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Occupant Satisfaction in Mixed-Mode Buildings

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Abstract

"Mixed-mode" refers to a hybrid approach to space conditioning that uses a combination of natural ventilation from operable windows (either manually or automatically controlled), and mechanical systems that provide air distribution and some form of cooling (air-conditioning, radiant cooling, etc.). By utilizing mechanical cooling only when and where it is necessary to supplement the natural ventilation, a well-designed mixed-mode building offers the potential to improve the indoor environmental quality while minimizing the significant energy and operating costs of air-conditioning. But there is limited information about the performance of mixed-mode buildings, particularly with regard to occupant satisfaction, and this can potentially be a powerful part of the argument to avoid or minimize the use of air-conditioning.

This paper describes the results of web-based surveys conducted in 12 mixed-mode buildings, in comparison to our overall benchmarking survey database of 370 buildings, with over 43,000 individual responses. The survey focuses on seven areas of indoor environmental performance, including thermal comfort, air quality, acoustics, lighting, cleanliness, spatial layout, and office furnishings. The data shows that only 11% of the 370 buildings, most of which have conventional air-conditioning systems, are meeting the intent of the thermal comfort standards to achieve 80% satisfaction in the buildings. In comparison, the mixed-mode buildings are performing exceptionally well compared to the overall building stock, especially with regard to thermal comfort and air quality. Among the mixed-mode buildings, the best performers were those that were in more moderate climates, were newer, had radiant cooling or mechanical ventilation only (instead of an air-cooled system), and allowed high degrees of direct user control without changeover window interlock systems.

Introduction

In current commercial buildings in the U.S., cooling and mechanical ventilation account for over 30% of total energy use, approximately 20% of electricity use, and approximately 40% of peak demand. However, prior to the 1950s, air conditioning and mechanical ventilation were not yet commercially viable, and so commercial buildings had little choice but to utilize natural ventilation for cooling. Buildings typically had extended perimeter zones so that every office could have access to windows that would open to the outdoors, and provide the primary source of light and fresh air. But the availability in the 1950's of large-scale mechanical ventilation and cooling, along with other technologies such as curtain walls and fluorescent lighting, led to the more common commercial building forms of today that are typically all-glass, flush-skin buildings with large floor plates and no operable windows. These buildings miss out on the large number of documented benefits of operable windows – thermal comfort over a wider range of temperatures based on the adaptive comfort zone (Humphreys, 1975; deDear and Brager, 1998), reduced energy consumption compared to conventional air-conditioned buildings (Emmerich and Crum, 2005), and fewer Sick Building Syndrome symptoms (Seppänen and Fisk, 2001).

But even with all these potential benefits, there are a variety of concerns and design challenges associated with operable windows. The ability to rely solely on natural ventilative cooling is limited by loads and climate. And given our modern day expectations, engineers are often uneasy about the lack of predictability and control over indoor thermal conditions in naturally ventilated buildings. As a result, many innovative engineers are exploring "mixed-mode" buildings – a way to combine the best features of naturally ventilated and air-conditioned buildings, and essentially extend the range of climates in which operable windows are feasible even when they can't provide acceptable comfort year round.

"Mixed-mode" refers to a hybrid approach to space conditioning that uses a combination of natural ventilation from operable windows (either manually or automatically controlled), and mechanical systems that provide air distribution and some form of cooling. A well-designed mixed-mode building allows spaces to be naturally ventilated during periods of the day or year when it is feasible or desirable, and uses mechanical cooling only as necessary for supplemental cooling when natural ventilation is not sufficient. The goal is to maximize comfort while minimizing the significant energy use and operating costs of air conditioning.

While mixed-mode buildings are much more common in Europe, it is a relatively newer concept for American engineers. The U.S. building design industry is generally unfamiliar with mixed-mode cooling strategies, and there is a lack of published case studies or design and analysis tools to facilitate their ability to chart new territory. To address this need, CBE developed a web-based library of mixed-mode building case studies, covering a range of climates, design approaches, and control strategies (CBE, 2006). The library offers two levels of information: 1) a database with a broad list of buildings and basic project information, and 2) more detailed case studies. The database includes approximately 150 mixed-mode buildings, with over 60 of them in North America. It is downloadable as an Excel spreadsheet to allow for easy sorting, and includes basic information about each project including location, year built, type of building, owner, architect, engineer, brief comments about the mechanical system, operable windows, and control & operation strategies and web links for more information. The 8 case studies provide more detailed narrative and graphic descriptions obtained from literature reviews, drawings and photographs, and interviews with building owners, architects, engineers, and facility managers. The case studies include information about the windows, HVAC system, control strategies, building design process (design tools used, commissioning, relevant code issues), cost (where available), and additional green features of the building. The Resources section of the website also includes a more recent report with 23 new case studies that focus on control algorithms (Brager et al., 2007).

What motivates building owners and the design team to move beyond conventional air-conditioning and design a mixed-mode building? Without question, it is absolutely crucial to reduce energy consumption in buildings, and help avoid the potentially devastating impacts of climate change. But in terms of the building owner's pocketbook, energy costs are still relatively small compared to worker salaries, which represent over 90% of the total operating costs of a commercial building. In addition, the cost of worker recruitment and retention is significant. So from the building or company owner's point of view, perhaps the most persuasive argument for sustainable design in general – and operable windows in particular – is one that makes the connection between a higher quality indoor environment, and increased comfort, health and productivity of the workers. If we can demonstrate that occupant satisfaction is higher in buildings with operable windows, then that can be a powerful part of the argument to avoid or minimize the use of air-conditioning.

So how does one learn about the quality of the indoor environment? Sadly, very few architects or other members of the design team are likely to know how well their building is working after it's completed and occupied, the fees have been paid, and they're on to another project. Without learning from experience in an objective way, building industry professionals are less likely to make design or economic decisions that will truly enhance the performance and experiential quality of their buildings. Physical measurements can be valuable, but by themselves they also need to be interpreted in terms of how they impact the occupants. Buildings occupants themselves are a rich yet underutilized source of direct information about how well a building is working, but the challenge is how to collect both the positive and negative feedback in a systematic way. Detailed thermal comfort field studies that include both physical measurements and subjective surveys are the most revealing, but are also time consuming and expensive, and therefore the number of buildings that can be investigated is inherently more limiting.

Web-based surveys are an effective way to study building performance from the occupants' point of view. They can be used as a diagnostic tool to help designers, building owners and operators, and tenants evaluate how well their office buildings are working from the occupants' perspective, and to help prioritize investments to improve performance. The surveys can also be used as a research tool for specific projects requiring the assessment of occupant response, or for broader benchmarking and comparative analysis of the performance of particular building design, technologies, and operation strategies. It was with these dual purposes in mind that the Center for the Built Environment (CBE) developed their survey.

Methods

CBE Survey

In 2000, CBE began developing a web-based indoor environmental quality (IEQ) survey and accompanying online reporting tools. Advantages of the web-based format are 1) it is quick and inexpensive to use; 2) it allows for branching questions to get more detailed information where appropriate (in particular, when the occupant indicates dissatisfaction with a certain area), thus avoiding making the survey too long for everyone with overly detailed or inappropriate question; and 3) survey results can be accessed using an automated, advanced reporting tool that allows users to filter, aggregate, compare, or benchmark their data.

In addition to basic questions about demographics and workspace descriptions, the core CBE survey measures occupant satisfaction and self-reported productivity related to nine environmental categories: office layout, office furnishings, thermal comfort, air quality, lighting, acoustics, cleanliness and maintenance, overall satisfaction with the building, and with the workspace. Satisfaction questions use a consistent 7-point scale ranging from “very satisfied” (coded as 3) to “very dissatisfied” (-3), with a neutral midpoint (0). We use a secure SQL (standardized query language) server database for collecting and recording the responses. It takes approximately 5-12 minutes to complete the survey, depending on the number of branching questions one receives, and the number of open-ended comments one writes in. Additional, custom survey modules can be added which gather data about additional topics, depending on available building features or the client's particular issues. Examples of existing modules include accessibility, safety and security, daylighting, and operable windows. In addition to the occupant survey, a representative of the building owner or design team fills out a building information form to provide descriptive information about the building and its systems, such as the age of the building, the number of occupants, the type of air-conditioning and whether the windows are sealed or operable.

CBE also developed an automated web-based reporting tool that researchers and clients can use starting approximately one week after the survey is completed, allowing time to create a final data set where responses of participants who answer less than 15 questions are removed. The reporting tool allows one to produce standardized summaries of the responses in a particular building, compare them to the overall benchmarking database, or do more in-depth data mining to compare responses from selected subgroups of people or explore relationships between questions.

The CBE Survey benchmarking database represents the portion of buildings we've surveyed that meet certain quality control criteria, such as the number of responses or % response rate. At the time of our analysis, the CBE Survey benchmarking database included over 370 buildings, with over 43,000 individual responses, and 3.8 million data points.

More information about the CBE Survey can be found in Zegreus et al. (2004). One previous study focused on comparing the performance of green and LEED[1] buildings to the overall database (Abbaszadeh et al, 2004), where it was found that there was not necessarily a correlation between buildings with a large number of LEED IEQ points, and the IEQ performance from the occupants' perspective. Another focused on the role of air movement and personal control in influencing thermal comfort and perceived air quality for the database overall (Huizenga et al, 2006). Not surprisingly, it was found that satisfaction with both thermal comfort and air quality increases significantly in buildings that provide people with some means of personal control over their environment, such as thermostats or operable windows.

Mixed-mode buildings

The purpose of this analysis was to examine occupant satisfaction in mixed-mode buildings, with the aim of showing that we do not need to rely on sealed, air-conditioned buildings to maintain good indoor environmental quality. The 12 mixed mode buildings that were analyzed for this study were identified from the CBE Survey database. A representative of the building fills out a "building characteristics" form, which helps us identify basic descriptive information about the building. Unfortunately, this form is not always filled out fully or consistently. So while there are most likely additional buildings in the CBE database that may have operable windows, we only included those in the study for which we had sufficient information about the building from the characteristics form, and where we could find additional available case study material

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[1] LEED® stands for Leadership in Energy and Environmental Design, and is a green building rating system developed by the U.S. Green Building Council.

confirming that they all were mixed mode buildings. Also, we only included surveys that had a response rate of over 50% for buildings with fewer than 50 occupants, or a response rate of over 25% for buildings with 50 or more occupants.

Table 1: Building Characteristics - Mixed Mode vs. Rest of Database

	Mixed Mode	Database
Number of buildings	12	358
Avg. occupancy	100	426
Avg. building age	2.4	23 years
Avg. building floor area	4756 sq. meters	21,886 sq. meters
Avg. floor area per person	47 sq. meters /person	51 sq. meters /person
Number of LEED-certified	9 (75%)	44 (12%)
Number of underfloor air systems	4 (33%)	28 (7%)
Number of survey respondents	520	42,700
Avg. response rate	64%	50%

Table 1 summarizes some basic characteristics of the 12 mixed-mode buildings compared to the other 358 buildings in the database. Overall, the mixed mode buildings are relatively newer and smaller, but not necessarily less dense. The buildings were more likely to incorporate other green building features (75% were LEED-certified, compared to only 12% of the general building stock), including innovative mechanical cooling systems such as underfloor air distribution.

Table 2 identifies the location and general control scheme for the 12 mixed-mode buildings. The group of mixed mode buildings that was analyzed in the study represents a broad range of climates, building types, sizes, and uses. They range in size from 1100 square meters to over 14,000 square meters. The buildings also ranged in number of occupants; the buildings often had a significant transient occupancy, especially in educational buildings, but we only offered the survey to employees and so the occupancy numbers in Table 2 reflect the number of employees rather than all occupants. The buildings also represent a variety of different organizational or control strategies, including zoned systems (where the natural ventilation and mechanical cooling essentially occurs in different areas), changeover systems (where the mechanical cooling is shut off when the windows are open), concurrent systems (where the windows and mechanical cooling can be operated simultaneously), and “red light/green light” systems (what we call “informational controls”, where indicator lights controlled by temperature and humidity sensors tell occupants when they can open windows.) As seen in the table, sometimes buildings can combine more than one of these operational strategies.

Table 2: Mixed Mode Buildings

Bldg Num-ber	Location	Mixed Mode Type	Building Type	Number of Occupants	Gross Floor Area (in sq. meters)	Year Constructed
1	Richmond, BC	Changeover	Office	350	11,148	2000
2	Ebensburg, PA	Changeover	Office	95	3344	2000
3	San Mateo, CA	Changeover	Laboratory	25	2647	2003
4	Annapolis, MD	Changeover	Education	92	3633	2001
5	Stanford, CA	Concurrent	Education & Lab	35	1114	2004
6	Chicago, IL	Concurrent	Office	27	2634	2002
7	Menlo Park, CA	Natural Vent.	Office	110	4459	2002
8	Santa Barbara, CA	Changeover	Education	120	7896	2002
9	Olympia, WA	Natural Vent.	Education	230	14,851	2003
10	Leominster, MA	Changeover	Education	18	1334	2004
11	Cupertino, CA	Concurrent	Education	8	2043	2005
12	Seaside, CA	Natural Vent.	Education	35	1972	2006

Three of the 12 mixed mode buildings have no option for air conditioning except in more limited areas. Instead, they are using natural ventilation in the primary occupied spaces, and in two of the cases, mechanical fans bring unconditioned outdoor air into the rooms directly. In these three buildings, which are all educational spaces, air-condioning is only provided in spaces that have a programmatic need for more cooling (e.g., laboratories, large assembly rooms, etc).

Results

Overview of IEQ scores

Figure 1 shows a summary of the average (mean) scores in each IEQ category, for the 12 mixed-mode buildings (total of 520 individuals) and the full survey database (total of 42,700 individuals). One thing we commonly see is that people may give a building low scores in individual categories, but will tend to give better marks for general satisfaction with the building or workspace. Across the entire database, thermal comfort, air quality, and acoustic quality received the lowest scores. These are also areas that can be potentially and significantly impacted by operable windows and mixed mode systems, and so we will focus on these areas.

On average, mixed-mode buildings are performing significantly better than the remaining (primarily air-conditioned) buildings in the database in nearly every category except lighting and office layout (where performance is close to being equal), and acoustics (where performance is only marginally better). The improvement in office furnishings is most likely attributable to the mixed-mode buildings being newer.

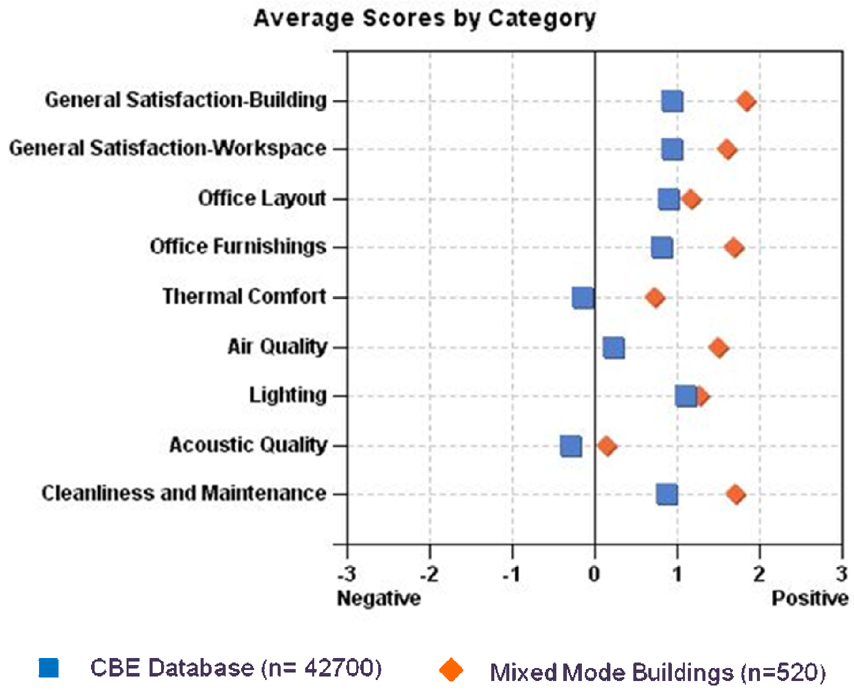

Figure 1: Average Scores by IEQ Category

The biggest IEQ improvements in mixed-mode buildings over sealed, air-conditioned buildings are for thermal comfort and air quality. Even the slight improvement in acoustics is surprising given that one might anticipate that open plan offices that facilitate natural ventilation often contribute to poorer acoustic environments, and outside noises are often perceived to be a barrier for operable windows - but perhaps this was not the case for these particular sites. The higher acoustics performance may also be attributable to the lower level of occupancy of the mixed mode buildings compared to the database. Also surprising was the higher rating for cleanliness and maintenance in mixed-mode compared to sealed buildings. This is often perceived as a problem with operable windows, but perhaps the mixed-mode buildings being newer offset this.

Thermal comfort

Looking first at the overall database (i.e., primarily air-conditioned buildings, with the 12 mixed-mode buildings removed), when we analyze responses by individuals, we find that 42% of all workers are expressing some level of dissatisfaction with the thermal environment (Figure 2). This is a far cry from the goal of thermal comfort standards, which aim to create environments in which no more than 20% of the people are dissatisfied.

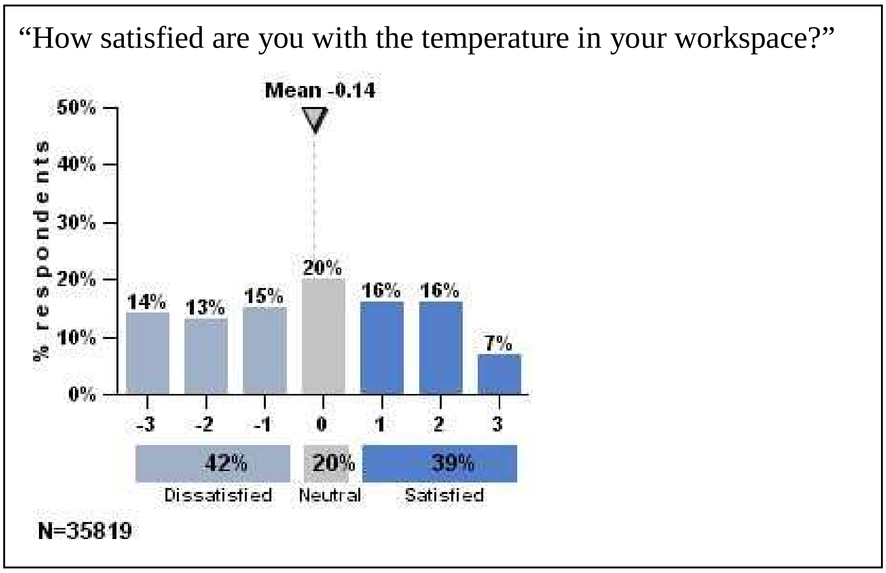

Figure 2: Thermal Satisfaction – by individual

We wondered if there were perhaps just a small fraction of poorly performing buildings contributing to this number, so we did the analysis again by building (Figure 3). These results were equally concerning, revealing that only 11% of the buildings in our database were meeting ASHRAE Standard 55's 80% acceptability threshold (where "acceptability" here is defined as votes of $\geq$ 4, or neutral plus the top 3 categories of satisfaction). This is rather convincing evidence that the standard practice of air-conditioned buildings is not reliably providing occupants with a satisfactory thermal comfort.

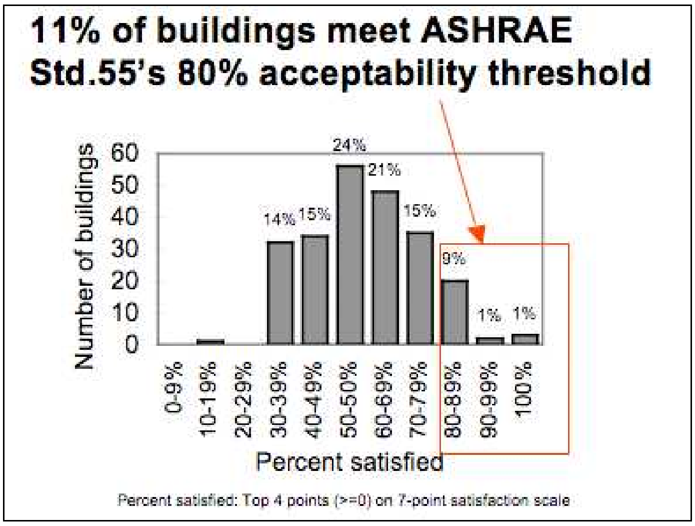

Figure 3: Thermal Satisfaction – by building

When we looked at results from the branching questions, inquiring about reasons for dissatisfaction (Figure 4), we found that the top reasons were about spatial non-uniformity ("my area is hotter/colder than other areas"), control ("thermostat is inaccessible", or "…adjusted by other people"), lack of air movement ("air movement too low"), and speed of response ("heating/cooling system does not respond"). Only 3% of the dissatisfied respondents referred to drafts from windows.

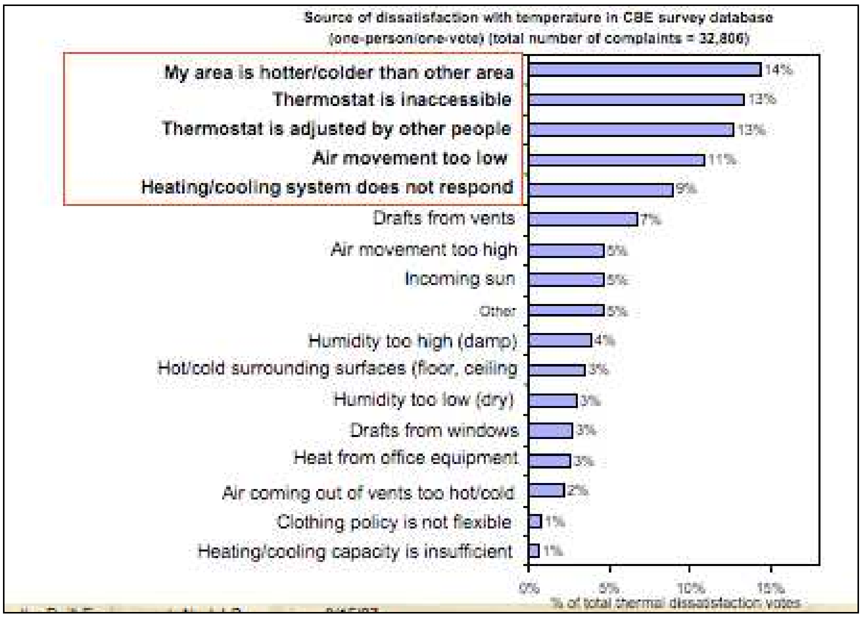

Figure 4 - Reasons for Thermal Dissatisfaction

Figure 5 is a cumulative frequency graph showing the percentile ranking of all 370 buildings in the database, based on the building's mean score for the "thermal satisfaction" question. The triangles represent buildings that are mixed-mode, while the diamonds represent the remaining buildings in the database. The median satisfaction score for each of these building sets is shown as colored symbols on the y-axis.

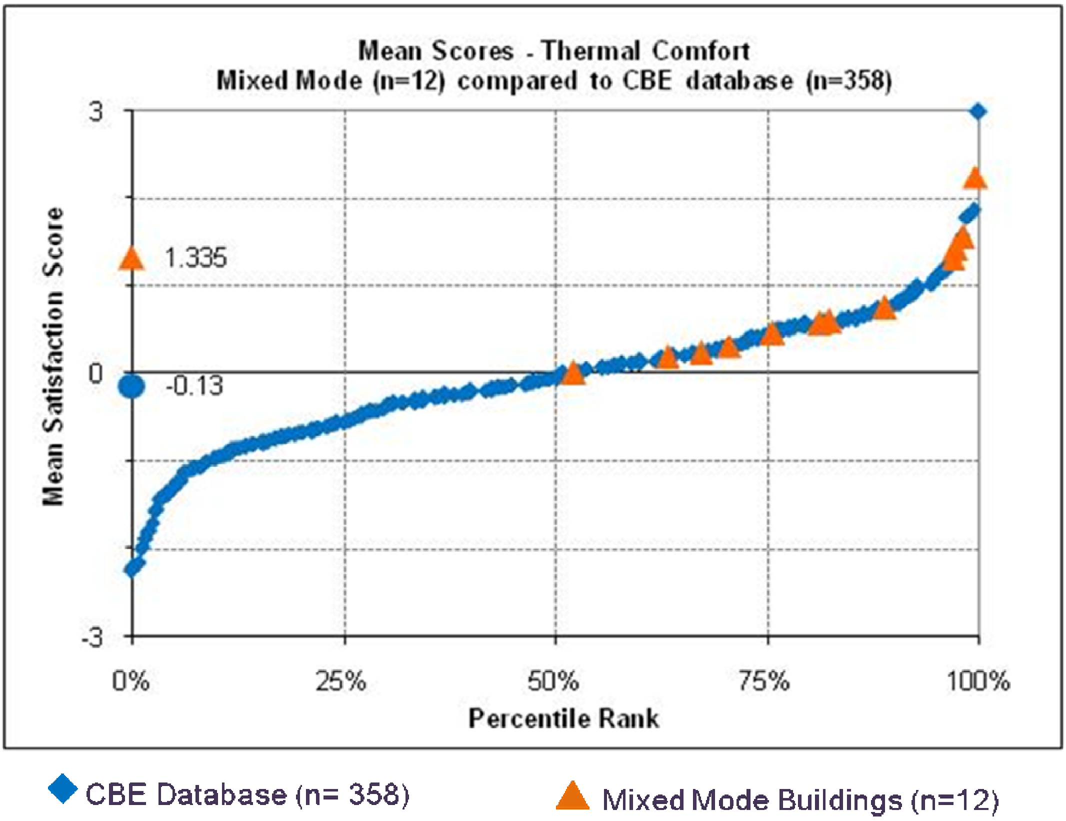

Figure 5 – Cumulative frequency distribution for thermal satisfaction

The mixed mode buildings were all in the top half of the percentile ranking, with a few of them being among the very best performers. In fact, 8 out of 12 mixed mode buildings are in the top quarter of the percentile ranking. Of the mixed-mode buildings that had relatively lower scores, comments referred to complaints about conditions being too cold (sometimes referring to winter, other times suggesting that the air-conditioner was on when it didn't need to be); complaints about drafts from vents, or thermostats not working. Only one building had a few complaints related to the windows, and didn't like that the mechanical air distribution was turned off when a window was opened, because sometimes only a limited number of people got the benefit of the window while the air circulation was shut off to a larger zone.

Using these cues, we looked further into the thermal comfort scores for this group, testing for a variety of different indicators that might be contributing to the high satisfaction scores, including size of the building, number of occupants, year of completion, and climate. We found that there was a correlation with the climate that the buildings were situated in. Figure 6 shows the relationship between annual heating degree days (HDD) and the thermal comfort scores reported in the mixed-mode buildings. The cluster of 6 buildings in more moderate climates had mean satisfaction scores over a wide range, and also included the buildings with the highest thermal satisfaction scores. But we can see that most of the buildings in the colder climates (higher HDD) have somewhat lower satisfaction scores than warmer ones. Looking through comments and sources of dissatisfaction for the colder climate group, we did not find evidence that occupants were opening windows during the winter. As noted above, problems generally focused on thermostats that were not working, drafts from vents, etc.

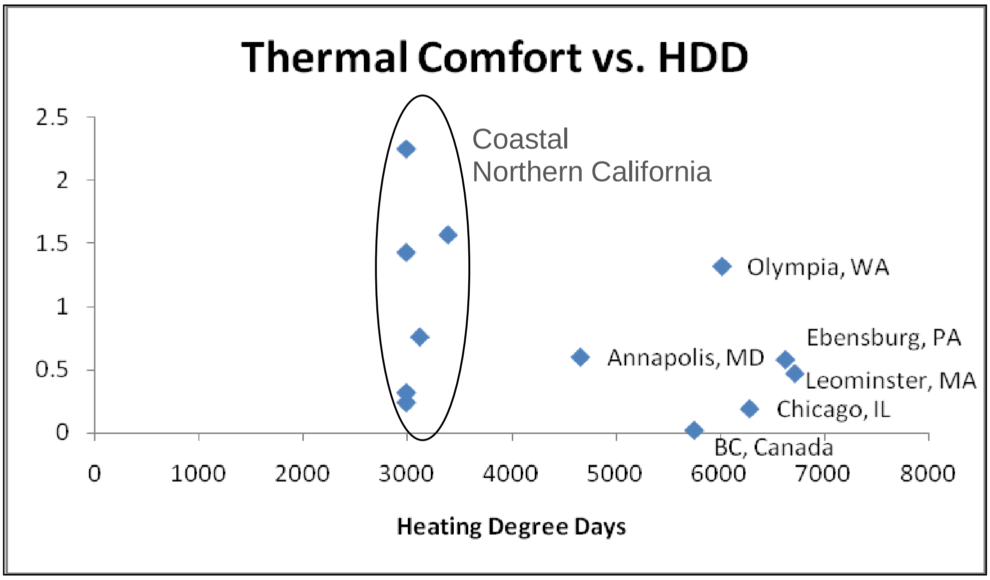

Figure 6 – Thermal Comfort vs. Heating Degree Days

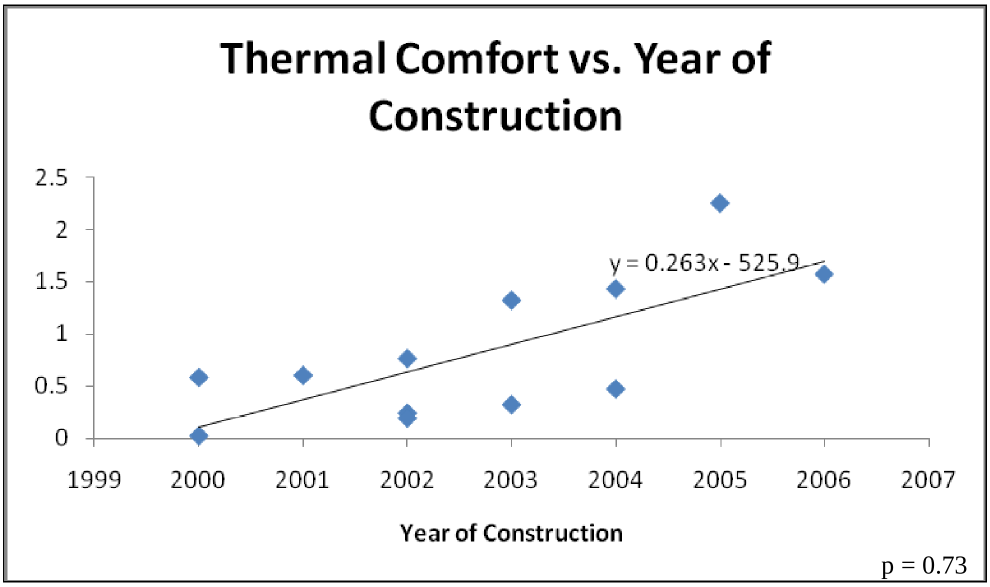

Figure 7 – Thermal Comfort vs. Year of Construction

In addition, there was a positive correlation between thermal comfort and the year that the building was built (Figure 7), which is promising for the future of mixed mode buildings. In our database overall, there is a similar, but much less pronounced trend towards higher thermal comfort satisfaction levels in newer buildings.

There was some commonality with the systems in the lower scoring buildings in this category. The systems are primarily 'changeover' systems, where the HVAC system has been interlocked with the windows so that when the windows are opened, the HVAC system turns off. In these cases, there were specific complaints that when one occupant would open a window, the subsequent HVAC shut-down would make others uncomfortable.

Finally, there was also some commonality with the systems in the higher scoring buildings in this category. None of the top five have air conditioning systems in the commonly occupied parts of the building; instead, two have radiant cooling systems, and the other three rely on ventilation systems (both natural and mechanical) for cooling.

Air quality
Air quality fared slightly better than thermal satisfaction. Again, when we analyze responses by individuals, overall 32% of workers are dissatisfied with air quality (Figure 8), and only 26% of the buildings are meeting the common 80% acceptability threshold (Figure 9). The most common complaints from those who were dissatisfied were that the air was "stuffy/stale", "not clean", and was "smelling bad".

"How satisfied are you with the air quality in your workspace?

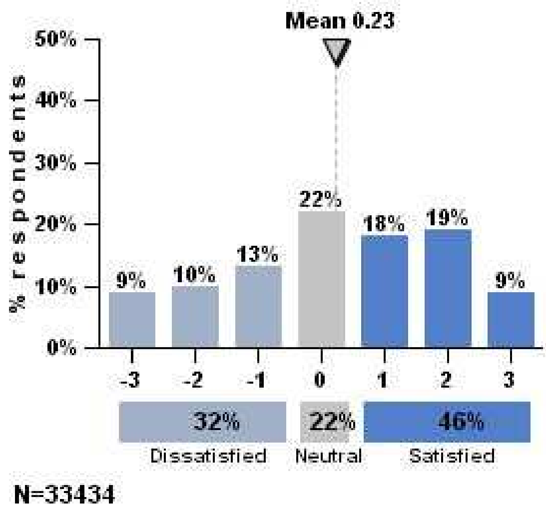

Figure 8 – Air Quality Satisfaction – by individual

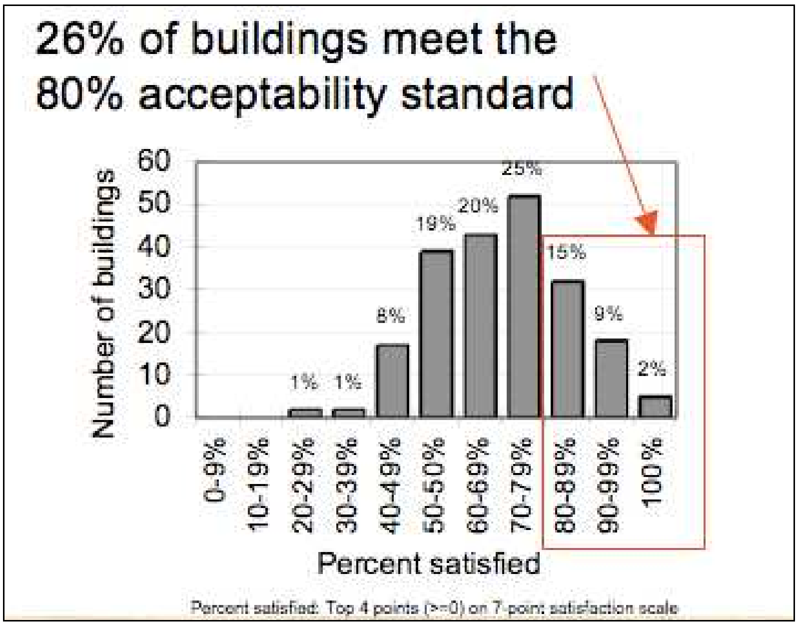

Figure 9 – Air Quality Satisfaction – by building

The cumulative frequency graph (Figure 10) shows that mixed-mode buildings are typically performing very well, with all but two falling in the upper quartile. Complaints from one of the buildings that did not perform as well spoke frequently of dryness, while another referred to smells from a nearby cafeteria and the lack of fresh air.

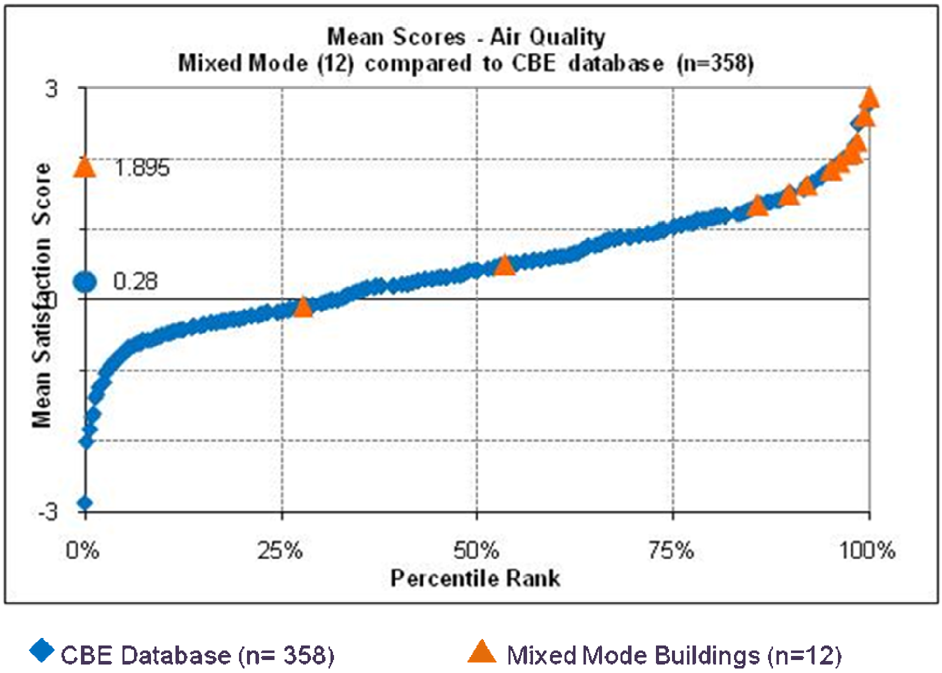

Figure 10 – Cumulative frequency distribution for air quality satisfaction

In comparing air quality satisfaction with annual heating degree days (Figure 11), we found the same general trend towards a slightly lower satisfaction level as heating degree days increase. In particular, the two outliers with the lowest satisfaction scores are both in cold dry climates. In both cases, occupants complain that the air is too dry and stuffy and that there is not enough fresh air in the building. The comments indicate that the windows might not be open often (especially in the winter), so the air quality problems are more likely stemming from the lack of humidification in the mechanical systems of the building.

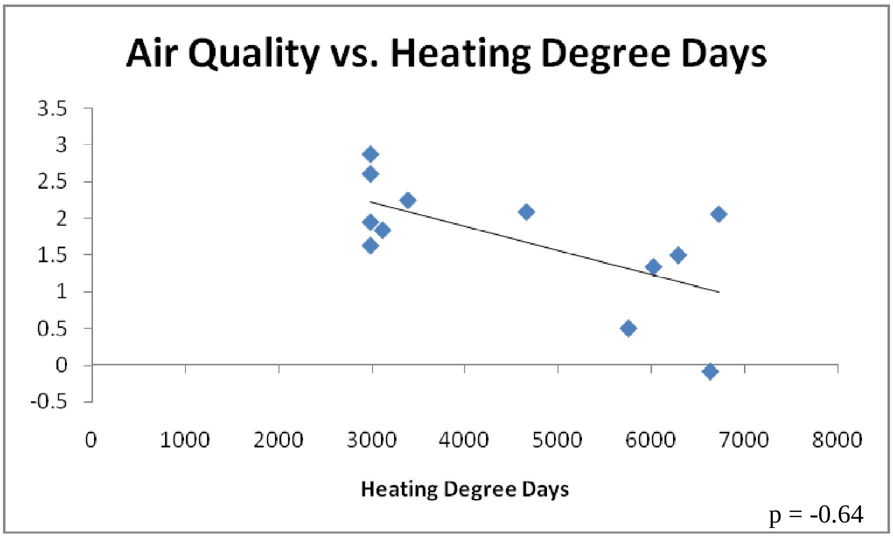

Figure 11 – Air Quality vs. Heating Degree Days

There is also a positive correlation between the year of completion of the building and air quality satisfaction, as seen in Figure 12. This relationship is more pronounced than the similar thermal comfort correlation (Figure 7).

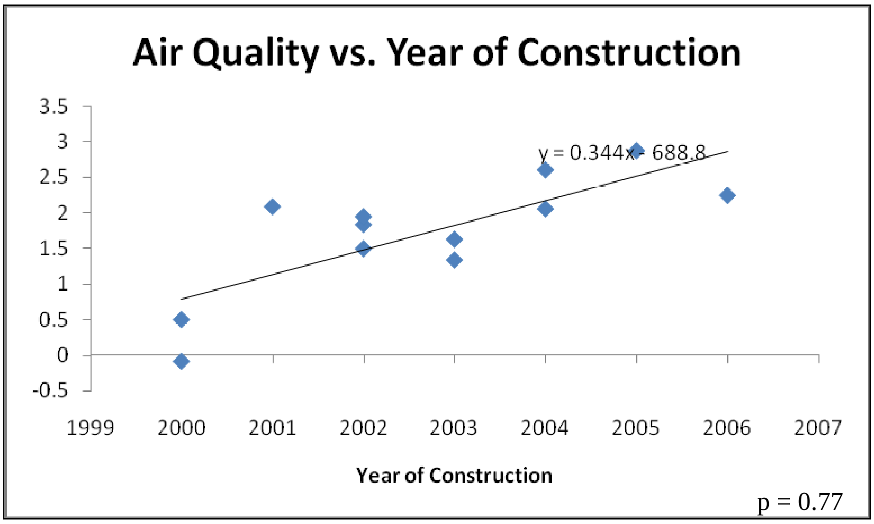

Figure 12 – Air Quality vs. Year of Construction

Acoustics

For the entire database, acoustics received the lowest mean satisfaction scores. Figure 13 shows that mixed mode buildings performed only slightly better on average, but the distribution shows they cover the full range – from the best to the worse. This is where the comments can be particularly revealing. In one building, people spoke of being under a metal roof that was noisy during heavy rain and snow. In another, people complained about the public address system and the disruption of tours going through the laboratory. Only one person in all of the mixed mode buildings complained of acoustical issues that were related to open windows- a teacher in a classroom that was situated next to a noisy playground.

Given that mixed mode buildings generally outperform the larger database of buildings in many areas, it was notable to see that they received scores closer to the overall database average in this area. Most of the mixed mode buildings are 'green' buildings that have been designed for daylighting and good indoor air quality, leading to open plan offices that contain many hard finish materials. Comments from respondents indicate that these factors may be the cause of the higher levels of acoustical dissatisfaction in these buildings, who often note that there is little acoustical privacy in their space. For instance, one occupant notes this relationship particularly, saying "There is a certain openness to the building and that lends to the acoustics not being very effective."

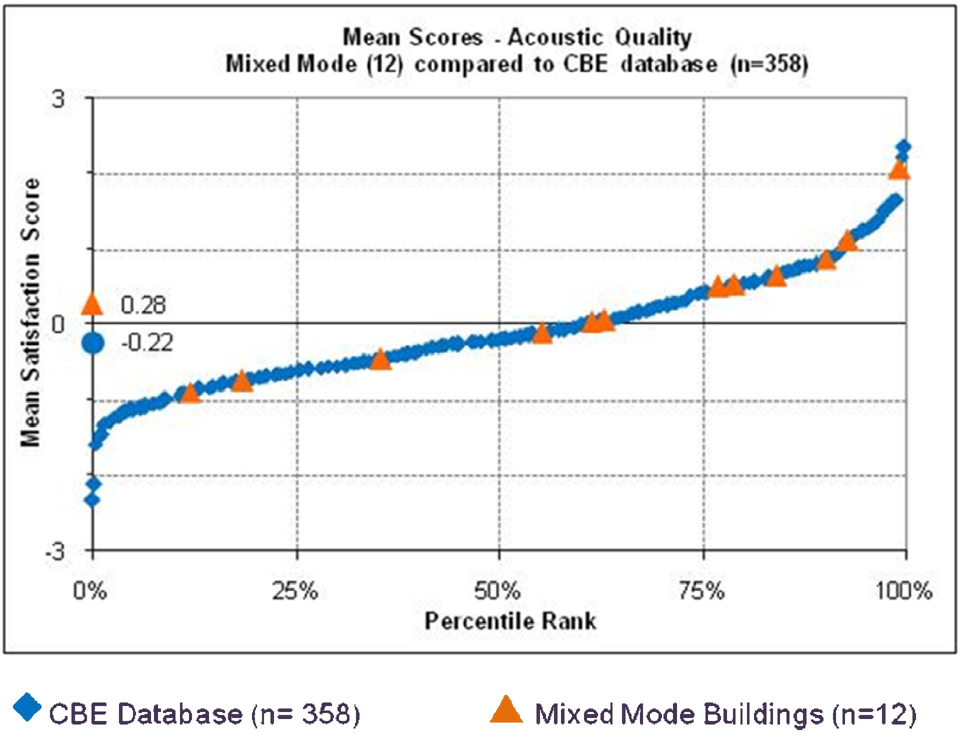

Figure 13 – Cumulative frequency distribution for acoustic satisfaction

Conclusions

ASHRAE publishes standards for both thermal comfort and acceptable air quality in buildings (ASHRAE Standard 55-2004, and 62.1-2004, respectively), both recommending conditions in which 80% of the occupants are satisfied. But when we look at satisfaction scores from the 370 buildings in our database, most of which have conventional air-conditioning systems, we find that buildings are falling far short of these standards. It was disturbing to find that only 11% of the buildings met the intent of the thermal comfort standard, with an overall average of only 59% of the occupants expressing satisfaction with the thermal environment. Thermal dissatisfaction was most commonly related to people feeling that they did not have enough control over their environment, in addition to complaints about air movement being too low. This is particularly interesting given that thermal comfort standards are geared towards limiting air movement, mistakenly believing that drafts are a more common problem.

Mixed-mode buildings, are performing much better than the overall building stock in the database, particularly with regard to thermal and air quality satisfaction. Using a 7-point satisfaction scale of +3 (very satisfied) to -3 (very dissatisfied), the median thermal satisfaction in mixed-mode buildings was 1.34, compared to -0.13 for the overall database (a difference of 0.47 points). The difference was even bigger for air quality, with a mixed-mode median of 1.90, compared to 0.28 for the overall database (a difference of 0.62 points). For both thermal and air quality satisfaction in mixed-mode buildings, we found a relationship between climate (the highest scoring buildings were in more moderate climates, while buildings in colder climates scored lower on average, particularly with regard to air quality), and age of buildings (there was greater satisfaction in the newer buildings, again even more pronounced for air quality).

In the group of mixed-mode buildings, we saw some general trends related to the types of mechanical systems and controls. The best performing buildings had either radiant cooling or only mechanical ventilation, but no air-cooled systems in the spaces primarily occupied by workers (i.e., they may have had air-conditioning in large assembly rooms). The lowest performing mixed-mode buildings tended to be changeover systems, where there were problems with the window interlock systems. This suggests the importance of a well-integrated design where the mechanical and natural systems can work well together, and occupants have the ability to override automated controls as needed or desired.

Occupants who have taken our survey can often provide very useful cues for understanding how the building is working not just at their individual desks, but for the building as a whole. In mixed mode buildings, comments indicate that the relationship between the mechanical and natural systems in the building are not always working as planned, which can lead to the windows being shut more often than necessary. As one respondent who worked in the building that scored lowest on thermal comfort noted, “I do wonder why they put windows in then told us not to open them, as they would mess up the air system.” This type of disparity between how the buildings were designed and how they are running needs to be actively addressed through building commissioning and clear and robust communication to building occupants. While these issues are, of course, important in conventional air-conditioned buildings as well, they are particularly critical given the unfamiliarity of mixed-mode design and operation.

A combination of the survey results reported here, and general lessons learned from interviews, suggests that there is a place for both manual and automated windows. Automated windows seem to work best in either high spaces that are out of reach (stacks, atria, clerestories, roof vents, etc.), or in public spaces that are not "owned" by anyone. They may also be of greatest benefit in controlling for minimum ventilation requirements, nighttime ventilation, controlled ventilation during high winds and rain, or for maintaining overall ambient conditions in the building. Beyond these needs, manual windows should be provided as much as possible to give occupants direct control over at least some of the windows, in order to garner the benefits of adaptive comfort. Manually controlled windows are best placed at the point of need where they can be readily accessible, and the user controls should be visible, convenient, and intuitively obvious.

Providing workers with a quality indoor environment should be a goal of any building design, but is particularly important for green buildings that claim to be more responsive to supporting occupant comfort, health and productivity. Improving the quality of our buildings critically depends on accountability and learning from experience – what works, what doesn't, and what choices about building design or operation can make the biggest difference. The voices of the occupants are an invaluable component of that assessment. As we move towards embracing high-performance, green buildings as the industry standard (as we must), we must also insist that post-occupancy evaluations be a natural part of that process. In the end, everyone benefits from learning how a building performs in practice.

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