Neutral to Positive. ➢ Measurements – none taken ➢ Observations – no evidence of poor IAQ
Air Quality overall, Cleanliness	LEED Credit 5: Indoor Chemical & Pollutant Source Control		➢ Mainly janitorial and operations ➢ Below human ability to perceive ➢ Associated odors common and may not relate to true AQ issues.	➢ Interviews – Positive to neutral ➢ Measurements – none taken ➢ Observations – all measures (mats and sealed rooms) in place

Industrial Sub table 1.1 **Air Quality** - *Interviews*			
Credits	**Designer**	**Operations/Management**	**Occupant (6 interviews)**
Credits: 2 & 5	➢ AQ important – directly impact operations of business. (product development and testing) ➢ No problems – nothing remarkably different. Weren't able to do much. ➢ Limits - Highly industrial, close to RxR tracks. ➢ Some operable windows – but limited – gym. R&D lab	➢ No problem with mats or sealed rooms. ➢ Not a problem within zones. ➢ Complaints of too much and not enough. Many improvements and going to be better - hired BMS expert to upload new software and troubleshoot system improve performance. ➢ Expert training with property management engineer, and PM.	➢ Telephone rooms and conference rooms can get hot and stuffy. (note observations of being overloaded) ➢ Good - plants and lots of air. ➢ Gas issue initially - resolved. ➢ Conference rooms can be stuffy. ➢ Can be drafty under and around vents.

Industrial Sub table 1.2 **Air Quality** – *Measurements and Observations*	
Measurements	**Observations**
None taken	Cleaning materials examined while in use. Organically based and within standard.
	Cleaning performed at night and on a regular cycle- appeared to be clean even with all activity and dogs.
	Do not notice or perceive air movement issues. Future study could be recommended.
	All LEED strategies in place as outlined.

Industrial Table 2 - **Thermal Comfort** - *Summary*				
Survey Question (table xx)	**LEED Credit**	**Survey**	**Expert**	**Building Assessment**
Not pursued	LEED Credit 6.2: Controllability of Systems, Thermal Comfort			
Temperature, Air Quality	LEED Credit 7.1: Thermal Comfort, Design And	Questions Thermal Comfort: **43% satisfied**/ 51% percentile	➢ Difficult to achieve 80% satisfaction with current technology and client budgets, even with standards. System flexibility and controllability main issues. ➢ Survey not always performed as required.	➢ Interviews – neutral (issues but feeling building has gotten better and adapted) ➢ Measurements – mixed

	LEED Credit 7.2: Thermal Comfort, Verification	Comments: Cold and drafty. Too much circulation.	➢ Survey rarely followed up on with physical actions – addressing issues. Credit does not require. ➢ Required plan rarely done post cert – no one checks. ➢ System management driven by complaints of a few and not conditions. ➢ Little relation to LEED credit ➢ Rarely any occupant follow up. Occupants give up.	➢ Observations – clothing adaption evident

Industrial Sub table 2.1 **Thermal Comfort** - *Interviews*

	Designer	**Operations /Management**	**Property Manager**	**Occupant (6 interviews)**
Credit 6.2				
Credit 7.1 & 7.2	➢ Pulled workstations away from walls – share light and not be against thermal mass where colder in the morning. Limited number of units and zones possible. ➢ Two major things would have liked to have done; 1. Major intervention on exterior envelope. 2. Start from scratch with HVAC units.	➢ Most significant issue is Thermal – high ceiling areas. ➢ Adjustment of BMS and new contractor pending. ➢ % surveyed Satisfaction – would project that thermal comfort would be improved however the zones are what they are. ➢ Complaints of too much and not enough.	➢ Target getting temp between 71-75 – there are a few people in the space that say too hot or too cold, must meet in the middle. ➢ Not able to leave mechanical out of a pre-lease space (for build to suit use). Must be ready for 30 to 60 day turn around. Also restrictions on what is considered level of complete to lease.	➢ At first cold. Has gotten better. Using clothes to adapt. ➢ Sitting under, near or between vents - not comfortable. ➢ Inconsistent - hot to cold. ➢ "Pockets" or "microclimates" of conditions.

Industrial Sub table 2.2 **Thermal Comfort**– *Measurements and Observations*

Measurements*	Observations
Temperature: ▪ Avg 72 ▪ High 81 ▪ Low 63 With Atrium conf rms: ▪ Avg 72 ▪ High 111 ▪ Low 63	Two all glass rooms sharing a window wall with the atriums where not included in the measurements to the right. They logged temperatures over 100 degrees and fall within two of the studied zones. Average temperatures ranged from 70 to 75 degrees across zones. These variations could explain the feeling of "microclimates" or "pockets" cited in the interviews. Considerations: 1. Not meeting staying between property management temperature range goal. 2. There are a variety of spaces and conditions to choose from and all were being used at some point for a variety of uses.
RH: ▪ Avg 49.57 ▪ High 57.27 ▪ Low 40.234 With Atrium conf rms: ▪ Avg 9.59 ▪ High 66.51 ▪ Low 22.92	No issues with humidity reported or observed.
*(17 zones, 20 loggers) Duration 3/18/15 to 4/1/15	Heavy use of conference rooms - some heavily loaded beyond expected capacity.
	Many variations of layered clothing. Predominately coats or sweaters. Much activity and movement.

Industrial Table 3 - **Lighting/Visual Comfort** - *Summary*

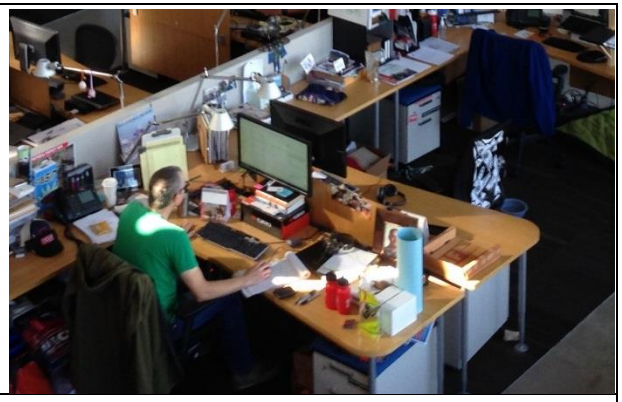
Survey Question (table xx)	LEED Credit	Survey	Expert	Building Assessment
Amount of light, Ability Light, Visual comfort, Temperature	LEED Credit 6.1: Controllability of Systems, Lighting	Questions Lighting: **75% satisfied**/ 76% percentile Comments ➢ Proximity to views and natural light positive.	➢ Human inclination to shades down or up. ➢ Many other factors affecting - nuanced issue. ➢ Glare not addressed.	➢ Interviews –Few changed lights or blinds. Glare very short amount of time. Natural light #1 favorite aspect. ➢ Measurements – Average fall in acceptable OHSA desktop
Amount Light, Ability Light,	LEED Credit 8.1: Daylight & Views, Daylight			

Visual Comfort, Visual Privacy, Noise, Air Quality		➢ Glare. ➢ Blinds difficult. ➢ Task inadequate. ➢ No window coverings. (note operational changes – added tinting, task, and blinds)	➢ Foot candle measurement not useful and light not actually getting into space based on LEED spec.	foot candle level (25-50). Some high contrast ratios – but very short duration. ➢ Observations – Some dark areas but most light filled. High saw tooth and open front windows provides significant light.
Not pursued	LEED Credit 8.2: Daylight & Views, views from seated spaces			

Industrial Table 3.1 **Lighting/Visual Comfort -** *Interviews*			
	Designer	**Operations/Management**	**Occupant (6 interviews)**
Credit 6.1	➢ Massive challenge – originally 3 crane bays – window orientation E/W exactly opposite for saw tooth as to what you would want. Layout important but limited on controllability	➢ Lights for individual either on or off - occupants do use. ➢ Some Sensors - also good in common areas. ➢ People care by contact the building to change - mostly like.	➢ Turn on in morning and off at night. Lights on welcoming. Don't turn on unless I have too. Large banks so allow others to control. ➢ The overall reason it's like a new blender with 20 settings, you only end up using just one. People can appreciate an advanced approach without knowing every detail or using every aspect. ➢ Don't notice blinds too high. Someone else responsible, don't touch. Shades won't help at desk level. Can see through them but do not block glare.
Credit 8.1	➢ Personal best liked strategy – Daylight – had the fun of going through to take Foot candle reading after built - how well was lit.	➢ Best liked and most cited strategy ➢ Good access to daylight and views from most everywhere. Pretty	➢ #1 favorite aspect - Daylight and views. Daylight: ➢ Beautiful. Light. Outdoors in - relate to changes in day. Now - many spaces to use. ➢ Strongly positive. Love it.

	➢ Looking at using skylights more to help individual tiny little cubicles boxed design. ➢ Glare issue - looked at putting in automated blinds – no budget. Unfortunately blinds closed and tend to stay closed. Unfortunately negative effect on overall lighting strategy – designed for no supplemental electric lighting during daylight hours. ➢ Blinds down tend to make space feel darker than otherwise. ➢ Lessons learned - Would have tried earlier to push and find $ to put back in that operation.	happy - "everybody has a window". Love the feeling of indoor/outdoor especially during the rain.	➢ Connected to outside. Visual comfort: ➢ Glare but only small amount of time. Wear hat or glasses when it is - strong. ➢ Not great views - Emeryville not much nature - but plants in atrium and front open - dynamic and positive in a different way. Can see variety in buildings, cars, etc. ➢ Atriums are great view and seeing sky positive.
Credit 8.2			

Industrial Sub table 3.2 **Lighting/Visual Comfort** – *Measurements and Observations*	
Measurements*	**Observations**
Illuminance Morning: ▪ Average: 25 ▪ High: 59 ▪ Low: 9 (Foot candle)	Appears overhead lights dictated by just a few people.
Illuminance Afternoon: ▪ Average: 28 ▪ High: 78 ▪ Low: 9 (Foot candle)	Blinds used by occupants in mezzanine area where windows are adjacent to work spaces

Luminance ▪ Morning: 3 of 17 rations above ▪ Afternoon: 1 of 16 readings above 40:1 ratio	Glare possibilities seem very brief - see photo. Light moved within 2.5 minutes. Follows interview responses and survey comments.	
* Readings taken on 3/18/15 and 4/1/15		

Industrial Table 4 **Building Overall** - *Summary*

Survey Question (table xx)	General LEED insights	Survey	Expert	Building Assessment
Building Overall	➢ No one has full LEED submission - relied on LEED electronic because too big - purged in LEED system after several years. ➢ All interviewed parties knew about LEED and understood the context to this building.	lding overall**: 83% satisfied**/78% percentile	➢ BMS – is it working ➢ Complexity verses simplicity – application and short and long term investment matter ➢ Engaged facilities operator – design to occupancy ➢ Enhanced commissioning and planned operations	Important aspects: ➢ Company commitment to employees ➢ Common belief ➢ Use of multi-spaces to relieve occupant's when IEQ not what they want ➢ Consistent attempts to improve conditions and systems ➢ Discourage use of thermostats and heaters may affect occupant willingness to use features

				overall. Feel building doesn't want them to.

Industrial Table 4.1 **Building Overall -** *Interviews*		
Designer	**Operations/Management**	**Occupant (6 interviews)**
➢ Occupant engagement can be an effective strategy for certain aspects. ➢ Lessons learned to new projects – yes, making sure have the conversations very clearly. Not always successful to get them to spend more money in some cases it's just what it takes. Should have pushed to find budget for automated blinds for example in lieu of manual.	➢ Occupants engaged? Thinking of adding to training about building. ➢ Becomes "doing laundry" - people don't think about what's right, just when things go wrong. ➢ Controls system – hard to regulate separate areas – conference room. People changing. New contractor to update and streamline. ➢ Polices or programs – want to create orientation/training aspect. Underfloor heaters not encouraged – issues with circuit. A few exceptions ➢ (Property Manager) In order to understand from survey or interview, must break down aspects (lamps used, and green features). But the question is do they care and a larger question is what is	Occupant-Controlled features - ➢ Lighting: Turn on in morning and off at night. Lights on welcoming. Don't turn on unless I have too. Large banks so allow others to control. ➢ Blinds: don't notice too high. Someone else responsible, don't touch. Shades won't help at desk level. Can see through them but do not block glare. ➢ T-stats: don't ever touch - building makes clear. Don't change anything in the building frankly because don't want to mess up the systems. I can find other spaces to make it work but discouraged from changing individual environments. No touch policy - it seems the building is complicated and its better we don't. ➢ Fans: no. Can't even tell you where they are. ➢ Windows: only one person said they open - conference rooms where available. ➢ Overall: "it's like a new blender with 20 settings, you only end up using just one. People can appreciate an advanced approach without knowing every detail or using every aspect."

	standardized so you can use a standardized scale.	
➢ Best liked strategy – Daylight – had the fun of going through to take Foot candle reading after built - how well was lit. Looking at using skylights more to help individual tiny little cubicles boxed design	➢ Best liked and most cited strategy - Good access to daylight and views from most everywhere. Pretty happy - "everybody has a window". Love the feeling of indoor/outdoor especially during the rain. ➢ Occupant's perception – proud. Perhaps a bit for granted.	➢ Favorite aspect - Daylight and views. ➢ 2nd favorite aspect: Space open - contributes to feeling of team. Multi spaces. Outdoors in. ➢ Least Favorite aspect – Thermal. Issues (related findings - existing equipment. Balancing cost, efficiency and comfort)
This project: ➢ Mission of company real project driver. ➢ TI – long term lease, anything to the shell had to have permission of building owner but at client's expense. Tough for a company to capital resources in a building they don't own. ➢ Two major things we would have liked to have done; 1. Major intervention on exterior envelope to bring it up to at least close to code. 2. Start from scratch with HVAC units. Handed serviceable albeit not efficient units. ➢ 3 different sites – process help - familiarize the team with each other and move conversations quickly. By third it was easy to see what LEED would work and wouldn't.	Multi-Use Spaces: ➢ Building meets intended purpose – flexible.	Multi-Use Spaces: ➢ Active space - many uses of spaces - meetings and desk ➢ Movement - grouping of work groups. (management said intentionally put where thermal, noise levels, and light works for people) ➢ More collaborative. More satisfied. "The place has intention." Multiple spaces incredible. Natural light better.
General: ➢ Repeats it's self over and over in warehouse – owner puts package units on	General: ➢ (Property Manager) Not able to leave mechanical	General: ➢ Peaceful and welcoming. Sense of Community. Happy to come back from vacation.

what was a warehouse. Client thinks they got a great deal – ask for design and get hit with the new equipment falling short. Don't own and costly to replace. Difficult discussions about levels of comfort. Typical for industrial, open plan buildings. ➢ Need industry shift to allow design teams to be involved through operation.	out of a pre-lease space (for build to suit use). Must be ready for 30 to 60 day turn around. Also restrictions on what is considered level of complete to lease. ➢ (Property Manager) One of the biggest issues from a property management perspective is many times designers have great ideas but don't think of long term operations. Disconnect from design to implementation. ➢ 6 month tune up period – so survey questionable. Time gap between LEED and survey – results could be much different. Still in tune up at the time of survey. Many issues resolved. ➢ Major changes – move into new space (expansion from LEED) – 3 departments. Noise levels considered – seems by department it makes sense to consider. One moved specifically for IEQ related – dynamic nature of the staff is more challenging.	➢ Sound - better than other places I've worked. Acoustic panels and plants help! ➢ Pride because directly mission related to do good in the world. People can appreciate an advanced approach without knowing every detail. ➢ Have deeper sessions maybe bi-yearly to know about the building - promote even more pride of place. ➢ Currently building alarm issue. Only what's wrong and most prevalent in mind.

	➢ Had walk around training. Some systems trained, others not. No on-going training. ➢ No shared operations manual – but have easy-to-use work order system with property management company. ➢ HVAC PM good so don't need to check. ➢ Building staff - Simple scope – warehouse – 3 people. Property management HVAC and all things requiring lifts, also janitorial. Just got new contractor to upgrade BMS. ➢ "work-arounds" – not always immediate to get resolved because of operations through property management	
General LEED: ➢ For LEED love that opens conversation around different ideas. ➢ Helpful when owner says – want Certification on the wall or recognized in industry. ➢ Owner key champion for the project – has provided continuity throughout life of building. ➢ Value is when it allows for conversation with clients. ➢ Down side is so many variables in buildings and LEED doesn't always create more sustainable building.	Property Manager General LEED: ➢ Company policy to make buildings LEED –re-cert every 5 years– takes a consultant to navigate and advise on new standard every time. ➢ The commitment and ability to achieve LEED is different building to building – one may be 20 years old and easy to achieve another may be 10 years old have 15 changes needed and have high cost. ➢ With upcoming changes in LEED it seems people will be	General LEED/Green buildings: ➢ The overall reason it's like a new blender with 20 settings, you only end up using just one. People can appreciate an advanced approach without knowing every detail or using every aspect. ➢ A lot of pride. Not a huge amount of knowledge. Have faith company is following mission.

➢ Talk about what client wants to accomplish with the building from a broad sustainability perspective and let's apply LEED as it make sense. ➢ If chasing a point doesn't make sense or spend so much to achieve one point that could support larger impacts, need to re-examine. ➢ Comes down to having a certain amount of resources and have to put them to the greatest use. ➢ Becoming more of the norm to have open clients who appreciate good resource allocation. ➢ Good to factor client focus somehow. Wonder how LEED impacts occupant satisfaction – is it because they don't know what have or maybe because from an occupant standpoint it isn't fundamentally better than what they get in a standard building?	able to buy the higher certifications and initially LEED seemed more dedicated to making real, effect change. My opinion is owners are beginning to question the value of LEED if others can buy a platinum, it will have less value. 10 year cycle it will be less prominent. *Do you think LEED adds value* – Depends on where, who and the competition of buildings around.	

REFERENCES

Altomonte S and Schiavon S (2013) Occupant satisfaction in LEED and non-LEED certified buildings. *Building and Environment,* 68, 66-76.

ASHRAE (2012) *Performance Measurement Protocols for Commercial Buildings: Best Practices Guide.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

ASHRAE (2010) *Performance Measurement Protocols for Commercial Buildings.* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Atlanta.

Attride-Stirling J (2001) Thematic networks: An analytic tool for qualitative research. *Qualitative Research,* 3, 385-405.

Berg BL, Lune H, Lune H (2004) *Qualitative Research Methods for the Social Sciences.* Pearson Boston, MA.

Brager GS and Baker L (2009) Occupant satisfaction in mixed-mode buildings. *Building Research & Information,* 37, **4**, 369-380.

Collinge WO, Landis AE, Jones AK et al (2012) Integrating indoor environmental quality metrics in a dynamic life cycle assessment framework for buildings. , pp.1-6.

Deuble MP and de Dear RJ (2014) Is it hot in here or is it just me? validating post-occupancy evaluation. *Intelligent Buildings International,* 6, **2**, 112-134.

Deuble MP and de Dear RJ (2012) Green occupants for green buildings: The missing link? *Building and Environment,* 56, **0**, 21-27.

El Asmar M, Chokor ASrour I (2014) Occupant satisfaction with indoor environmental quality: A study of the LEED-certified buildings on the Arizona State University campus. , pp.1063-1070.

Fang L, Clausen G, Fanger PO (1998) Impact of temperature and humidity on perception of indoor air quality during immediate and longer Whole-Body exposures. *Indoor air,* 8, **4**, 276-284.

Ferguson CJ (2009) An effect size primer: A guide for clinicians and researchers. *Professional Psychology: Research and Practice,* 40, **5**, 532.

Frontczak M, Schiavon S, Goins J et al (2012a) Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. *Indoor Air,* 22, **2**, 119-131.

Frontczak M and Wargocki P (2011) Literature survey on how different factors influence human comfort in indoor environments. *Building and Environment,* 46, 922-937.

Frontczak M, Schiavon S, Goins J et al (2012b) Quantitative relationships between occupant satisfaction and satisfaction aspects of indoor environmental quality and building design. *Indoor air,* 22, **2**, 119-131.

Goodman E, Kuniavsky M, Moed A (2003) *Observing the User Experience: A Practitioner's Guide to User Research.* Morgan Kaufmann, Burlington, Massachusetts.

Heerwagen JH, Kampschroer K, Powell KM et al (2004) Collaborative knowledge work environments. *Building Research & Information,* 32, **6**, 510-528.

Heerwagen J and Zagreus L (2005) The human factors of sustainable building design: Post occupancy evaluation of the Philip Merrill Environmental Center.

Hua Y, Gocer O, Gocer K (2014) Spatial mapping of occupant satisfaction and indoor environment quality in a LEED platimum campus building. *Building and Environment,* 79, , 124-137.

Huizenga C, Laeser KArens EA (2002) A web-based occupant satisfaction survey for benchmarking building quality. In: Proceedings of Indoor Air, Monterey, CA.

Huizenga C, Zagreus L, Arens EA et al (2003) Measuring indoor environmental quality: A web-based indoor occupant satisfaction survey. In: Proceedings of Greenbuild Conference, Pittsburgh.

Institute of Medicine (2011) Climate change, the indoor environment, and health. The National Academies Press, Washington, DC.

Kim J and de Dear RJ (2012) Nonlinear relationships between individual IEQ factors and overall workspace satisfaction. *Building and Environment,* 49, 33-40.

Kim J, de Dear R, Candido C et al (2013) Gender differences in office occupant perception of indoor environmental quality (IEQ). *Building and Environment,* 70, 245-256.

Krueger RA (2009) *Focus Groups: A Practical Guide for Applied Research.* Sage, London.

Leder S, Newsham GR, Veitch JA et al (2015) Effects of office environment on employee satisfaction: A new analysis. *Building Research & Information*.

Martin B, Hanington B, Hanington BM (2012) *Universal Methods of Design: 100 Ways to Research Complex Problems, Develop Innovative Ideas, and Design Effective Solutions.* Rockport Pub.

Melikov AK and Kaczmarczy K J (2012) Air movement and perceived air quality. *Building and Environment,* 47, 400-409.

Newsham GR, Birt BJ, Arsenault C et al (2013) Do 'green' buildings have better indoor environments? new evidence. *Building Research & Information,* **ahead-of-print**, 1-20.

Newsham G, Birt B, Arsenault C et al (2012) Do green buildings outperform conventional buildings? Indoor environment and energy performance in North American offices.

Occupational Health and Safety Administration (1996) *Standard 29 CFR (1926.56) Minimum Illumination Intensities in Foot Candles.* Available at: https://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10630 2015).

Pasut W, Zhang H, Arens E et al (2014) Energy efficient comfort with a heated/cooled chair. *Proceedings of the 13th International Conference Indoor Air*.

Patton MQ (2005) *Qualitative Research.* Wiley Online Library.

R Development Core Team (2013) R: A Language and Environment for Statistical Computing. R version 3.0.2, .

Rocky Mountain Institute (2014) How to calculate and present value for deep retrofits, A guide owner-occupants. RMI, Boulder, CO.

Rumsey P (2011) *Out of Control Controls.* Available at: http://greensource.construction.com/opinion/2011/1109_Out-of-Control.asp .

Schiavon S and Altomonte S (2014) Influence of factors unrelated to environmental quality on occupant satisfaction in LEED and non-LEED certified buildings. *Building and Environment,* 77, 148-159.

Sundell J, Levin H, Nazaroff W et al (2011) Ventilation rates and health: Multidisciplinary review of the scientific literature. *Indoor air,* 21, 191-204.

Tham KW, Wargocki P, Tan YF (2015) Indoor environment quality, occupant perception, prevalence of sick building syndrome symptoms, and sick leave in green mark platinum-rated versus a non-green mark-rated building: A case study. *Science and Technology for the Built Environment,* 21, **1**, 35-44.

Tracy SJ (2012) *Qualitative Research Methods: Collecting Evidence, Crafting Analysis, Communicating Impact.* John Wiley & Sons.

U.S. Green Building Council (2015) *Credits.* Available at: http://www.usgbc.org/credits .

U.S. Green Building Council (a) *About LEED.* Available at: http://www.usgbc.org/articles/about-leed .

U.S. Green Building Council (b) *Three Billion Square Feet of Green Building Space LEED-Certified.* Available at: http://www.usgbc.org/articles/three-billion-square-feet-green-building-space-leed%C2%AE-certified .

U.S. Green Building Council (c) *What is a Green Building?* Available at: http://www.usgbc.org/articles/what-green-building .

Ubbelohde MS (2015) High dynamic range imaging (HDRI) as design tool for assessing daylight discomfort glare.

US Census Bureau (2015) *Census Regions and Divisions of the United States.* Available at: http://www2.census.gov/geo/pdfs/maps-data/maps/reference/us_regdiv.pdf .

US DOE (2015) *Building Science-Based Climate Maps.* Available at: http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/4_3a_ba_innov_buildingscienceclimatemaps_011713.pdf .

US Green Building Council (2015) *Green Building Information Gateway.* Available at: http://www.gbig.org/ .

USGBC (2015) *LEED Certified Project Directory.* Available at: http://www.usgbc.org/projects .

Vischer JC (2008) Towards a user-centred theory of the built environment. *Building Research & Information,* 36, **3**, 231-240.

Ward G (2015) *Universial Version of Photosphere 1.8.7U, HDR Imaging.* Available at: http://www.anyhere.com/ 2015).

Wargocki P, Frontczak M, Schiavon S et al (2012) Satisfaction and self-estimated performance in relation to indoor environmental parameters and building features. In: Proceedings of 10th International Conference on Healthy Buildings, Brisbane, Queensland.

Zagreus L, Huizenga C, Arens EA et al (2004) Listening to the occupants: A web-based indoor environmental quality survey. *Indoor Air,* 14 (Suppl. 8), 65-74.

Zhang H, Arens EA, Kim D et al (2010) Comfort, perceived air quality, and work performance in a low-power task–ambient conditioning system. *Building and Environment,* 45, **1**, 29-39.