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What School Buildings Can Teach Us:
Post-Occupancy Evaluation Surveys in K-12 Learning Environments

By

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What School Buildings Can Teach Us:
Post-Occupancy Evaluation Surveys in K-12 Learning Environments

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By

Lindsay Alana Baker

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Post-Occupancy Evaluation Surveys in K-12 Learning Environments**

Table of Contents

1	Introduction	1
1.1	Statement of the Problem	2
1.2	Objective	2
1.3	Significance	3
2	Background	4
2.1	Literature Search Methodology	4
2.2	Assessing School Buildings.....	5
2.3	Assessable Features in School Design	7
2.3.1	Daylighting	7
2.3.2	Acoustics	9
2.3.3	Air Quality	9
2.3.4	Thermal Comfort.....	11
2.4	Post-Occupancy Evaluation	12
2.5	High-Performance School Design.....	13
2.5.1	Are High-Performance Schools Meeting their Energy Goals?.....	15
2.5.2	Are High-Performance Schools Meeting Comfort & Productivity Goals?	15
2.6	New Research Directions.....	16
3	Methodology.....	16
3.1	CBE Occupant Indoor Environmental Quality Survey	16
3.2	Survey Development for Schools	18
3.2.1	Considering Surveying Students.....	18
3.2.2	Survey Content Revisions for School Environments	19
3.3	School Recruitment	20
3.4	Survey Collection	22
3.5	Data Analysis Methods.....	27
3.6	Limitations of Study	28
4	Findings.....	28
4.1	General Trends in School Surveys	29
4.1.1	Survey-Taker Trends	29
4.1.2	Overall Satisfaction Levels in School Environments	31
4.1.3	High Performance School Programs and Occupant Satisfaction.....	32
4.2	Lighting.....	34
4.2.1	Sources of Lighting Dissatisfaction in Schools vs. Offices	34
4.2.2	Daylighting & Visual Comfort	36
4.2.3	Lighting Satisfaction in High Performance Schools.....	39
4.3	Thermal Comfort	42
4.3.1	Climate Variations in Thermal Comfort and HVAC Design	42
4.3.2	Patterns of Thermal Control in Schools vs. Offices	42
4.3.3	Thermostat Control and Thermal Comfort Satisfaction.....	45
4.3.4	Thermal Satisfaction in Certified Green Schools	47
4.3.5	Operable Windows and Thermal Satisfaction	49
4.4	Air Quality	51
4.4.1	Age of Building and Air Quality Satisfaction.....	51

4.4.2	Certified Green Schools and Air Quality	52
4.4.3	Air Conditioning and Air Quality Satisfaction	53
4.5	Acoustics.....	54
4.5.1	Acoustic Satisfaction in Schools and Offices	54
4.5.2	Open Plan Classrooms and Acoustic Satisfaction	56
4.5.3	Acoustical Issues and Certified Green Schools.....	58
5	Discussion	59
5.1	Green Certifications and Occupant Satisfaction.....	59
5.2	Occupant Survey Research and Facility Management	60
6	Conclusions.....	61
6.1	Summary of Findings.....	61
6.2	Future Research Directions	62
7	References.....	64

LIST OF FIGURES

Figure 2.2.a A Proposed Causal Model for the effect of school design on academic outcomes	6
Figure 3.1.a The typical 7-point satisfaction scale in the CBE survey	17
Figure 3.2.a A Schematic Outline of the CBE Schools Survey Instrument	20
Figure 3.4.a School Building Age Distribution: Study sample vs. US stock.....	26
Figure 4.1.a Demographics: Number of years worked in building	30
Figure 4.1.b Demographics: How long at current workspace?	30
Figure 4.1.c Demographics: Number of hours/week in workspace	30
Figure 4.1.d Demographics: Occupation	30
Figure 4.1.e Demographics: Age.....	30
Figure 4.1.f Demographics: Gender.....	30
Figure 4.1.g Mean Satisfaction Scores by Category: Offices vs. Schools	31
Figure 4.1.h General Satisfaction Scores by Era	32
Figure 4.1.i Mean Satisfaction Scores by Category: Certified Green vs. Conventional built since 1999	33
Figure 4.1.j General Satisfaction in certified green vs. new conventional vs. all other schools	34
Figure 4.2.a Schools vs. Office Occupants: Reasons for Lighting Dissatisfaction.....	36
Figure 4.2.b Visual Comfort Satisfaction Comparison in Classrooms: Windows.....	37
Figure 4.2.c Date of construction vs. windows in classrooms.....	38
Figure 4.2.d Lighting Satisfaction in 1970's schools vs. others	38
Figure 4.2.e Visual Comfort Satisfaction in Classrooms: Shades	39
Figure 4.2.f Lighting Satisfaction in certified green vs. conventional new vs. pre-1999 schools	40
Figure 4.2.g Reasons for Lighting Dissatisfaction: certified green vs. conventional new buildings	41
Figure 4.3.a Schools vs. Offices: Access to Thermal Control	43
Figure 4.3.b Reasons for Thermal Dissatisfaction: Schools vs. Offices.....	45
Figure 4.3.c Thermal Comfort Satisfaction: Cooling Thermostat.....	46

Figure 4.3.d Thermal Comfort Satisfaction: Heating Thermostat	46
Figure 4.3.e Thermal Comfort Satisfaction: certified green vs. conventional new vs. pre-1999 schools	48
Figure 4.3.f Reasons for Thermal Dissatisfaction- certified green vs. conventional new schools	49
Figure 4.4.a Correlations between satisfaction scores	51
Figure 4.4.b Air Quality Satisfaction vs. Date of construction.....	52
Figure 4.4.c Air Quality Satisfaction: Green vs. new vs. all other schools.....	53
Figure 4.5.a Reasons for Acoustic Dissatisfaction in Schools	55
Figure 4.5.b Noise Level Satisfaction: Occupants with windows vs. those without	56
Figure 4.5.c Acoustic Satisfaction in Open Plan Classrooms	57
Figure 4.5.d Sound Privacy Satisfaction: Open Layout schools vs. all other schools.....	58
Figure 4.5.e Acoustic Satisfaction in certified green vs. conventional new vs. pre-1999 schools	59

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1 Introduction

In considering the built environment in America today, it is tempting to divide the landscape primarily into two building types- commercial and residential buildings. Yet, a quarter of the country's population spends most of their day in a third type of building- the school building. A recent study by the Building Educational Success Together (BEST) collaborative estimates that from 1995 to 2004, public school districts across the US spent \$504 billion in school construction (capital projects), making this sector, by some estimations, the largest non-residential building sector by cost in the country.

And yet, despite this investment, school buildings are deteriorating. After decades of under-investment in America's aging school infrastructure, these facilities are not meeting the needs of the teachers and students who occupy them. Perhaps more notable is that many of our new schools are not meeting expectations, and require expensive maintenance and modernization procedures that can cripple school budgets. Inefficient and ineffective educational buildings are not only taking resources away from the educational mission itself, but are creating problematic learning environments. Failing school buildings have been shown to be linked to increased health problems in students, as well as lower grades and academic performance, in research that will be explored in section 2 of this paper.

But how can we design excellent learning environments without having reliable sources of information on how to do this? Many design professionals and facilities managers use intuition and habit to support the decisions they make in providing school facilities, without testing their assumptions and hypotheses. And although intentions are usually good, the construction and maintenance of buildings can be disorganized and messy, and designs are not always built as planned. Few architects and engineers stay engaged with the performance of their buildings after occupants have moved in, which disconnects them from useful feedback loops that may help inform their future work. This disconnect is often a result of a lack of available funding for follow-up work, and the perception that this work can be tricky and time-consuming. Thus, the field of Post-Occupancy Evaluation (POE) research has sought to develop methods to help standardize feedback loops.

Feedback loops are especially necessary in regards to energy performance goals in school buildings. Since the energy crisis of the 1970s, much attention has been given to the need for energy efficiency in buildings in the US, and school buildings are no exception. Today, the average school spends 32% of its operations budget on utility bills (NCEF Data & Statistics website). In the past decade, emphasis has shifted to "green" or "sustainable" buildings, which are not only designed to maximize energy efficiency, but also occupant well-being and a variety of other environmental impact areas. Yet again, the impacts of these strategies are not well known, nor are they investigated post-construction. School districts, like many building owners, are satisfied to know that their buildings were *intended* to perform well, even if they have little hard evidence to back this up. Now is a crucial moment to establish a reliable feedback loop to assess the effectiveness of school design methods, especially those in the high-performance school field. In particular, we need feedback that integrates effects of

specific facility design and management decisions on energy use *and* occupant satisfaction and behavior.

1.1 Statement of the Problem

As noted above, today's school facilities planners face many challenges in prioritizing and planning school construction and renovation projects. There are many new considerations to manage, like information technology integration, in addition to increasing pressure to save energy and operating expenses through new technologies. There has been a surge of interest in specific features such as daylighting, building management or energy management systems (BMS or EMS), smart boards, and other technologies like occupancy sensors for lighting. These techniques are shared in the industry through trade magazines, conferences, and word-of-mouth. The ad hoc spread of technology would not pose a problem necessarily, but anecdotes and stories are beginning to emerge that bring to question the effectiveness of some of the strategies being introduced into school buildings. Some daylighting strategies are having significant issues with glare and overheating, complex control systems for lighting and heating are being overridden and used ineffectively, and less toxic finish materials are being found to be less durable than the typical materials used for school facilities. Few comprehensive feedback loops have been developed to inform the school facilities industry on the success or failure of new design strategies. This absence of structured feedback can be risky, as one anecdote has the potential to change industry trends, however poorly founded or robust it may be. Controlled studies that frame trends in a more robust way can help to provide more reliable information to the industry.

Still, controlled studies, which look rigorously and fairly at the effects of design decisions in real buildings with real occupants providing feedback, have generally been hard to find in recent years. In researching the effects of specific building strategies and features, it is often difficult to isolate the variable of interest, because typically, every building is different. Especially in the case of so-called "green" buildings, studies often neglect confounding variables of age, climate, cost, and quality of the building process in their analysis. This study, and the larger research project it belongs to at the Center for the Built Environment (CBE), attempt to control for more of these variables in order to provide a more isolated and objective set of findings to provide feedback for specific new design trends.

1.2 Objective

The primary objective of this research is to demonstrate the usefulness of occupant feedback mechanisms in school buildings, both for individual building feedback loops, but also for school districts and the industry as a whole. The study aims to show that POEs can produce a variety of interesting, relevant and targeted results with minimal effort and inconvenience to staff and students. Finally, the study aims to identify some trends in school buildings that may have a positive or negative impact on teacher satisfaction. This can ultimately help designers to better understand the implications of certain school design features, and support the argument that school facilities impact overall school quality.

1.3 Significance

Although POE surveys, such as the CBE's Building Occupant Survey (BOS) have become more common in office buildings, an equivalent tool had yet been developed to gather specific feedback for schools, especially in a manner that could be executed easily. This study involved the creation of a tool based on the BOS for K-12 school buildings. The ease of use of the BOS for schools allows for another significant accomplishment of this study, which was collecting occupant satisfaction data and building characteristics for an initial sample of school buildings across the country. The great strength of this work will be more fully realized as larger numbers of buildings are entered into the survey collection tool. As the set grows, the potential for analysis and trending grows, as has been seen in the larger CBE dataset for office buildings. For this initial set of 61 school buildings, some trends are noticeable and may be indicative of larger trends in the country.

2 Background

Roughly one quarter of our nation's population spends the majority of their day in America's K-12 school buildings- they are our youngest citizens. Although these spaces have long been considered and analyzed (scholarly studies have been published as far back as 1915- see Mills, 1915 and Baker, 1918), recent scholarship in building performance has focused primarily on commercial buildings. But school buildings are very different from offices; they have different occupants, different daily routines, different management systems, different budgets, and different decision-making structures during the design and construction phases. Additionally, as more schools move towards "green" design, there is an increased need for testing systems in the field to ensure that they are achieving expected energy-related goals. Post-occupancy evaluation, including the CBE Building Occupant Survey (BOS), offers the means for a comprehensive evaluation of the effects of design choices on users, operators, and the measured performance of buildings (Zagreus et al 2004). This is especially important in high-performance buildings, where design decisions are based on expectations of performance that may or may not be met. Feedback to designers on these matters is crucial. Research into school building performance has grown rapidly in the past decade, producing many new theories, insights and research questions.

The following discussion of relevant scholarship in the evaluation of school building performance begins with the history and theory of school building assessment to show that, in comparison to office buildings, there are more stakeholders and perspectives represented in the scholarship, often because of the different decision-makers involved in school buildings. The section following reviews the various aspects of school environments that have been studied in recent years, with a focus on those related to occupant comfort. Next, the history of the Post-Occupancy Evaluation (POE) field is discussed, to provide background for the methodology chosen for this study. Finally, the last section reviews key literature needed to understand one facet of this research that looks specifically at certified green school buildings (also referred to in this paper as "green" school buildings). The section concludes with a short set of recommendations for future related research in these fields.

2.1 Literature Search Methodology

I searched a number of electronic databases for literature on this subject, including publications and search engines in building science and educational administration. Major search terms included "occupant comfort", "teacher satisfaction", "school environments", "school buildings" and related terms more specific to each technical area. The aim was to find all scholarship that considered how to build and run school facilities in a way that maximizes their potential, both in terms of operating costs (including energy and durability issues) and occupant satisfaction (and, as a related sub-set, student performance). Google Scholar, WorldCat, and Web of Science were all especially useful in this pursuit. I was grateful to the authors of a group of literature reviews which provide broad introductions to the areas of study investigated (Mendell and Heath 2005, Schneider 2002, Woolner et al 2007). Excluded from this review were papers that focused on aspects beyond the control of architects or facility managers,

such as planning issues, community-level design, or IT (information technology) in the classroom. Also excluded were aspects of school environments that do not directly relate to daily occupant comfort, such as Crime Prevention Through Environmental Design (CPTED) and wayfinding. All of these topics have bodies of scholarship that are key in gathering a full understanding of the design of school facilities, but fall outside this study's focus on occupant comfort and productivity in school facilities.

2.2 Assessing School Buildings

Controlled studies examining the effects of the school environment on learning date back to the turn of the century. In fact, some of the earliest studies done on ventilation, heating and lighting on American buildings were done in schools, perhaps because, as one earlier researcher put it, "it is a case in which the lives and health of your children, and your neighbor's children, are at stake, and it is your duty to know (Mills, 1915)." As decades past, new problems with school buildings emerged ranging from overcrowding to air quality to lighting, leading to deteriorating school facilities. A 1995 report by the General Accounting Office (GAO) estimated that roughly \$112 billion was needed to "repair or upgrade America's multibillion dollar investment in facilities to good overall condition," while a more recent report including new school construction needs, raised that estimate to \$322 billion (NEA, 2000). In fact, the past decade has seen an unprecedented investment in school facilities, with over \$20 billion being spent annually in school construction (Abramson, 2007).

In order to enhance the quality of school buildings, we must first be able to effectively *measure* and *assess* school building performance. Many designers, researchers and education scholars have developed indices, rubrics and protocols to assess school buildings. Most commonly, school districts use anecdotal information to support decisions about facilities management and construction- no formal process is used to evaluate school building quality or performance, even after a recent construction project. Other schools and school districts keep a rough "condition" index, which can cover major components of their school building stock; their age and state of disrepair, in what is often called a Facilities Condition Index (FCI). Researchers in educational fields have used FCIs when answering the question of whether school facilities affect academic outcomes (see Durán-Narucki 2008 for an example of this). In a recent study, Roberts points out that FCI-style assessments are highly subjective, and can leave out key aspects of facilities that affect academic environments and teaching (Roberts 2009). FCI-style assessments tend to gloss over aspects of the facility that are harder to measure, or are not showing obvious signs of deterioration. Their main message tends to privilege the importance of good maintenance practices, rather than lessons for designers and educational facility planners, and is thus not the focus of this research. Instead, I focus on understanding links between design decisions and school performance with teacher satisfaction being used as a proxy measurement. Figure 1 shows a causal model that further defines this chain, in an effort to better define the different goals and aims of research in this arena.

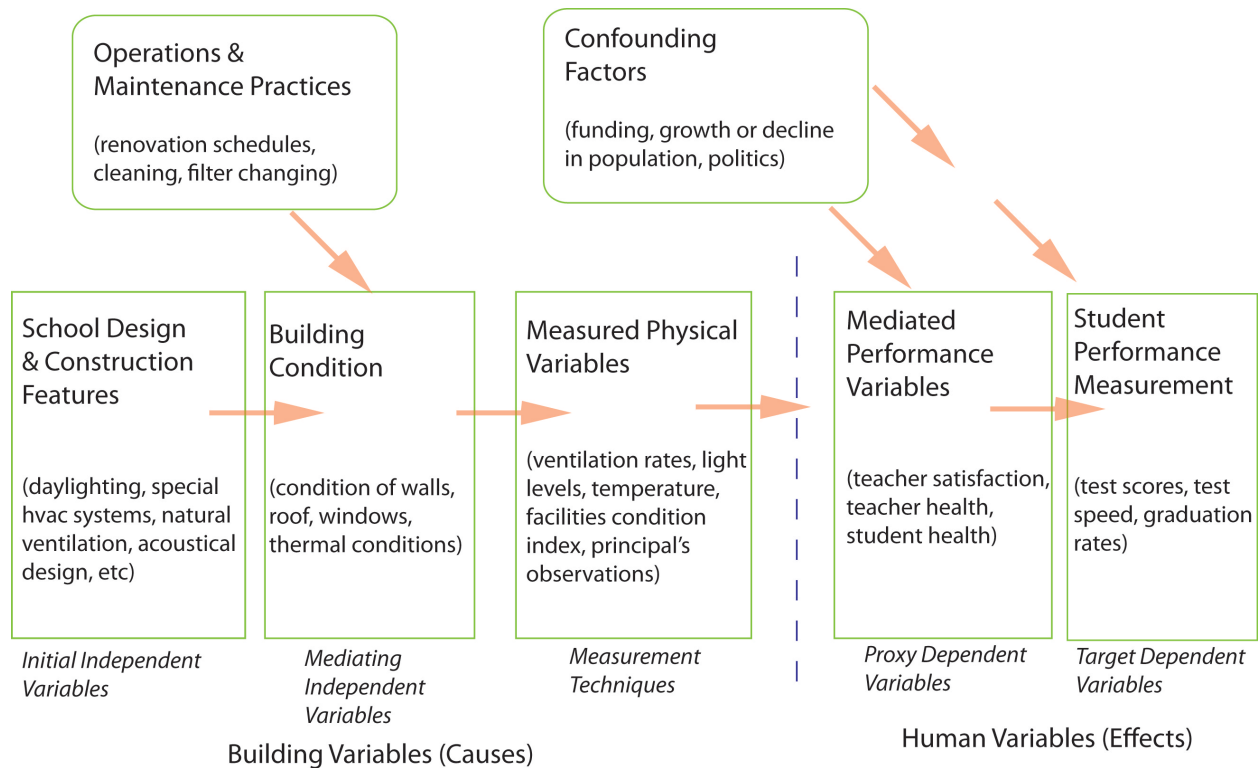


Figure 2.2.a A Proposed Causal Model for the effect of school design on academic outcomes

Many design researchers have derived their own methods for assessing school building design, often involving observation during the operation of the building. In a recent example, Tanner described his own facilities assessments in a recent paper from 2009 looking at connections between design features and student achievement. However, Dr. Tanner's facilities assessment methods were highly subjective. Based on the theoretical work of Christopher Alexander in the 1977 book *A Pattern Language*, they required experienced educational facilities planners to properly conduct the assessment. In 2002, Henry Sanoff and his colleagues popularized an assessment protocol, which has been broadly cited. Sanoff makes key suggestions about the assessment process, emphasizing the importance of inclusive planning, cultural appropriateness, and design for different learning styles. A qualitative and relatively lengthy set of questionnaires, Sanoff's method includes questions like "Do the subdivided parts of the building appear to have a function that is easy to identify?" The protocol is highly subjective, as it involves no objective measurements or means for determining whether the school building meets any defined and achievable standard. Although Sanoff's questions are interesting, this protocol seems to be more useful during the design process to set goals for educational facilities, rather than during an assessment that is aimed at improving an existing facility.

More recent survey techniques have been used to conduct more effective assessments of school facilities. Earthman (2009) takes the approach of asking for principals' opinions and feedback, using a protocol developed by his colleague, Cash, for this purpose. This protocol is again not written with designers as an audience, but covers more specific information about building systems and design features

(daylighting is included, for example). And in 2009, Uline and Tschannen-Moran used a teacher survey to ask about the quality of school facilities, with most questions focused on how the facility helped or hindered the teaching process. Since their audience was not designers or facility managers, this method lacked a robust documentation of the design and descriptions of the building components present in each classroom.

The scholars discussed up to this point are approaching the issue of school building performance in a relatively new way, seeking to quantify the effect that facilities have on effective learning and teaching. They advocate that a more rigid FCI-style assessment of facilities is insufficient since it may fail to capture aspects of a building that are crucial for educational purposes. Their audience is school administrators, and thus they are sending the message “school facilities affect student performance”. However, since my audience is the people who design and maintain these facilities, the question to be asked here is “*how do we build and maintain school facilities that positively affect student performance,*” with consideration to the budgetary and political constraints facing public schools in America. While the field has many stories to tell of schools that provide great learning environments, very little research has been devoted to understanding exactly *how these school buildings differ from their peers.*

2.3 Assessable Features in School Design

On the other end of the research spectrum, are studies and researchers who focus on isolating specific building features or systems in schools, in an effort to inform design and maintenance practices. Often, they are asking whether system functionality (or presence/absence) has an effect on school performance. That these studies have decided to use school performance indicators (such as test scores, absentee rates, respiratory illness rates, etc) as their measure of success arises from one of two motives. The first is in an effort to find ways to boost the quality of school environments through design and maintenance (as is the case with Mendell and Heath, Heschong, and others). Others are using schools because it is easier to measure “productivity”, and thus quantify the affects of building systems on occupants. This is difficult to do in office buildings or other building types where performance indicators like test scores and attendance are not routinely collected. These more quantitative studies generally do not collect information on more holistic educational outcomes, as is the concern of the research noted in section 2.2, but rather they focus on specific building systems, assessing whether they have an affect (positive or negative) on occupants and on aspects of building performance.

2.3.1 Daylighting

Significant research has been conducted on the effects of daylighting in schools, primarily focusing on the potential correlations between daylighting and student productivity. In the first half of the 20th century, schools were built with sufficient natural light, because lighting technologies had not yet evolved to allow for electrical lighting in schools (incandescent light bulbs would have produced too much heat, and fluorescent bulbs were not yet common). However, as lighting technologies evolved, more schools (along with other building types) were built to rely on electrical light.

Studies in the 1960s and 1970s reinforced this practice, showing evidence that daylight was not needed in classrooms (Larson 1965).

The 1990s brought a new era of daylighting related studies, with a variety of researchers trying to find a connection between daylight and student performance. By far the most widely cited of these was a study conducted by the Heschong Mahone Group in 1999. The Heschong Mahone study looked at daylighting in classrooms in three public school districts in the US, and compared different daylighting design strategies to student test scores. The most significant finding in the study emerged from one of the districts (Capistrano, CA), where it was found that students in sufficiently daylit classrooms had significantly greater improvement over the course of one school year in math and reading skills (20% for reading, 26% for math) than students in classrooms with no daylight. Multiple linear regressions were run using 50 other factors that might have influenced student performance, and Heschong Mahone still maintained that the daylighting correlation was significant. However, as Fay pointed out in his comprehensive literature review in 2002 on daylighting and productivity, “The authors show a 99% statistical certainty that there was an increase in performance, but the correlation value, R^2 , was 0.25-0.26”, showing that, in fact, the likelihood that the increase in student performance was due to daylighting was quite small (Fay, 2002). The authors of the Heschong study were quite clear on this point, noting in the 1999 study (p. 57), “We have merely shown an association between the presence of daylight and higher student performance, not shown that daylighting causes students to learn more.” However, the study has been widely touted by advocacy groups as evidence that students learn better when daylight is present¹. A paper by Boyce et al notes that ultimately, the percentage increase in student performance that can be attributed directly to daylighting is 0.3%, a considerably smaller number than 20% (Boyce, 2003). It is still a positive impact, but must be seen in the larger context of all other factors that might contribute to student performance.

Another study that investigated the connection between daylight and student performance was an investigation by Bailey and Nicklas of North Carolina schools in the mid-1990s (resulting in 2 studies published in 1997). Bailey and Nicklas compared student test scores in a before/after scenario, in which students were moved into new schools, after their old (non-daylit) schools had been burnt down. The new schools provided daylighting, and test scores went up. This was not a controlled study, in that it did not consider the multiple confounding variables at play (including the ‘newness’ factor, which is a well-known confounding variable for green building research). Ultimately, most school districts in the US now believe it to be beneficial to have daylighting in classrooms, and the question of whether daylighting contributes to higher student achievement has become less controversial in the past 5 years or so. However, this has produced a new set of problems, associated with the recent surge in daylighting design for high-performance schools.

¹ In particular, publications from the US Department of Education's National Clearinghouse for Educational Facilities and the non-profit group the US Green Building Council show the findings of this report, often with inaccurate statements regarding a cause and effect relationship.

Although research has not been done directly on the effects of new high-performance school daylighting metrics, a recent study by Mardaljevic et al (2009) points out that voluntary green building standards like the LEED (Leadership in Energy and Environmental Design) Rating System and the UK's BREEAM (BRE Environmental Assessment Method) have daylighting metrics that do not adequately consider the effects of glare and visual comfort. As more school districts use these metrics to design new facilities, anecdotal stories are emerging that newly designed daylighted spaces are not necessarily comfortable for occupants. The consequences of this may vary- do occupants react to these situations by closing the blinds and turning electric lights on (thus negating the intended energy savings, view opportunities, and presumed educational benefits)? Or do they remain visually uncomfortable? This thesis hopes to help answer some of these questions, and thus inform the development of better daylighting metrics.

2.3.2 Acoustics

Research in classroom acoustics is a robust field, which has produced its own ANSI standard based on years of rigorous research. The research is carefully described in Annex A of the ANSI Standard 12.60, where a clear causal chain has been developed to support the theory that proper acoustic design in schools has a direct effect on acoustic performance, which in turn has a direct effect on speech intelligibility, which then finally produces a direct effect on student learning outcomes (ANSI/ASA 12.60, 2002).

Acoustical considerations in school design cover two primary areas: reducing background noise level and reducing reverberation time (echo). These aims can be addressed through a number of strategies, from using materials that reduce sound transmission through walls to providing soft interior finishes that help reduce echoes in the classroom. Privacy can also be an issue if voices can be heard through walls, or in the case of open classroom environments. Although acoustic strategies are well-known and the metrics used in the ANSI standard are achievable, acoustical practice has typically gotten less recognition than other aspects of IEQ in the past. However, good acoustics are crucial to the learning environment, and thus deserves more study as the research community seeks to better understand the operational and occupant-related barriers to good classroom performance.

2.3.3 Air Quality

One measureable and definable impact that school buildings can have on teachers and students is in the area of air quality. Building systems and materials can either have a positive impact on overall air quality in a building (when HVAC systems filter out pollutants in ambient air), or they can contribute to a deterioration of air quality, through increased particulate matter, volatile organic compounds, moisture intrusion that leads to mold problems, and other problems. This area of research has been developed significantly in the past 20 years, as HVAC system technology has evolved, and as the prevalence of Sick Building Syndrome (SBS) has spread across the U.S. SBS is a loosely defined term that has emerged as a way of describing the phenomenon of occupant sickness that arises from contaminants (usually in the air) in

buildings. This field of research is highly technical, involving a good deal of medical research methodologies and an understanding of chemical and biological systems that affect air quality.

A comprehensive literature review by Mendell and Heath (2005) on the impacts of indoor pollutants and thermal conditions on student performance provides a more understandable summary of this field. The authors of this review note that while significant research has looked at potential impacts of air quality in schools, few have managed to make a direct correlation between one pollutant or IEQ factor and a measure of student performance or productivity. However, the research has shown correlations between health indicators such as asthma and respiratory illness and air quality indicators. Mendell and Heath conclude by noting the importance of not overstating the causal relationships that are found in these types of studies, and the need for additional research to better understand the potential impacts that air quality have on student performance.

Since epidemiological research has developed a well-established causal link between air pollutants and health, the focus of research in the area of school environments has been on determining *how design decisions such as HVAC system design and materials specifications* impact overall levels of pollutants in school buildings. As such, the most informative research in air quality considers HVAC design and materials specifications as the independent variables, and examines the effects these decisions have on either a) direct air pollutant measurements, b) health impacts, or c) productivity impacts, in rare cases. One well-done example of this last type is a study done by Wargocki and Wyon (2007) for ASHRAE, which showed that increased outdoor air delivery (increasing from 11 cfm/person to 20.3 cfm/person) improved student performance by 8% on average, after considering all confounding factors (Wargocki and Wyon, 2007). Other influential studies in this field include a field test in Michigan, written up in a 2006 study by Godwin and Batterman, who showed that many classrooms in their sample set were under-ventilated, and were producing unhealthy conditions for students and teachers, arising from high CO₂ levels and high particulate matter. In this situation, the researchers determined that the sources of pollution were inside the classroom, but that the ventilation systems were not effectively removing them from the classrooms during occupied hours. Another study in this field, published by Smedje and Norback in 2000, showed a decrease in respiratory illness in schools in Sweden that had new ventilation systems installed (compared to schools with older ventilation systems or none). This study supports the notion that the better (new) HVAC systems can have a positive impact on student and teacher health. However, there is still much to be learned to determine best practices in design, operations and renovations to ensure good air quality. In particular, there is less known about air quality in the field, aside from the Godwin study, to better understand the extent of the problems that need to be addressed in this field.

One last air quality study that should be mentioned is one by Smedje in 1997, which showed a strong correlation between subjective air quality (as measured by occupant perceptions) and measured air quality. This study showed that occupants can be reliable indicators of air quality in classrooms. This study is a key basis for my research,

which uses occupants as indicators of air quality, since more quantitative measurements are outside of the technical scope of this study.

2.3.4 Thermal Comfort

In a related field, researchers have long considered the optimal thermal environments for buildings, and specifically for school buildings. Prior to the invention of air conditioning, interior environments were much more dependent on natural conditioning techniques like stack ventilation, passive heating, and simple operable windows. But as air conditioning became the norm, especially in the U.S. over the past 60 years, these techniques were largely lost, as architects and engineers began the quest for a uniform, ideal thermal environment in buildings. Studies in the 1970s supported the notion that interiors needed to be kept within a small band of temperatures to be comfortable, and this in turn influenced building codes in the U.S. and internationally (Brager and deDear 1998). This trend grew to its most extreme in the 1970s in school buildings, as designers eliminated windows altogether, in an attempt to keep temperatures constant while reducing energy use (a priority that arose partially due to the oil crisis of the early 1970s). The idea that a constant and neutral thermal environment is needed in school environments is still perpetuated in this decade, as is shown in a well-regarded literature review by Schneider in 2002. In this oft-cited paper, he relies heavily on 1970's research (including Harner 1974). While Schneider does later mention the importance of occupant control, he fails to mention the contradictory guidance these different design aims provide. Indeed, this literature review leaves the reader with the questions that many practitioners have today; how much thermal control is appropriate in a school building, to optimize comfort and energy use?

Recent studies in this area have produced a more nuanced perspective on the thermal needs and wants of occupants in buildings. First, studies in the 1990s showed that teachers have a strong preference for thermal controls of some kind, and see it as an influence on student achievement and their own performance (Heschong 2002, Lackney 1999 and Lowe 1990). While this became common knowledge, questions remain regarding how to provide individual thermal control while keeping energy use in check.

One established vein of research in this area has been that of mixed-mode HVAC design. This approach calls for the use of natural ventilation through operable windows and other user-controlled devices, as a means of both reducing energy use (through the reduction of mechanical heating and cooling) and for enhanced occupant control. However, the 'mixed' aspect of the design refers to the concept that some mechanical systems are also needed. So mixed-mode design is a field that is currently developing best practices and metrics to guide designers in how to effectively and efficiently run natural ventilation and mechanical heating and cooling simultaneously (Brager 2006). Mixed-mode systems are generally broken down into a few types. First, zoned systems where natural ventilation services some areas of a building, while mechanical systems service others (that are perhaps more sensitive to temperature change, have higher heat or humidity loads, or are inaccessible to natural ventilation). Second are changeover systems, where one space can be either naturally ventilated or mechanically conditioned, with a regulating mechanism, like an interlock

on the windows that tells the HVAC system to shut off when windows are open. Thirdly, there are concurrent systems in which some combination of zoned and changeover is employed, with different strategies used in various parts of a building. Recent research has shown these spaces to have high thermal comfort satisfaction compared to their peers (Brager and Baker 2009). Other research in the field of air quality and natural ventilation has given even more reasons to continue pursuing mixed-mode designs. One study by Mendell et al (1996) as a part of the California Healthy Buildings Study has shown that naturally ventilated buildings can have lower prevalence of respiratory disease than either mechanically ventilated or air-conditioned buildings. Another study looked specifically at 104 childcare buildings in Singapore, noting the same results—lower levels of respiratory disease and better air quality in naturally ventilated childcare centers (Zuraimi 2007).

To date, no comprehensive controlled studies have shown that mixed-mode systems are guaranteed to save energy, although they are often designed to do so. There are many factors that influence whether or not these systems perform as intended, so commissioning, occupant education, and post-occupancy evaluations are key in ensuring that comfort and energy goals are met for any building.

2.4 Post-Occupancy Evaluation

The field of post-occupancy evaluation has been created to address problems in building design and construction, through comprehensive studies of buildings after they have been built and operated (Zagreus et al, 2004). Through a quantification of human and energy-related impacts of selected design strategies, we can begin to critically assess these strategies, both as isolated variables and in their interactions with related design strategies.

The current field of practice that is called Post-Occupancy Evaluation (POE) is certainly not the first intentional effort to examine buildings after they have been built. For centuries, buildings have been scrutinized for their effectiveness at dealing with climate, addressing the needs of occupants, and at remaining useful and intact over time. The contemporary field of POE emerged in the 1970s, but significantly developed in the 1990s, when this practice became established as a unique field of practice that involved measurement and verification of building systems (Weiss 1972, Leaman and Bordass 2001). The major PROBE studies in the UK of the 1990s established the potential usefulness of POE, in taking a large sample of buildings across the country and evaluating them for energy-related issues, as well as occupant comfort (Leaman and Bordass 2001). They found that there was often a large disconnect between the intended use and function of buildings and how they actually performed, in multiple areas. This study helped to build awareness of the problem that buildings tend not to perform as intended, and that feedback loops are needed to inform designers and engineers on how to more effectively build. The PROBE studies also identified some key areas where that disconnection occurred, including in the assumptions about how buildings would be managed by facilities professionals, and how well occupants would understand the systems they were meant to control.

Starting in the late 1990s, the school facility field was also starting to pick up on the importance of POE as a method of assessment. In 1999, one of the central theorists of the school facility industry, Dr. Jeffrey Lackney, published a paper on the usefulness of POE studies, specifically in surveying occupants (Lackney 1999). In 2005, the Council of Educational Facility Planners International, the major trade industry group that supports school facility professionals, came out with a guide to POE in their Guide for Educational Facility Planning, which included a checklist of questions to ask occupants (CEFPI 2005). This new trend provoked more research, to better understand the ways in which we can design buildings to meet their full potential, especially in terms of energy and occupant comfort. In particular, it sparked the building research fields to develop reliable methodologies to gather information from occupants on their satisfaction with indoor environmental factors, through surveys, observation and other methods. Notably, the work of Jennifer Veitch and her colleagues through the COPE field studies in recent years has contributed through testing occupant survey methodologies for reliability and accuracy (Newsham, Veitch and Charles, 2008).

Meanwhile, the Center for the Built Environment (CBE) at Berkeley was working on creating a more streamlined approach to the occupant survey component of POE studies, through an online survey tool. It began as a tool primarily for U.S. office buildings in 2003, but has since expanded to include multiple building types and different languages (Zagreus et al, 2004). The CBE survey is discussed in more detail in Section 3.1 of this thesis. The CBE survey database grew quickly to include almost 500 benchmarked buildings today, and has thus allowed for trends to be examined, such as a study in 2006 that looked at the differences in occupant satisfaction in "green" and LEED certified buildings compared to other buildings without this designation in the database (Abbaszadeh et al, 2006).

In recent years, more scholarship has emerged that uses the methodology of POE surveys, even in school buildings. In a recent study in Brazil, POE surveys along with focus groups and physical observations were used to evaluate a High School in Sao Paulo, showing the value of qualitative observations in school quality assessment (Ornstein et al, 2009). However, POE surveys and larger POE studies are still not common practice in the US and many other countries, as many schools still rely on the simpler and seemingly objective method of FCI, which essentially relies on the facility staff who are responsible for the buildings to evaluate them objectively and thoroughly.

2.5 High-Performance School Design

Over the past decade, many school facilities have been built or renovated with specific energy-efficiency goals, often because of mandates or incentives from state and local governments (Bernstein, 2003). This has been done primarily as a means of reducing operating costs, but also in reaction to growing societal concerns about climate change. In a report by Turner Construction from 2006, it was estimated that U.S. schools spend approximately \$6 billion on energy costs every year. In another survey, conducted by the American Association for School Administrators, 99% of superintendents reported that rising energy and fuel costs were having an impact on their school system, and 60% were implementing energy conservation strategies as a result (AASA, 2008). Other studies have had similar results, noting the increased interest

in energy saving and “high-performance” facilities (Building Design & Construction 2004, Kats 2006). These efforts have often been associated with the “green building” movement, which promotes energy and environmentally-sensitive building designs. In particular, the LEED Green Building Rating System has been particularly influential in the larger building industry, as a way of defining “green” buildings, and has been used either as a certification or as a benchmark for schools looking to “go green”. Although initially schools used the basic LEED rating system for design and construction (LEED for New Construction), which was a general rating system for all non-residential buildings, a specific system for schools, LEED for Schools was launched in 2007. Other recently developed rating systems and metrics relating to green building have also been very influential, including:

- EPA's ENERGY STAR Program for K-12 Schools. This program primarily consists of a rating that is given to schools with low utility usage, as compared to a baseline that is established by all of the school buildings that have been entered into their tool (Portfolio Manager). It's a simple benchmark that helps schools understand whether they are performing better or worse than their peers (it is weighted for climate), specifically for energy usage. While simple and easy to use, the program does not require much information regarding plug loads and process loads, which makes the benchmark somewhat unreliable. Still, it is being used by many schools for basic energy benchmarking.
- The Collaborative for High Performance Schools (CHPS) Criteria. This system was started in California as a means of helping to provide a set of measurable criteria for high performance school building design and construction, and was based heavily on the LEED system (which, at the time, was not as easily applied or appropriate for school buildings). However, unlike LEED, the initial CHPS Criteria program did not include a third-party verification system, so school buildings initially self-certified. Today, they have developed a third-party certification system and a program for certifying existing school buildings for high-performance operations and maintenance.
- DOE's Energy Smart Schools Program. Primarily an awareness program, this office promotes energy efficiency in K-12 school buildings through case studies, guidelines and other informational tools. They provide protocols for design and Operations and Maintenance (O&M) of school buildings, including the recently published “Guide to Operating and Maintaining Energy Smart Schools”. However, this group does not appear to be focused on occupant comfort issues, and the balance between energy use and comfort. In their “Top Ten O&M Tips” contained in the O&M Guide, tip #3 is to keep windows closed. As the guide notes, “[o]pen windows waste heating and cooling energy.” This oversimplification of HVAC design and abandonment of windows as a potential energy-saving strategy is one of the mindsets that I hope to influence through this study and future research. Building off of mixed-mode research, evidence needs to be built up to help dispel the notion that operable windows are necessarily bad for energy efficiency. These types of programs that focus exclusively on energy efficiency tend to be less concerned with occupant comfort and well-

being, but do provide some good basic guidance on how to save energy in existing schools.

- ASHRAE Advanced Energy Design Guide for K-12 Schools. This is a simple, relatively prescriptive guide for K-12 school buildings, which helps to provide specific guidance on optimizing energy efficiency during design. While it also covers some aspects of indoor environmental quality, it is most focused on energy use reduction, without a significant consideration of occupant comfort and well-being issues.
- AIA Committee on the Environment Top Ten Award Competition. This award, given by the appointed Committee on the Environment (COTE) of the American Institute of Architects, awards ten projects every year, in the U.S. and internationally, that are, according to their website, “the result of a thoroughly integrated approach to architecture, natural systems and technology.” Firms can nominate their buildings, and a jury of AIA members selects the winners, based on a set of core principles that include energy efficiency, water use, durability, and more. It should be noted that this award is given based on design intents, rather than performance data.

This new information on sustainability and health is helping schools find the resources they need to achieve their goals, and the programs have been effective market transformation tools. However, further research is needed to assess the impacts that the green building movement is making on energy use and occupant health in schools.

2.5.1 Are High-Performance Schools Meeting their Energy Goals?

Recent scholarship has questioned the actual energy savings of LEED certified buildings, as the industry is realizing that energy use predictions can be wildly inaccurate (Turner 2008, Scofield 2009, Leaman and Bordass 2001). This issue is partially attributed to the problem that, as the saying goes, “buildings don’t use energy, people do” (Janda 2009). Since energy use is often closely tied to comfort issues related to lighting, heating and cooling, this has led many to call for more research on the human factors in energy performance. In one notable report, EPA ENERGY STAR researchers noted that high efficiency equipment in buildings did not necessarily produce energy efficiency (as measured by the ENERGY STAR rating), and suggested the need to “look beyond technologies and design when defining building performance, and consider building operations and management practices as critical to the realization of a building that performs as well in the ground as it does on paper (Von Neida and Hicks, 2002).” To date, no comprehensive feedback loops have been developed to inform the school facilities industry on the success or failure of these new design approaches.

2.5.2 Are High-Performance Schools Meeting Comfort & Productivity Goals?

There is little evidence to support the notion that schools built with green standards are performing as well as intended in terms of occupant comfort. Indeed, in its 2007 report, a committee appointed by the National Research Council found that there were no “well-designed, evidenced-based research studies” on the overall effects of

green schools on human health, learning and productivity (NRC 2007). This was partially a reaction to studies like the 2006 Kats report (not a peer-reviewed work), which advertised enormous 'operating cost savings' that would be realized from increases in worker productivity, a claim made without significant data to support the assumption that green buildings improve productivity of occupants in any way. The NRC committee called on the school facilities industry to produce more than simply anecdotal information, and show verifiable and reliable causal chains between "green" design characteristics and measures of school effectiveness. As yet, no studies have answered this call through research examining high-performance schools, since this type of study makes controlling variables quite difficult. However, studies by researchers like Mendell, Wargocki, Wyon and others continue to investigate the effects of specific aspects of high-performance schools.

2.6 New Research Directions

In a paper written in 2002, Hansen and Hansen argue that school buildings have been shaped by the eras in which they were built, and the perspectives and political dynamics that influenced these public buildings. Although they look specifically at the politics of their home country, Norway, the same could be argued for the US. In comparing school buildings from different eras of school building theory, we see noticeable effects that those theories have had on the well-being of students and teachers, even today. Schools are built to last, and they are built with many complex and competing priorities. Our design theories and decisions have a profound affect not only on how we build now, but also on how these facilities will perform for generations to come. It is critical that we bring together the many fields of scholars who are interested in school buildings to develop comprehensive yet manageable protocols to assess building performance, and ensure the lasting quality of schools in decades to come. This study aims to introduce one method that can help in this task, through the practice of POE surveys. The following section will describe this proposed methodology in more detail.

3 Methodology

3.1 CBE Occupant Indoor Environmental Quality Survey

Since 2003, the Center for the Built Environment (CBE) at the University of California at Berkeley has administered occupant surveys in over 400 buildings through its Indoor Environmental Quality Occupant Survey tool. The CBE survey was designed to assist building industry professionals in obtaining useful feedback data to manage facilities and for other uses in the building industry such as gaining insight into occupant perception and comfort in buildings. It measures occupant satisfaction with aspects of the indoor environmental quality (IEQ) in their workspaces, and has been primarily used in office environments. From a participant's point of view, the survey is anonymous and voluntary; building occupants are invited to take the survey by their building managers, owners or supervisors, but are not obliged to do so. Participants receive the invitation via an email, with a link to the online survey, and basic information about the survey (notice that the survey is confidential, that it will take roughly 15 minutes, etc). Typically, the CBE BOS survey period lasts for 2 weeks, although it can be extended if the

response rate is low. For the purposes of this thesis, school contacts were challenged to get a response rate of at least 50%, and so in some cases the survey period was extended in an effort to achieve this level of participation. The CBE recommends that building contacts send reminders to occupants when they have one week left to complete the survey, and again one day from the deadline.

The CBE BOS survey is typically split into the following ten categories of questions: Background (demographic questions), Workplace Description, Office Layout, Office Furnishings, Air Quality, Acoustics, Lighting, Thermal Comfort, Cleanliness and Maintenance, and General Satisfaction. Along with collecting basic information about each respondent's access to various types of controls (like light switches or thermostats), the survey collects information about the approximate location of occupants (asking for specific locations would compromise confidentiality). Within each of the survey's categories, a series of satisfaction questions are asked, on a 7-point Likert scale (see Figure 3.1.a for an example), which is generally labeled on a scale from "Very Dissatisfied" to "Very Satisfied".

How satisfied are you with the level of visual privacy?



Figure 3.1.a The typical 7-point satisfaction scale in the CBE survey

In an effort to learn more detail about the sources of dissatisfaction in indoor environments, there are also "branching" questions in the survey. When a respondent answers with a negative score (below "Neutral") on general satisfaction questions like the one in Figure 3.1.a, they are asked for the reason(s) why they are dissatisfied. This allows the CBE BOS survey to collect more specific information without extending the length of the survey as significantly.

The format and wording of the questions in the CBE survey have remained relatively unchanged over the past 7 years, to facilitate comparisons between buildings in the database. For this reason, the survey has also been primarily used by commercial buildings and spaces that fit the language of the questions of the survey best. The survey frequently refers to offices, workspaces, getting one's job done, etc, in a way that has made its application somewhat difficult in different building types such as residential buildings, healthcare facilities, and of course, educational buildings. However, in recent years, the center has begun development and pilot testing of new survey tools for all of these building types.

The CBE survey research team considered and ultimately excluded questions in the survey regarding health impacts such as respiratory illness, absenteeism attributed to building issues, etc. These questions were avoided to ensure that building managers and owners felt comfortable conducting the surveys in their buildings without fear of liability issues that can often arise in working environments. The survey's questions remain more subjective, asking occupants to report their satisfaction levels, and the influence that various IEQ factors have on their ability to get their job done.

In the context of educational commissioning and other types of surveying techniques used for school buildings, it should be noted that the CBE survey remains a tool for building industry professionals. As such it has focused less on teaching effectiveness, and on the aspects of environments that are not under the control of building professionals (such as information technology, which tends to be excluded from the scope of this industry's role in schools). In addition, this study does not actively consider the equity and financial factors that affect a school's facilities and resources to maintain facilities. Future work will likely extend the survey to address other educational and policy-related aspects of the built environment of schools, for the sake of better understanding the full scope of high-performance learning environments. But for this study, the surveys remained in the scope of the existing CBE survey framework.

In general, the CBE tool has proved a very useful tool for architects, building managers, portfolio owners, engineers, and others who seek to gain a better understanding of the buildings they engage. The survey has gained popularity as it offers a convenient strategy for achieving points in the LEED rating systems, as mentioned above. It continues to expand its reach in new building markets, in new countries and languages, and in the variety of building systems it can address².

3.2 Survey Development for Schools

Starting in the spring of 2008, we started developing a BOS survey at the CBE specifically for schools, based on the existing survey, which at that time was focused exclusively on office environments. This was one of the first times that the survey had been revised for a specific building type. The CBE occupant survey research group (which I belong to) decided that it was important to maintain a significant level of consistency across all survey types, to allow for comparison of different buildings. Luckily, the wording of the existing survey was relatively neutral on many accounts, and it was therefore possible to adapt the survey for use in schools. However, many other issues demanded consideration, which are outlined in the following sections.

3.2.1 Considering Surveying Students

An early and crucial methodological step in this study was the decision was to avoid surveying students. The reasons for this were numerous, but primarily related to the difficulty of getting permission from school districts and from the UC Berkeley Committee for the Protection of Human Subjects to use students as study subjects. School districts and the federal government are particularly strict, and appropriately so, when it comes to the involvement of children in scientific research. In the interest of involving as many schools as possible in this phase of the research, we decided to avoid this barrier to participation.

However, it was important for us to consider whether we could get an accurate perspective on the performance of school building, without gathering the perspectives of the students. I sought out precedents for this in recent POE literature, and found that similar studies have been done without direct student input (see CEFPI 2005, Sanoff

² For more information about the CBE survey, please visit the website: www.cbesurvey.org.

2001). In addition, we felt that teachers would be reliable proxies for the satisfaction of students for the topics covered by this study, a sentiment that was also shared by many other researchers in the past (Schneider 2003, Rowan 2002). The nature of a teacher's work requires a high level of attentiveness to the needs and comfort of students. Indeed, in the survey results of this study, teachers frequently reported their observations about student comfort in a variety of areas.

Additionally, the CBE conducted a survey of a middle school in the early phases of the survey tool development, using the same questions that were used for office buildings. This survey was given to middle school students, with very little success. This was particularly evident in comment responses provided by the students, which often indicated a low level of understanding of the purpose of the survey. Student responses often strayed from the concepts they were asked about.

And finally, it is difficult to survey students in school buildings, because they often do not have a primary workspace. Our research group has recently faced this issue with surveys of higher education buildings, where college students use a variety of different classrooms over the course of a week. It is yet undetermined if valuable feedback can be gathered from transient occupants about specific spaces in buildings.

3.2.2 Survey Content Revisions for School Environments

In terms of specific survey content, the original survey was adjusted in three important ways:

1. Patterns of occupancy: many full-time staff in school buildings are teachers, who a) might not occupy a single desk area for a full day, but rather might move from classroom to classroom, and b) certainly might supervise spaces larger than an individual workstation or desk. Therefore, a series of questions were developed addressing Classroom Layout and Classroom Furnishings, and these were only given to subjects who noted that they spent more than 10 hours in a classroom each week. See Appendix B for the questions asked in these sections, and see Figure 3.2.a for an outline of the survey tool.
2. Use of Controls: since classrooms tend to be more controllable than office spaces by nature of their use, more questions were asked regarding the frequency of use for various thermal comfort controls such as thermostats and operable windows.
3. Administrative vs. Educational staff: the survey gathered satisfaction scores for the two basic types of staff in the building- educational staff (teachers and aides) and administrative staff (see Table 3.2a for more details on this split). Administrative staff answered questions about their office space, while teachers answered questions about their classroom space (and their office space, if they used office space more than 10 hours per week). This allowed for easy separation of data into classroom and office categories. While the purpose of this study was primarily to look at classroom environments, office information was collected and organized for analysis in the future.

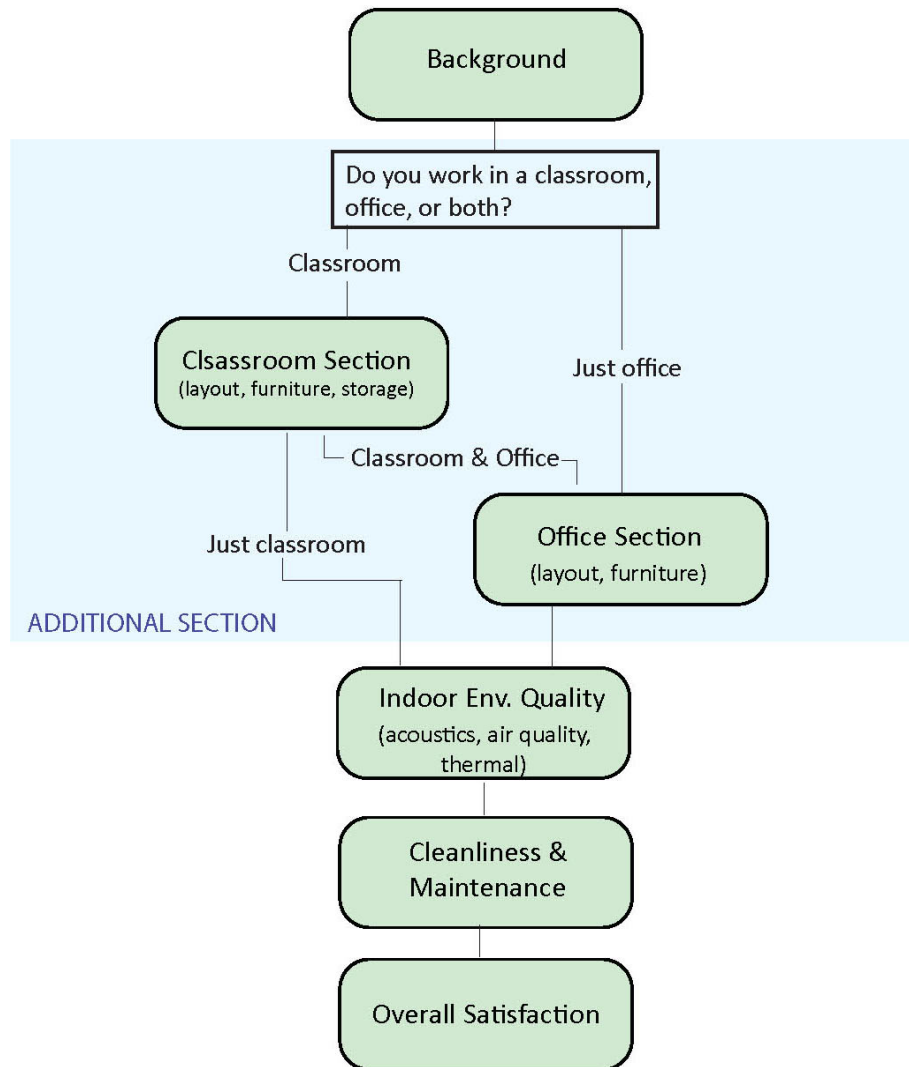


Figure 3.2.a A Schematic Outline of the CBE Schools Survey Instrument

Appendix B presents the full survey instrument. It is important to note that some of the questions would only be reached by a survey-taker if they responded to a previous question in a particular way (“branching” questions, as described above). To view the online version of the survey, you may contact me or the CBE to see a demo version.

3.3 School Recruitment

In order to find a sufficient sample set of school buildings across the country, I contacted educational organizations with large memberships that may be interested in participating in the study. For this project, CBE fees for the BOS survey were waived, to encourage more participation. An announcement (which can be found in Appendix A) was sent to the following email list serves and online newsletters, in the fall of 2008:

- Center for the Built Environment Industry Partners Group
- USGBC (US Green Building Council) LEED for Schools Corresponding Committee

- CEFPI (Council for Educational Facilities Planners International) Communicator (newsletter to members) and official organization blog
- AIA (American Institute of Architects) Committee on Architecture for Education
- Healthy Schools Campaign email list
- Society for Building Science Educators listserv
- Big Green listserv, hosted by Building Green, Inc.

In addition, schools were recruited at the CEFPI Annual Conference in 2008 and the Greenbuild 2008 conference. Efforts were made to ensure that the recruitment process did not favor high-performance schools, schools from a particular state or locality, or either public or private schools. The goal was to get a sample that was as well-distributed and random as possible. The announcement clearly stated the following requirements for schools that wished to participate:

1. You must be able to contact teachers via a superintendent, principal or other direct supervisor, using email.
2. You must be able to provide the information listed in the building characteristics form, for each building that you would like to survey, to the best of your ability.
3. The school(s) you would like to survey must be K-12 (no childcare or universities) within the US or Canada that were fully occupied during the '07-'08 school year.

In addition, we received verbal confirmation from all contacts that they would make an effort to obtain at least a 50% response rate from all staff in the building, through email announcements or other means, if necessary.

In order to confirm participation in the study, all contacts were required to complete a basic building characteristics form, shown in Table 3.3.a. This form asked for the location of the building (including an address), the gross square footage, energy data (if available), and information on occupancy, such as whether the school building was open year-round, or if it was closed during the summer. The form was designed to gather as much information as practicable, without discouraging participation. This may have been due to unavailable data, but more likely just waning interest in the project, as I sent follow-up emails to these contacts via email, largely without response.

Table 3.3.a Building Characteristics Form completed by study schools

<i>Sample School</i>	
School building name	Acme Elementary Classroom Building #1
School District	Dekalb County Schools
School Contact Name (principal or other)	Jane Doe
School Contact Title	Principal
School Contact Email	jane.doe@dekalb.co.ga.us
School Address	123 Elementary School Lane
City	Decatur

State	GA
Zip	30030
May we contact the person listed above for a follow-up interview after your survey has been completed?	Yes, by email
Occupancy	
School Type (public, private, parochial)	public
What grades are taught in this building?	1st through 6th
How many weeks is the building occupied in an average year (the typical school year is 36 weeks)?	49 weeks
Is the building going to be renovated within the next year?	No
How long is the building occupied on an average day? Please explain if it is less or more than 8 hours.	12 hours. We have an after-school program, and teachers often work at night.
Building Specifics	
How many floors does the building have?	2, plus the basement
What percentage of the classrooms have operable windows (roughly)? Feel free to clarify/explain.	75%. The 1970's addition does not have operable windows.
What percentage of classrooms have air conditioning (roughly)? Feel free to clarify/explain.	10%. We only have air conditioning for the science classrooms and admin offices.
Year the building first opened	1935
Year of most recent renovation	1998
Gross Square Footage	150,000 sq ft.
Is the building LEED certified? What level, and in which rating system?	NC 2.1 Silver
Do you have energy data for the building? For instance, Energy Use Intensity? <i>This is optional, but please provide anything you have.</i>	EUI is 10.5 kWh/sq ft/year
# of full-time staff & faculty	68
# of full-time students	400
Comments?	
Do you have any other comments you'd like to make about the building?	The building has three portables behind it, which might also be surveyed. Also, we have a radiant heating system. There's a community health clinic in one wing of the school, which isn't being surveyed.

3.4 Survey Collection

The first survey used for this study was actually conducted in the summer of 2007, and so does not share some of the specific questions about classroom environments. However, it fit the other criteria for participation, and was therefore used in a limited fashion in the data analysis. The next survey was run in the spring of 2008, during the survey drafting phase, as a pilot for the new survey instrument. The survey instrument then received minor revisions during the summer of 2008, while the study methodology was finalized. Most of the participating schools were recruited in the fall of 2008, and most of the surveys were conducted in the winter and spring of 2009. Surveys were

completed by the end of the 2008-2009 school year. Additional surveys have been conducted in schools since May 2009, but the results of these have not been included in this study.

Table 3.4.a shows a summary of characteristics for each building involved in the study, with names removed for confidentiality. It should be noted that roughly half of the schools in the study were from one district in an urban area in Montana. While this may seem to skew results to some extent, it also provided a valuable test of comparability, given that this large group of buildings had many other characteristics in common. But it should be noted that the results from this first preliminary study may not be as evenly representative of the school buildings in the country as we hope that the eventual data set will be, as it expands over time. Throughout the data analysis phase, I tested to ensure that the population in this district was not inappropriately skewing the results, by comparing the results of the dataset with and without this group of schools, and found no significant areas of skewed data.

Table 3.4.a Summary Table of Characteristics for all Study Schools

Year of Construction	Gross Square Feet	Type?	DOE Climate Zone	Private or Public?	# Invited to Survey	Response Rate	School Location
1902	30,994	Elementary	3	Private	101	52%	Philadelphia, PA
1906	43,556	Elementary	1	Public	29	72%	Central Montana
1910	32,868	Elementary	1	Public	30	53%	Central Montana
1926	73,049	Elementary	4	Public	35	80%	Northern California
1938	232,789	High School	1	Public	166	74%	Central Montana
1947	72,152	Elementary	1	Public	29	62%	Central Montana
1948	36,064	Elementary	1	Public	25	72%	Central Montana
1950	96,802	Elementary	2	Public	40	40%	Boston, MA
1950	112,000	Elementary	2	Public	40	70%	Boston, MA
1952	41,502	Elementary	1	Public	24	71%	Central Montana
1953	27,000	Elementary	1	Public	31	74%	Central Montana
1955	121,086	Elementary	1	Public	37	76%	Central Montana
1955	147,000	Elementary	1	Public	30	67%	Central Montana
1956	46,600	Elementary	4	Public	70	63%	Phoenix, AZ
1956	135,200	Elementary	1	Public	29	62%	Central Montana
1956	30,072	Middle	1	Public	78	55%	Central Montana
1958	30,276	Elementary	1	Public	32	69%	Central Montana
1959	219,662	High School	1	Public	155	57%	Central Montana
1960	139,963	Elementary	1	Public	30	63%	Central Montana
1962	386,080	Elementary	1	Public	37	68%	Central Montana
1962	21,230	Elementary	1	Public	36	69%	Central Montana
1963	143,280	Middle	1	Public	70	51%	Central Montana
1964	42,825	Elementary	1	Public	25	84%	Central Montana
1964	32,072	Elementary	1	Public	39	67%	Central Montana
1965	87,844	Elementary	1	Public	37	86%	Central Montana
1967	76,009	Elementary	4	Private	20	110%	N. California*
1967	90,360	Middle	1	Public	48	67%	Central Montana
1970	57,930	Middle	4	Public	89	52%	Phoenix, AZ
1970	66,863	Elementary	4	Public	89	60%	Phoenix, AZ
1974	40,330	Elementary	4	Public	77	48%	Phoenix, AZ
1974	39,346	Elementary	1	Public	32	63%	Central Montana
1975	107,500	High School	1	Public	55	98%	Central Montana
1978	71,269	Elementary	1	Public	31	68%	Central Montana
1978	41,714	Elementary	1	Public	36	92%	Central Montana
1979	43,591	Elementary	1	Public	33	67%	Central Montana
1979	151,000	Middle	1	Public	68	60%	Central Montana
1986	31,690	Elementary	1	Public	35	80%	Central Montana
1986	53,933	Elementary	1	Public	38	66%	Central Montana
1987	239,000	High School	1	Public	125	53%	Central Montana
1999	57,933	Elementary	4	Public	100	35%	Phoenix, AZ
2001	61,788	High School	2	Public	80	48%	Boston, MA
2002	98,000	High School	2	Public	80	54%	Boston, MA
2004	38,785	High School	1	Public	132	76%	Calgary, ON

Year of Construction	Gross Square Feet	Type?	DOE Climate Zone	Private or Public?	# Invited to Survey	Response Rate	School Location
2005	39,817	Elementary	3	Public	45	58%	Seattle, WA*
2005	34,429	High School	2	Public	200	28%	Boston, MA
2006	45,000	Middle	5	Public	75	76%	Little Rock, AK*
2006	65,987	Elementary	3	Public	50	64%	Portland, OR*
2006	67,000	Elementary	3	Public	32	41%	Seattle, WA*
2007	35,209	Elementary	5	Public	87	45%	Houston, TX
2007	41,714	Elementary	4	Public	90	71%	Coastal NC
2007	104,372	Elementary	4	Public	90	84%	Coastal NC
2007	55,017	Elementary	4	Public	35	80%	N. California*
2007	150,478	Elementary	5	Public	50	74%	Little Rock, AK*
2007	475,000	High School	5	Public	75	24%	Inland NC*
2007	461,147	High School	4	Public	326	15%	Washington, DC Area*
2007	72,500	Middle	4	Private	45	51%	Washington, DC Area*
2008	150,000	Middle	5	Public	82	55%	Houston, TX
2008	137,277	Middle	5	Public	100	60%	Houston, TX
2008	64,400	Elementary	5	Public	47	79%	Little Rock, AK*
2008	55,000	Elementary	3	Private	25	100%	Seattle, WA
2004	135,000	Middle	4	Private	55	98%	Honolulu, HI*

As Table 3.4.a shows, the sample group of buildings represents all of the major DOE climate zones, including buildings in more humid climates along with dry ones. The group includes 41 elementary schools (which tend to be smaller and more numerous), 10 middle schools and 10 high schools. The size of the buildings ranges from 21,000 gross square feet (a small elementary school) to 475,000 gross square feet (a large high school). The buildings range in age from an example built in 1902 to schools just completed in time for the 2007-08 school year (since all schools had to be fully occupied during that school year to be eligible for this study). The range of building ages is roughly representative of the US school building stock, as is shown in Figure 3.4.a below, except that the study sample has more new buildings built in the past decade.

School Building Age Distribution

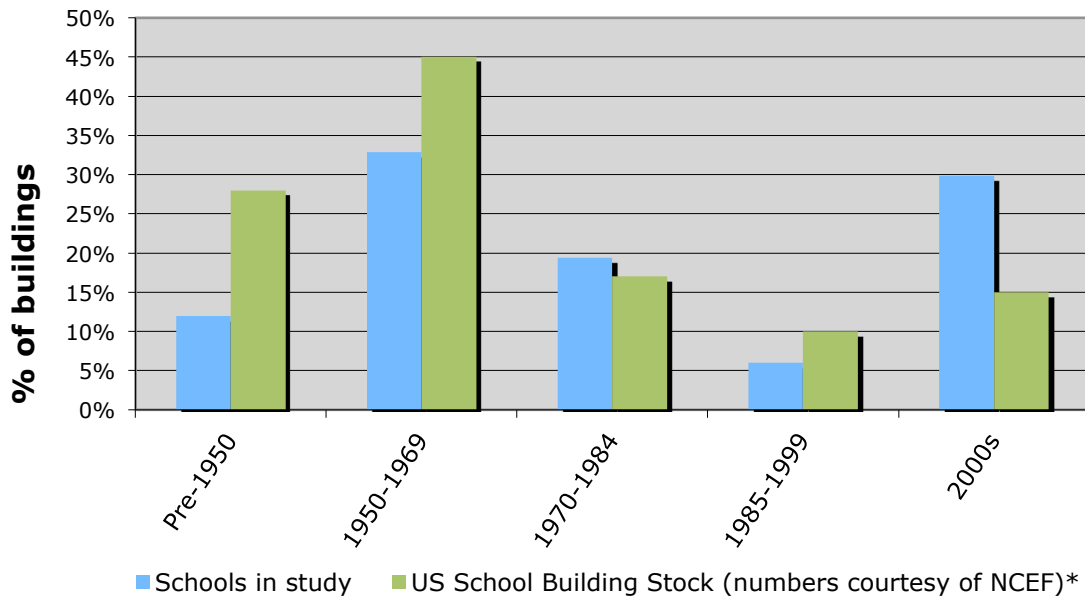


Figure 3.4.a School Building Age Distribution: Study sample vs. US stock

A primary goal of this research is to help public schools (more so than private ones) specifically, because of their greater need for cost-effective and tested advice on improving facility performance; public schools have reasons to be more risk averse than private schools. But a small number of private schools (five) were still included in the study. The private school buildings selected are an interesting group, because they are often innovators in the field of educational design and high-performance design, and so have a number of design strategies and systems that were worth examining. The lessons learned from these innovators can still be used by public schools, especially once results have been successfully proven in private schools. Other than these considerations, more specific measures of demographics or finances were not considered for this study (such as the percentage of students with Free and Reduced Lunches, a common metric of student affluence). Although finances and equity can certainly affect facility performance, this study attempts to isolate variables in buildings that are relatively common, such as the presence or absence of windows, rather than complex building systems.

Asterisks by the location of the school in Table 3.4.a indicate the schools that are **certified green** schools, a status assigned to buildings that have received a LEED certification, a CHPS designation, or an AIA Top Ten Committee on the Environment (COTE) award. Although other schools in the dataset may have certain features that help to save energy, or provide daylight, or eliminate the use of VOC paints and finishes, etc, this study only placed those with a certification in the 'certified green' dataset. Throughout the findings section, they will be referred to as either 'certified green' schools, or 'green' schools when it is necessary to be brief (in graphs, primarily). This is not to say that all other buildings in the study are low-performing, but rather that

these schools have a certification or award that deems them 'high-performing'. Indeed, whether or not they are living up to expectations in the design of the building is unknown, so they may even be performing worse in energy, or occupant comfort, or elsewhere than other schools in the database.

3.5 Data Analysis Methods

This section will review the methods used in the investigation of trends and notable discoveries during the study. This thesis is a consideration of the ways in which school buildings can produce either negative or positive responses from occupants, and how occupants can serve as indicators of problems (or successes) in buildings. The analysis involves comparing sets of respondents to each other, and by comparing sets of buildings to each other. When an independent variable in question is a variable relating to the occupant, such as whether or not they have access to windows, the analysis was done at the user level, by comparing all users with window access to all users without access in the schools dataset. However, when examining trends in certified green buildings, the analysis was done at the building level, by using mean averages of all users in the building, and comparing those with similar buildings (in this case, the comparison group is all new buildings). This type of analysis means that a building with many more respondents is weighted the same as a building with fewer respondents, whereas the respondent-level analysis gives equal weight to all respondents. On the respondent-level analysis, there may be some unwanted effects given that school buildings with a larger population of respondents might weight the results towards their building. However, the difference in respondent population size was not extreme. As Table 3.4.a shows, the largest number of respondents was in a high school in Montana which had 123 respondents (out of 166 occupants).

In order to provide more reliability in data analysis, individual survey results had to meet threshold criteria before inclusion in the dataset used for analysis. Respondents with fewer than 15 answers logged into the survey were removed. In addition, buildings in the database that have fewer than 15 respondents, or a response rate of less than 10% were removed from the "benchmark" set that is used for research.

Since this study was primarily looking for general trends, there were not many areas in which I was attempting to draw a clear statistical relationship between two variables within the study. Exceptions to this will be found in the Lighting section, and in the Thermal Comfort controls section. In these cases, the satisfaction scale scores are compared to a binary (or categorical) characteristic of a user, such as whether or not they have access to a thermostat. Thus, Pearson's chi-squared test was used to assess the trends. Pearson's correlation coefficient (presented either as r or r^2) is also listed for these correlations.

Additionally, cross correlation investigations were done using respondent-level data to find significant correlations between different variables in the study. However, this exercise did not produce any particularly notable results.

Finally, excerpts from the open-ended comment questions are included in the analysis for illustrative purposes. In these cases, occasional grammatical spelling

oversights have been corrected for the purposes of readability. Some content analysis was performed on the comments, by using a spreadsheet to search for common word appearances in the responses, to ascertain the significance of particular issues. However, this was not done to produce original findings, but to support the more numerical findings and investigate particular phenomena more thoroughly (an example of this can be seen clearly in section 4.3.5 on operable window control and thermal comfort).

3.6 Limitations of Study

There are four major limitations in this study. First, we cannot draw any causal relationship between design features and occupant outcomes of any kind, as discussed in the Background section of this study. The dataset is likely not yet large enough and diverse enough to eliminate bias by minimizing the effects of factors such as budgetary influence, political structures that may affect facilities management, socio-cultural factors, etc.

Secondly, the group of schools participating in the study are self-selected, thus do not represent a random or representative sample of school buildings in the US. However, as the Findings chapter will show, the group of buildings in the survey is fairly representative of the US building stock, roughly speaking.

Thirdly, the sample size of 11 certified green school buildings is likely not enough to be representative of the overall stock of school buildings with some kind of high-performance certification (although admittedly, there are fewer than 300 of these built with a certification in the US, which is still a small number). These buildings all tend to have a different mix of characteristics, and this study is only meant to compare them in a general manner.

Finally, an advantage to the occupant survey methodology can also be its biggest limitation: researchers need not visit the sites or observe the buildings we are studying. This study works with limited data available in terms of building characteristics, which inherently limits the conclusive nature of the research. The conclusions of this study will discuss this limitation in more detail, and address some potential next steps to include more objective data characterizing the physical features of these school buildings.

Despite these limitations, this thesis offers significant contributions to the field, by showing trends in school building performance and as a preliminary exercise in examining the relationships between physical attributes of school buildings and occupant satisfaction and well-being. Hopefully this research will lay the groundwork for future studies that eliminate the limitations mentioned here, by growing the sample populations and incorporating more robust building characteristics and objective measurements of buildings to support the compelling findings of POE survey research.

4 Findings

The following section will provide an overview of notable findings in the Building Occupant Survey of schools, focusing on the Air Quality, Thermal Comfort, Lighting and Acoustics categories. The data set likely contains many interesting results arising in

particular buildings, or in comparing a smaller group of buildings to each other, that are not covered in this analysis. Hopefully future research at the CBE will consider these data and contribute to the body of research with these other stories.

The findings of this thesis also focus on issues that may affect or be affected by energy consumption in the school buildings in this study. While important, issues like lighting color, speech intelligibility, or odor source identification are not considered here, for reasons that are discussed in more detail in the introduction and conclusions of this paper.

4.1 General Trends in School Surveys

As noted above in section 3.2, Survey Development, the survey tool used for this set of school buildings has many similar and identical questions to the standard CBE Building Occupant Survey for office buildings. While this allows us to compare across building types, it seems prudent to avoid too much comparison between offices and school buildings, due to differing expectations, standards, and activities associated with each type. However, there are a few notable areas in which these two building types differ in their survey results, and some areas in which user response trends are reassuringly similar.

4.1.1 Survey-Taker Trends

This study sought to involve a representative group of school buildings and occupants, and to achieve a high level of participation amongst building occupants. The following section summarizes the demographic profile of survey-takers in brief, illustrating that the study polled a representative sample of people who work in schools. These figures also show the types of individuals who responded to the survey.

The average response rate for all surveys was 64%, with the average number of employed (adult staff) occupants in each school building at 65, and the average number of respondents per school at 37. Across the 61 schools in the study, a total of 3877 occupants were invited to take the survey, and 2211 people completed the survey.

Figure 4.1.a shows the spread of respondents' answers to the question, "How many years have you worked in this building?" showing that a significant portion of the respondents were fairly new to their buildings, while 30% had been working in their buildings for over 5 years. Figure 4.1.b goes further to show how long respondents have been working in their current workspaces. Figure 4.1.c shows that respondents largely spend over 30 hours a week in their workspaces, illustrating that these are primarily full-time occupants of the buildings. Figure 4.1.d shows the spread of different occupations represented in the sample set, showing that a significant majority (79%) are licensed professionals (such as teachers). Figure 4.1.e and Figure 4.1.f show the age and gender of the respondents. It is notable and representative of US teachers that 79% of the respondents are female.

DEMOGRAPHICS

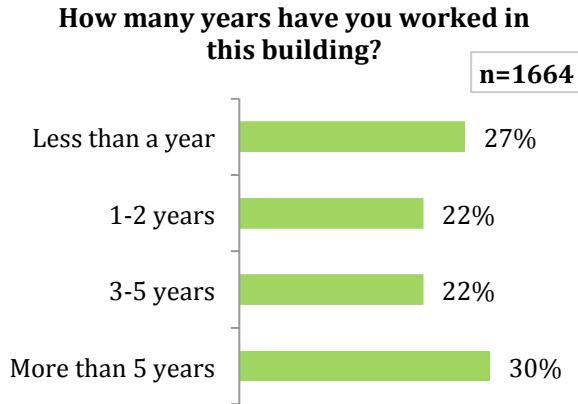


Figure 4.1.a Demographics: Number of years worked in building

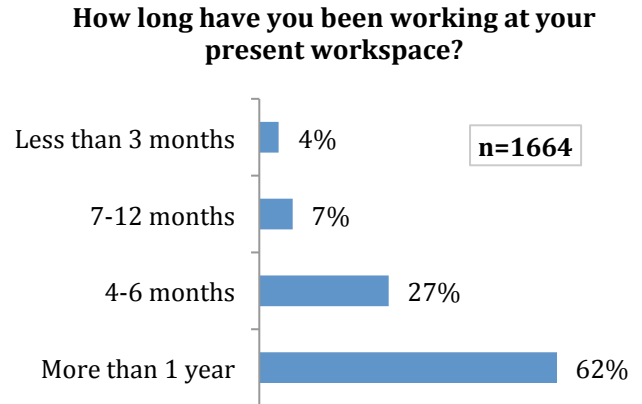


Figure 4.1.b Demographics: How long at current workspace?

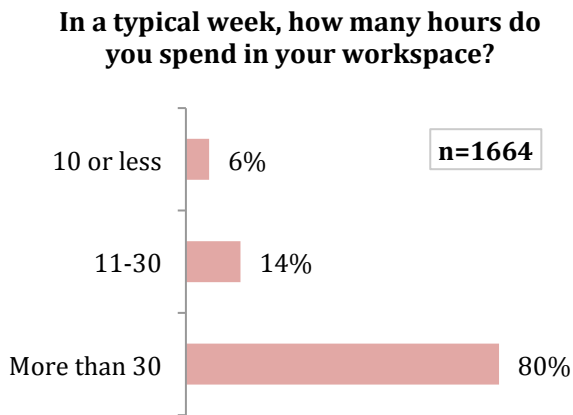


Figure 4.1.c Demographics: Number of hours/week in workspace

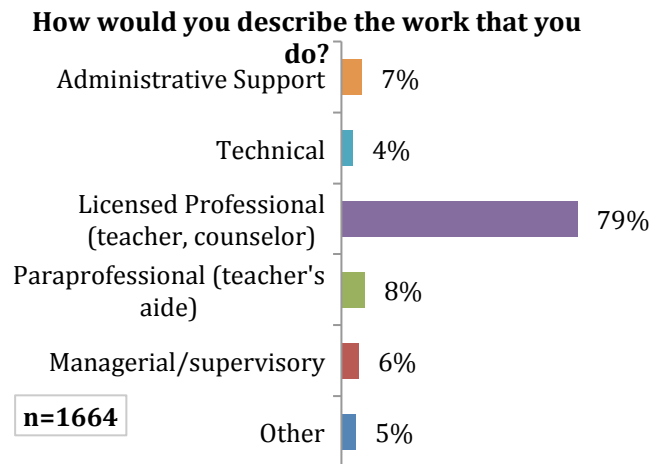


Figure 4.1.d Demographics: Occupation

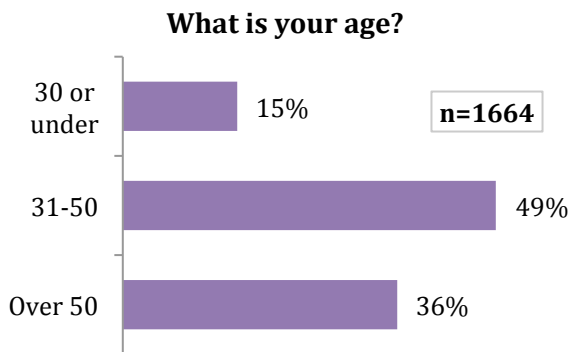


Figure 4.1.e Demographics: Age

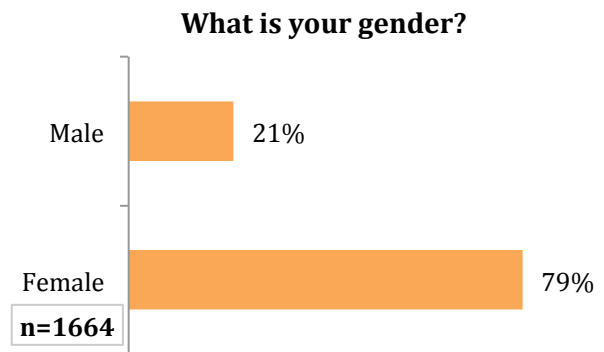


Figure 4.1.f Demographics: Gender

As previously described, a large portion of the analysis for this study was done only on those respondents who answered “yes” to another question: “Do you spend more than 10 hours a week in a classroom?” This qualifier was meant to separate teachers from administrative staff. 77% of respondents answered ‘yes’ to this question (a sample set of 1694 individuals). Henceforth, this set of respondents will be referred to as “teachers”.

4.1.2 Overall Satisfaction Levels in School Environments

Overall, average satisfaction scores in the different categories of the CBE survey are quite similar in school buildings and office buildings. See Figure 4.1.g for a summary graph of these values. It is important to note that generally, the average satisfaction scores for school occupants and office occupants are strikingly similar, with the exception of Acoustic satisfaction. However, it is notable to see how differently school building occupants rate their Acoustic satisfaction, compared to office building occupants. This will be discussed in more detail in section 4.5.3, the Acoustics findings discussion.

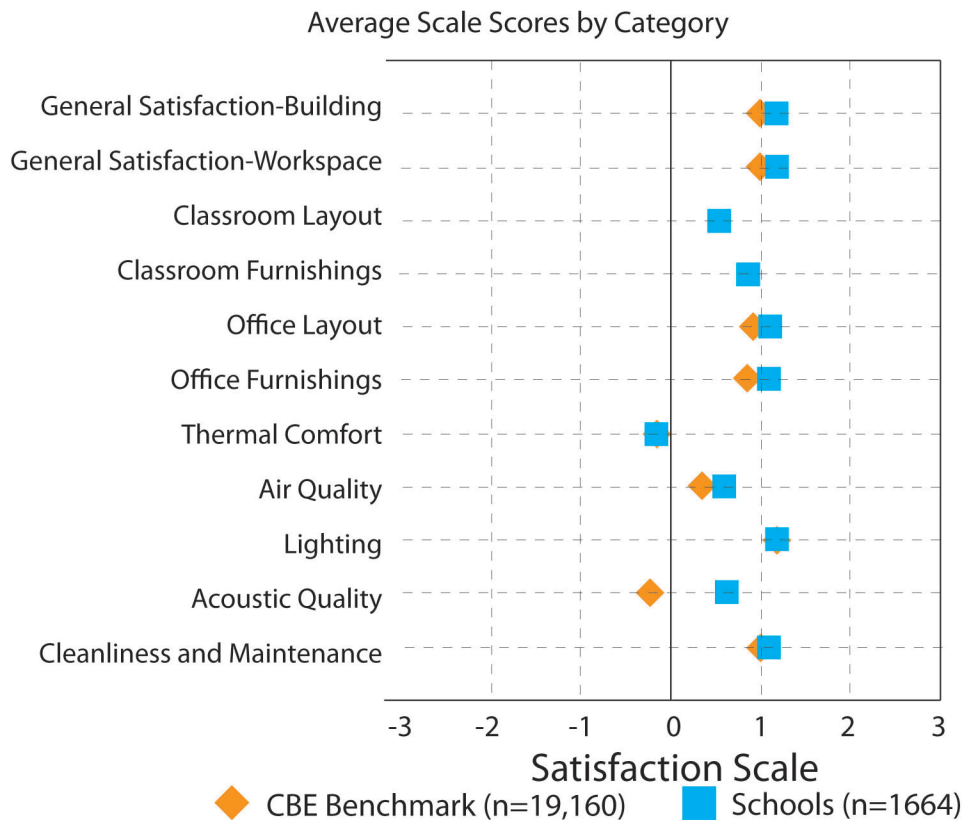


Figure 4.1.g Mean Satisfaction Scores by Category: Offices vs. Schools

It should also be noted that there was no correlation between location (climate) and satisfaction in any category of the survey and location (climate), nor any correlation between satisfaction levels and type of building (elementary vs. middle school vs. high school), or size (gross square footage) of the school building. There was, however, a correlation (the Pearson r^2 is 0.23) between the age of the school building

(as determined by the date of initial construction, regardless of renovations) and general satisfaction. In general, occupants were more satisfied with newer buildings than older ones, as shown in Figure 4.1.h, which shows average general satisfaction scores for each building compared to the date of construction. However, it should be noted that this is merely a trend, likely influenced at least in part by the fact that newer schools generally have fewer broken systems, and tend to look cleaner and more functional. This does not necessarily indicate that they are better designed schools. The oldest school building in the study, a small private school building in Pennsylvania originally built in 1902, had some of the highest scores in the study, across the board. In addition, a large urban public high school in Montana built in 1953 also reported some of the highest satisfaction scores in the study.

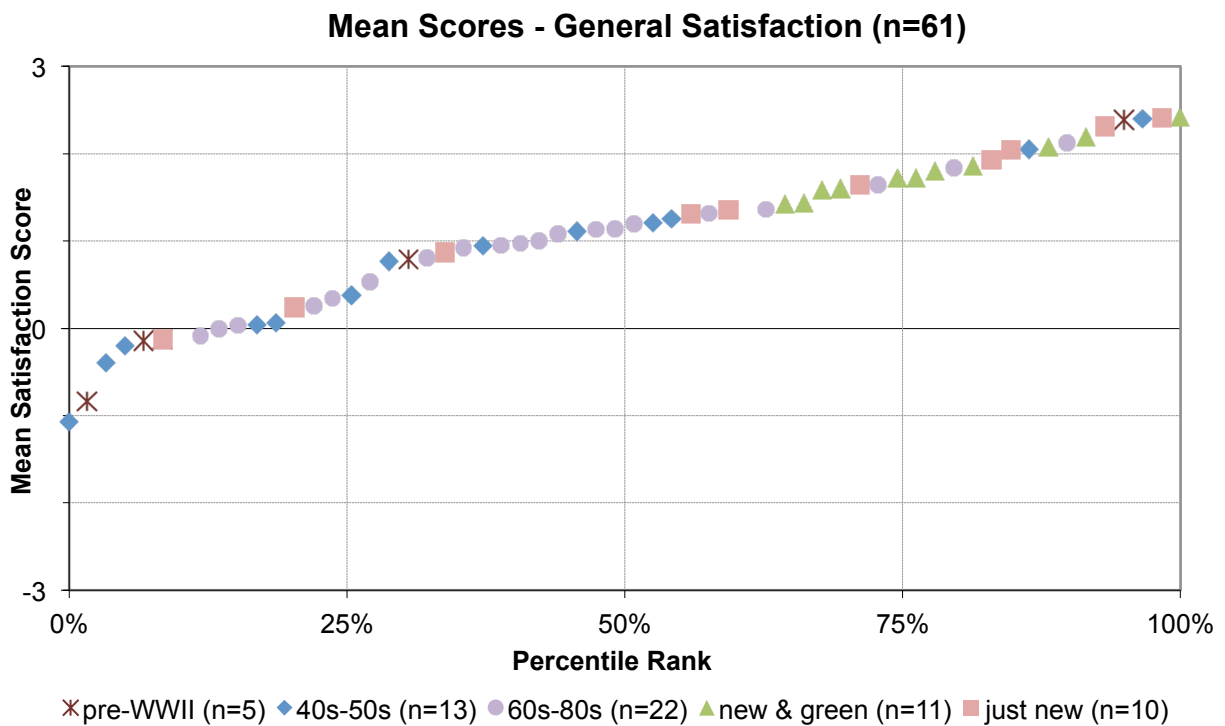


Figure 4.1.h General Satisfaction Scores by Era

4.1.3 High Performance School Programs and Occupant Satisfaction

Within the group of 61 school buildings, 11 of the buildings had received, or were about to receive, a certificate designating them as a “green” building, whether through the LEED rating system, an AIA Committee on the Environment Top Ten award, and/or through CHPS (see above for more details on these rating systems). Although the certified green schools did not necessarily have any physical characteristics in common, on average they performed better than the other schools in a few categories. However, one cannot ignore the fact that these schools also have the above-noted advantage of being newly constructed. Recent scholarship comparing green buildings to non-green buildings has often ignored this fact, to the detriment of the overall believability of the research in this field. Therefore, all comparisons in this

study between certified green schools and other schools has been limited to considering, as a comparison cohort, only schools that were built in the past 10 years. The study surveyed 11 schools that did not have a designated 'green' label but that were built in the past 10 years. It should be noted that it's entirely possible that this 'control' group of schools is comparatively as green as or greener than buildings built prior to 1999, due to recent trends in school construction that suggests that more schools are being built with energy saving systems, better daylighting, and less toxic materials than their predecessors. Figure 4.1.i shows a summary of satisfaction scores in certified green school buildings compared to others built in the past decade.



Figure 4.1.i Mean Satisfaction Scores by Category: Certified Green vs. Conventional built since 1999

Figure 4.1.i shows that the certified green schools outperform their contemporaries in a number of categories, most notably in thermal comfort, air quality, lighting and in general satisfaction. These trends will be discussed more in detail in topic-specific sections to follow below, with the exception of general satisfaction. As Figure 4.1.j shows, the schools built to meet a high performance standard tended to have higher overall satisfaction than their new counterparts, and overall higher satisfaction than other buildings.

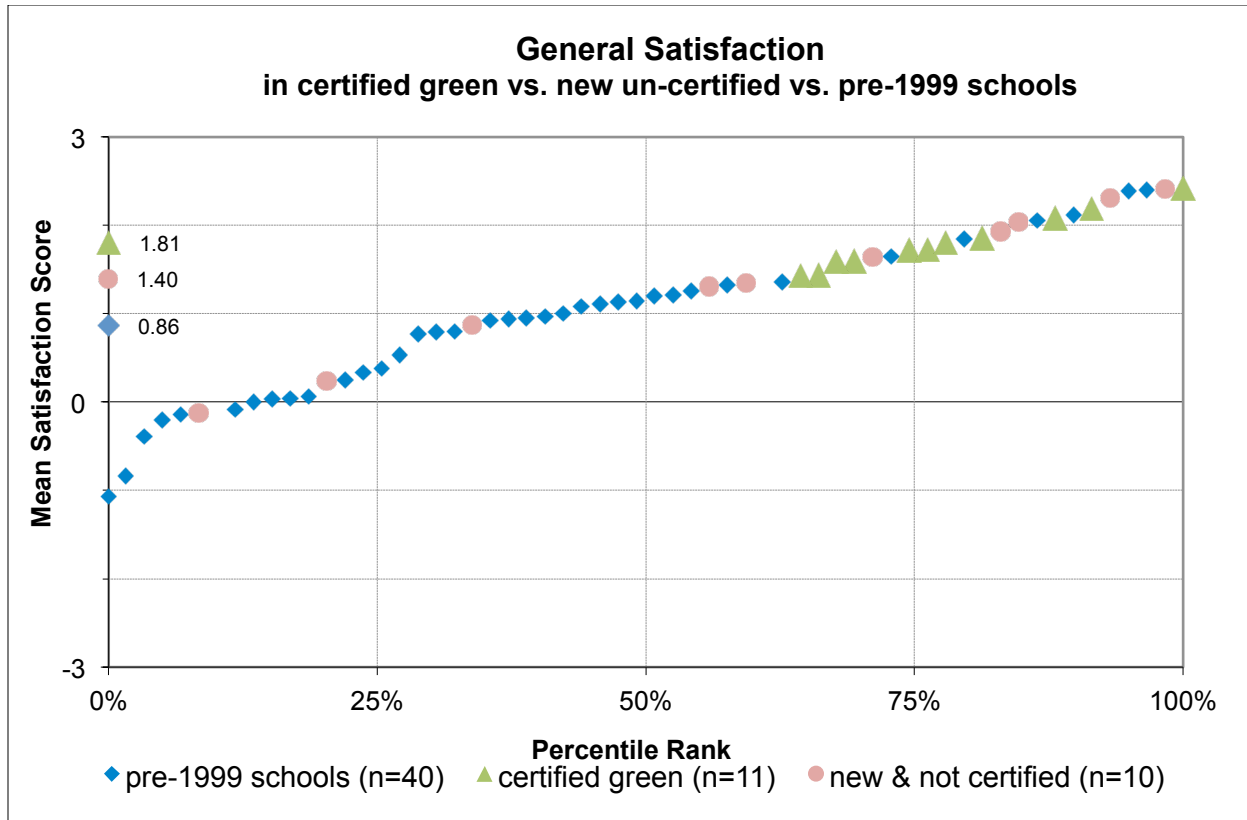


Figure 4.1.j General Satisfaction in certified green vs. new conventional vs. all other schools

Although general satisfaction is a broad topic, and one that makes the sources of satisfaction difficult to determine, it is nonetheless interesting to note that all of the certified green schools have scores above the 60th percentile. Meanwhile, the new schools without a certified green designation do not all fall in the top half of the study scores. This indicates, however vaguely, that occupants are more satisfied with their school buildings if they have a green certification, and thus validates the certification programs themselves, in providing environments that occupants like. Future sections will discuss this situation in more detail, as it pertains to specific aspects of the indoor environment.

4.2 Lighting

There are many different approaches taken to effectively illuminate classroom environments, reflecting different eras of school construction with more or less emphasis on natural light, audio-visual presentations, and varying educational activities. This study found some significant trends in lighting satisfaction that resulted from architectural choices, which should be considered in future school designs.

4.2.1 Sources of Lighting Dissatisfaction in Schools vs. Offices

The lighting environment in classrooms is quite different from the environment of offices. Much like offices, classrooms need different lighting levels for different tasks, but

in classrooms, the occupants tend to stay in the same room while changing tasks (such as audiovisual presentations or group work), while in offices, occupants move to designated areas for different tasks. Thus, it was not surprising to see some differences in reported sources of dissatisfaction, from the group of occupants who were dissatisfied with their lighting conditions, as shown in Figure 4.2.a. These groups of people all reported dissatisfaction with their lighting, which 'branched' them to the question listed, regarding the sources of dissatisfaction with lighting, so this figure is not reporting all occupants, but rather just the ones dissatisfied with lighting. Compared to office workers, school occupants list the following sources of dissatisfaction more frequently than office workers: "too much electric lighting", "too bright", "not enough daylight", "lighting is an undesirable color" and "electric lighting flickers". Many respondents pointed out the need for better lighting when presenting audio-visual material, or when using white boards or electronic boards that tend to have a sensitivity to glare. One occupant notes, "*[w]e have tons of natural light which is wonderful, but it interferes with the use of the ActivBoard.*" Another discusses the importance of controls for the varying activities that occur in classrooms, noting, "*If our lighting could be in the classroom with 3 switches, we would be able to control and dim 1 row of lights thus saving electricity and controlling the brightness of the room.*"

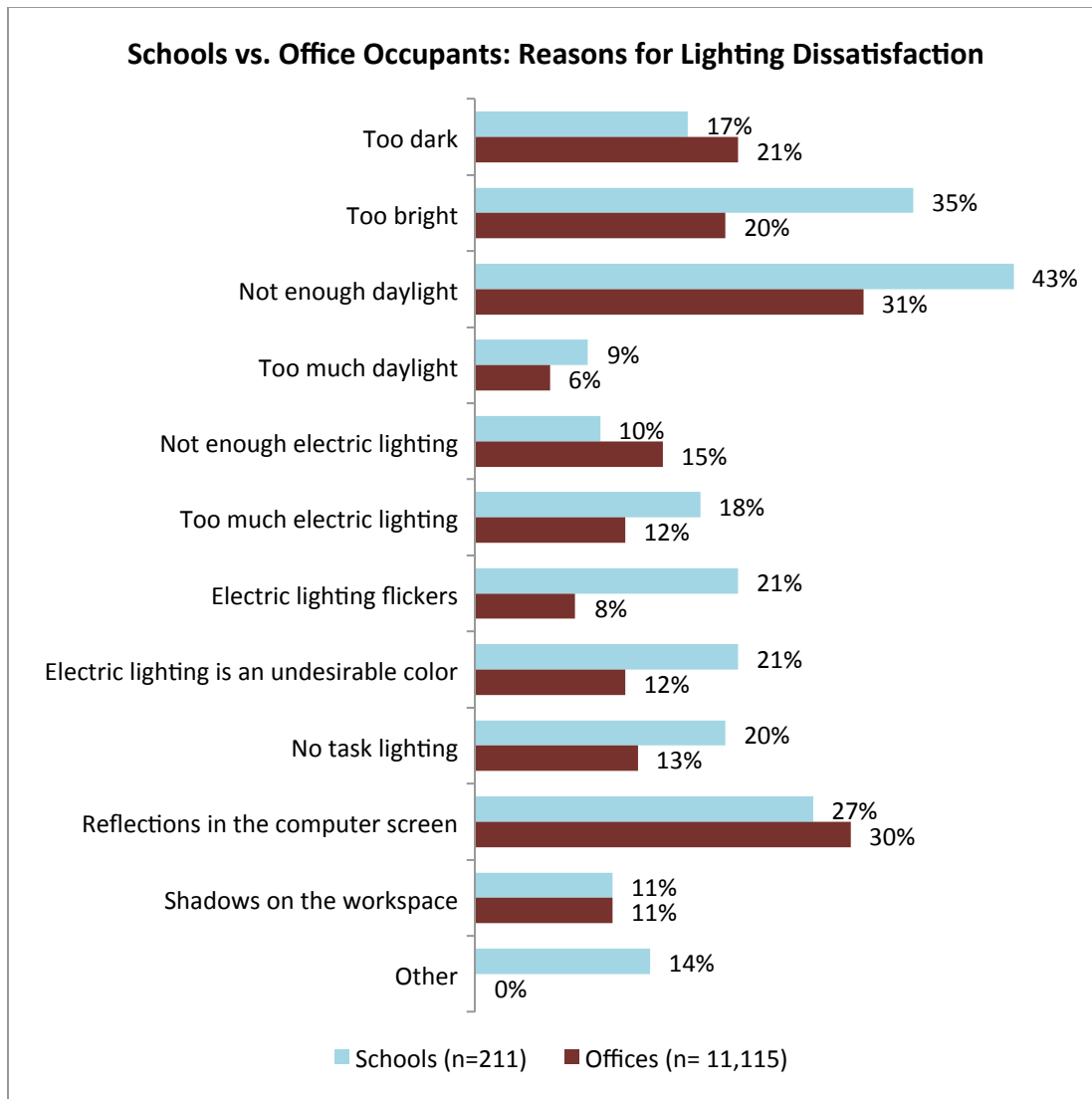


Figure 4.2.a Schools vs. Office Occupants: Reasons for Lighting Dissatisfaction

Some typical comments provided in reference to lighting dissatisfaction in schools referred to old magnetic fluorescent ballasts that cause lamps to flicker. One teacher notes, “Autistic students cannot tolerate flickering florescent lighting.” In addition, a handful of occupants noted that flickering fluorescent lighting fixtures were, in their opinion, giving them headaches and pains associated with eyestrain. These complaints were more common from occupants who did not have access to natural light in their classroom, a trend that is discussed in the following section.

4.2.2 Daylighting & Visual Comfort

Perhaps unsurprisingly, teachers in classrooms with at least one window were more satisfied with their lighting than teachers without any windows. It should be noted that most teachers reported having at least one window- 1368 out of 1694 teachers reported having at least one window in their primary classroom. My speculation is that

this should be roughly on par with national averages for windowless classrooms, but there is no known source for this statistic. However, as Figure 4.2.b shows, occupants with access to windows have satisfaction scores significantly higher on average compared to the 326 respondents without a window in their classroom. The correlation between having a window and visual comfort satisfaction was shown to have a small positive correlation, with a Pearson correlation coefficient of $r=0.2$, with a 99% statistical certainty.

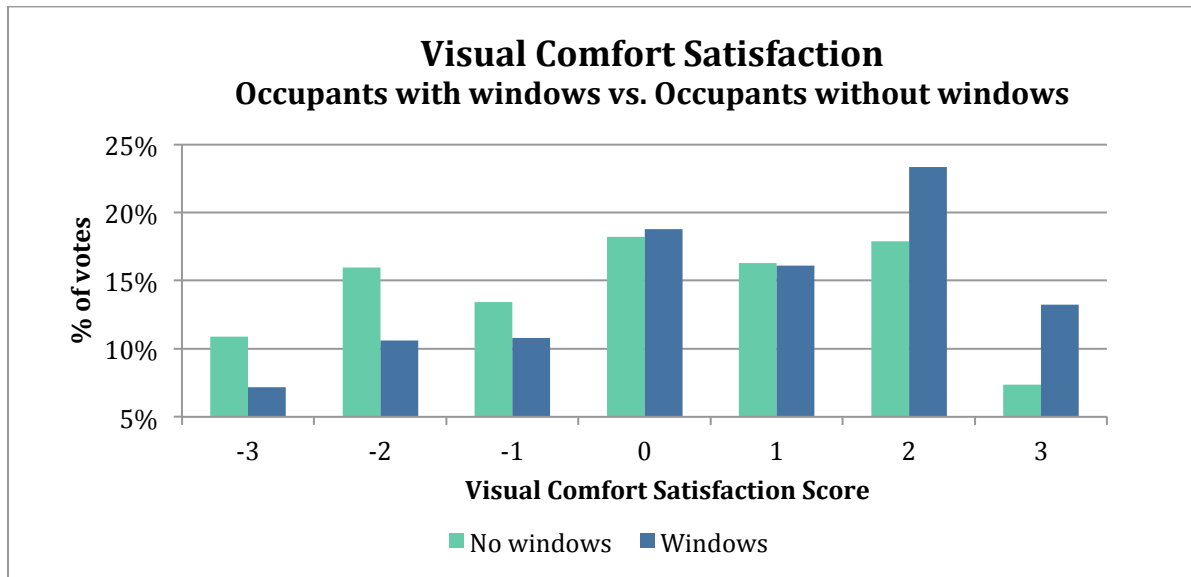


Figure 4.2.b Visual Comfort Satisfaction Comparison in Classrooms: Windows

Ample comments from occupants on this issue further illustrate the dynamics of these situations. One teacher noted, amusingly, *“I do the in-school suspensions, detentions & time-outs. In my opinion, no windows, no clock and a smaller classroom environment enhances the student's feeling that ‘Your next step could be the truancy center.’”* Another reported the difficulties of working with particularly challenging groups, noting, *“Teaching emotionally disturbed youth in a windowless, stagnant environment makes things even more difficult.”* On the other extreme, one occupant in a new certified green school noted that the positive impact of natural light was striking, saying, *“I am amazed at how much impact the natural light and indoor/outdoor space has on the students and my own overall wellbeing.”*

We can also look at the topics of daylighting and visual comfort through inter-building comparison. Although there were no schools in the study that lacked windows in every classroom, there was a group of buildings in which a high percentage of classrooms lacked windows. When mapped out in comparison to the age of the building, one can see the clear trend of windowless classrooms built in the 1970s (see Figure 4.2.c). As noted earlier in the consideration of daylighting research, the 1970s were a time when daylighting was deemed unnecessary in classroom designs, and thus many schools were built without many windows. The effects of this trend can be seen in Figure 4.2.d, which shows the average lighting satisfaction scores for the study buildings, in which all schools built in the 1970s are highlighted.

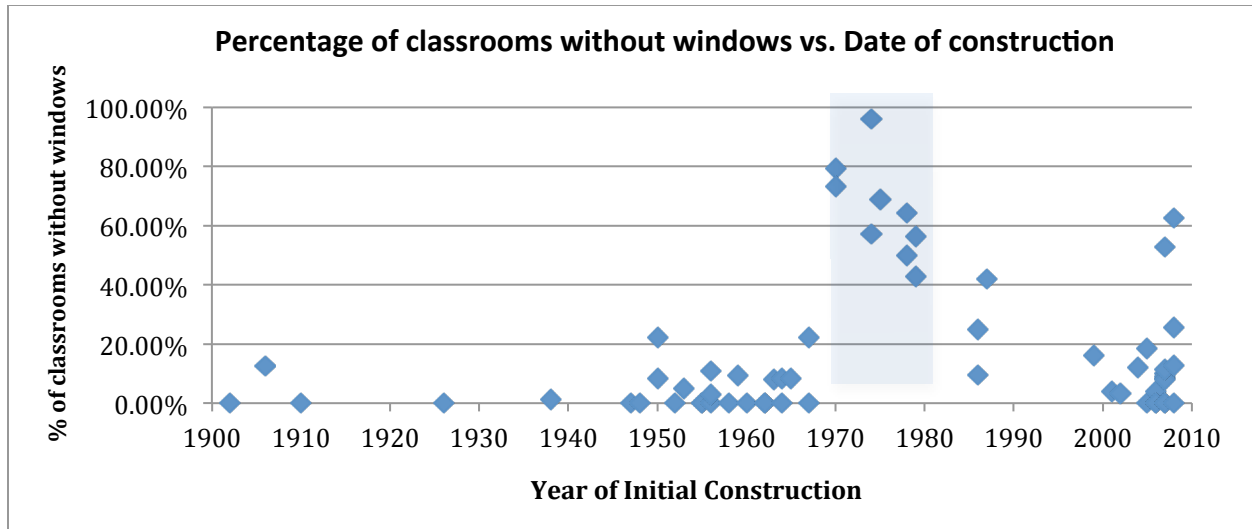


Figure 4.2.c Date of construction vs. windows in classrooms

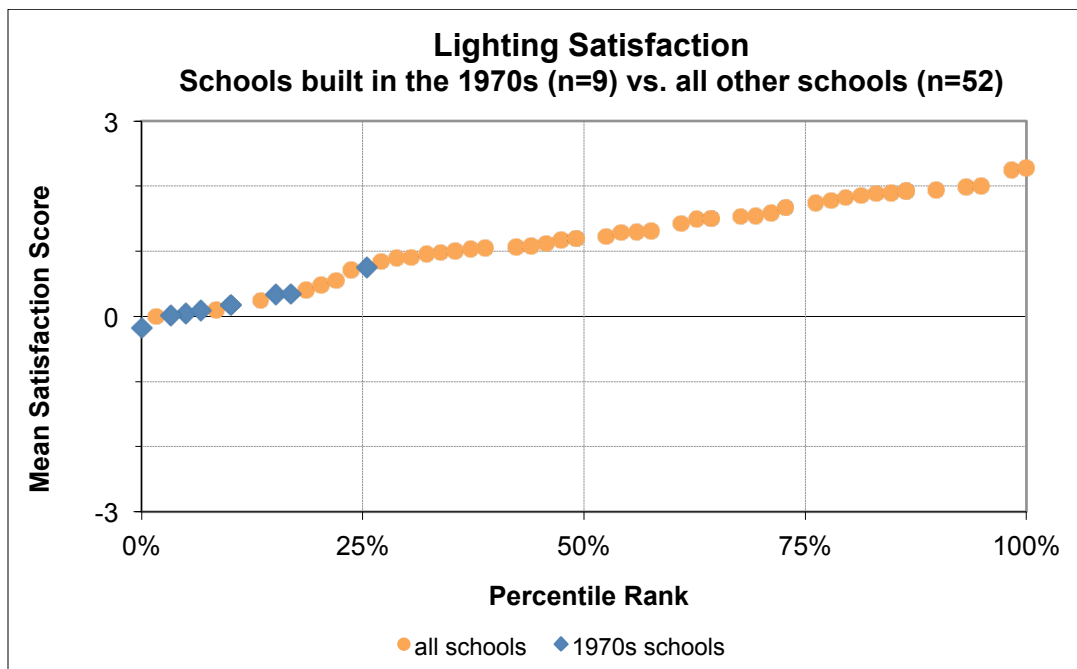


Figure 4.2.d Lighting Satisfaction in 1970's schools vs. others

It should be noted that this study did not collect data about the configuration or amount of daylighting in classrooms surveyed, but rather looked at larger trends, due to the limitations of not being able to conduct site visits. But in reading some of the comments provided, there is both wisdom and design advice in the observations of the school's occupants, in reference to the specific designs of their windows and daylighting effectiveness. One occupant notes, "For classrooms and other spaces facing south, it would seem to be a good idea to include in the architecture some structural screening of the direct sunlight assault (roof overhangs, lattice overhang,

adjustable exterior shading of some kind). This seems to be another handy way to be green in all kinds of sunlight conditions." Another told of the dissatisfaction that can result from not being able to utilize natural light, saying, "The sun comes in through my eastern windows in such brilliance that I can NEVER open my tattered, ugly shades. Even the sliver of sun that escapes through the gap between the shade and the window has the power to blind, so I have to tape my blinds to the window."

The only notable design feature that was considered in this analysis was the presence or absence of window blinds or shades. Those with access to a window shade or blind (n=1100) had an average visual comfort score of 1.2, compared to those without access to a window shade but with access to a window (n=185), had an average score of 1.0. Figure 4.2e shows the spread of votes for teachers with and without window shades on the survey question, "How satisfied are you with the visual comfort of the lighting in your workspace?", showing a correlation between access to window shades and visual comfort satisfaction, which in this dataset was shown with a 99% Pearson statistical certainty, but is still somewhat low, with an $r = 0.17$.

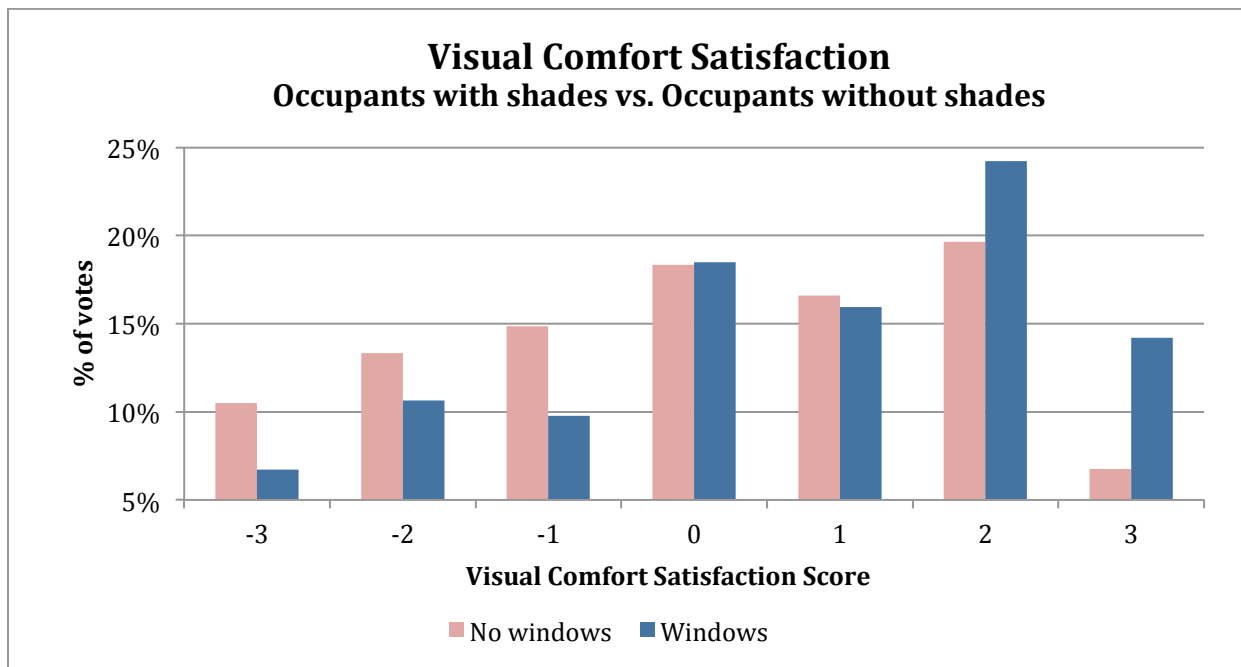


Figure 4.2.e Visual Comfort Satisfaction in Classrooms: Shades

The group that reported dissatisfaction with lighting provided a few comments that help explain why the lack of shades would be so frustrating. One occupant notes, "[w]indows let in too much light when using the overhead, and the school says they can't afford curtains."

4.2.3 Lighting Satisfaction in High Performance Schools

One of the primary goals of certified green school buildings is providing an efficient and comfortable lighting scheme for classrooms, often through the use of daylighting strategies. Thus, it was of interest in this study to see whether these 11 certified green

schools in the study produced high satisfaction scores with lighting. Figure 4.2f shows the mean satisfaction scores for all 61 school buildings, with the certified green schools and the new conventional schools highlighted. In general, certified green schools outperformed other schools in lighting satisfaction, and outperformed other new schools as well (means for each set are found on the vertical axis).

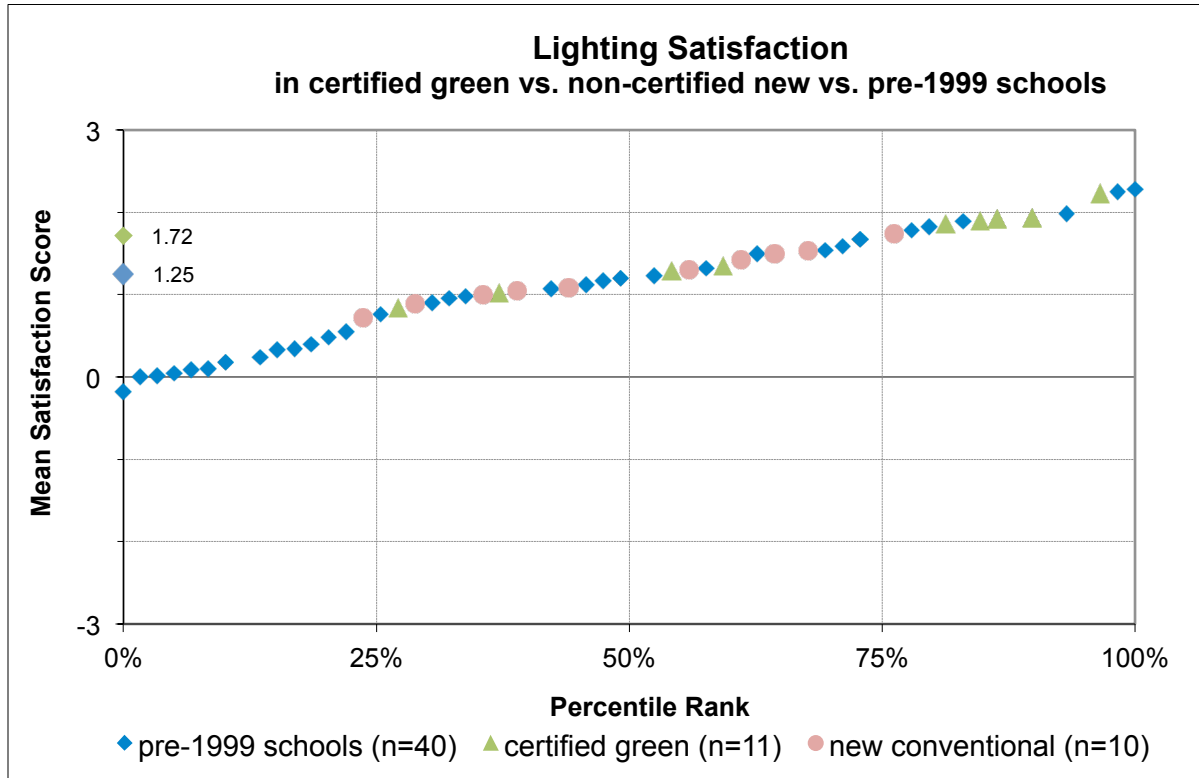


Figure 4.2.f Lighting Satisfaction in certified green vs. conventional new vs. pre-1999 schools

However, by investigating the results of the new and certified green school surveys in more depth, we see that there are some issues, especially for those schools scoring lower than the average school. One occupant notes, "My program requires and relies on the use of slides, videos and/or projection of visual material. These technical supports enhance my teaching and curriculum. While the amount of natural light entering my workspace is fantastic - I am unable to control this sufficiently. The shading system that was installed is inadequate and very un-user friendly. Some ideas, while 'cool', do not pan out in practice."

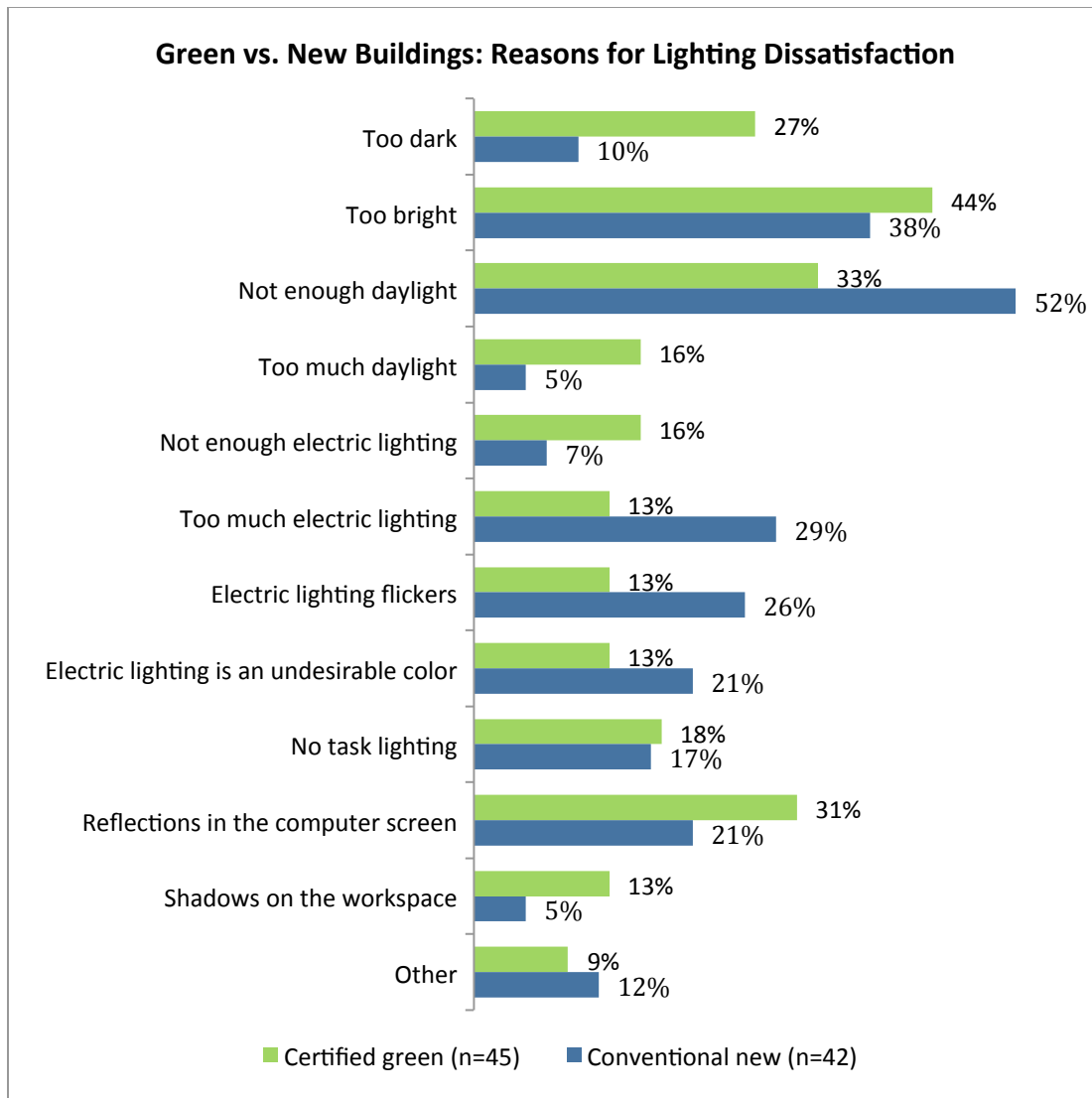


Figure 4.2.g Reasons for Lighting Dissatisfaction: certified green vs. conventional new buildings

Similarly, Figure 4.2.g shows the reported sources of dissatisfaction in the certified green schools compared to their contemporaries built since 1999, showing that the certified green schools seem to have more complaints about brightness, reflections on computer screens, and other issues associated with daylighting. Meanwhile, the biggest complaint in the new schools without a green certification is the lack of daylighting, a finding that again reinforces the importance of this feature, and the fact that teachers notice the absence of daylighting and are dissatisfied with it. This final observation in the lighting category is one to consider. It is more common for occupants to complain about dysfunctional or inadequate features than to complain about elements that are not present – this shows an awareness of possibilities outside their daily experience. This thesis reinforces the notion that teachers actively desire classrooms with natural light, rather than just being more satisfied when natural light is present.

4.3 Thermal Comfort

Thermal comfort is a central concern when addressing the balance between energy use and occupant comfort, and thus a core topic of this study. This section will focus on a few key investigations that were conducted in the area of thermal comfort. First, findings show that climate variations are not a significant factor in the relative thermal comfort of occupants, and section 4.3.1 will discuss these findings in more detail. Secondly, some brief comparisons will be drawn by looking at thermal comfort related building features in schools versus offices in section 4.3.2, to show that, comparatively, school occupants tend to have more control over their environments. Thirdly, one of the strongest indicators of thermal comfort satisfaction in this dataset was access to thermostats for heating and cooling. This trend will be discussed in section 4.3.3. Section 4.3.4 will focus on findings that compare thermal comfort satisfaction in certified green school buildings, and note some of the areas where these buildings excel, but also identify issues of concern. Finally, section 4.3.5 will discuss findings related to the thermal comfort of occupants who have access to operable windows.

4.3.1 Climate Variations in Thermal Comfort and HVAC Design

An initial investigation in the study was to consider potential climatic variations in the dataset. Would schools in warmer climates be more or less likely to have operable windows? Would air-conditioning systems in colder climates have an impact on thermal comfort? And would occupants show different reactions to certain control issues, depending on their adaptations to their climates? A series of correlations were run in looking at a variety of responses in the schools survey, but without any significant results. In this dataset, climate (as measured by Heating Degree Days) does not seem to be correlated with any satisfaction variable, or even the presence or absence of various control options, with one exception. The few school buildings located in hotter climates (near Houston, Texas and Phoenix, Arizona), had fewer windows in classrooms, a feature that was correlated with thermal dissatisfaction (see section 4.3.5 for more on this issue). However, the sample set was too small to determine whether windowless classrooms are really more common in hotter climates in the US, or whether this was simply an anomaly for this survey dataset.

4.3.2 Patterns of Thermal Control in Schools vs. Offices

In order to better understand the situations of many school building occupants, it may be helpful to consider the differences between school occupants and office occupants, in terms of thermal conditions and access to controls. In school buildings, which are mostly classrooms, employees (teachers, often) typically have more control over their thermal environment than an office worker, as shown in Figure 4.3.b.

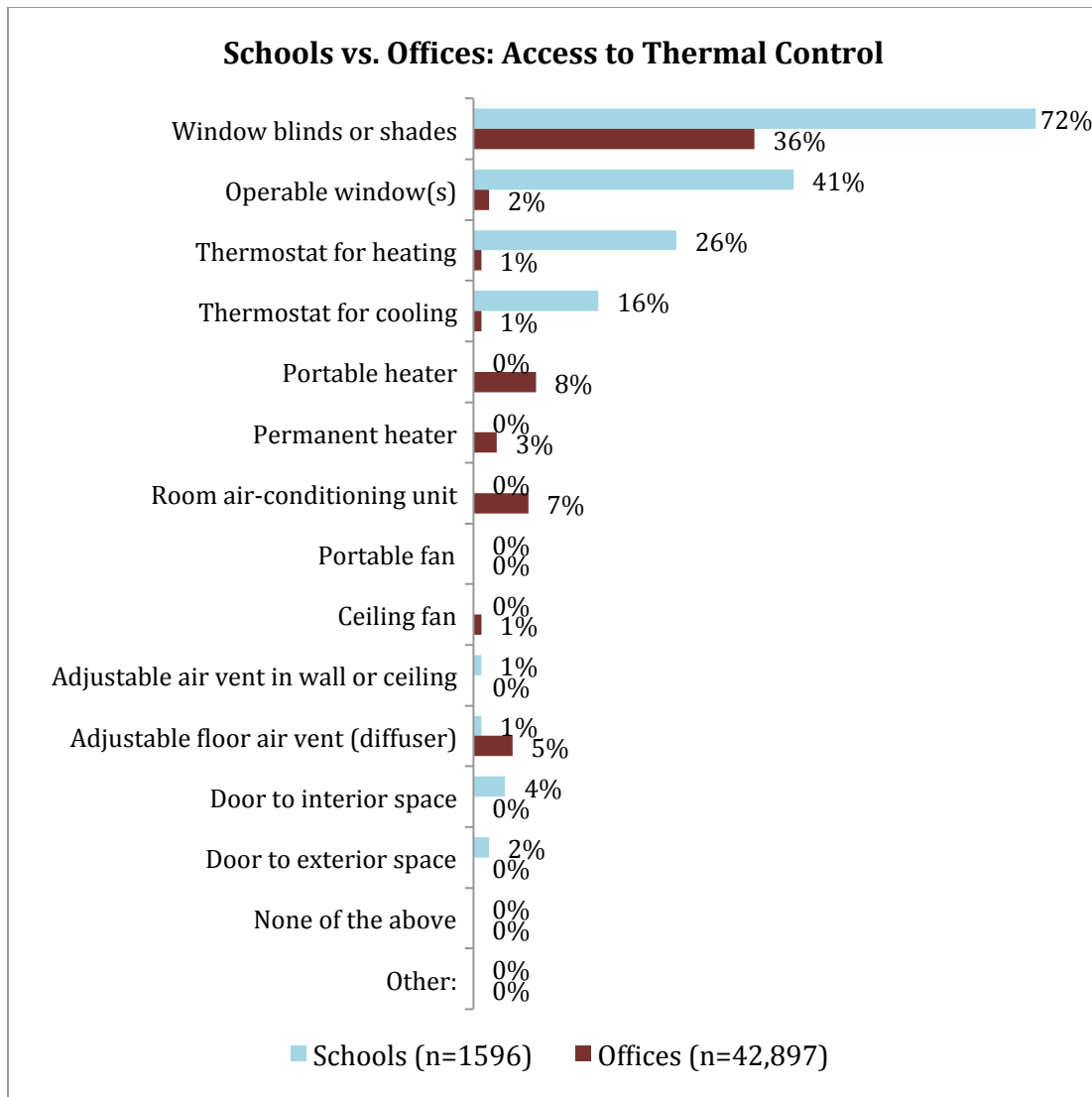


Figure 4.3.a Schools vs. Offices: Access to Thermal Control

Indeed, school occupants note the importance of having some level of thermal control in their classrooms, given the types of activities that may occur in classrooms, the differing needs of students, and issues of attentiveness in educational settings. As one occupant notes, regarding his classroom’s recent ceiling fan addition, *“The room used to get very warm prior to the ceiling fan. Students often complained about the temperature in the room. The ceiling fan is a real asset to the enclosed environment.”* As this individual notes, in circumstances where occupants do not have access to a window, controls of other kinds are even more crucial.

However, with this greater level of control, a new set of problems arise. Figure 4.3.b shows sources of dissatisfaction in schools compared to office buildings, noting that school occupants tend to report much higher levels of dissatisfaction associated with controls, or their individual lack thereof (since many of their peers have significant controls). Note that this graph only reports the responses of occupants who have noted

some dissatisfaction with the temperature in their workspace (this represents roughly 41% of all school occupants, and roughly 44% of office occupants). Occupant dissatisfaction also stems from issues relating to windows, particularly leaky operable windows. Finally, a comparatively large number of school respondents complain of 'other' sources of dissatisfaction. Comment analysis reveals that these are largely people complaining that the HVAC systems do not, in their opinions, work properly. As one occupant notes, *"heating/cooling system does not respond at all to the thermostat, and there is no way to increase ventilation without leaving the doors open to students."* Others note issues like a lack of heating or cooling entirely, or a system that only works intermittently. Further research on the condition of HVAC systems in these buildings would contribute significantly to the understanding of these issues. Without knowing more about the performance of the mechanical systems in question, it is difficult to know whether schools occupants show higher levels of dissatisfaction with the thermal environment because of expectations and personal factors, or because school buildings tend to run poorly relative to office buildings, perhaps due to less maintenance funding and failing equipment.

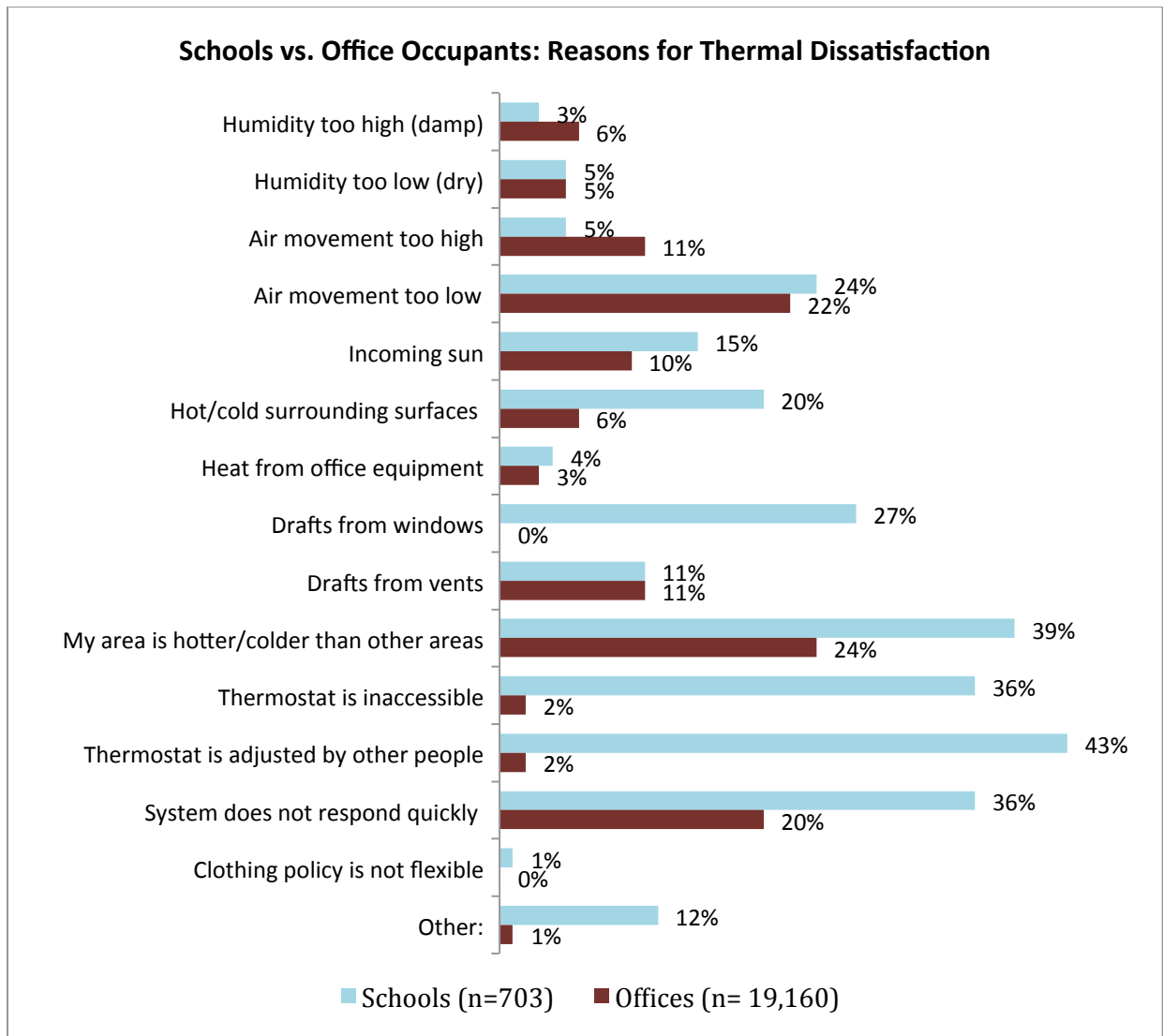


Figure 4.3.b Reasons for Thermal Dissatisfaction: Schools vs. Offices

This data shows that control issues are central to the comfort and satisfaction of occupants in schools, to a greater degree than office occupants. As mentioned above, this is likely related to the fact that a higher level of control in classrooms is expected and depended upon for the proper functioning of classrooms. These findings are supported by more general research on teacher preferences in classrooms (Lackney 1999 and Lowe 1990). This circumstance plays a role in the findings that follow, as they relate to specific types of thermal comfort control in classrooms.

4.3.3 Thermostat Control and Thermal Comfort Satisfaction

Looking specifically at the types of thermal comfort controls available to respondents in this survey, the clearest positive correlations between thermal comfort satisfaction and controls were related to thermostats. As Figure 4.3.c and Figure 4.3.d show, occupants with either a cooling or heating thermostat were generally more

satisfied with their thermal environments. These results have a 99% statistical significance, but an r of 0.22, in both cases (cooling and heating thermostats), showing that there are other factors contributing to thermal satisfaction. Nonetheless, this was one of the strongest relationships in the study, and one of the only statistically significant relationships between a building characteristic and IEQ satisfaction trends.

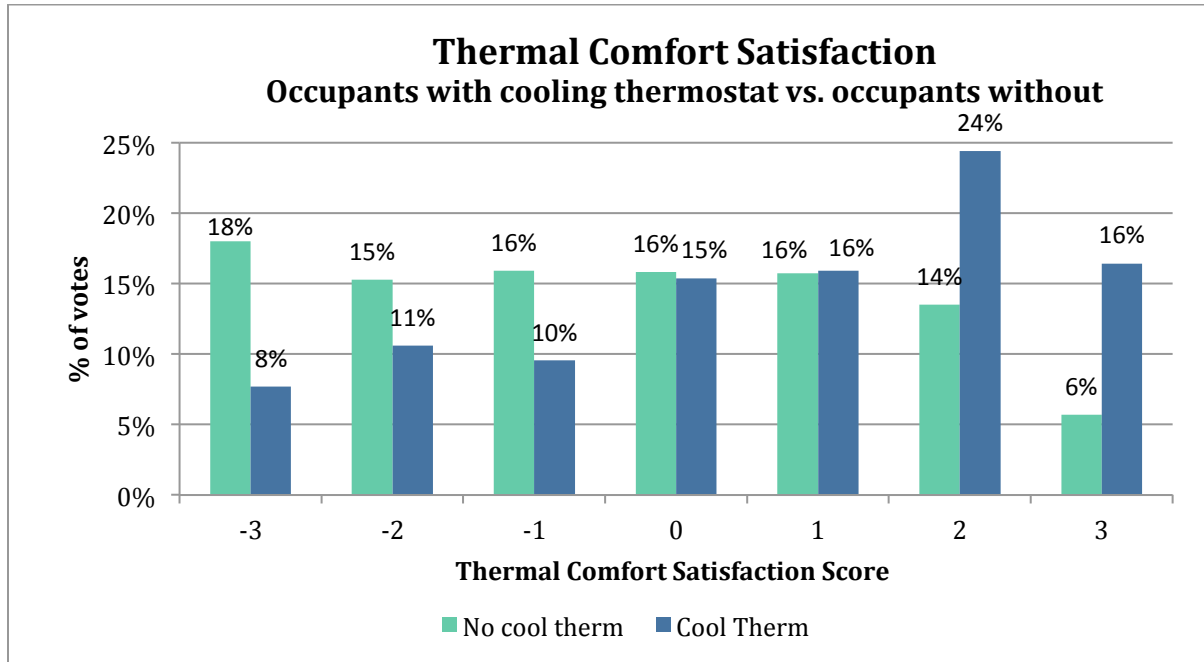


Figure 4.3.c Thermal Comfort Satisfaction: Cooling Thermostat

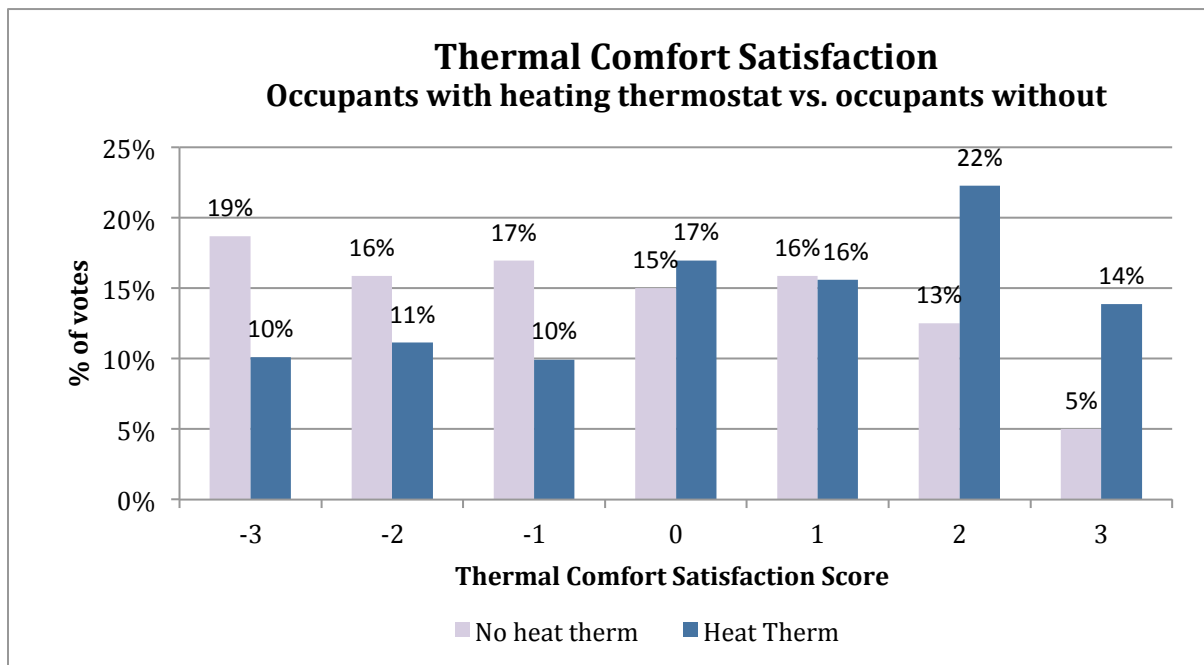


Figure 4.3.d Thermal Comfort Satisfaction: Heating Thermostat

However, not all occupants with thermostats are satisfied with their thermal environment. Thermostat-enabled respondents still offered complaints, largely centered on the functionality of thermostats, and the widespread belief that they are, as one occupant put it, “*purely decorative*”. Another occupant notes more obscure problems with thermostats, saying, “*we were told that the thermostat in our room was installed upside down; however, we don't feel that it is working at all because we never hear (or feel) air coming from the vents.*” But most comments regarding thermostats were along the lines of one occupant, who wrote, “*I believe that the thermostat is controlled by the main facilities office. We try to adjust but I don't think anything happens.*” In situations where thermostats are purposefully not functional (or only functional within a small range of temperatures), occupants are more likely to express frustration and discomfort. But overall, survey results support the notion that functional thermostats in classrooms are related to thermal comfort in those spaces.

4.3.4 Thermal Satisfaction in Certified Green Schools

High-performance school certification programs emphasize a number of design strategies that have an impact on thermal comfort. Energy-saving strategies often call for less occupant control (and more centralized control) of energy-consuming equipment like heating and cooling systems. Daylighting strategies may affect thermal comfort either through increased solar gains in perimeter classrooms, or heat loss associated with daylight-admitting windows. Thermal comfort control is also encouraged in these certification programs, so it was interesting to see the results, which do not show a clear improvement in the thermal comfort reported by respondents in certified green schools compared to other schools (including new ones), as is shown in Figure 4.3.e.

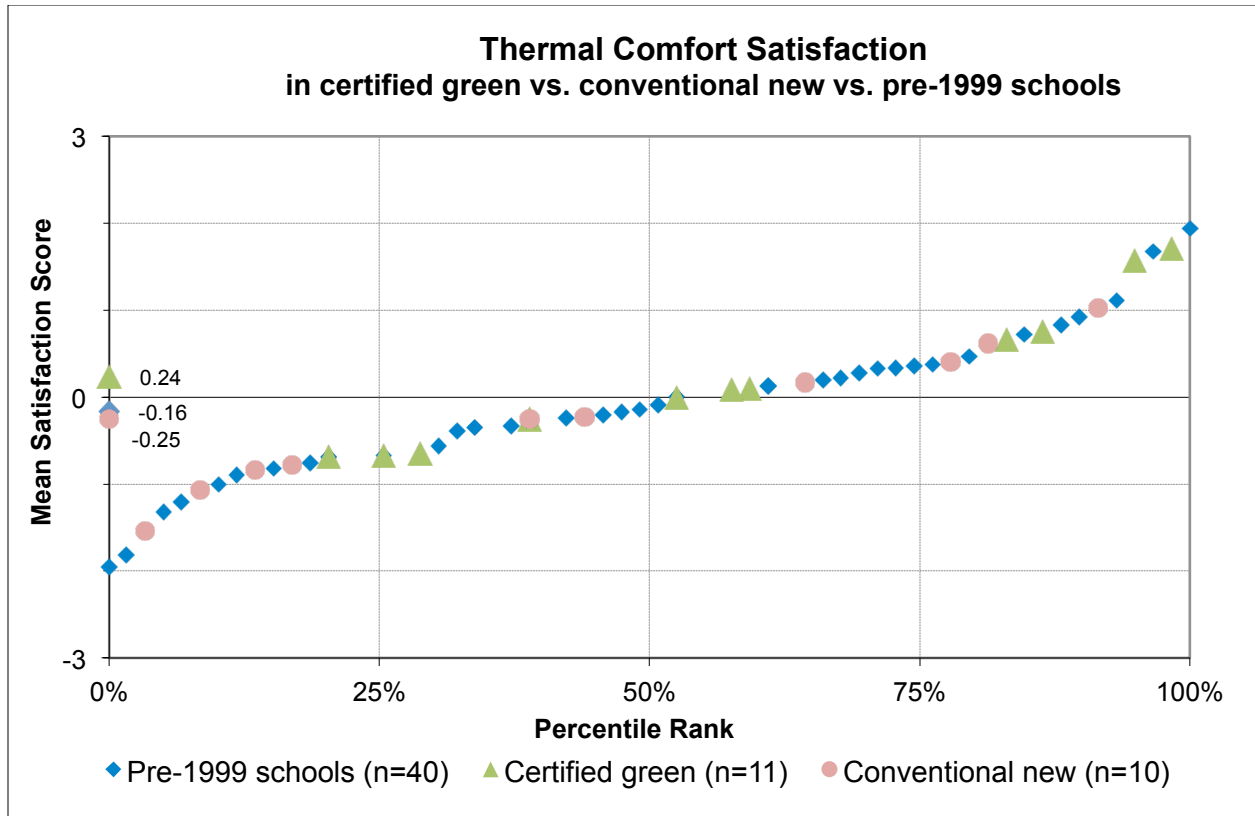


Figure 4.3.e Thermal Comfort Satisfaction: certified green vs. conventional new vs. pre-1999 schools

Some certified green schools are quite high-performing, while others are less so. In reviewing the specific comments and complaints lodged by individuals in these low-performing school buildings, a few general insights were un-earthed. As one occupant notes, *“for a building that is supposed to be passively comfortable, and easily controlled, it is odd that it often feels as if an air conditioner is on full blast.”*

However, there is reason to believe that certified green school buildings may still be an improvement in other areas, compared to what might have been done. One occupant in a new school that doesn't have a high-performance certification notes, *“[Our] new heating/cooling system doesn't work- temperature does not stay consistent at all, single pane windows/drafty due to no weather stripping.”* Many occupants in the new but not “green” group of schools complain of workmanship problems in their new schools, but few occupants in green schools note these issues.

The specific reasons for thermal dissatisfaction in certified green schools (compared to new schools built since 1999) are interesting. Figure 4.3.f shows these responses, and highlights the fact that there are a few areas in which certified green schools have fewer complaints, primarily in the control area, than other new schools (“Thermostat is inaccessible”, “Thermostat is adjusted by other people”, etc). However, certified green school occupants also report more frequently that they are dissatisfied due to incoming sun, which may be related to daylighting-related features that often accompany certified green classroom designs (see comments reported in the lighting section for information about overly daylit spaces in high performance schools).

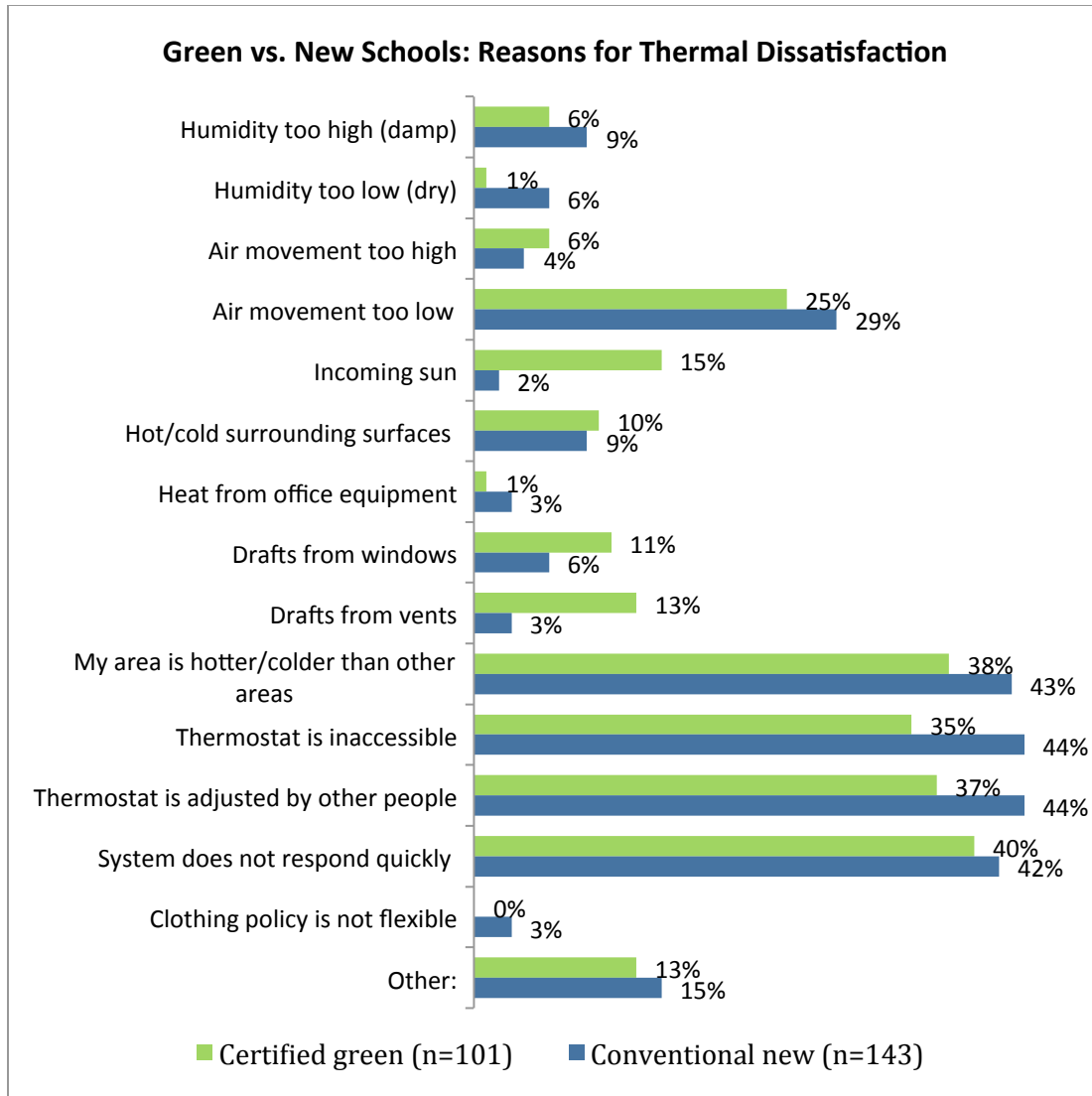


Figure 4.3.f Reasons for Thermal Dissatisfaction- certified green vs. conventional new schools

4.3.5 Operable Windows and Thermal Satisfaction

Operable windows in this study were initially a major area of focus for this study, in the hopes that some clear correlations between various satisfaction scores and access to operable windows would be found. Basic correlation tests showed that occupants with operable windows are actually *less satisfied*, on average, with their thermal comfort than those who do not have access to an operable window. The result was initially surprising, because current design trends have encouraged operable windows as a means towards greater thermal comfort, as well as energy savings through natural ventilation techniques. It is also surprising given that this trend is not present in the office buildings that the CBE has surveyed. This may be due to differences in the condition of schools and office buildings, and the fact that most of the office buildings in the CBE database are either privately managed or managed by the General Services

Administration, and thus may have more resources for building maintenance and operations than public school districts.

Upon further investigation of comments from respondents regarding why they were dissatisfied with their windows, the story became clearer. Thus, this section of the study relies more heavily on specific occupant comments to elucidate sources of dissatisfaction and building conditions associated with operable windows.

As noted above, many occupants in schools complain of drafts from windows (27% of those dissatisfied). Many of these operable windows are quite old, having been installed in the 1950s, 60s, or 70s. They are often single-paned windows with parts that are breaking or broken. One occupant notes this situation in depth, saying, "*[t]hese windows are sad and pathetic. It is incomprehensible how we can claim to be concerned about energy use in our district (turn off the lights, the computer, turn down the heat etc.) but we can't change out one of the biggest energy loss components in our building. When the wind blows, dirt blows in through the gaps in the windows onto the student work areas - visual proof as to how poorly these things seal.*"

Another reason that occupants with operable windows in this group of buildings seem to be dissatisfied is related to the overall HVAC system integration. Many occupants complained that they had to open windows to cool off their rooms in the winter, like this occupant, who writes, "*Sometimes in midwinter, I have had three windows open as the unbearably hot air is being pumped out of my blowers.*" Another occupant notes, similarly, "*I am grateful to have windows that open. That is the most effective way to cool down the room when it overheats (daily).*" Yet another occupant reports that, "*[w]e are not supposed to open our windows because of the 'environmental controls' (heating and air conditioning).*"

It may also be that the operable windows are still being used without any air-conditioning systems, and expectations of occupants are not being met (they may have previously worked in air-conditioned buildings, or have air-conditioning in their homes, or experience air-conditioning in other parts of the school building or district). One occupant notes some dissatisfaction with her operable windows, but then notes, "*I have to open the windows daily in August, September, May and June, due to lack of air conditioning. I have the good fortune of having my room at an angle that turns away from the sun, so I do not get a lot of direct sunlight.*"

Another source of dissatisfaction with operable windows comes from the configuration of the windows themselves, and how this contributes to usability. Of course, in older school buildings, there are issues of malfunctioning parts, as in the case of one occupant, who notes her difficulties opening windows, saying, "*The windows only open 3 to 5 inches at most and only with extreme effort. The knobs are almost impossible to turn to get the windows open or closed. I have to go outside and push while a child turns the crank in order to close the windows. I don't know what people do on the 2nd and 3rd floors.*"

Newer buildings with operable windows also have their problems. One comment frequently made (without prompt) is that screens were needed for occupants to be able to open windows. Across several climates, the only thing holding

occupants back from opening windows was the fact that they did not have screens on them. One occupant explains this situation, saying, *“There are no screens on our windows, so they are rarely opened due to students' allergy problems and fear of getting stung. In the fall, there is a large bee problem and I have had a child get stung in my room.”* Another notes that many of her windows don't open, or don't have screens, and that *“[i]t would help air movement if more windows could be opened.”* In certified green schools, occupants noted a few problems with the operable windows as well. One noted safety issues, saying, *“[w]e have had to install various safety devices to keep students from being injured by open windows,”* while yet another reports, *“[the windows are] very difficult to open and close -- must stand on the furniture and use the crank, which doesn't work very well on half the windows.”*

Occupants in buildings or rooms without operable windows, however, often point out (without prompt) that they would prefer to have operable windows, in such comments as, *“Windows that open would have been very helpful.”* An occupant in a new school building spoke of this more passionately, writing, *“I think our new building is beautiful and I love all the bells and whistles; however, sometimes it is TOO hot and makes it difficult to be in a classroom all day. With no windows, I can no longer open one up to try to regulate the temperature to keep kids from falling asleep because of the temperature. I have brought a fan from home, but it doesn't seem to help the issue. I hope our “it's what's best for kids” attitude can kick in because we all know that physical comfort is important to students' learning.”*

In summary, there are many factors that relate to the use of operable windows, and many issues that should be addressed during the design of operable window systems, or during renovation projects that impact windows. This area of the research deserves a sustained effort to identify best practices in operable window design, especially as it pertains to climate adaptations. Hopefully this study will help to provoke further considerations in this area.

4.4 Air Quality

Interestingly, in the CBE database and in this specific dataset of school buildings, air quality satisfaction is the most strongly correlated IEQ factor correlated with general satisfaction (see Figure 4.4.a for these values).

	Acoustic	Air	General	Lighting
Air	0.6056			
General	0.746	0.8711		
Lighting	0.704	0.6893	0.6325	
Thermal	0.4409	0.4499	0.4083	0.2573

Figure 4.4.a Correlations between satisfaction scores

4.4.1 Age of Building and Air Quality Satisfaction

In examining potential correlations between satisfaction scores and physical building characteristics, one of the strongest correlations found was between mean satisfaction scores with air quality and the year that the building was constructed.

Figure 4.4.b shows this relationship, which has a correlation of $r=0.45$. It should be noted that one of the oldest buildings in the dataset, a small school in Pennsylvania, still had very high satisfaction scores, which may be related to the fact that the building has been continuously renovated throughout its lifetime, and had recently undergone a renovation. Further research should be conducted to assess this relationship that incorporates considerations such as maintenance, renovation history, existing building features and set-up, and operations budgets. It should also be noted that not all new schools are performing well in air quality scores. This will be discussed in more depth in the following section, which breaks down the scores between the certified green schools and the other new schools.

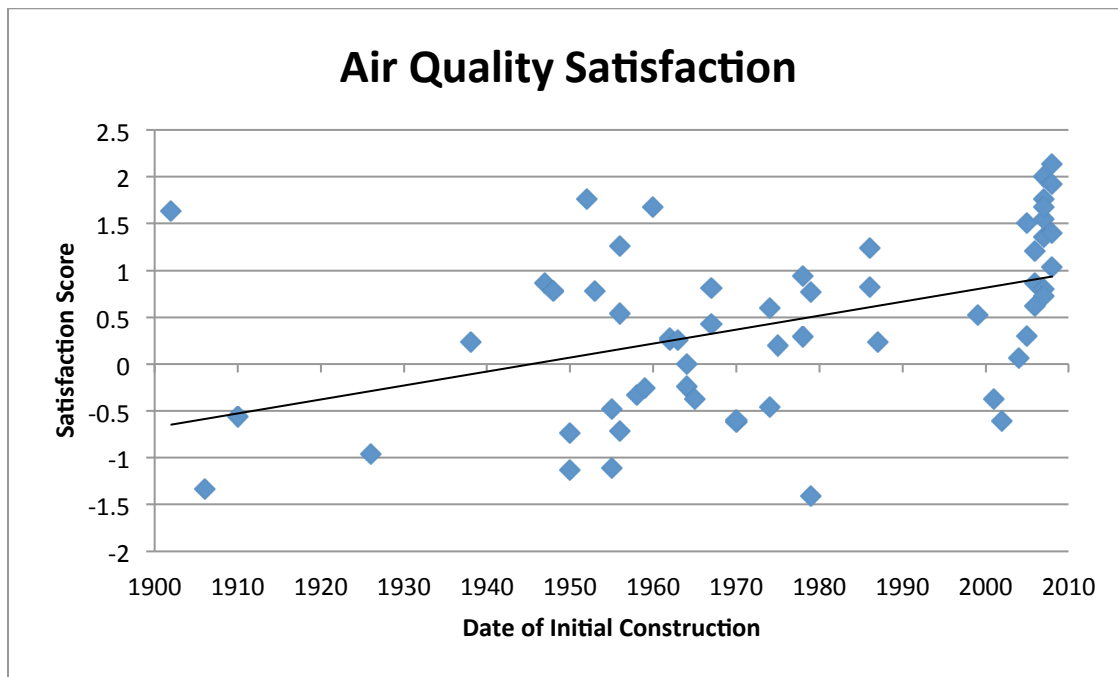


Figure 4.4.b Air Quality Satisfaction vs. Date of construction

4.4.2 Certified Green Schools and Air Quality

One area in which high performance schools clearly outperformed their peers (both the new schools and all others) was the category of air quality. Occupants of high performance schools tended to report very high satisfaction scores, with a mean score in that group of buildings of 1.49 (see Figure 4.4.c for these scores). This could be resulting from the tendency of these buildings to install low-VOC paints and finishings, thus reducing pollutants in the indoor environment especially in the initial months and years of occupancy. These buildings also tend to have more effective ventilation strategies and system control that can allow for increased ventilation. As one occupant noted, *"I appreciate the CO2 fan, and I feel more alert because of this fresh air. The lights, the radiant heating, the windows, etc. all enhance the working and learning environment!"*

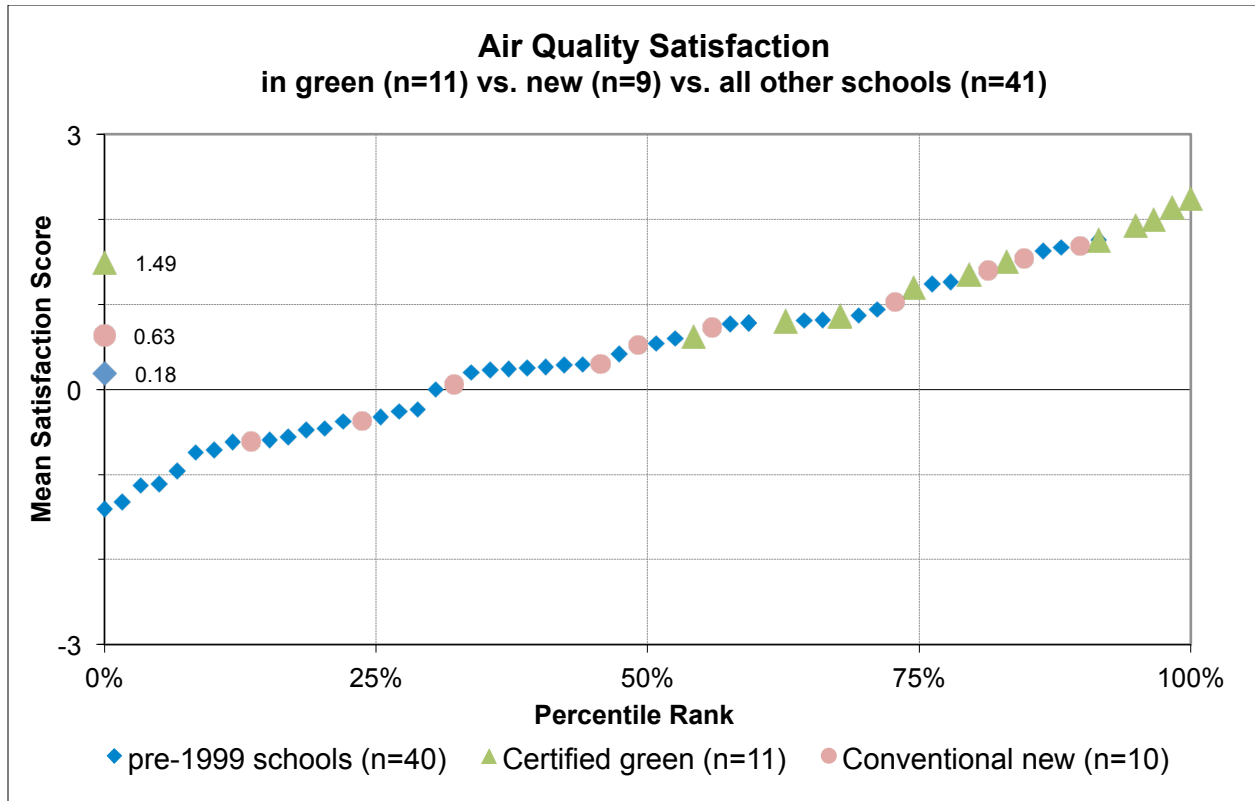


Figure 4.4.c Air Quality Satisfaction: Green vs. new vs. all other schools

Since air quality is the feature of buildings that also tends to correlate most strongly with general satisfaction in buildings, this is a notable result. It is especially notable, given that some of the new schools built without the aid of a high-performance standard performed relatively poorly in this area. Although occupant comments associated with air quality dissatisfaction did not specifically identify the cause of their complaints, there were comments in the same dissatisfied population noting the lack of controllability of thermal comfort systems (like windows and thermostats), which may be contributing to the problem, since the absence of these features may lessen occupants' ability to adjust the air flow in their rooms.

4.4.3 Air Conditioning and Air Quality Satisfaction

In recent decades, many schools have followed the trend and installed air conditioning systems, often in the name of comfort for occupants, and to support year-round programming (for schools that were previously left empty in summers). Because of this trend, I investigated the relationship between mean air quality satisfaction scores in buildings reported to have air-conditioning systems with those that did not. In the dataset, 22 of the school buildings did not have air-conditioning systems, while 37 did (the remainder had portions of the building air-conditioned, or did not provide this information clearly). It should be noted that all schools in warmer climates had air-conditioning. Therefore, to provide a cleaner comparison, non-air-conditioned schools were only compared with air-conditioned schools that were in cooler climates (as defined by having higher numbers of Heating Degree Days). Comparing the mean

scores in these two groups, the data shows a small difference in mean air quality scores; the mean air quality satisfaction score for buildings with air-conditioning was 0.49, while the mean score for buildings without air-conditioning was 0.24. While this result was not statistically significant, it is still worth noting for future research, since it builds on existing research that draws attention to the air quality and thermal comfort issues that often arise in air-conditioned buildings (see Section 2.3.4). One occupant touched on an issue that might contribute to dissatisfaction in schools that don't have air-conditioning, noting, *"we had mold growing on the books in the library because it was too hot and too humid in here over the summer."* The effects of air-conditioning may be direct, or they may be indirect, in the sense that A/C systems may prevent mold growth in summer (often less occupied) months, which in turn has an effect on air quality satisfaction for occupants.

4.5 Acoustics

When asked about the effects of the school building on student performance, many teachers will respond that acoustics are the aspect that they notice most. The ability of students to hear teachers is compromised when classrooms have high background noise levels or too much reverberation off of hard interior surfaces. This can also impede small group activities, audio-visual presentations and other alternative teaching methods. This section investigates some of the key findings that occupants in this study reported regarding the acoustical conditions of their classrooms.

4.5.1 Acoustic Satisfaction in Schools and Offices

As noted in the introduction to this section, acoustics was the only area in which satisfaction scores in schools and offices differed significantly. As Figure 4.1.i shows, school occupants seem to be, on the whole, more satisfied with their acoustics than office workers. Although there is little to explain this result in the comments and responses of the survey-takers in the study, there is reason to believe that this may be a result of differing expectations regarding acoustical environments. In classrooms, teachers expect a certain level of noise, due to the higher activity level of students in classes, and the higher number of people occupying a small space. In office environments, there is an expectation of sound privacy and low noise levels. It's also possible that acoustics are more carefully considered in schools, due to their importance in the learning process. Whatever the reason, this could be an interesting area of further study, to help scholars better understand the role that personal expectations have in acoustic satisfaction.

Of course, this study's survey did find some significant sources of acoustic dissatisfaction. Figure 4.5.a shows the reasons for dissatisfaction in classrooms, noting that occupants tend to be most dissatisfied with overhearing others in neighboring areas (with 64% of those dissatisfied listing "People in neighboring rooms", and 63% of those dissatisfied listing "People in hallways").

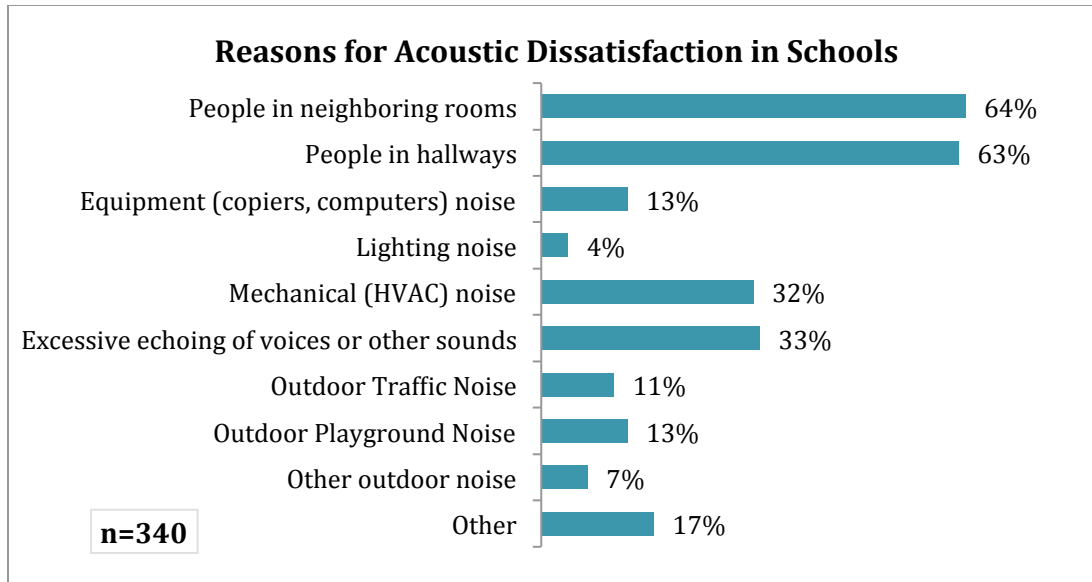


Figure 4.5.a Reasons for Acoustic Dissatisfaction in Schools

This study examined the potential negative impacts operable windows could have on noise level satisfaction. When windows are open, outdoor noise can compromise the acoustical environment in the classroom, thus encouraging teachers to keep windows closed for acoustical reasons, even though they may prefer to open them for thermal comfort. Therefore, this study tested the relationship between occupant satisfaction with the noise level in their workspace and their answer to whether or not they had a window in their classroom. No correlation was found, either negative or positive. Figure 4.5.b shows the distribution of votes on this question, in which the group of occupants that have access to a window roughly follow the same pattern as the group without a window. The correlation coefficient for the relationship between windows and noise level satisfaction in this dataset is $r=0.09$.

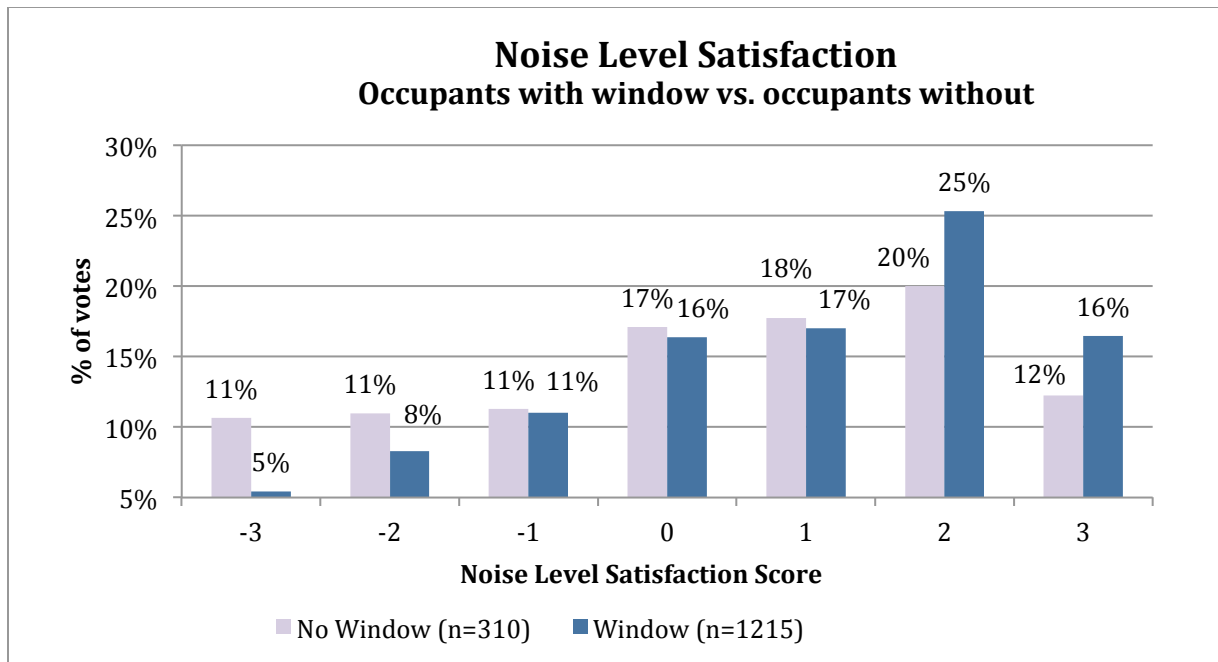


Figure 4.5.b Noise Level Satisfaction: Occupants with windows vs. those without

4.5.2 Open Plan Classrooms and Acoustic Satisfaction

During the survey process in one school district, representatives from that district informed me that they had 5 “open plan” schools they were particularly interested in assessing for acoustic performance. They had been considering a renovation of these schools, since they had been getting some complaints, and hoped that the survey process would shed some light whether the incidental complaints were representative of overall sentiments in these schools. These schools, all built in the 1970s, were designed with a concept popular at that time, that schools “without walls” would contribute to a better learning experience for students, by emphasizing collaborative learning and community-building. Thus, the interiors of the schools have no permanent walls, nor floor-to-ceiling partitions of any kind. In addition, district officials and the occupants noted that these “classrooms” (which are essentially just areas that are visually screened by low flexible partitions) do not feature windows or controls for their thermal or lighting environments. Respondents were quite clear about their perspective on these school buildings. Figure 4.5.c shows the average acoustic satisfaction scores for all schools, with the 5 open plan classrooms highlighted. All 5 schools scored in the bottom 10%. Comments on these schools described the acoustic dissatisfaction that occupants feel. One occupant noted, “[b]ecause there are no “real” walls (only cardboard partitions) defining classroom space, sound travels easily from room to room. Additionally, there are no “halls”, which is extremely distracting.” Another commented on the effects of the open layout more generally, noting, “An ‘open school’ was a bad idea with good intentions. Schools need windows, walls, and halls to operate at their optimal levels. Workspaces and classrooms need to be clearly defined by walls and doors.”

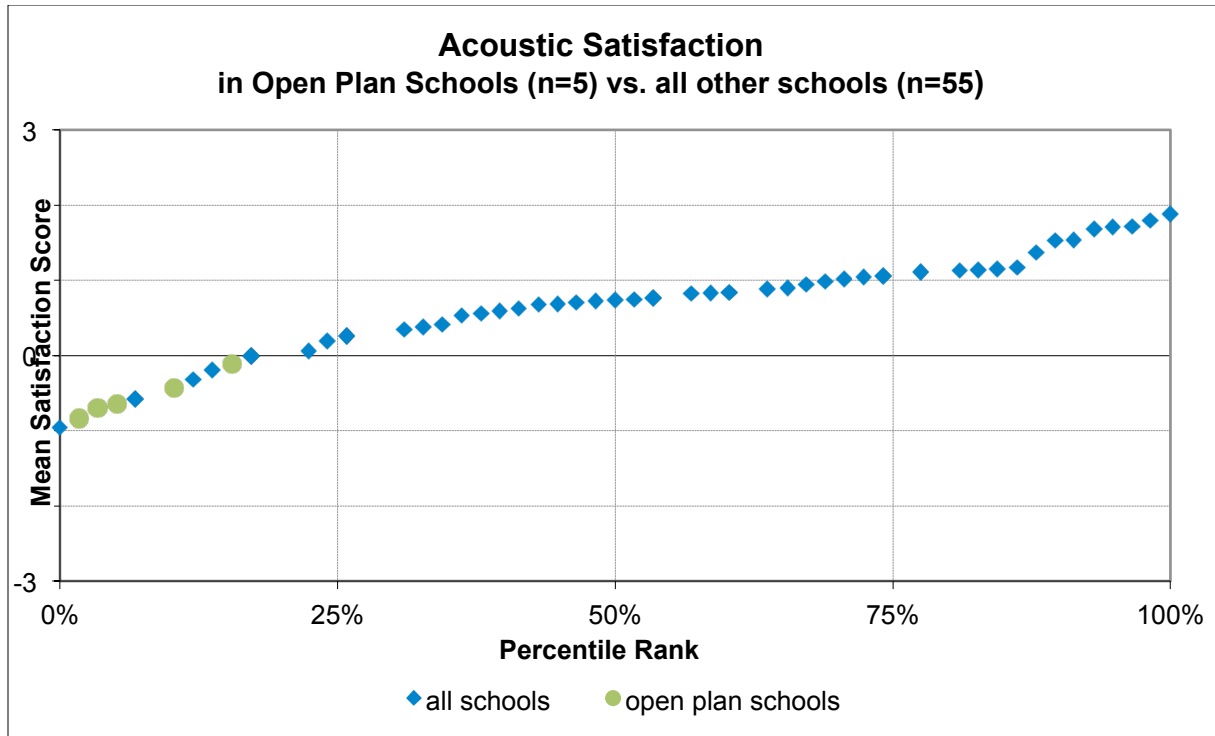


Figure 4.5.c Acoustic Satisfaction in Open Plan Classrooms

This instance not only illustrates a clear trend regarding occupant satisfaction in open plan classrooms (as compared to normative classrooms), but also provides a great example of the practicality of running occupant satisfaction surveys to prioritize and assess known issues. Representatives from this school district noted that following the survey, they were able to show their school board the results of this study, as evidence of the need to install permanent interior walls and better acoustical systems in a renovation of these schools. Without these quantified data, it was possible for administrators to believe that the open classrooms, while disliked by some, might be preferred by the silent majority. Figure 4.5.d shows that this was not the case; 55% of all occupants in the open plan schools were at least somewhat dissatisfied with the acoustics in their workspace.

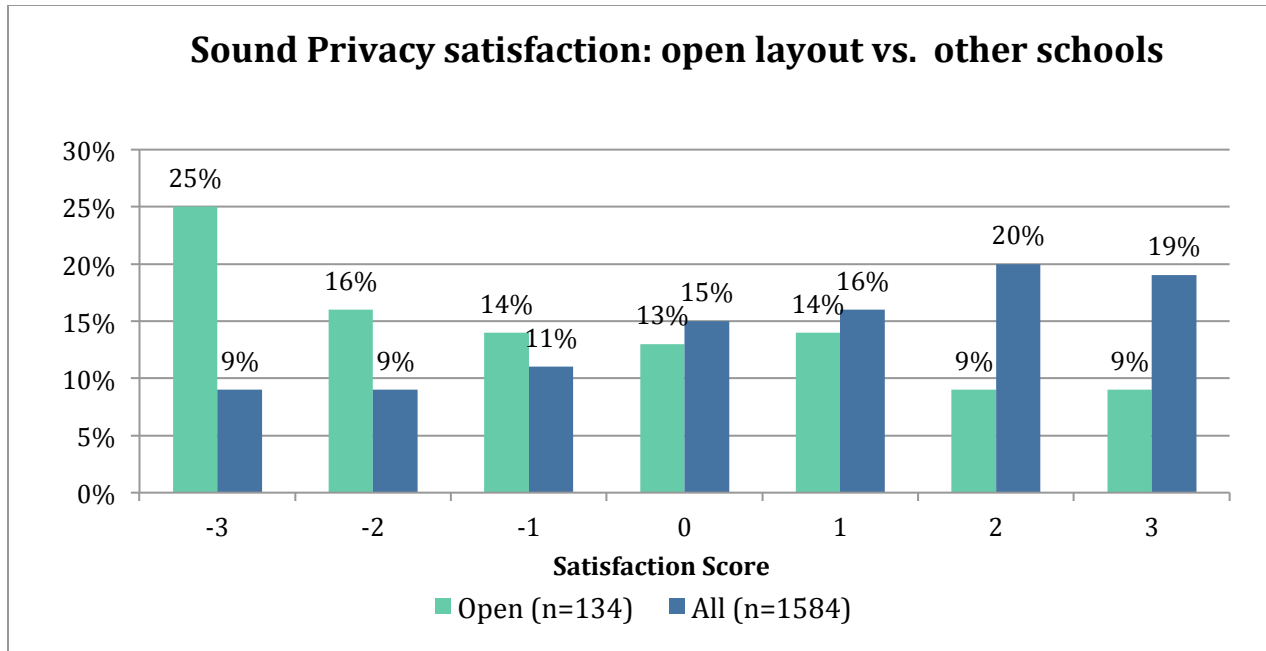


Figure 4.5.d Sound Privacy Satisfaction: Open Layout schools vs. all other schools

4.5.3 Acoustical Issues and Certified Green Schools

Acoustics is a relatively new issue in the high-performance building industry, compared to a long-standing engagement of air quality, lighting and thermal comfort. However, in 2007, the LEED for Schools Rating System launched, with a prerequisite and series of credits for acoustics, which were based on an ANSI Standard (12.60) for classroom acoustics. The school buildings in this study did not use the ANSI standard, but rather older standards for schools that did not include performance metrics or prescriptive guidelines for acoustical design. Thus, it may not be surprising to see, in Figure 3.1.a, an absence of clear improvement of acoustic satisfaction in certified green schools. In fact, the mean scores for new schools and “green” schools are 0.92 and 0.95, respectively. While these newer schools seem to generally out-perform schools built prior to 1999, there is no strong trend here.

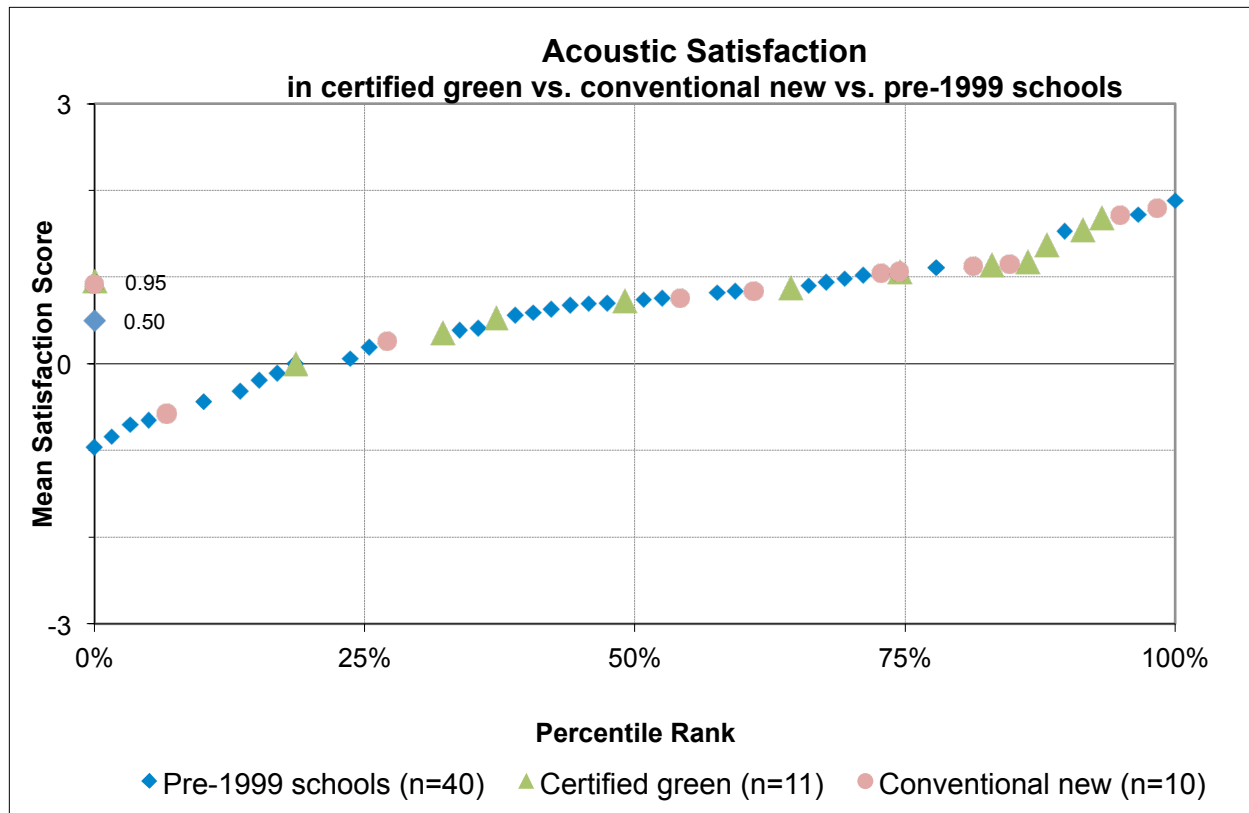


Figure 4.5.e Acoustic Satisfaction in certified green vs. conventional new vs. pre-1999 schools

As the school building industry begins to accept the standards and metrics used to evaluate acoustic performance in schools, this situation may change significantly. Further research may be useful to continue to gather occupant feedback as this aspect of school design evolves more rapidly in the coming years.

5 Discussion

While the findings of this study are useful and reassuring in their patterns of satisfaction in school environments, some of the most interesting general findings emerged from other areas. The following sections will review some of these concepts, as a way of reflecting on the larger issues influencing satisfaction with the environments offered by our schools.

5.1 Green Certifications and Occupant Satisfaction

Overall, occupants report higher levels of satisfaction in certified green schools than in other schools built in the past 10 years (and schools built prior to 1999). This is most notably evident in the areas of lighting, air quality and general satisfaction. This is a positive indicator that Green Certification programs are adding value for districts, on top of any environmental or energy-related benefits they may also produce. It should be noted that these results may be partially due to the higher percentage of private schools in the 'certified green' set, compared to the other new schools. However, there is no reason to believe that public schools would not (or do not) see similarly positive

results in pursuing a green certification like LEED or CHPS. These programs require a higher level of quality assurance and commissioning of the basic building systems that support occupant comfort, while encouraging thorough design solutions that provide high indoor environmental quality for all occupants. It should not be surprising to see that teachers are more satisfied with their schools when these systems are used. There is also likelihood that teachers know about the green certification, and may derive a sense of pride and appreciation for the extra level of effort that leadership and facility staff devoted to provide a high-performance learning environment, and thus rate their satisfaction higher. One occupant hints at her delight in the green aspects of the school, in an unusually effusive comment, saying, *"I hope heaven is just as nice as [my school]. It is awesome here! It's the perfect setting for a teacher. I am extremely thankful every morning I step onto campus. The custodial and grounds staff do an incredible job. I have strong allergies to dust, but I never have any problems in my room. Ruby is the best! Thank you! :)"* Whatever the reason, faculty and staff are more satisfied with their indoor environmental conditions in certified green schools. However, there are still many problems that arise in high-performance schools, as is evidenced by the results of these surveys, especially in the open-ended comments sections. For example, certified green schools may be more likely to use newer technologies that have a higher potential to malfunction. In one school, an occupant notes, *"The toilets randomly flush all day and night and no one has fixed the problem. We are supposed to be a green school but the amount of water wasted is insane."* When new systems that are designed to save energy and water malfunction cause the opposite effect, frustrations are evident. For instance, this commenter in a new conventional school, notes, *"We have had many, many problems with the air and heat. The installation was obviously done poorly. I think that the company in charge of actual construction did a poor job and did not have any idea what was actually necessary in a school building. They were sloppy and very rude to us as we began to move in. Their sloppy work continues to cause problems even in our 3rd year."*

Designers and facility professionals should be sensitive to these aspects of new school buildings, as occupants move in and as systems are tuned. Opinions formed in the first few months of operation can be strong and lasting, and can affect the overall satisfaction level of occupants in the long run. This can be true of any school building project, certified green or not. In summary, occupants in green certified schools tend to be more satisfied than their peers in non-certified schools, but this should not give us reason to believe that a green certification will always lead to more satisfied occupants. These buildings tend to be better executed and more rigorously tested, but can still result in problems for occupants. Feedback loops that investigate the success of building projects are necessary to ensure that design intentions are met.

5.2 Occupant Survey Research and Facility Management

For facility managers and those assessing school buildings, POE studies can be useful in identifying problems and solutions. Teachers and staff in school buildings have years of experiences in their facilities that help them understand the sources of problems, the easy fixes, and the more complex remedies that might or might not work for their school. There is also evidence that, beyond a concern for their own personal comfort and control, they also care deeply about energy conservation and good facility management. As one teacher notes, when asked about whether he/she thinks

that the building is using energy efficiently, *“Energy conservation is great and I am all for it. Our approach to conserving is honorable (i.e. shutting off lights, computers, printers etc.). What troubles me is the lack of focus on the structure itself. Doors and windows are terrible sources of energy loss.”*

In addition, general deterioration can serve as a complicating factor in many school buildings, where the functions of the building are already compromised by dysfunctional or non-functional systems. There is also evidence that poor management can lead to general frustration with building performance. One occupant in a Montana school notes, *“Windows that were replaced or taken out were replaced by plywood. There is very little R value in plywood. Insulate them!!!!!!!!!!!!”* Clearly, these types of issues, left unaddressed, affect the level of satisfaction teachers have with their overall indoor environment.

But perhaps the most convincing stories are those where a clear trend of satisfaction can be seen when similar school buildings are compared to each other. As this dataset grows to include more school buildings, we will have opportunities to make these comparisons and learn more about the effects of design and operation decisions on teachers and students.

6 Conclusions

In the design and management of today’s school buildings, districts face growing pressure to cut costs while keeping the quality of facilities high. And yet, energy and occupant well-being outcomes are rarely assessed to identify opportunities for improvement. Rarely are they investigated thoroughly following a new construction projects. Especially in the case of schools with green certifications, districts are satisfied to know that their buildings were intended to perform well, even if they have little hard evidence to back this up.

To investigate these issues, I conducted Post-Occupancy Evaluation (POE) Surveys in 61 school buildings across the country, 11 of which were designated as “green” buildings. I also collected detailed information about each building surveyed, including occupancy demographics, size, and age. Through a comparison of user satisfaction and high-performance design intentions, the study identified successes in design and management, along with areas where school buildings are failing the teachers and students they house..

6.1 Summary of Findings

As noted throughout this thesis, the findings of this study suggest trends that might be found in school buildings across the country. Many of the findings support previous research done on indoor environmental issues in schools, and illustrate a method that can be used to gather more specific information about how teachers and students are reacting to their school environments. This performance information can help to identify problems and solutions at several scales – for the individual school and its improvement needs, for districts as they prioritize renovations, and for the larger school building industry as it evolves new strategies for providing better learning environments. This section will briefly summarize some of these lessons. Many of the findings in this

thesis support other research in helping to strengthen the connections between various design features in schools and teacher satisfaction and well-being. Most notably:

- Teachers prefer classrooms with natural daylight, especially when they can control the amount of daylight with blinds or shades. Certified green schools tend to execute designs that support this preference better (although there are exceptions), as evidenced by higher average levels of lighting satisfaction.
- Teachers prefer classrooms with thermal controls, such as a thermostat or operable window. Certified green schools do not necessarily respond more effectively to this preference.
- Teachers report higher satisfaction with the air quality in certified green schools than with the air quality in other schools, both old and new.
- Acoustic satisfaction in schools is generally higher than in offices, but problems do arise. In particular, open-plan classrooms receive low scores from occupants in acoustics.
- Operable windows, while theoretically desirable and potentially useful for low-energy cooling and ventilation, can have problems, especially in older schools. Where window assemblies are deteriorating, occupants are very dissatisfied with both the resultant discomfort and perceived energy inefficiency.

This thesis also raises newer questions about interactions between school facilities and occupant comfort, particularly in the areas of new and high-performance schools. Evidence from this study shows that new schools can have problems, particularly with thermal comfort, and that occupants can be helpful in identifying problems in the first few months and years of operation. This thesis also shows interesting trends related to the epochs of school building in the U.S., which questions the premise that older school buildings are less valued by occupants. Future research in this area would be valuable, to determine what eras of school building have produced buildings that are most effective today.

6.2 Future Research Directions

In examining some of the satisfaction trends and facility issues in a sample of school buildings this thesis has produced questions in addition to answers. As research in this area moves forward, there are many exciting threads worthy of further study. Foremost, it will be valuable to have a larger, more representative set of school buildings follow this same survey methodology, so that trends seen in this smaller sample set can be verified, and larger industry trends can be identified.

Another area for future research is a more controlled analysis of the effects of building systems, using districts that have a number of similar school facilities (known often as 'prototype' schools). In the course of this research, it was discovered that some school buildings had almost identical facilities, with only minor differences. This is one area in which building science research in school buildings can be particularly useful - investigating potential causal relationships. With a larger building sample there are more opportunities for controlling variables such as layout, age, and materials, as well as budget, decision-making structure, and maintenance policies that tend to be confounding factors when attempting to draw connections between building design features and occupant well-being or productivity.

The findings of this thesis form the foundation of a future, more detailed study of the interactions between occupant comfort and energy use in K-12 schools in the US. In the next phase, a smaller set of the school buildings analyzed for this study will be assessed in greater detail. The central questions for this in-depth analysis are more central to the use of energy in schools, in the hopes of identifying ways to save energy through involving occupants more effectively in the optimal operation of buildings. Specifically, this research will investigate the interactions between occupants, controls, and energy-consuming systems like lighting and space conditioning. The aim is to identify situations where occupants are satisfied with their environmental conditions, have significant control, and also their buildings are performing well in terms of energy use (ideally without a high capital cost in construction or high operations costs). If case studies can be found that demonstrate energy savings without removing the control of teachers to adjust their indoor environmental conditions, it can serve as a model for schools across the country. As districts grapple with this perceived trade-off between occupant control and energy use, such findings could help to inform the design and modernization of school buildings in the coming years. And more fundamentally, this thesis and the research that follows will contribute to the growing body of knowledge that supports continuous and rigorous assessment of school buildings. As we face the daunting task of saving America's school infrastructure, these types of feedback loops provide thoughtful and comprehensive guidance on how to best provide excellent learning environments for future generations.

References

- 1 ANSI (American National Standards Institute) (2002). Standard 12.60: Acoustical Performance Criteria, Design Requirements and Guidelines for Schools. Washington, DC: ANSI.
- 2 ASHRAE (2008). *Advanced energy design guide for K-12 school buildings*. American Society of Heating, Refrigeration and Air-Conditioning Engineers.
- 3 Abbaszadeh, S., Zagreus, L., Lehrer, D., & Huizenga, C. (2006). Occupant satisfaction with indoor environmental quality in green buildings. In *Proceedings of Healthy Buildings* (Vol. 3, pp. 365–370).
- 4 American Association of School Administrators, 2008. *AASA Fuel and Energy Snapshot Survey*. Washington, DC.
- 5 Abramson, P. (2007). "2007 Construction Report". *School Planning & Management*, C1-C16.
- 6 Baker, S. Josephine. "Classroom Ventilation and Respiratory Diseases among School Children." *American Journal of Public Health* 8.1 (1918): 19.
- 7 Bernstein, Tobie, 2003. *Building Healthy, High Performance Schools: A Review of Selected States and Local Initiatives*. Washington, DC: Environmental Law Institute.
- 8 Brager, Gail S., and Richard J. de Dear. "Thermal Adaptation in the Built Environment: A Literature Review." *Energy and Buildings* 27.1 (1998): 83-96.
- 9 Brager, G. S. (2006). Mixed-mode cooling. UC Berkeley: Center for the Built Environment. Retrieved from: <http://www.escholarship.org/uc/item/1f639548>, accessed Feb.16, 2010.
- 10 Brager, G. & Baker, L. (2009). Occupant satisfaction in mixed-mode buildings. *Building Research & Information*, 37(4), 369-380.
- 11 Buckley, J., Schneider, M., & Shang, Y. (2005). Fix it and they might stay: School facility quality and teacher retention in Washington, DC. *The Teachers College Record*, 107(5), 1107–1123.
- 12 Building Design & Construction, Reed Research Group. 2004. *Green Building White Paper Research*. Accessed October 1, 2009. <<http://www.cefpi.org/pdf/GreenBuildingPerceptions.pdf>>.
- 13 Chaney, B., & Lewis, L. (2007). Public School Principals Report on Their School Facilities: Fall 2005. Statistical Analysis Report. NCES 2007-007. *National Center for Education Statistics*.
- 14 Clements-Croome et al. (2008). Ventilation rates in schools. *Building and environment*, 43(3), 362–367.

- 15 Durán-Narucki, V. (2008). School building condition, school attendance, and academic achievement in New York City public schools: A mediation model. *Journal of Environmental Psychology, 28*(3), 278–286.
- 16 Earthman, G. I., & Lemasters, L. K. (2009). Teacher attitudes about classroom conditions. *Journal of Educational Administration, 47*(3).
- 17 Fay, C., Rea, M. S., & Figueiro, M. (2002). Daylighting and Productivity: A Literature Review. *Lighting Research Center, Rensselaer Polytechnic Institute*.
- 18 Filardo, M. W., Vincent, J. M., Sung, P., & Stein, T. (2006). Growth and Disparity: A Decade of US Public School Construction. *21st Century School Fund, 40*.
- 19 Geller, R. J., Rubin, I. L., Nodvin, J. T., Teague, W. G., & Frumkin, H. (2007). Safe and healthy school environments. *The Pediatric Clinics of North America, 54*(2), 351–373.
- 20 Godwin, C., & Batterman, S. (2007). Indoor air quality in Michigan schools. *Indoor air, 17*(2), 109–121.
- 21 Hansen, H. L., & Hanssen, S. O. (2002). Education, indoor environment and HVAC solutions in school buildings—consequences of differences in paradigm shifts. *Proceedings of Indoor Air, 800–806*.
- 22 Harner, David P. 1974. Effects of thermal environment on learning skills. *The Educational Facility Planner 12* (2): 4-6.
- 23 Heerwagen, J. (2000). Green buildings, organizational success and occupant productivity. *Building Research & Information, 28*(5), 353–367.
- 24 Heschong, Lisa (2003). Windows and Classrooms: A Study of Student Performance and Indoor Environment: Technical Report.
- 25 Heschong Mahone Group (1999). "Daylighting in schools: An investigation into the relationship between daylighting and human performance." Fair Oaks: California Board for Energy Efficiency Third Party Program. Submitted to Pacific Gas and Energy.
- 26 Janda, K. B. (2009). "Buildings Don't Use Energy: People Do." In Proceedings of the International Conference on Passive and Low Energy Architecture (PLEA), June 22-24, 2009 (Québec, Canada), pp. 9-14. Les Presses de l'Université Laval.
- 27 Kats, G. (2006). "Greening America's Schools—Costs and Benefits." A Capital E Report. Accessed October 1, 2009 <www.cap-e.com/ewebeditpro/items/O59F9819.pdf>.
- 28 Lackney, J. A. (2001). The State of Post-Occupancy Evaluation in the Practice of Educational Design. For full text: <http://schoolstudio.engr.wisc.edu>. Retrieved from <http://www.eric.ed.gov/ERICWebPortal/contentdelivery/servlet/ERICServlet?accno=ED463646> on December 10, 2009.

- 29 Larson, C. T. (1965). "The effect of windowless classrooms on elementary school children." Architectural Research Laboratory, Department of Architecture, University of Michigan.
- 30 Lavy, S., & Bilbo, D. L. (2009). Facilities maintenance management practices in large public schools, Texas. *Facilities*, 27(1/2), 5–20.
- 31 Leaman, A. and B. Bordass (2001). "Assessing building performance in use 4: the Probe occupant surveys and their implications". *Building Research & Information*; 29(2), p129-143
- 32 Lowe, J.M. 1990. The interface between educational facilities and learning climate in three elementary schools. PhD dissertation. College Station, Tex: Texas A&M University.
- 33 J Mardaljevic, L Heschong, and E Lee. 2009. Daylight metrics and energy savings. *Lighting Research and Technology*, Vol. 41, No. 3, 261-283.
- 34 Mendell et al. 1996. Elevated Symptom Prevalence Associated with Ventilation Type in Office Buildings. *Epidemiology*, Vol. 7, No. 6, pp. 583-589.
- 35 Mendell, MJ and Heath GA (2005). "Do Indoor Pollutants and Thermal Conditions in Schools Influence Student Performance? A Critical Review of the Literature." *Indoor Air* 15.1: 27.
- 36 Mills, Wilbur Thoburn (1915). *American School Building Standards*. Columbus, OH: Franklin Publishing Group.
- 37 National Education Association (2000). "Modernizing our Schools: What will it cost?" Washington, DC: National Education Association.
- 38 National Research Council (2007). *Green Schools: Attributes for Health and Learning*. (National Academies Press, Washington, DC).
- 39 Newsham, G.R., Veitch, J.A., and Charles, K.E. (2008). Risk factors for dissatisfaction with the indoor environment in open-plan offices: an analysis of COPE field study data. *Indoor Air*, 18, (4), August, pp. 271-282.
- 40 Nicklas, M., & Bailey, G. (1996). Energy Performance of Daylit Schools in North Carolina. <http://www.innovativedesign.net/energyperformance.htm>, accessed on December 1, 2009.
- 41 Nicklas, M., Bailey, G., & Design, I. (1996). Analysis of the performance of students in daylit schools. In *PROCEEDINGS OF THE NATIONAL PASSIVE SOLAR CONFERENCE* (Vol. 21, pp. 132–137).
- 42 Ornstein, S. W., Moreira, N. S., Ono, R., Franca, A. J., & Nogueira, R. A. (2009). Improving the quality of school facilities through building performance assessment: Educational reform and school building quality in Sao Paulo, Brazil. *Journal of Educational Administration*, 47(3), 350–367.

- 43 Ribéron, J., O'Kelly, P., Maupetit, F., & Robine, E. (2002). Indoor air quality in schools: The impact of ventilation conditions and indoor activities. *Proceedings of Indoor Air*, 109–114.
- 44 Roberts, L. W. (2009). Measuring school facility conditions: an illustration of the importance of purpose. *Journal of Educational Administration*, 47(3), 368–380.
- 45 Rowan, B., Correnti, R., & Miller, R. J. (2002). *What Large-Scale, Survey Research Tells Us about Teacher Effects on Student Achievement: Insights from the "Prospects" Study of Elementary Schools*. CPRE Research Report Series. CPRE Publications, Graduate School of Education, University of Pennsylvania.
- 46 Sanoff, H., Pasalar, C., and Hashas, M. (2001). *School Building Assessment Methods*. Washington, DC: National Clearinghouse for Educational Facilities.
- 47 Schneider, M. (2002). *Do School Facilities Affect Academic Outcomes?* (Report No. EF006238). Washington, DC: National Clearinghouse for Educational Facilities. (ERIC Document Reproduction Service No. ED470979)
- 48 Scofield, John (2009). "Do LEED-certified Buildings Save Energy? Not Really..." *Energy and Buildings*, v. 41, Issue 12, December 2009. Pages 1386-1390.
- 49 Smedje G, Norback D, Edling C. 1996. Mental performance by secondary school pupils in relation to the quality of indoor air. Proceedings of the 7th International Conference on Indoor Air Quality and Climate–Indoor Air '96, pp 413-19. Nagoya, Japan: Indoor Air 1996.
- 50 Smedje, G., & Norbäck, D. (2000). New ventilation systems at select schools in Sweden—effects on asthma and exposure. *Archives of environmental health*, 55(1), 18.
- 51 Smedje, G., Norback, D., & Edling, C. (1997). Subjective indoor air quality in schools in relation to exposure. *Indoor Air*, 7(2), 143–150.
- 52 Tanner, C. K. (2009). Effects of school design on student outcomes. *Journal of Educational Administration*, 47(3).
- 53 Turner, C., (2008). *Energy Performance of LEED® for New Construction Buildings*. Vancouver, Wash.: *New Buildings Institute*.
- 54 Uline, Cynthia and Megan Tschannen-Moran (2008), "The Walls Speak: The Interplay of Quality Facilities, School Climate, and Student Achievement," *The Journal of Educational Administration*, v. 36, No. 1, 2008. Pages 55-73.
- 55 United States General Accounting Office. (1995, February). "Condition of America's Schools" (GAO/HEHS-95-61 Publication No. B-259307). Washington, DC: U.S. Government Printing Office.
- 56 USGBC (United States Green Building Council) 2009. LEED for New Construction. Available at www.usgbc.org, accessed last on February 20, 2010.

- 57 Von Neida, Bill and Tom Hicks, 2002. "Building Performance Defined: the ENERGY STAR National Energy Performance Rating System". U.S. Environmental Protection Agency. http://www.energystar.gov/ia/business/tools_resources/aesp.pdf
- 58 Wargocki, P. "The Effects of Classroom Air Temperature and Outdoor Air Supply Rate on the Performance of School Work by Children." *Indoor air* 1 (2005): 368.
- 59 Wargocki, P. and Wyon, D.P. (2007) The effects of moderately raised classrooms temperature and classroom ventilation rate on the performance of schoolwork by children (RP-1257), HVAC&R Res., 13, 193–220.
- 60 Weiss CH. Evaluation Research: Methods of assessing program effectiveness. Englewood Cliffs (NJ): Prentice Hall; 1972.
- 61 Woolner, P et al. "A Sound Foundation? What we know about the Impact of Environments on Learning and the Implications for Building Schools for the Future." *Oxford Review of Education* 33.1 (2007): 47.
- 62 Zagreus L, Huizenga C, Arens E, Lehrer D (2004) "Listening to the occupants: a web-based indoor environmental quality survey." *Indoor Air* 14 (2004): 65–74.
- 63 Zuraimi, M. S., Tham, K. W., Chew, F. T., & Ooi, P. L. (2007). The effect of ventilation strategies of child care centers on indoor air quality and respiratory health of children in Singapore. *Indoor air*, 17(4), 317–327.