

Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction



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ABSTRACT

In the past twenty years, more stringent energy codes and environmental standards have led to many higher performance building designs that use less energy. Oftentimes, high performance buildings that incorporate passive building strategies require active occupant engagement [Brown et al. (2009) [1]] but the people who work in these buildings on a daily basis may not comprehend how their actions (*negatively or positively*) affect the building's energy use [Janda (2009) [2]]. Additionally, minimal research exists surrounding educational strategies for how to best educate building occupants. The purpose of this study was to investigate existing occupant training in high performance buildings to provide recommendations for future occupant education efforts.

A sequential mixed methods study was conducted to better understand the relationships between occupant behaviors, reported environmental satisfaction, and learning in high performance buildings. First, expert interviews were conducted ($n = 3$) to determine the study population. Second, a survey was sent to ten high performance buildings in the United States ($n = 118$), and third, follow-up occupant interviews ($n = 41$) were conducted to better understand the survey responses. It was hypothesized that participants who had received effective training for high performance building features would be more satisfied with their environment than those who had not received training. Results indicated a significant difference between the two groups (those who had received effective training and those who did not), and individuals who reported *effective* training were significantly more likely to be satisfied with their office environment. Follow-up interviews provided additional insight into occupant satisfaction and behaviors.

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1. Introduction

Climate change, rising fossil fuel costs, and a paradigm shift in how we, as a culture, regard sustainability have started to influence how energy use is perceived. In general, the market has seen a rise in more sustainable and energy efficient goods and services over the past two decades within the building sector [3]. Buildings are an ideal sector to target as they account for nearly 40% of total energy use in the United States; lighting (25.5%), heating (14.2%), and cooling (13.1%) are some of the leading energy consumers in

commercial buildings [4]. The building and design communities have responded to this issue, and the way in which buildings are conceived is beginning to transform towards sustainability [5].

Specifically, high performance building designs are becoming more prominent. The rationale for many high performance buildings is to increase energy efficiency and to promote health and productivity for building occupants [6]. Energy efficient design strategies have gained traction in the commercial office building industry for a litany of reasons including more stringent building codes, company policies geared toward environmental stewardship, government regulations, cost effectiveness, utility incentives, energy use reduction goals, and occupant productivity and satisfaction [7–11]. However, the success of many of these design strategies is heavily dependent on how occupants interact with the building [12].

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Passive design strategies, such as daylighting or natural ventilation, are intentionally designed to decrease or eliminate the need for energy, but these may also have adverse impacts on the overall building energy use if occupants do not understand how to operate building systems effectively. A window blind left open on the south side of a building during a hot summer day over the weekend may contribute to excess heat gain, requiring additional mechanical cooling. Alternatively, if an operable window were left open overnight during the cold winter months, it would lead to unnecessary building heating; in either scenario, the occupant plays a major role in the overall building's energy-use.

These outcomes are not difficult to understand; it is common sense to most. Growing up at home, many of us were told to turn off our electric lights when we left the room, or to close the windows when it was too cold or hot outside. However, these seemingly common sense ideals are complicated in an office building where occupants are not paying for the energy bills, the office culture may not support these actions, and individuals may not feel the same sense of control over their environment as they might in their own homes [13].

So, who cares if occupants understand how to operate their office building? From a business standpoint, the simplest explanation is that if occupants understand the building and environmental control systems, then they may contribute to lower building energy use, which ultimately costs the owner less money, and they may increase their overall satisfaction with the interior work environment [2]. This is a win/win situation for both the building owner or company and the building occupant. Alternatively, if users do not understand building controls, then energy use may increase if systems are overridden incorrectly, or occupants may be less satisfied with their environment due to decreased thermal or visual comfort.

Ultimately, passive design strategies in high performance buildings, such as daylighting and natural ventilation, have the potential to greatly reduce energy use, positively impact worker productivity, increase satisfaction, and increase indoor air quality (IAQ) if controls are operated as intended [14–16]. However, negative outcomes can arise from uninformed or unintentional interactions with the high performance building systems. For example, access to natural daylight within the office space has been proven as advantageous to building occupants' psychological and physiological health [17]. Yet, daylight is a dynamic light source that changes on a daily basis, so an understanding of daylight controls and seasonal and diurnal patterns of the sun are crucial to its overall success. If occupants fail to operate blinds when needed, it may lead to issues such as glare, which can have adverse health consequences such as headaches, eye strain or migraines [18]. In this example, it may seem completely unnecessary or even offensive to “teach” people how to use blinds, but other factors may impact the use of blinds. Thermal preferences, visual comfort, social dynamics in the office, and the sheer complexity of the given blind system (many blinds are now automated and one must understand how to override computer controls to even move the blinds) all come into play and influence occupants' decisions. These challenges are further compounded by poor occupant understanding of building design strategies and their intent and use.

The purpose of this study was to investigate the overall success of existing occupant training in high performance buildings with regard to energy use, corresponding occupant behaviors and environmental satisfaction. It was hypothesized that participants who had received effective training for high performance building features would be more satisfied with their environment than those who had not received training. The hypothesis and research questions were explored through an interdisciplinary and mixed methods approach to identify and assess existing occupant

educational strategies and occupants' comprehension of varying high performance building strategies. Buildings with varying high performance building design strategies were sought out in multiple climate zones, and many other data types were collected including surveys, interviews, and documents. The unit of measurement for statistical analyses in the quantitative phase was based upon individual survey respondents rather than individual buildings.

The remainder of this article is structured as follows: first, a brief review of relevant literature surrounding building energy use, occupant behaviors, thermal and visual comfort, and occupant education is reviewed. This is followed by an explanation of the research methodology used in the study. Next, the results of the study are summarized. The paper concludes with a brief discussion of results, study delimitations and limitations, and recommendations for future research.

2. Literature review

2.1. High performance buildings

High performance buildings use various sustainable strategies to reduce overall energy use, optimize all installed systems, and to promote health and productivity for its occupants [6]. High performance buildings offer many benefits to both employers and employees, which is further discussed in the sections below.

2.1.1. Employer benefits of high performance buildings

There are many reasons owners or companies might choose to build a high performance building including the environmental mission or value of the company, stakeholder pressure, employee attraction and retention, government regulations, and economic opportunities or disincentives [19]. For businesses, one of the major motivators for building a high performance building is the potential to increase profits. Some of the monetary benefits for employers include potential energy efficiency upgrade incentives and rebates, decreased operating costs from energy use, and increased employee productivity [8,15,20,21]. Additionally, in high performance buildings with access to natural ventilation, employers may see monetary benefits in terms of fewer sick/short-term leave from sick building syndrome (SBS) symptoms such as inflammation, respiratory infections, and asthma [22].

Overall, these potential cost savings are very important aspects of high performance buildings to employers, but there are also several equally important benefits to the building occupants, such as the potential for increased occupant satisfaction [23], productivity, and overall well-being.

2.1.2. Employee benefits of high performance buildings

Employee benefits attributed to high performance building strategies include increased performance and productivity, increased environmental satisfaction, and positive impacts on both physiological and psychological health.

Sustainable building strategies, such as daylighting and natural ventilation, have been specifically linked to improved productivity and occupant performance in both schools and offices [8,20,24,25]. Natural ventilation has been found to play an important role in supporting air flow in buildings, which can promote thermal comfort, IAQ, and productivity [15,26]. Many studies have also shown how occupant performance can be affected by the quality of light in a space, and occupants with access to natural daylight perform better when compared to those who only have access to electric light [8,24].

Passive design strategies, when designed properly, can have positive impacts on occupants' physiological and psychological health. For example, access to natural daylight has been linked to

decreased eye-strain and headaches, lowered fatigue, and a reported increase in well-being in general [27,28]. Natural light and access to views have also been correlated with improved mood, reduced stress, enhanced morale, and decreased symptoms from Seasonal Affective Disorder (SAD) [14,17,18,29].

Similarly, natural ventilation strategies that allow more fresh air into a building can contribute to increased physiological health by decreasing indoor air pollution and increasing air flow [26,30,31]. Although, it should be noted that natural ventilation also has the potential to negatively impact occupant health in some cases. For instance, opening a window fully during a high ozone day may support occupant thermal comfort, but may have long-term health consequences. In this particular scenario, it is clear that occupant training for operation of natural ventilation strategies, window use, and active information or control systems is warranted [32].

In addition, daylighting and natural ventilation in high performance buildings have also been linked to increased occupant satisfaction [33]. However, access to control of daylighting and natural ventilation strategies is crucial to their overall success. For example, if an occupant cannot control the daylight source, glare could potentially reduce satisfaction and productivity and actually contribute to adverse health issues such as eye-strain or headaches [34–36]. Likewise, occupants require control for natural ventilation strategies to maintain thermal comfort [37].

As evidenced from the literature, there are many positive aspects to high performance buildings including reduced energy use and both employer and employee benefits, however, these may not be realized if occupants are not using the building as intended.

2.2. Occupant behaviors & energy use

In a high performance building, occupant behaviors and interactions with the building can negatively or positively affect energy outcomes. Many studies focus on occupant energy saving behaviors for times when the occupant is actually in the building (i.e. regularly occupied hours) [38–42]. However, occupants' behaviors can also negatively impact the energy use of a building when they are not even present. In their study, Masoso and Grobler (2010) found more energy was used “during non-working hours (56%) than during working hours (44%),” which arose mostly from occupants leaving lights and equipment on at the end of their work day (p.173) [43].

It is crucial that occupants understand how to control these sometimes-complicated automated and passive systems in high performance buildings to maintain personal visual and thermal comfort. Additionally, occupants' behaviors within their environment can have a tremendous impact on a building's energy use and overall energy savings potential. Occupant behaviors in high performance buildings may be affected by many factors including occupant comfort (or discomfort), social influences, or lack of knowledge surrounding building systems. Each of these topics will be discussed briefly in the next few sections.

2.2.1. Occupant comfort

Occupant comfort in high performance buildings is highly complex and there are many factors that can influence one's comfort including personal preferences, social influences, and cultural norms.

2.2.1.1. Thermal comfort. Thermal comfort can be defined as a person's cognitive state that expresses satisfaction or contentment with their surrounding thermal environment [44]. One of the most impactful factors in building energy use is the issue of thermal comfort and temperature control [45]. Thermal comfort is extremely complicated because there is a wide range in people's

perception of comfort due to various indicators including air temperature, radiant temperature, air velocity, humidity, amount of clothing insulation, and metabolic heat [46,47]. Other factors may also include personal preferences, gender, body composition, or location within a given building [33,43,44]. Cultural expectations and standards for thermal conditions may also play a role in thermal comfort [23,48,49].

Conventional buildings are mechanically regulated and aim to provide thermal comfort to only 80% of occupants, meaning that 20% will most likely be uncomfortable at some point during the day [50]. In high performance buildings, where natural ventilation is often used as a primary design strategy, the temperature may shift even more than those in conventional, mechanically controlled buildings. It is argued in the literature that occupants may have to redefine their acceptable range for thermal comfort in high performance buildings [51,52] because (a) it is more difficult to maintain constant temperatures in high performance buildings, and (b) space heating, ventilation, and air-conditioning utilize such a large amount of energy in buildings that expanding our thermal comfort standards would reduce greenhouse gas emissions and help to conserve energy [52].

Some studies have found that occupants may be more willing to tolerate wider temperature ranges in naturally ventilated buildings when they are given the option of control (i.e. opening windows themselves) [53,54]. If occupants accept a wider range of temperature as “comfortable,” then less cooling and heating will be required, therefore reducing energy use [2,23,51,55]. However, it is important to understand that when occupants are given control over their thermal environments through operable windows, while this control may help maintain their personal comfort for some, it may disrupt others' thermal comfort, and may actually negatively impact the energy use in a building if windows are opened (or left open) when outdoor temperatures are too high or too low to support energy use goals [56,57]. Oftentimes, high performance buildings are also fitted with active control or signaling systems that notify when conditions are appropriate for opening windows (i.e. air quality, temperature or humidity) [32,58]. In each of these cases, active occupant engagement is required, and it is crucial that occupants are appropriately trained on these systems and window opening protocols to truly maximize energy efficiency, while also supporting thermal comfort. Much like thermal comfort, maintaining visual comfort also requires active occupant engagement in high performance buildings.

2.2.1.2. Visual comfort. Many high performance buildings use daylighting as a passive design strategy. While daylight has been shown to have many benefits including increased productivity, satisfaction and health benefits, daylight can also lead to undesirable conditions, such as glare and heat gain in buildings [35,59]. As discussed in Section 2.1.2, glare and visual discomfort can affect workers' productivity and it can also have negative health effects such as headaches, eye-strain or even migraines [60,61].

Daylight, as a light source, is variable by nature, and it changes daily and seasonally, depending on the angle of the sun and the sky conditions, therefore, it is critical that occupants have access (and the knowledge) to control shades or blinds [34]. Controls are also important for electric lights because high levels of electric lighting can also lead to visual discomfort and glare [62]. Not only do occupants perceive increased comfort when they have access to controls [63], but it is also necessary for occupants to interact with the daylighting controls to maintain comfort and to reduce the need for electric lighting throughout the day [36].

Visual and thermal comfort may play a large role in occupants' behaviors (and building energy use) in a given building, but there are other factors that may also contribute to occupant behaviors such as social influences and lack of knowledge of building systems.

2.2.2. Social influences

Social influence is when a person's actions are prompted by the actions of another person in a social group. In the case of energy, a user may use less energy because they see their peer is using less energy [39]. Therefore, it is likely behaviors in high performance buildings may also be influenced by social cues or norms within a given building. People's behaviors often echo what they perceive as the norm [64]. Thus, it is important for companies to create an environment in which employees are encouraged to interact with the building with the goal of energy saving through competition, feedback, or incentives [64].

2.2.3. Understanding high performance buildings

Learning, as a whole, is considered to be a reflective and continuous process [65,66], so occupant training for high performance building strategies should be structured to facilitate this process. To truly maximize energy savings, occupants need to understand specific strategies and corresponding behaviors as they relate to the building they inhabit [2,51].

Much of the current literature draws the following conclusions: 1) occupants play a crucial role in energy outcomes and 2) architectural solutions alone cannot achieve energy reduction goals [1,2,43,51,67,68]. If energy reduction is a primary goal of a company, then the building occupants must *understand* how to interact with the building systems in a way that supports both personal comfort and energy efficiency.

2.3. Literature review summary

Ultimately, occupant behaviors can positively or negatively affect a building's overall energy use. In addition, factors such as visual comfort, thermal comfort, and access to controls are important for how and why occupants may behave in a certain way. Occupants are more likely to alter their conditions, change the blinds, and interact with other building strategies if they see other occupants exhibit these same behaviors [39]. There are many ways to nudge occupants into changing their behaviors, including providing feedback and/or incentives, goal setting, and competitions [64]. However, even if occupants are encouraged to behave in a way that promotes energy efficiency, a lack of knowledge surrounding building systems may present a barrier to these energy efficient behaviors [69].

Frequently, education and training efforts surrounding building performance are targeted toward design students and professionals, but building occupant education programs are lacking [55,70]. Furthermore, design strategies vary widely based on climate, design goals, and the designers themselves; occupants need to understand the elements they can affect in the specific building they occupy. If architects have specific expectations of the building function and corresponding behaviors, then occupants may need additional training and guidance.

2.3.1. Identified research gap

Many studies link passive design strategies and energy use or environmental satisfaction [26,71–74]. However, there is a lack of research that successfully links passive design strategies with an occupant's knowledge of building systems, resulting behaviors and the corresponding relationship to environmental satisfaction and a building's energy use.

2.4. Hypothesis

Based on the aforementioned discussion in section 2, this research specifically addresses the following hypothesis.

H¹: Occupants who received training for high performance building strategies (such as blinds, natural ventilation, thermal controls, or electric lighting) will demonstrate an increased level of reported environmental satisfaction when compared to individuals who did not receive any kind of training.

Although multiple research questions were also explored in this research project, this paper will specifically focus on the findings for the hypothesis listed above. The following section presents the study methodology including the sampling techniques, study participants, data collection methods, and measurement.

3. Methodology

A mixed-methods approach was deemed most appropriate due to the interdisciplinary nature of this research. As such, the methodology relied upon varying disciplinary perspectives and research tactics from architecture, interior design, building science, and education, which included quantitative Post Occupancy Evaluation (POE) surveys and qualitative interviews and thematic coding. Blending these techniques provided a deeper understanding of the research problem.

3.1. Mixed-methods design

This research followed a sequential explanatory mixed-methods design. The first phase of the study included open-ended interviews with experts in the field, examination of records, databases and literature.

The second phase of the study implemented a large-scale survey, which was distributed online via email to individuals in high performance office buildings. Additional quantitative data were collected during the study including building energy use data (when available) and climate data.

In the third phase of the study, semi-structured phone and email interviews with facility managers, occupants, and architects were conducted, and building specific documents such as photographs, site plans, green building certification documentation, and architectural drawings were also collected. The following sections will discuss the sampling selection, participants and types of data collected in greater detail.

3.2. Sampling

3.2.1. Target population and research context

The population of interest for the survey included individuals who worked in high performance office buildings in the United States. One single list or database for all high performance buildings does not exist. For this reason, a comprehensive database was compiled for high performance office buildings, and buildings were located through initial interviews, literature review, and searches of several building databases.

3.2.2. Sample selection

Early in the study, it was established that one major threat to external validity could be varying high performance building strategies by climate type (threat of generalizability to other places). Therefore, it was important to select buildings that varied by size and climate type so a diverse range of building strategies and occupant education programs could be identified and assessed. Stratifying buildings by ASHRAE climate zones initially minimized this threat to external validity. Buildings were stratified by climate zone (i.e. 5B, 4C, 2A, etc.), and a weighted sample was randomly selected based on an aggressive goal of 100 total buildings. These

various strata were intended to comprise the sampling frame for the first phase of the study.

The stratified random selection method was originally used to minimize any potential threats to the external validity. However, it became readily apparent that randomly cold-calling buildings for survey participation was an ineffective strategy. Many buildings were unwilling to participate because they had no previous relationship or experience with the researcher, and additionally, although these were high-performance buildings, most did not have an occupant training or tenant engagement program. After several months of this initial sampling approach, both an alternative sampling method and more realistic sample size was required. Even though four building owners had agreed to participate in the survey with this method, and several others had shared some form of data, more participation in the study was needed.

Therefore, the sampling method shifted from stratified random selection to purposive selection for the quantitative phase of the study. Purposive samples are typically selected “using the expert judgment of researchers and informants” (p. 173) [75]. To obtain the remainder of the sample, high performance buildings with some form of occupant training were targeted and identified through literature reviews, personal contacts, suggestions from experts in the field, and online searches. This method proved to be much more successful because oftentimes, it was possible to establish credibility with a building representative through a mutual contact, which made it more likely the building owners would agree to participate in the survey or share data. In addition, although this form of sampling is not as strong in terms of external validity, purposive sampling does help to generate a depth of knowledge within a specific population, and it has been frequently used in both qualitative and mixed-methods research [75]. The study participants are noted below in section 4.

3.3. Data collection

As discussed in section 3.1, both quantitative and qualitative data were collected from a total of 56 buildings (see Fig. 1); 53 of the buildings were scattered throughout the United States, one

building was in Canada, and two were selected from Europe. Data collected included location, zip code and climate zone for each building. Additionally, energy use, surveys, interviews, photographs, architectural drawings, educational materials, existing reports, other documentation, and presentations or online lectures were gathered for buildings when possible. The majority of analyses focused on the survey responses ($n = 118$) and interviews ($n = 41$), but the other data collected helped to supplement individual responses.

3.4. Measurement

3.4.1. Survey design

In total, there were 51 questions on the survey. The survey was divided into five main categories to better understand the following: (1) office attributes, (2) the presence and type of training for (a) manual blinds, (b) automatic blinds, (c) natural ventilation, (d) temperature controls, and (e) electric lighting, (3) satisfaction with the office environment, (4) learning styles, and (5) demographics.

Both open-ended and closed-ended questions were included on the survey. Satisfaction responses were assessed through a seven point Likert scale, which ranged from “strongly disagree” (1) to “strongly agree” (7). A five-point scale, from “never” (0) to “always” (4), was used for frequency ratings under the learning style section. Multiple choice and yes/no responses were used throughout the survey. Before data analysis, each of the questions within the survey was coded as nominal, ordinal, categorical, interval or open-ended so the appropriate statistical tests could be selected. See Appendix A to see the questions that were sent out to the survey participants. It should be noted that the results for the learning style portion of the survey, and the majority of the interview responses will be reported elsewhere.

3.4.1.1. Reliability and validity. To increase the content validity of the survey tool, previously validated questions were used from both a variety of POE surveys [11,34,76–79] and a learning style



Fig. 1. Locations of study buildings. Image made with Google Fusion Tables.

survey [80]. Content validity refers to how well a given research tool or instrument measures a concept or domain of content [81].

3.4.2. Interviews and document collection

The qualitative phase included semi-structured and open-ended interviews, along with collection of building specific documentation such as photographs, maps, architectural documents, plans, and training materials if available. The interview responses, visual data and documents were collected to help answer the *how* and *why* aspects of the hypothesis and research questions.

4. Results

4.1. Survey participants

In the quantitative phase, 154 individual survey responses were received from ten buildings in total (these ten buildings are included in 56 total buildings noted in Section 3.3). Two buildings were excluded because only one response per building was received. In total, 50% of the total survey buildings (5) had access to natural ventilation through either passive or mixed-mode strategies, and all ten of the buildings surveyed had implemented some form of intentional daylighting or daylight harvesting strategies.

After data cleaning, 118 individual survey responses were collected from eight high performance buildings. Surveys were excluded if they were deemed unreliable (i.e. some had simply clicked the same response all the way through the survey) or if there was a high incidence of missing responses. Table 1 outlines the building, building location, number of survey participants, building size, and estimated response rate for each building respectively. Response rates were estimated for some buildings because it was not possible to know exactly how many surveys were sent by the building staff.

4.1.1. Demographics of study participants

Demographic data were gathered for survey participants including age and gender; 55% of respondents were male, 43% were female, and 2% preferred not to answer. Ages were grouped into five ranges: 18–29 (16%), 30–39 (18%), 40–49 (30%), 50–59 (34%), and 60+ (2%). Participants were also asked if they had corrected vision and if they had any vision related health issues. In total, 47% of respondents wore glasses, 17% wore contacts, 27% did not have corrected vision, and the remaining 9% reported surgically corrected vision (i.e. Lasik eye surgery). In addition, 36% of respondents reported some kind of vision related health issue, and the remaining 64% reported none.

For the second phase, there were 41 interview participants. Of these, 54% were male and 46% were female. Interviews were

conducted over the phone (75%), in person (5%), and over email (20%). Age demographics for interview participants were not collected.

4.2. Environmental satisfaction descriptive statistics

The descriptive statistics for the environmental satisfaction portion of the survey showed that while the average assessments of environmental satisfaction did vary, the majority of the occupants were still mostly satisfied with their environment, as seen in Fig. 2.

4.3. Hypothesis testing

Although there were three distinct phases for data collection and data analysis, both quantitative and qualitative results are presented below simultaneously to provide a more comprehensive understanding of the results.

The hypothesis was the driving force for this research. To investigate whether or not occupants who received training for high-performance building strategies were more satisfied than those who did not, the data were recoded in a few different ways to understand the differences between groups.

First, a Pearson chi-square test was calculated between environmental satisfaction and effectiveness of training. The summated satisfaction scale responses were recoded into “mostly dissatisfied” and “mostly satisfied” to reduce the number of cases compared in the cross-tabulation. Since satisfaction was measured on a scale from (1) to (7), occupants were grouped into the “mostly dissatisfied” category if their score was less than (3.5), and if their score was greater than (3.5), then they were grouped into the “mostly satisfied” category. This new satisfaction variable was measured against the effectiveness of training variable, which was also recoded before analysis. If occupants had received any type of training (on any type of building feature), and they had reported the training as “helpful” or “very helpful,” then they were assigned a (1). If occupants had not reported any training at all, or if they had reported the training they received as “neutral,” “not helpful,” or “not helpful at all,” then they were assigned a (0). It was assumed that even if a participant had received training, but they had reported the training as unhelpful, then those responses could be added in to the “no training” category for analysis. Recoding the varying measurements of training into one variable made it possible to run statistical tests that would have not been possible otherwise.

Table 2 illustrates the results of the Pearson chi-square test and shows that when compared to individuals who reported their training as either non-existent or not helpful (69%), individuals who did report their training as helpful (90.3%) were significantly more satisfied with their office environment ($\chi^2 = 5.498$, $df = 1$, $N = 118$, $p = .019$). Therefore, the null hypothesis, claiming no significant difference between those who received training and environmental satisfaction, was rejected. Phi, which indicates the strength of the association between the two variables, was 0.216, which is between a small to medium effect size according to Cohen (1988) [82].

There was a significant difference between the presence of training and satisfaction. It should be noted that the majority of the sample (from both the training and non-trained groups) were still mostly satisfied with their office environment. However, if an individual was mostly dissatisfied, then the odds they did not receive training for the building systems were much higher than if they did receive training. In other words, people who reported helpful training were significantly more likely to be satisfied with their environment than those who did not receive training.

To further investigate the significant difference found between groups through the chi square test, an independent *t*-test was run

Table 1
Estimated response rates for survey buildings.

Building	Location	Number of responses analyzed ^a	Building size	Response rate
Building 1	Seattle, WA	23	>25,000 SF	Unknown. Est. 30%
Building 2	Waimea, HI	2	<25,000 SF	50%
Building 3	Boise, ID	14	<25,000 SF	87%
Building 4	Barrow, AK	4	<25,000 SF	100%
Building 5	Charlotte, NC	18	<25,000 SF	Unknown. Est. 74%
Building 6	University Place, WA	39	>25,000 SF	Unknown. Est. 50%
Building 7	Spokane, WA	17	>25,000 SF	Unknown. Est. 42%
Building 8	Anchorage, AK	1	>25,000 SF	Unknown. Est. 5%

^a Totals represent calculated values after missing values and incomplete responses were removed.

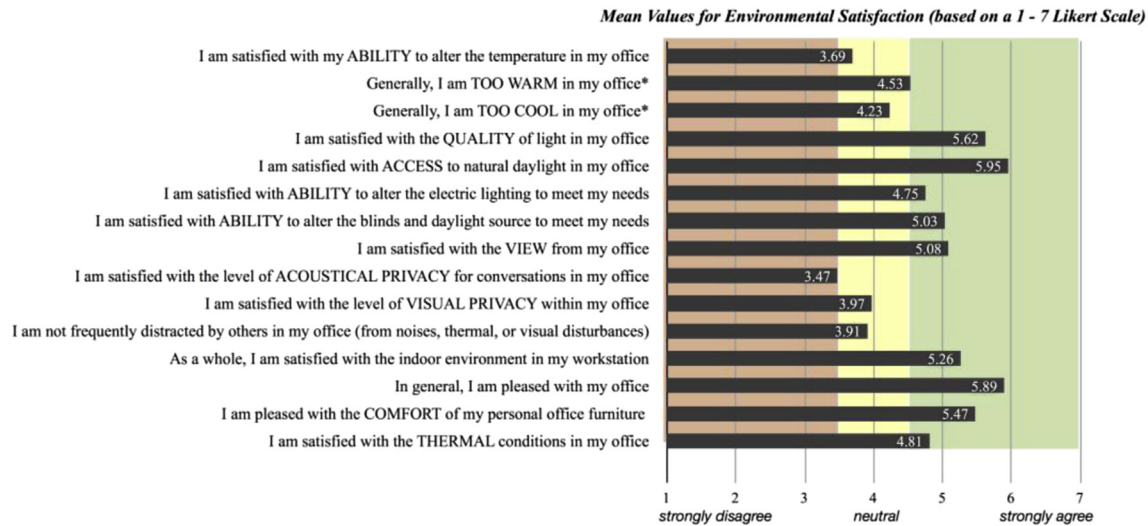


Fig. 2. Mean values for environmental satisfaction section, in response to: "please rank the following for your office".

between the two groups (received training or did not) for multiple summated satisfaction variables: (1) all satisfaction responses, (2) for only the satisfaction questions about thermal comfort, (3) for only the satisfaction questions about visual comfort, and (4) for the remaining satisfaction questions.

Table 3 shows that respondents who received training were significantly more likely to be satisfied with their environment than those who did not receive training (or helpful training) for all environmental satisfaction categories tested (environmental satisfaction as a whole ($p < .001$), thermal satisfaction ($p < .002$), visual satisfaction ($p < .001$), and the remaining satisfaction questions ($p < .016$). Equal variances were assumed for all of the categories (except for the thermal satisfaction ratings) since the F test results were found to be significant (Sig. $< .05$). The effect sizes for each test were also calculated and included in Table 3, which were all between a moderate and large effect size (again, except for thermal satisfaction, which was between small and moderate effect size) [82].

Review of the two group means indicated that the average environmental satisfaction rating for people who received training

($M = 5.38$) was significantly higher than those who did not receive training ($M = 4.56$). The difference between the means was 0.82 points on a 7-point scale. The effect size d was approximately 0.4, which was between a moderate and large effect size [74]. Results were similar for all of the environmental satisfaction categories tested.

Both effectiveness of training and environmental satisfaction were tested in various ways. A significant difference ($p < .05$) was found between groups for both the Pearson chi-square test and for the independent t -tests. Therefore, the null hypothesis was rejected. Occupants who received training for high performance building strategies (such as blinds, natural ventilation, thermal controls, or electric lighting) demonstrated an increased level of reported environmental satisfaction when compared to individuals who did not receive any kind of training.

There were many comments made on the open-ended portion of the survey that may help explain the significant differences found during the quantitative phase. The comments were coded and grouped into themes. The majority of comments related to the hypothesis specifically mentioned thermal or visual comfort issues.

Table 2
Pearson chi-square test: environmental satisfaction* effectiveness of training.

			Training		Total
			No training reported, or reported that training was not helpful	Training was helpful	
Environmental Satisfaction	Mostly dissatisfied	Count	27	3	30
		Expected Count	22.1	7.9	30.0
		% within 'effective training'	31.0%	9.7%	25.4%
	Mostly satisfied	Count	60	28	88
		Expected Count	64.9	23.1	88.0
		% within 'effective training'	69.0%	90.3%	74.6%
Total			Count	87	118
			Expected count	87.0	118.0
			% within 'effective training'	100.0%	100.0%
Chi-square tests		Value	df	Asymp. Sig. (2-sided)	
Pearson chi-square		5.498 ^a	1	.019	
N of valid cases		118			
Symmetric measures			Value	Approx. Sig.	
Nominal by Nominal		Phi	.216	.019	
N of Valid Cases			118		

^a 0 cells (0.0%) have expected count less than 5. The minimum expected count is 7.88.

Table 3Independent *t*-test: environmental satisfaction* effectiveness of training.

	Training	<i>N</i>	Mean	Std. deviation	Std. error mean	<i>d</i> (Cohen's <i>d</i>)	<i>r</i> (effect size)			
Environmental Satisfaction (all)	no training reported, or reported that training was not helpful	87	4.56	1.059	.114	0.87	−0.39			
	training was helpful	31	5.38	.810	.146					
Environmental Satisfaction (thermal)	no training reported, or reported that training was not helpful	87	4.08	1.133	.121	−0.72	−0.34			
	training was helpful	31	4.97	1.316	.236					
Environmental Satisfaction (general)	no training reported, or reported that training was not helpful	87	5.35	1.518	.163	−0.57	−0.27			
	training was helpful	31	6.06	.921	.165					
Environmental Satisfaction (visual)	no training reported, or reported that training was not helpful	87	5.21	1.459	.156	−0.77	−0.36			
	training was helpful	31	6.15	.939	.169					
Independent samples test		Levene's test for equality of variances				t-test for equality of means				
		<i>F</i>	Sig.	<i>t</i>	<i>df</i>	Sig. (2-tailed)	Mean difference	Std. error difference	95% confidence interval of the difference	
									Lower	Upper
Environmental Satisfaction (all)	Equal variances assumed	4.750	.031	−3.940	116	.001*	−.825	.209	−1.239	−.410
Environmental Satisfaction (thermal)	Equal variances not assumed			−3.339	46.783	.002*	−.887	.266	−1.422	−.353
Environmental Satisfaction (general)	Equal variances assumed	6.135	.015	−2.452	116	.016*	−.712	.290	−1.287	−.137
Environmental Satisfaction (visual)	Equal variances assumed	10.714	.001	−3.325	116	.001*	−.935	.281	−1.491	−.378

Note: *significant difference found.

See Table 4 for a list of open-ended questions from the survey, or refer to Appendix A for more detail.

Examples of responses to the open ended questions are shown in the Table 5 below.

After the Likert scale environmental satisfaction section, depicted above in Fig. 2, respondents were asked the following open-ended question: Please add any additional comments surrounding your satisfaction with any of the environmental conditions in your office. The responses for the open-ended question were primarily negative in nature; the question seemingly gave occupants an open forum to complain about their respective buildings. Responses were coded for themes and word frequency; the most frequently occurring words surrounded thermal comfort (feel, cold, hot, uncomfortable), acoustics (acoustical, loud), or privacy (privacy, distracting, interrupt). However, there were some positive comments as well, primarily surrounding views and natural light. There was a mix of a positive and negative comments

surrounding electric lighting. Many occupants really liked the natural lighting whereas others complained about the brightness and “glary” nature of the daylight.

One of the interviewees also addressed the issue of training and environmental satisfaction. “I didn’t actually receive any training because I am a part time employee ... I guess ... but I do think that understanding the big concepts of the building envelope, windows and daylight, how the toilet and the water system works ... understanding all of those things might make people more actively participate and also figure out ways to change the building to suit their needs.”

The quantitative results, coupled with the qualitative responses from both the open-ended answers and interviews, revealed that occupants who understood how to operate the passive design strategies were (1) more likely to be satisfied with their environment and (2) they were better able to manipulate their environment to maintain thermal and visual comfort.

5. Conclusions

This paper examined reported environmental satisfaction in relation to occupants’ understanding of high performance building features. It was hypothesized that if participants had received training for high performance building features, they would be more satisfied with their environment than those who had not received training. Results indicated there was a significant difference between the two groups, (those who had received effective training and those who did not), and the null hypothesis was rejected. The individuals who reported having received effective training were significantly more likely to be satisfied with their office environment than those who did not receive any training, which was not surprising.

5.1. Discussion

In terms of thermal comfort, visual comfort, and similar environmental factors, it makes sense that individuals who understood

Table 4

Open-ended questions from survey.

Is there anything you particularly LIKE about your office building?
Is there anything you particularly DISLIKE about your office building?
Did you find this type of training to be effective in helping you learn about daylight controls? [likert response] ... If not, what do you wish would have been done differently? Please explain:
Did you find this type of training/education to be effective in helping you learn about the windows/natural ventilation controls? [likert response] ... If not, what do you wish would have been done differently? Please explain:
Did you find this type of training/education to be effective in helping you learn about thermal controls? [likert response] ... If not, what do you wish would have been done differently? Please explain:
Did you find this type of training/education to be effective in helping you learn about lighting controls? [likert response] ... If not, what do you wish would have been done differently? Please explain:
Please add any additional comments surrounding your satisfaction with any of the environmental conditions in your office if applicable:
Your office building was selected because of its high performance nature and its ability to save energy. Were you taught, trained or educated about any other sustainable building elements? If so, please explain:

Table 5

Selected survey responses to open-ended questions surrounding training and/or satisfaction.

ID	Survey response	Theme
15	"I often open my office and classroom windows—even when the red light is on in the hallways (which we were never actually trained to understand) because it is often too hot to function well."	Thermal comfort
26	"The lighting controls are not intuitive and hard to find. I have been told how to use them and figured it out on my own, but others in the office haven't bothered and just leave all the lights on when they leave the office. It's an energy waste."	Visual comfort Energy
35	"I have a problem remembering which way to tilt the blinds so they maximize daylight and reduce glare and heat gain."	Visual comfort Thermal comfort
38	"There are mechanical blinds on the building, just not where I sit. They work automatically half the time at best ... Unbearable morning/afternoon sun glare off of adjacent buildings creates hostile work environment. Automatic "fresh air" louvers open even when it's very cold in the office. Automatic light sensors don't function very well."	Visual comfort Thermal comfort

how to change their conditions were more satisfied with their environment than those who did not understand how to change their conditions. People who did not receive training, or those who did not find their training to be effective, were perhaps less satisfied with their environment because they did not know how to alter controls to meet their visual or thermal comfort needs (i.e. overriding an automatic blind or controlling natural ventilation louvers for fresh air). Maintaining thermal comfort and visual comfort were identified as important factors in the literature review. People were more productive and more satisfied when they perceived their environment as comfortable [27,33,46], so it is not unexpected that people were less satisfied if they did not know how to change their environment for comfort.

Additionally, in a sense, people who did not understand how to operate their controls might be equated with people who did not have access to building controls whatsoever. When placed in this context, these results also reflect findings from the literature review surrounding controls and satisfaction. Many studies found that occupants with access to controls for daylighting strategies, natural ventilation strategies or otherwise, were more satisfied than those without control [34,63,76,83,84].

Proponents of fully automated buildings posit that we can avoid energy wasting behaviors by cutting the human aspect out of the equation. However, people want control over their environment and need to be able to modify their conditions for comfort and personal preferences [34,37,63,85].

As soon as the option of control is taken away, people are frequently less satisfied. We can provide control to occupants, but must do so with the understanding that people need to be taught how to use the controls correctly if the designer and owner intend to conserve building energy use [2]. This desire for control over the environment was reflected in both the survey and interview responses, especially in reference to thermal and visual comfort.

With regard to the word frequency image, Fig. 2, many of the prominent words, such as acoustics and privacy could not have been resolved with training; those were primarily design issues. However, some of the words expressing dissatisfaction with thermal comfort and visual comfort may have been related to a lack of training for those specific building elements (operable windows, thermostats, electric lighting overrides, and blinds). For example, analyses of interview responses revealed that people would "deal" with issues of glare or thermal comfort because they did not remember either how or when to change their conditions. One

participant said they wanted to change their blinds sometimes, but they could not remember the best way to alter them to maximize the light and still control glare for others. In this instance, the blind system the participant was referring to was automated and quite complex, so it is understandable these would be complicated and intimidating to control for someone who might not be as technologically savvy as others. The sheer complexity of the blind system further supports the need for proper education surrounding those controls.

Another participant would remain uncomfortable in the mornings due to glare because he or she did not want to bother anyone else by changing the blinds; it appeared as if the culture in this particular building did not really support or encourage interactions with passive building features. However, in another building, it was quite common for occupants to voice their discomfort and to discuss solutions with other people before changing the thermostat, opening a window, or closing the blinds. The building had elements that could be easily modified to support visual or thermal comfort, and interactions with these features were highly encouraged (and taught), and results showed that these individuals were more satisfied with their environment.

In the example discussed above, in the first building, a participant would suffer from glare because he or she did not want to disturb others, and in the second building, occupants spoke of an interactive office culture that had been fostered to maintain comfort for all. These examples directly link back to the literature, which suggested social influence could be leveraged to drive behavioral energy savings in buildings [39].

Ultimately, people who understood how to operate the high performance building strategies in their office space due to effective training were more satisfied with their environment than those who were not effectively trained. The results also revealed that other factors came into play surrounding occupants' behaviors such as lack of control and social influence.

5.2. Delimitations and limitations

5.2.1. Delimitations

The population for this study was delimited to individuals in high performance office buildings in the United States. High performance buildings were identified through colleagues in the field, the literature, and multiple database searches. Conventional office buildings were not considered for the study because occupant education of passive design strategies is not typically applicable to these buildings, as opposed to a high performance building where active occupant engagement is typically required to achieve energy reduction goals and occupant comfort.

Although there are many types of high performance buildings (retail, academic, residential, etc.), this study was focused specifically on office buildings. While lessons could certainly be learned from other building typologies, it was necessary to narrow the scope of this research and to eliminate additional factors that may have further complicated the findings. High performance office buildings were deemed as the most appropriate building type to study because (a) office buildings represent a the largest portion of the commercial building sector (17%) [86], (b) the majority of existing published POE studies are for office buildings, so results can be compared, and (c) because of the large percentage of office buildings in the U.S., there may be an opportunity to increase energy savings through occupant education.

5.2.2. Limitations

First, the sample selection method shifted from random selection to purposeful selection during the study. Although it has been proven as a valid sampling technique in research, the purposive

selection method limits the generalizability of the quantitative phase of the study.

This sample selection method led to an additional study limitation. Most of the purposefully selected buildings were identified through professional contacts, so many of the study buildings housed design or engineering firms, which may have skewed the sample population. Not only do designers most likely better understand the passive design strategies studied, but they may have a different learning style as well. Ideally, the study population should have been more evenly representative of different types of participants with different job types. This study cannot prove or disprove there were statistically different responses based on job type because the survey did not ask for their job description, but it is certainly a possibility.

A third limitation revolves around the inability to report an accurate response rate. Surveys were administered to many buildings and occupants, but the total number of occupants was only available for some of the buildings, which resulted in an estimated response rate.

5.3. Recommendations for future research

There are many opportunities for future research. First, it would be ideal if a similar study could be repeated with a larger and more random sample. The fact that the sample was selected purposively was probably the biggest threat to validity for the quantitative phase of the study. Steps were taken to ensure results from the study would still be valid, but repeating this study with a larger number of randomly selected buildings from all climate types, with a wider cross-section of people from various backgrounds, would be the most logical next step for this research.

Future research should also include more information about energy use. Initially, one of the main goals of this study was to collect building energy use. But due to time and budget constraints, it was not possible to collect energy data for all of the buildings and thus, energy use and occupant behaviors could not be effectively compared. A funded study could take a similar overall approach as this study, but could also collect more meaningful energy use data.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.buildenv.2014.11.003>.

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