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Case study of Kresge Foundation office complex.

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Abstract:
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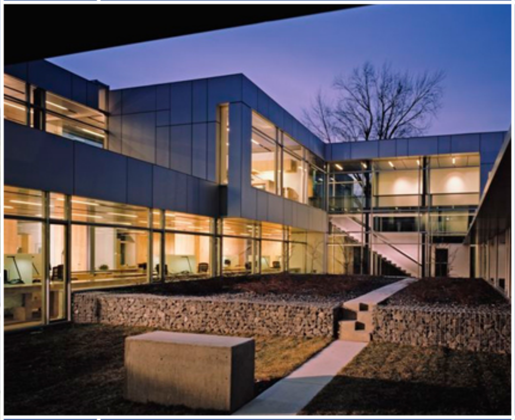
The results were derived from CBE's occupant satisfaction database; the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Performance Measurement

Protocols (PMP); LEED‐NC Version 2.1 design criteria; and other relevant criteria for biodiversity,[1] operations, and life‐cycle costs. Appendix A contains a complete description of the basis for the scoring for each of the 20 evaluations.

Table 1 shows a summary scorecard of the Complex's performance, for all 20 evaluations. The (+) sign indicates conformity with these criteria and performance consistent with what the authors consider appropriate for high‐performance buildings. The (−) sign indicates nonconformity with relevant criteria or other causes for concern. The building meets or exceeds performance criteria in 14 of the 20 areas evaluated.

The occupant survey results in Table 1 were obtained from the CBE Occupant Satisfaction Survey, which is cited in several guidelines and green building rating systems, including LEED‐NC. PMP results in Table 1 are based on ASHRAE's PMP. Although the United States Green Building Council, which developed the LEED‐NC rating system (USGBC 2002), is a coauthor of PMP, PMP differs from the LEED‐NC Version 2.1 rating system under which the building was certified. It describes performance measurement techniques for buildings in operation and is based on industry standards where applicable. It does not cover buildings in design, does not specify performance hurdles, and is not a rating system. Neither does PMP cover site issues. Instead, PMP and other criteria represent a way to evaluate how well the performance objectives of LEED‐NC were achieved.





CASE STUDY OF KRESGE FOUNDATION OFFICE COMPLEX TROY, MICHIGAN

Final Report: April 2011

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[1] An example of “other” criteria is the Michigan Floristic Quality Index (FQI)

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Background

The Kresge Foundation awards grants to nonprofit organizations in the areas of health, the environment, community development, arts and culture, education, and human services. In 2010, the foundation chose to analyze the current energy and environmental performance of its own facilities.

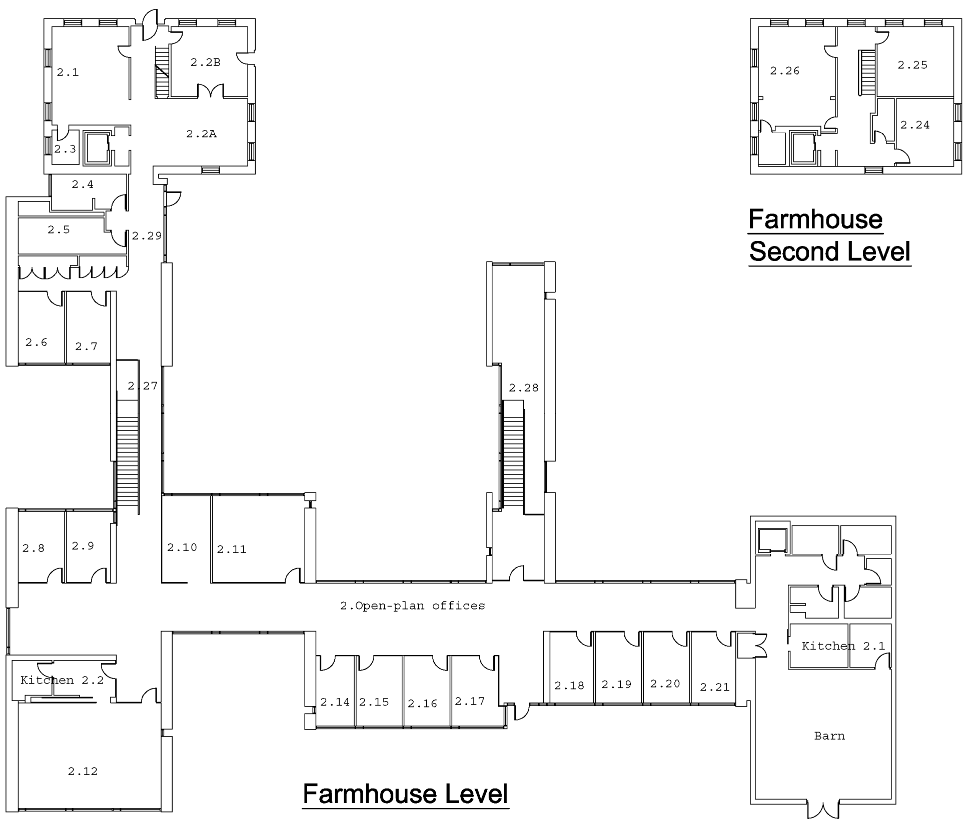

Figure 1: Plan of the farmhouse level with the room numbers used for referencing the location of environmental measurements

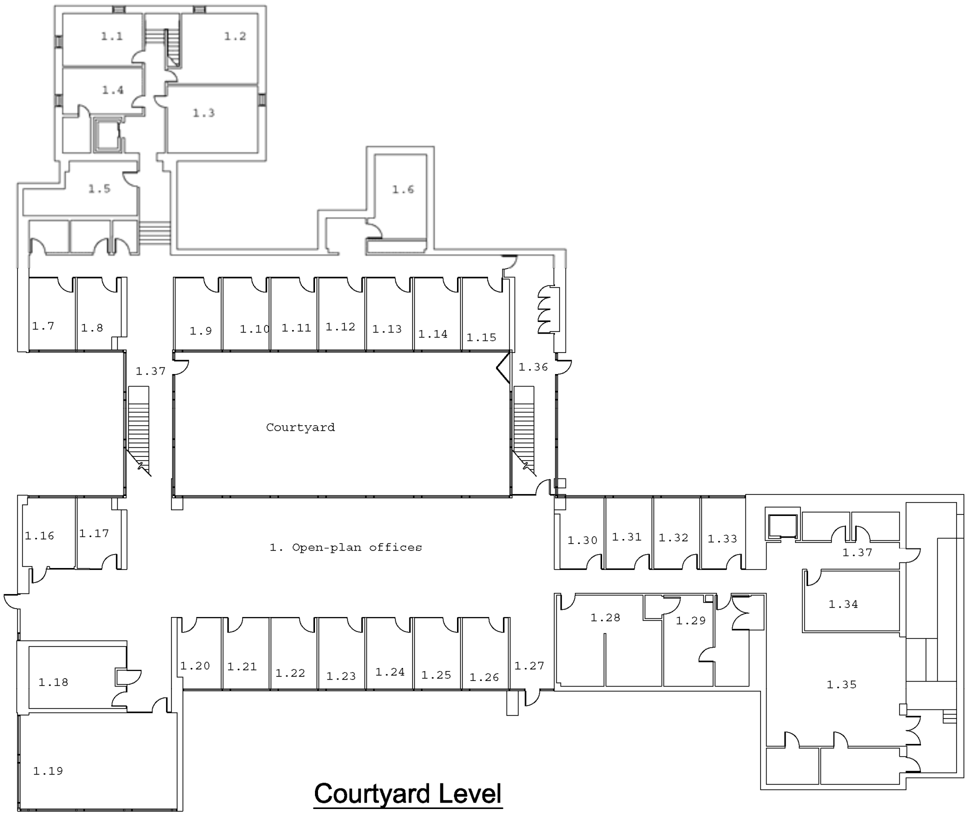

Figure 2: Plan of the courtyard level with room numbers used for referencing the location of environmental measurements

Construction of the Kresge Complex was completed in 2006 on a 2.77-acre site in an urbanized/commercial area of Troy, Michigan. The Complex farmhouse, barn, and courtyard office areas house the approximately 60 employees of the Foundation. Figure 1 shows the Complex's farmhouse level and Figure 2 shows the courtyard level.

The Complex received a Leadership in Energy and Environmental Design (LEED-NC) Platinum rating, the highest possible, as well as numerous awards for its high-performance design. A state-of-the-art green design project, the Complex features many high-performance elements. Some of its most notable features are listed below.

General

- ~ 26,000 ft^2 total
- ~19,000 ft^2 new, ~12,500 below ground level
- oriented with longest sections facing north/south

Glazing/Facade

- Overall 30-50% window to wall ratio, solar heat gain coefficient = .38
- Super-insulated walls
- Heating, ventilation and air conditioning

- New areas: ground source heat pump with underfloor ventilation
- Old areas: ground source heat pump with overhead ventilation
- Mid-efficiency variable speed axial fan air handling unit (supply and return fans), variable speed pumps
- Ground source heat pump water-water service water heating
- Demand controlled ventilation

Occupant Comfort

- Day lighting and occupancy lighting controls
- Low volatile organic compound (VOC) paints and finishes
- Sun shades and light shelves

Landscaping and storm water

- Rainwater catchment via on-site cistern
- Green roof planted with native grasses
- Extensive use of native plantings throughout site

The Complex was designed using an integrated process that involved the architect and engineers. This process included a charrette, site observations, and discussions with Foundation management. The Foundation also commissioned occupancy and programmatic needs projections, which were used to understand space requirements. From these data, the following design goals were developed:

- Ensure sustainability,
- Integrate the historic building with the new building and site,
- Avoid "in-your-face" design, and
- Build a great workplace

Special consideration was given to whether the foundation should stay at the current site and whether the modern building that existed on the site at the time should be retrofitted or demolished. Ultimately, the foundation decided to demolish the modern building to reduce project costs and alleviate problems with a large west-facing curtain wall that negatively affected comfort and energy consumption.

The Center for the Built Environment (CBE), whose research focuses on linking occupant experience in buildings to the measured performance and environmental quality of buildings, analyzed the Complex's performance using CBE's Occupant Indoor Environmental Quality (IEQ) Satisfaction Survey as well as on-site measurements and observations. The team collected building data, then compared the data to CBE's database of building occupant satisfaction results; to the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Performance Measurement Protocols (PMP); to LEED-NC Version 2.1 criteria; and to other relevant criteria for biodiversity and operations and life-cycle costs.

Summary of Building Performance

The Complex meets or exceeds performance criteria for 14 of 20 evaluations, as shown in Table 1. From the occupants' perspective, the building is a high performer. It received ratings in the top quartile of the CBE database in 5 of 7 categories when compared to over 500 other buildings. Eighty-nine percent of occupants are satisfied with the building overall. Eighty percent are *very* satisfied with the building. Seventy-two percent are satisfied with their personal workspace. As is common among buildings in the CBE database, occupants in enclosed private offices are happier with their workspaces than their counterparts in shared or open-office configurations.

All of the indoor environmental quality (IEQ) factors received positive ratings from occupants. More specifically, all IEQ factors have a mean score above zero, or in the "satisfied" range.[2] Occupants also report satisfaction with the underfloor air distribution (UFAD) system when compared to a standard overhead system. However, sections of the building are not controlling to the thermal comfort standards specified in ASHRAE Standard 55 (ASHRAE 2004), and the building is generally overcooling during the summer. Nevertheless, half of the occupants are satisfied with the thermal comfort (and rarely adjust settings themselves), and half are very satisfied with air quality that the system provides. It should be noted however, that even greater occupant satisfaction could be achieved by offering training about appropriate use of occupant-controlled features.[3] Air quality is likely also supported by the low-volatile-organic-compound (VOC) finishes and cleaners used in the Complex. However, measurements based on PMP indicate that indoor air quality (IAQ) standards are not met; ANSI/ASHRAE Standard 62.1 (2010) is violated because of the adjacent location of outdoor supply and exhaust grilles of the air-handling units (AHUs). Although short-term carbon dioxide (CO_2) readings indicate no serious IAQ degradation, this may not be true for other chemicals. This co-location of the exhaust and supply may also be affecting energy performance.

Although the building measurements met PMP acoustic standards,[4] occupants reported frustration with sound privacy, even in private offices. This frustration might be addressed by creating more space for collaborative work that is distant from workers whose tasks require focused concentration. Despite this issue, occupants felt the building supports them in their work. The building's proactive operators are a major reason for the building's success from a human perspective. Occupants report a high level of satisfaction with the availability and timeliness of building management staff, among several other criteria.

The building's resource efficiency meets standards in some areas but misses in others. Potable water usage is 21% less than in an average U.S. office building. However, the Complex is using more water than was predicted for the LEED-NC submittal – 179% more per occupant than predicted – on an annual basis. This is in part due to extended irrigation, which is discussed later.

Based on 12 months of energy data, CBE calculates the building's ENERGY STAR score as 31, which is insufficient for an ENERGYSTAR rating or LEED Existing Buildings certification. To be eligible for LEED certification under the Existing Building rating system, the building must achieve an ENERGY STAR score

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[2] Although IEQ factors were all "positive," Table 1 may indicate a "negative" if a factor was not in the top quartile for the CBE benchmark database. A high-performance building should be one that outperforms its peers.

[3] The Complex has a sustainable construction process kiosk that describes building features and systems. While instructive, it does not explain appropriate ways for occupants to interact with or use the building. Our suggestion is to create new training materials or sessions about appropriate use of specific occupant controls.

[4] See *Performance Evaluation Methods* in the Discussion section of the *Executive Summary*.

of at least 69. To achieve an ENERGY STAR rating, a building must score 75 or greater. The building's source energy use intensity is 266.6 thousand British thermal units per square foot per year (kBtu/ ft^2/yr). This is 20% higher than the national average of 222 kBtu/ ft^2/yr. This average is based on climate-normalized energy use data from similar kinds of buildings across the US. The building's source energy use is 12% greater than was predicted by a calibrated energy model developed for the building in 2009; but comparing actual energy use to calibrated model results is not a useful way to gauge energy performance as discussed in more detail in the *Energy Performance* section and *Appendix G*: *Energy Performance Analysis*.

It is worth noting that the choice of a different comparison building during design simulations may have offered better energy usage results. While the comparison made was appropriate according to the standard, it may not have been appropriate for this and similar high-performance buildings. At the same time, the building is performing near original LEED predictions. Suggestions about ways to select better benchmarks as well as a discussion of differences between these methods and results are offered in the Performance section *Performance Evaluation Methods* section, below.

Documentation for the complex suggests that it meets both of the LEED-NC 2.2 points available for water-efficient landscaping. Water Efficiency (WE) credit 1.1 requires a 50% reduction in irrigation, and WE credit 1.2 requires that the building have no irrigation system or use no potable water for irrigation. We found that, while the Complex complies with credit 1.1, it did not meet the requirements of credit 1.2 up to and including 2009, in part because of difficulty in establishing landscape plants, which resulted in unplanned potable water use. It is likely that the Complex was compliant during 2010, but this will need verification.

The site's biodiversity is noteworthy, exceeding requirements for the relevant LEED-NC credit. Site investigation revealed that 75% of intended plant species were present on the site in mid-May 2010. Volunteer species made up 36.7% of all plants species found. Although intended species are currently considered dominant, this condition cannot be expected to persist without continued hand weeding, occasional controlled burns, and other measures. The site is contributing, however, to local biodiversity, far exceeding LEED-NC requirements in this regard.

Rainfall and corresponding stormwater runoff monitoring indicates that, for the five rainfall events measured, the Complex site retained a significant portion of rainfall, with limited or no runoff. Additionally, the measured pollutant concentrations of water quality samples were below the standard detection limit for both TSS (total suspended solids) and TP (total phosphorus). Based on the performance measured to date, the Kresge site is meeting the intent of LEED-NC Sustainable Sites credits 6.1 and 6.2, for stormwater management. Additionally, a comparison of the measured results to standard engineering stormwater methodologies, such as the USDA Cover Complex Method, indicates that the site is managing stormwater more like a "natural woodland" than a built site. The Complex's stormwater and landscape design performs very well to provide significant water retention and reduced pollutant loads through prevention of pollutant generation, mobilization, and transport from the site. This site serves as a prototype for integrated site design techniques that meet the standards of both the LEED-NC rating system and the Sustainable Sites Initiative (American Society of Landscape Architects 2009).

Taken together, the cumulative construction cost premiums for the green aspects of the Complex's design and construction, including fees and overhead, are in the range of $1,200,000 to $1,300,000. Of this, roughly $900,000 is attributable to energy-use reduction.[5]

Overall, we would expect the combined annual and annualized periodic costs (replacement and major repair) to be moderately less for the Complex than for a conventional building, with a net operating cost reduction of approximately $0.30/ft^2, or $8,000 per annum. Most of this reduction is in the form of reduced replacement costs. We would expect the annual operating cost to be higher than that of a conventional building by approximately $26,000. It is worth noting that the majority of these increased maintenance costs relate to site measures; when energy-only measures are evaluated, the annualized operating cost reduction is in the range of $22,000. The calibrated energy model, prepared by the energy modeler in 2009, indicates an estimated energy cost saving of $41,613. This is larger than the $23,864 estimated in the original model prepared during design.[6] Water costs are very low, with the anticipated annual savings in the range of $1,300 per year. Using a 0% discount rate over a 50-year horizon, a 24-year return on investment is likely if current economic conditions persist.

Discussion

The State of the Green Building Industry and the Complex

The results in this report underscore a number of issues currently affecting the green building industry. In some cases, the Complex is a model and example for future projects. In others, it represents an opportunity to look for improvement. We start the discussion in an area where the Complex is a definite success.

Not all green buildings are appreciated by their occupants. The CBE database includes many disparaging comments by occupants about resource efficiency and human comfort deficiencies in their respective buildings. However, Complex occupants report that they largely appreciate working in this building. They especially enjoy the natural light and connection to nature. They feel that this green building addresses critical health concerns through improved air quality while decreasing negative environmental impacts through energy efficiency and materials selection. This response was overwhelmingly positive despite some apparent design, construction, and operational issues with the Complex.

Throughout our investigation – surveying the occupants and operations team, visiting the building, and conducting interviews – it became clear that there are challenges yet to be addressed. The research team found floor diffusers that had been covered or closed to prevent air movement, individual heaters or fans at desks, and occupants using earphones to block sound. Components related to thermal comfort and acoustic quality were frequently altered by building operators to optimize workspaces. For example, operators had to adjust or manually override HVAC settings to bring the building in line with occupant needs; some HVAC controls are not working. In addition, in most private offices, there is unusable space between the desks and the wall, and access to the operable windows is difficult, limiting their usability. In spite of the very high occupant satisfaction, these issues represent missed design opportunities. Finally, it should be noted that the operators have devoted substantial time and effort to overcoming a number of poor construction problems and issues not addressed during commissioning.

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[5] Costs are from the design development stage of the project.

[6] We use the difference between baseline and calibrated models since they likely contain the same assumptions. The measured energy data and simulations do not. A comparison against measured costs savings requires a measured baseline, which we do not have. Further, the difference between the calibrated and actual usage is small, so the simulated difference is likely close to the actual energy difference.

These functional issues are not unique to the Complex but are common challenges in designing, building, and operating resource-efficient buildings. Although high occupant satisfaction can be achieved through aggressive operation, this often negatively affects resource use and building system performance. In the sections that follow, we offer suggestions for promoting a good work environment without compromising system performance within the Complex.

The following are examples of some problems uncovered by CBE that may have negatively affected the building's performance. We cannot determine the relative effects of these issues. Additionally, operations staff have addressed some. Still, we mention them because they are indicative of the kinds of problems that can temporarily or even permanently handicap a projects' resource-saving potential. First, it appears that inaccurate occupancy projections might have led to higher than predicted water use. The implications of decisions based on these predictions are explained in the applicable sections of this report. Furthermore, although an integrated design process was used, our investigations suggest that an on-site operations perspective was missing from the process. This perspective is important for developing workable operations schedules and procedures that promote both occupant comfort and system optimization rather than one at the expense of the other. Incorporating this perspective might also have reduced or prevented excessive system maintenance labor. An incomplete commissioning process also potentially negatively affected the project.

A pre-design occupant survey or focus group might have been useful. Although observation reveals what people do and is a good way to learn about how to support or discourage current activities, observation is not well suited to discovering the *ideal* activities that would most improve workers' output or morale. This information has to be obtained through surveys or interviews. Though it is admittedly challenging to know which questions to ask and how to design environmental conditions based on the resulting data, without this information, opportunities to support occupants' most important needs may be missed, and unnecessary priority may be given to other aspects of the design. In addition, most occupant needs have cost and energy implications. Information about ideals would have enabled the design team to avoid giving priority to meeting occupant needs that offer only limited humanistic benefits but result in significant increases in cost or energy use. Additionally, occupant survey information highlights areas where occupants can and will meet their own needs if given the opportunity. Lighting controls are one example. A pre-design survey might have provided information about the willingness of occupants to use lighting and other controls.

Performance Evaluation Methods

CBE's analysis of the Kresge Complex performance included an assessment of LEED-NC and PMP performance evaluation methods. PMP and LEED-NC have fundamentally different audiences and purposes, yet each provides criteria that are useful for evaluating actual building performance and can thus be used to inform one another regarding metrics. LEED-NC can be considered a representation of *design intent,* expressed by comparing design estimates to certain criteria. On the other hand, PMP (and other measurement methods used in this study) is aimed at assessing actual or *operational performance*, which is the focus of this study. PMP has deficiencies and does not completely cover all factors of interest, so we have resorted to other methods and criteria when necessary to provide a complete assessment of operational performance. From this experience, we have conducted the following analysis of these methods. This analysis is by no means comprehensive. Still, these introductory results represent present issues in practice and may assist practitioners working on similar projects.

The ASHRAE PMP represents an improvement over the human factors approach in LEED-NC. It requires a complete occupant satisfaction survey than LEED-NC; LEED-NC suggests but does not require queries about thermal comfort only. PMP includes a full complement of indoor environmental quality factors. Because the primary purpose of workplace buildings is to support people and their work, occupant impact should be the start of any building performance inquiry. For buildings where occupant control strategies will be used to reduce resource use, a pre-occupancy or pre-design needs assessment should be implemented to gauge barriers to occupants' control use. This can include observations, but should also involve queries of occupants. The results from this assessment should be integrated into the design of occupant controls and occupant training programs.

It is clear from this study and others that design-based analysis like LEED-NC energy performance evaluation methods alone cannot always be relied upon to deliver good operational energy performance; construction/installation and operational issues are also important. The reliance of LEED-NC on simulations alone for awarding energy points appears to have limitations. . The analyses conducted in this study exemplify how energy simulations based on energy-intensive baselines can result in hypothetical energy savings during design, but lead to buildings that underachieve when benchmarked against databases of actual buildings' energy use. Better methods need to be developed that will provide greater assurance that energy goals will be achieved. These could involve elements of both LEED-NC (simulations) and PMP (benchmarking) methods. Until better methods are developed, methods such as ENERGY STAR's Target Finder may be a good way to identify performance issues during design. Target Finder was not intended as a design tool, but could be used to assist design in this context. For evaluating actual operational performance, a better approach than relying solely on simulations is the benchmarking method shown in the ASHRAE PMP (i.e., ENERGY STAR Portfolio Manager).

LEED-NC metrics for landscape water use (Water Efficiency credit 1.2) do not include the understanding that native landscapes (which offer benefits including biodiversity and long-term low water usage) may take longer to mature than typical lawn and shrub landscapes. The LEED-NC expectation that no water will be used for irrigation after one or two years may not be realistic for native landscapes.[7]

The CBE team also suggests the following specific improvements to the ASHRAE PMP:

- A first-level IEQ evaluation[8] should be uniform, requiring an occupant survey for a comprehensive set of indoor environmental quality factors, with measurements being required only for items with high levels of dissatisfaction. This approach would make studies such as these easier to complete and therefore perhaps more commonly undertaken.
- Currently, the first-level evaluation does not adequately measure acoustic privacy. The Kresge Complex suffers from private office noise leaking into the open-plan office. A measure for this IEQ factor could assist with locating similar issues in other buildings. A lack of acoustic privacy is a common issue among buildings in the CBE database and deserves special attention.
- PMP does not include site issues. Indoor potable water use is part of PMP, but in many cases, potable water is also used outdoors. PMP should address ways to reduce both outdoor and indoor potable water use.

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[7] PMP does not include any site issues. In this regard, LEED-NC is more comprehensive.
[8] PMP prescribes three levels of intervention. See *Performance Measurement Protocols for Commercial Buildings.*

Recommendations for Improved Energy and Comfort Performance

This section describes changes that might improve energy performance and occupant satisfaction. Water use, stormwater quality and quantity, and landscape and financial performance are not discussed in this section, as the building is performing at or above goals in these areas.

- An employee manual or training that covers appropriate use of occupant controls as well as the benefits of using controls could potentially save energy and increase occupant satisfaction.
- Upgrading the building management system (BMS) to include more robust data logging and analysis capabilities would permit operators to better understand and address performance and comfort issues,
- Occupants are not using lighting controls to reduce light levels; instead, lights remain on even when there is sufficient daylighting. Dimming has been limited to approximately 70% of maximum. Adjusting the lighting system so that it turns off overhead lights off when daylighting is sufficient would reduce energy use, and
- Temperature is not well managed because of problems with HVAC controls and inappropriate settings as well as inoperative or poorly placed floor diffusers; a number of portable heaters and local fans were observed which also increase energy use. Table 2 describes additional measures that would improve energy use and thermal comfort. Each of these measures should be weighed against occupant comfort and productivity as well as cost.

Table 2: Summary of key recommended actions to improve Kresge Complex building performance

Recommended action	Anticipated impact on performance
Establish consistent thermostat setpoints and an adequate dead band.	Resolve heating and cooling problems, reduce energy use, and possibly increase thermal comfort.
Implement control loops for supply plenum pressure control.	Reduce fan energy consequences associated with sucking room air into supply plenum; eliminate negative pressures; and increase control of interior zones, reducing energy use and increasing comfort.
Increase insulation/depth of geothermal field piping.	Reduce the energy use, maintenance needs, and operation problems (and perhaps increase the equipment life) of the water-source heat pumps and multi-stack unit.
Repair leaky, inoperative or poorly placed air diffusers.	Reduce energy use and increase comfort in perimeter zones.
Separate exhaust and return air intake.	Improve economizer performance and thus reduce energy use.
Increase air handler supply air temperature.	Improve economizer performance, thus reducing energy use --climate permitting-- and mitigate comfort problems in certain areas.
Reduce use of electric heaters for morning warm-up by implementing more comprehensive warm-up strategy.	Reduce energy use (though this may not be possible without substantive changes to the building in some cases, e.g., entryway).
Ensure accurate and frequent CO_2 measurement.	Reduce the excess energy used to move and cool outside air.

The remainder of the report describes methods of inquiry and analysis, detailed results, conclusions, and recommendations, respectively, for each of the 20 areas analyzed.

Human Factors

Background

This section details the Complex occupants' thoughts about their workplace. To the degree possible, we have contrasted occupant opinion with environmental measurements and information about relevant system performance.

Occupants of the Complex are knowledge workers as they are primarily engaged in information analysis and/or transaction processing. Sometimes their work requires focused concentration while at other times significant collaboration is required. A majority of occupants report spending approximately 21 hours per week engaged in informal communication with colleagues, phone conversations, and scheduled meetings in the building. Occupant responses and environmental measurements reflect the building's ability to support these activities.

Methodology

Since 2000, CBE has administered occupant IEQ satisfaction surveys. Archived survey responses contain data for more than 500 buildings and 60,000 occupants. The survey was developed by extensive testing and cognitive interviewing (Zagreus 2004), ensuring good coverage of a wide range of technical concerns.

The surveys are administered over the web and include a core set of questions on occupant satisfaction with the indoor environment including thermal comfort, air quality, lighting, acoustic quality, speech privacy, office furnishings, office layout, cleaning and maintenance, workspace in general, and the building in general. Occupants use a 7-point ordered-response scale to rate satisfaction. When respondents express dissatisfaction, they are asked to select one or more sources of dissatisfaction. Respondents who indicate dissatisfaction with a particular physical dimension can provide a text response giving further explanation. All respondents are given the opportunity to provide general comments on the workplace or building. In addition to the standard question set, the survey implemented at the Complex included questions about how and where occupants spend time in the building, how they commute to the building, the underfloor air diffusers in the building, the building management staff, and the building grounds. The analyses below highlight findings from all survey questions.

Data were analyzed via CBE's suite of reporting tools.[9] The tools facilitate filtering data across or within buildings. All 65 Complex occupants were given the opportunity to respond to the survey and all did. Occupants rated all areas as satisfied, which is an achievement. Yet the research team held the building to a higher standard given its LEED-rating and clearly defined sustainability goals. A high performance building must score in the top quartile of the CBE database or have a score that is higher than 75% of the other buildings in the database.

Results

As discussed in the performance summary above, the Complex scores in the top quartile of all buildings in the CBE database for five of seven environmental factors tested. The building also performs well in

[9] See http://www.cbe.berkeley.edu/research/survey_links.htm for more information about CBE reporting tools.

relation to several peer groups, including daylight-optimized and LEED-NC-rated buildings, buildings with operable windows and UFAD systems, and other office buildings in general.

Occupants report having many environmental controls for lighting and thermal comfort, thermostats being an exception. For thermal comfort, respondents noted having control over window blinds, operable windows, floor diffusers, doors to interior areas, and portable fans. For lighting, respondents reported having control over interior lights via dimmers, window shades, and task lights. Studies suggest that occupant control is associated with higher occupant satisfaction. However, during our site visit, we noted that many of these controls were not regularly used. Therefore, it is likely that centralized control has a larger effect on the satisfaction of Complex occupants. However, the presence of multiple forms of control presents opportunities for occupant training, which could indeed contribute to even higher satisfaction and reduced energy consumption in the future.

Several other opportunities for improvement exist. As in many other green buildings, dissatisfied respondents described noise from others as a major reason for discontent with acoustic quality. Dissatisfied occupants also reported a lack of visual privacy, insufficient partitions, and a lack of private meeting rooms as problems. All of these factors are related; this highly collaborative staff is generating noise that distracts other workers who need space for focused concentration. Private office noise is apparently escaping into the open-plan areas where occupants are engaged in work that requires concentration.

These kinds of complaints are common in green buildings. Our desire to fill offices with natural light often leads to long, thin buildings with large windows and open-plan offices. These compact, open floor plans require special attention to acoustic needs. In this case, the source of the disturbance is private offices. Although the private offices offer the potential to mitigate distractions in the open-plan areas, they do not prevent sound leakage into those areas.

The aspiration to reduce buildings' physical footprints can lead to build smaller buildings, which require unique spatial layouts, lest they be outgrown. A design strategy that assumes high worker mobility can reduce an organization's carbon footprint. However, real estate strategy and design that support mobility differ from a standard office layout. Unlike the Complex, a design that supports mobility would likely include more spaces for collaboration and fewer dedicated workspaces. In addition, the Complex was originally designed for 40 and now has more than 60 occupants.

The Complex's thermal comfort performance is far above average when compared to other buildings in the database. However, a mean score of 0.54 indicates a mixed reaction from occupants, which is corroborated by measurements (see *Thermal Comfort*); respondents pointed to both overcooling in warmer months and overheating in colder months. This complaint is common in LEED-NC-rated buildings, but Complex occupants reported more summer and winter over-conditioning than their counterparts in other LEED-NC buildings do. This result is corroborated by on-site measurements, as noted in the *Thermal Comfort* section. This is an easy issue to fix and has direct energy benefits. Occupants noted the lack of thermostats as a contributor to this problem.

Results and Conclusions by Indoor Environmental Quality (IEQ) Factor

This section presents survey results by IEQ factor. The bar in each section should be read as follows: blue, on the left in each bar, is the percentage of occupants satisfied with that IEQ factor; beige, in the center, is the percentage of occupants offering a neutral response for that factor; and red, on the right in each bar, is the percentage of occupants that are dissatisfied with that IEQ factor.

Office Layout

64% | 13% | 23%

More than 50% of respondents felt that the office layout was satisfactory. Dissatisfied occupants cited lack of storage and filing space, lack of private meeting rooms, lack of visual privacy, and insufficient wall partitions as major issues. Only a few (~6) occupants commented that there was not enough space for meetings. This may be a result of the large number of private offices in the building, which can be a potential space for collaborative activities. However, the acoustics measurements and responses suggest that sound leaks between spaces, which may detract from the privacy of enclosed offices.

Although more than 50% the respondents are satisfied with the office layout at the Complex, 53% of buildings in the CBE benchmarking set have a higher level of satisfaction with office layout. See Appendix B for the benchmarking graphs.

Office Furnishings

77% | 7% | 11%

General satisfaction was quite high for all aspects of office furnishings. Occupants responded positively regarding general comfort, colors and textures, and adjustable furnishings. In addition, 73% of occupants felt that the office furnishings enhanced their ability to do their job. Of the dissatisfied respondents, several felt that there were ergonomic issues with their workstations. This may be improved by training and a variety of workstation configurations to diversify the positions people sit in.

Air Quality

71% | 20% | 9%

Overall, occupants felt that air quality was quite good. There were, however, complaints about food odors from an open kitchen, low humidity, and dry eyes, as well as concerns about dust collecting because of poor air filtration. Some of these issues may be a result of the proximity of the building air exhaust to the intake. Exhaust is most likely mixing with fresh air and reentering the building. The *Indoor Air Quality* section of this report includes suggestions for addressing these issues.

Acoustic Quality

49% | 11% | 40%

Although acoustic quality had the lowest satisfaction rating, 50% of respondents said that the acoustic quality enhanced their working conditions; this positive response may be connected to a comment the about “a lovely white noise” coming from the floor diffusers. The low satisfaction scores seem to come from high dissatisfaction with sound privacy. Fifty-eight percent of people work in enclosed offices, so the acoustic issues do not stem exclusively from the open-plan office space as is the case in many buildings. Occupant comments pointed to “tiled floors” or hard surface flooring in some enclosed offices, “paper thin walls,” and spaces previously used for storage having been converted to office space. The *Acoustics* section discusses mitigation strategies for these issues.

Lighting

77% | 9% | 14%

The Complex lighting seems to be meeting the needs of all but a handful of people. Those who reported dissatisfaction commented that the space was too dark and that reflections were an impediment. Others commented that the motion sensors often turn off the lights while people are working. The complaints were not specific to an individual area but were made by individuals working in a variety of locations throughout the Complex. It is noteworthy that, although occupants are largely satisfied with lighting, this is most likely not due to personalized settings. During a multiday site visit, CBE staff noticed lights on in most offices even when natural light levels were sufficient.

Thermal Comfort

51% 19% 30%

The thermal comfort satisfaction scores for the Complex were similar to those in other LEED-NC and LEED-NC Platinum buildings but were higher than average for buildings in the CBE database (ranking at the 79th percentile, with a mean score of 0.54). Still, these scores were likely lowered by reports from dissatisfied occupants of thermal over-conditioning. Complex occupants were much more likely to be too hot during the winter and too cold during the summer than their counterparts in other LEED-NC buildings were. In addition, dissatisfied occupants in other buildings report being most dissatisfied earlier in the day, while Complex occupants reported feeling thermal discomfort at various times of day. The two primary reasons for these complaints were thermostats controlled by other individuals and noticeable drafts.

Cleanliness

79% 9% 12%

Cleaning and maintenance was one of the highest-rated aspects of the Complex. The building staff in particular received one of the highest ratings (at the 100th percentile) of any building that CBE has surveyed. Ninety-five percent of respondents were satisfied with the building management staff, and close to 80% reported satisfaction with cleanliness and maintenance. The only major complaint was dirty floors, which could be related to comments that the carpets are old and worn out.

Complete survey results can be found in Appendix B: Survey Report.

Potable Water

Background

This section describes the Complex's potable water use performance as gauged by PMP averages and LEED-NC Water Efficiency (WE) credit 3, for water use reduction. Although they include different benchmarks, both have the goal of reducing a building's potable water use, as moving and cleaning it is very energy intensive, and it is an increasingly scarce commodity. The Complex uses dual-flush toilets, waterless urinals, and low-flow faucets to achieve its water use reductions.

Methodology

To investigate indoor water use, CBE analyzed 12 months of water utility bills. Data were compared to water consumption in average U.S. office buildings, the indoor water benchmarks of PMP, as well as the per-person usage benchmarks in LEED-NC WE credit 3.

Results

Water use within the Complex is lower than in many US buildings and compares well to benchmark figures referenced in PMP. The Complex, however, is not meeting its LEED-NC modeled water use goals. Though the building is using 21% less water per occupant per year than an average U.S. office building, it is unfortunately using 179% more water per occupant on an annual basis than was predicted for LEED-NC. Seasonal variation in irrigation water use through 2009 explains most of this difference; water use is close to LEED-NC predictions during the winter but substantially higher than predictions in the summer. The cause of this seasonal variation was extended irrigation, which is discussed in the *Landscape Water Use and Biodiversity* section of this report.

The following table shows monthly water flow in gallons (gal) as well as per person and per square foot (ft^2) from August 2008 through July 2009:

Table 3: Complex water flow data

Date	Occupancy	Consumption (gal)	Per-person consumption (gal/person)	Per-person consumption (gal/person/day)	Per-ft^2 consumption (gal/ft^2)	Per-ft^2 consumption ($gal/ft^2/day$)
Aug-2008	51	40,691	797.9	26.60	1.46	0.05
Sep-2008	51	30,219	592.5	19.8	1.09	0.04
Oct-2008	52	17,825	342.8	11.4	0.64	0.02
Nov-2008	52	8,153	156.8	5.2	0.29	0.01
Dec-2008	53	6,134	115.7	3.9	0.22	0.01
Jan-2009	55	8,856	161	5.4	0.32	0.01
Feb-2009	56	8,782	156.8	5.2	0.32	0.01
Mar-2009	58	9,559	164.8	5.5	0.34	0.01
Apr-2009	60	11,003	183.4	6.1	0.4	0.01
May-2009	60	25,799	430	14.3	0.93	0.03
Jun-2009	61	45,194	740.9	24.7	1.62	0.05
Jul-2009	61	29,209	478.8	16.0	1.05	0.04
total		241,425	4,321.50	144.1	8.7	0.29

As is evident in Table 3, the Complex consumes significantly (as much as four times) more water during the summer months than during winter. Over 60% of the Complex's water use takes place during the summer months. (This trend is even more obvious in Table 4, which compares water use in the Complex to PMP benchmarks.) Interior waterfalls were installed during the summer of 2009, but it does not contribute significantly to the consumption seen in these data.

Comparison against Benchmarks
Although the raw water flow numbers provide some insight into the building's performance, comparing these figures to benchmarks is far more useful. PMP provides benchmarking data for office buildings on a per-employee and a per-ft^2 basis. These benchmark numbers are 15 gallons per employee-day and 0.03 gallons per ft^2-day.[10] The differences between the Complex's usage and the benchmarking data are shown in Table 4.

The seasonal difference in water usage is very apparent in these figures: summer numbers are higher than the benchmark and winter numbers are lower than the benchmark. Despite this variation during the year, the annual totals show that the building is performing better than an average U.S. office building as defined in PMP.

Table 4: Kresge Complex water use compared to PMP benchmark

Date	Difference between Kresge Complex water use and PMP benchmark			
	(gal/employee)	**(%)**	**(gal/ft²)**	**(%)**
Aug-2008	332.9	72%	0.42	40%
Sep-2008	142.5	32%	0.08	8%
Oct-2008	(122.2)	-26%	(0.40)	-39%
Nov-2008	(293.2)	-65%	(0.75)	-71%
Dec-2008	(349.3)	-75%	(0.82)	-79%
Jan-2009	(304.0)	-65%	(0.72)	-69%
Feb-2009	(263.2)	-63%	(0.63)	-67%
Mar-2009	(300.2)	-65%	(0.70)	-67%
Apr-2009	(266.6)	-59%	(0.61)	-61%
May-2009	(35.0)	-8%	(0.12)	-11%
Jun-2009	290.9	65%	0.61	61%
Jul-2009	13.8	3%	0.01	40%
total	(1,168.6)	-21%	(3.64)	-29%

Positive values indicate that the Complex is using more water than the benchmark, and negative values indicate less water consumed than the benchmark. The percent column shows how much the Complex's water consumption is above or below the benchmark value – i.e, the percentage of water being saved or spent as compared to the benchmark.

Comparison with LEED-NC
In addition to using the benchmark data, which simply compares the building to what one would expect to see in a similar-class building, we compared the Complex's expected performance to its actual performance. This comparison was performed by examining the LEED-NC WE credit 3, for water use reduction, which the building was awarded.

[10] The reference for the source of these benchmarks can be found in Appendix A: Performance Scorecard Details.

The LEED-NC calculations for the Complex are quite peculiar in that they assume occupancy of 450 people – evenly split between men and women – instead of the 60 people who currently occupy the building. In reality, the Foundation’s staff is heavily skewed towards women. For an occupancy of 450, LEED-NC modeling predicts a total daily volume of water flow of 2,902.5 gallons, or 696,600 gallons annually. Table 5 compares the Complex's actual water usage to the usage modeled for LEED-NC.

Table 5: Kresge Complex water use compared to usage predicted for LEED-NC. Positive values indicate that the Complex is using more water than predicted, and negative values indicate less water consumed than predicted. The percent column shows how much the Complex’s water consumption is above or below the predicted value.

Date	Difference between Kresge and LEED-NC predictions			
	(Gal/employee)	(%)	(Gal/ft^2)	(%)
Aug-2008	668.87	519%	(0.62)	-30%
Sep-2008	457.08	337%	(1.10)	-50%
Oct-2008	200.89	142%	(1.65)	-72%
Nov-2008	40.69	35%	(1.58)	-84%
Dec-2008	18.98	20%	(1.34)	-86%
Jan-2009	25.57	19%	(1.87)	-85%
Feb-2009	34.26	28%	(1.66)	-84%
Mar-2009	29.37	22%	(1.85)	-84%
Apr-2009	47.93	35%	(1.79)	-82%
May-2009	300.98	233%	(1.16)	-56%
Jun-2009	605.44	447%	(0.57)	-26%
Jul-2009	343.39	254%	(1.14)	-52%
1-year total	2773.50	179%	(16.30)	-65%

Even though calculations indicate that the Kresge Complex overall is using approximately one-third of its predicted water use, this is entirely a result of the large number of occupants assumed by the LEED-NC calculations. Given this large number of assumed occupants, comparing the Complex’s actual water consumption with the predicted values yields a very different view depending on how the comparison is normalized. Examining the comparison on a per-ft^2 basis (Table 4) makes it look like the Complex is saving quite a lot of water over the predictions. However, because these values were derived from a per-occupant water use figure assuming 450 occupants, this is not really a meaningful comparison. Yes, the building is using less water than predicted, but not a tenfold decrease in water use as would be expected in view of the difference between the predicted versus actual number of occupants. The better comparison is the per-employee figures, which show that the building is using quite a lot more water than predicted. However, it is interesting to note that the winter figures are relatively close to predictions—only approximately 20% higher. The summer numbers are significantly higher, leading to the overall dramatic annual increase.

If we use the submitted LEED calculations as a template and assume occupancy of 60, we find a predicted annual use of 92,880 gallons per year, rather than the 696,600 gallons that was submitted. Differences between actual and this prediction are listed in Table 6 below.

Table 6: Difference between actual use and LEED prediction with 60 occupants

Date	Difference between Kresge and LEED predictions – 60 occupants			
	(Gal/Employee)	(%)	(Gal/SF)	(%)
Aug-2008	668.87	519%	1.18	426%
Sep-2008	457.08	337%	0.79	272%
Oct-2008	200.89	142%	0.33	109%
Nov-2008	40.69	35%	0.04	17%
Dec-2008	18.98	20%	0.01	6%
Jan-2009	25.57	19%	0.03	9%
Feb-2009	34.26	28%	0.05	19%
Mar-2009	29.37	22%	0.05	18%
Apr-2009	47.93	35%	0.10	35%
May-2009	300.98	233%	0.65	233%
Jun-2009	605.44	447%	1.33	456%
Jul-2009	343.39	254%	0.76	259%
1-year total	2773.5	179%	5.3	160%

These figures show that the building is using a lot more water than predicted. However, it is interesting to note that, albeit a bit higher, the winter figures are close to predictions—only ~20% higher on a per employee basis and ~9% on a per square-foot basis. The summer numbers are much higher, leading to the overall annual high number.

In general, the Kresge Complex's water consumption is good for the size of the building and number of employees. Although the LEED-NC targets were not met, the winter use figures are quite close. The additional water use compared to predicted use is mostly a function of irrigation water use. We expect this problem to subside as the landscaping matures.

Stormwater Quality and Quantity

Background

The Kresge site is located in the Clinton River Watershed, which drains 760 square miles of southeastern Michigan and ultimately discharges to Lake St. Clair near the city of Mt. Clements. U.S. EPA has designated the Clinton River an Area of Concern because of nonpoint source pollutants (fecal coliform and nutrients), high total dissolved solids, contaminated sediments (metals, polychlorinated biphenyls, oil, and grease) and impacted biota (U.S. EPA 2009). Although historic industrial and municipal discharges were largely responsible for the river's degradation, U.S. EPA now cites nonpoint source pollution from urban stormwater runoff as the primary cause of water quality impairment.

Annual rainfall in Troy averages about 30 inches and is evenly distributed throughout the year. Natural vegetation composition is very much dependent on rainfall patterns. Michigan's southern Lower Peninsula was historically characterized by oak savannahs and prairies. In natural conditions, the majority of annual rainfall is utilized by vegetation through the process of evapotranspiration. Rainfall not taken up by vegetation infiltrates through the soil mantle to recharge the groundwater aquifer, and very little rainfall contributes to surface runoff.

Under developed conditions, the water balance is altered. The construction of impervious surfaces (rooftops and pavements) and the associated reduction in natural vegetation greatly increase runoff while reducing groundwater recharge and evapotranspiration. This increase in runoff volume and rate contributes to stream degradation; it increases bank full conditions in streams, resulting in stream bank erosion, associated loss of stream baseflow, and an increase in nonpoint source pollutant loads.

The Complex's stormwater management plan was designed to mimic the natural hydrologic cycle by integrating native landscapes, reducing impervious surfaces, and promoting stormwater infiltration and vegetative filtering. The Complex's landscape-based stormwater measures for runoff management include: bioretention and bioswales, constructed wetland ponds, intensive green roof systems, pervious pavements with subsurface infiltration beds, and a VortSentry water quality unit. A high-capacity cistern captures roof runoff and overflow from the constructed wetland ponds for reuse for landscape irrigation. The stormwater interventions are carefully integrated into the site to complement the building's architectural details and the overall site landscape plan.

Methodology

The Kresge site stormwater management plan was designed to meet Oakland County, Michigan's local regulations (Oakland County, Michigan Drain Commissioner 2007) as well as to achieve LEED-NC Sustainable Sites (SS) credits 6.1 and 6.2, which include points for stormwater rate, quantity, and quality. Oakland County criteria require that the stormwater management design provide peak rate attenuation based on an allowable discharge rate of 0.2 cubic feet per second per acre of drainage area (0.5 cubic feet per second from the entire 2.77-acre Kresge site). The LEED-NC SS credits 6.1 and 6.2 criteria include the following:

- The post-development 1.5-year, 24-hour peak discharge rate must not exceed the pre-development 1.5-year, 24-hour peak discharge rate, and
- The design must comply with the U.S. EPA's Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters (1993) for removal of 80% of the average

annual post-development total suspended solids (TSS) and 40% of the average annual post-development total phosphorous (TP).

This analysis measured stormwater parameters to verify that the site stormwater management measures and landscape are achieving the water quantity and quality goals of LEED-NC SS credits 6.1 and 6.2. In addition, we assessed the site’s overall water balance to determine how effectively the stormwater design mimics natural hydrologic conditions.

Stormwater was sampled over a 12-week period, from August 26 through November 11, 2010, and the following data were collected and analyzed:

- *Precipitation data*: a tipping bucket rain gauge was installed on site to record precipitation every 5 minutes with a minimum accuracy of 0.01 inches.
- *Stormwater flow data*: flow data were collected with a Teledyne ISCO 2150 flow module including an area velocity sensor and level.
- *Water quality data*: water samples were collected via a Teledyne ISCO GLS sampler. Samples were tested for TP using U.S. EPA Test Method 365.4 and TSS using U.S. EPA Test Method 160.2.

The flow and water quality sampling equipment was installed in a manhole in the northeast corner of the site within the property fence line. The manhole connects stormwater pipes that drain the north side of the site as well as the ultimate overflow pipe from the bioswale located along the east side of the site (adjacent to the parking area). This location was chosen to capture the total flow leaving the site. The flow measurements were taken just downstream of the VortSentry water quality unit so that samples taken would reflect the additional water quality reduction provided by the vortex unit.

Figure 3 shows the velocity sensor (left) and manhole (right). Figure 2 shows the rain gauge (left) and water quality sampler (right).

Figure 3: Velocity sensor and its location in manhole

Figure 4: Rain gauge and water quality sampler

The rain gauge was installed on a light pole at the north side of the site and was connected to a data logger (2105C Network Interface Module) that recorded and uploaded precipitation data every 5 minutes.

The same data logger was connected to the flow module. The area velocity sensor and level were installed in a 12-inch, double-wall, high-density polyethylene pipe accessed through the manhole. The flow module used the area velocity sensor and the level to calculate the flow rate automatically. All of this information was uploaded to a secure website every 15 minutes during low flow. During and following storm events when the water level reached a depth of 0.65 inches, the data were triggered to record every 2 minutes to capture the fluctuating flow rate accurately.

A GLS water quality sampler containing a 2.5-gallon polypropylene bottle, vinyl suction line, strainer, and 12-volt power supply was also connected to this system. When the data started to record every 2 minutes, the sampler began “pulsing” with every 2 gallons of stormwater that passed through the velocity meter. After 38 pulses (76 gallons), an 80-milliliter sample was extracted from the pipe through the suction line. This continued throughout the storm event until the level in the pipe dropped below 0.65 inches. Because of the efficient accessibility and timeliness of the website, the team could determine when the sampler was triggered after a storm event began and when the runoff had ended.

A local water-testing laboratory was contracted to collect water samples and test them for total TP and TSS. When a sufficient composite sample had been collected, the laboratory retrieved the sample, replaced the sample bottle, and performed water quality tests on the composite sample.

Results

Water Quantity

Rainfall and corresponding stormwater runoff monitoring indicates that, for the five rainfall events measured, the Complex site retained a significant portion of rainfall, with limited or no runoff, and that the site meets the stormwater quantity and quality requirements for the relevant LEED-NC credits.

The amount of runoff retained during a given rainfall event indicates how well a site meets the LEED-NC criteria for stormwater rate and quantity (SS credit 6.1) as well as treatment (SS credit 6.2). Specifically, sites that do not generate significant quantities of runoff but instead capture, infiltrate, reuse, or evapotranspire rainfall are similar in hydrologic behavior to the natural, undisturbed landscape. Because stormwater pollutants are conveyed in runoff, reduced runoff volume corresponds to a reduced pollutant discharge. In addition to the amount of runoff generated, the rate at which water is discharged from the site is also indicative of a site's performance. Sites that significantly reduce the volume of runoff are more representative of natural conditions than urbanized conditions.

Over the course of the evaluation, five rainfall events ranging from 0.22 to 1.09 inches of rainfall were measured at the site. For each of these rainfall events, the volume of rain falling on the site was compared to the volume of water discharged from the site. Figure 3 shows a summary graph of the "percent capture" for each rainfall event. The largest rainfall event, 1.09 inches, was on September 27, 2010, over a period of nearly 21 hours. Seventy-four percent of the rainfall was retained on site. For the smaller rainfalls, the site retained 87% to 100% of the rainfall. Most storms that occur on an annual basis are less than 1" in magnitude. Therefore, the sampled storms are representative of typical storms.

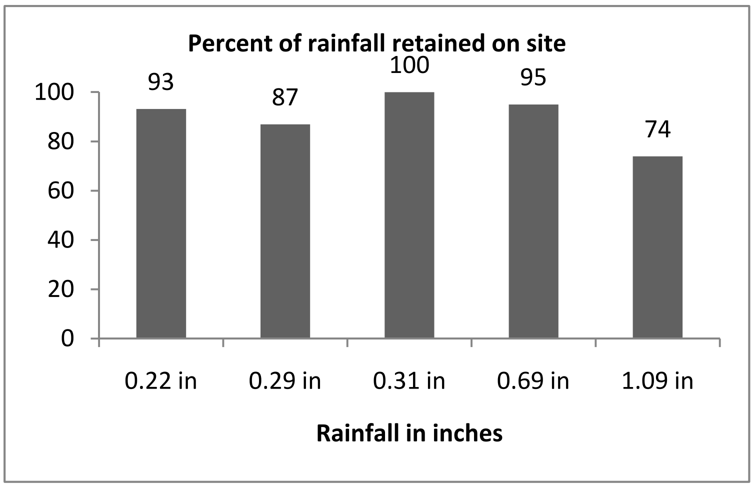

Figure 5: Summary of rainfall retained on site

Table 5 summarizes the data collected for each monitored storm event and analyzes the precipitation and flow data to determine the site runoff response.

For each storm, the following information is provided:

- Depth and duration of precipitation,
- Precipitation volume over the site area,
- Time between the start of rainfall and measured stormwater discharge,
- Total volume of stormwater discharge (in gallons and cubic feet),
- Depth of discharge over the site area (in inches),
- Duration of discharge, and
- Percent of precipitation captured by the site.

Storm	Date event began	Total precip	Total precip over site	Duration of precip	Time until discharge	Total discharge	Total discharge	Total discharge over site	Duration of discharge	Percent rainfall captured
		in.	cf	hr	gal	cf	in.	hr	hr	%
1	12-Sep	0.31	2,813.00	4.67	4.00	2.15	0.29		0.50	99.99
2	17-Sep	0.69	6,262.00	12.67	3.92	2,348.26	313.90	0.03	27.00	94.99
3	23-Sep	0.22	1,996.00	3.25	1.17	1,021.22	136.50	0.02	50.75	93.16
4	28-Sep	1.09	9,892.00	20.41	13.83	19,291.00	2,579.00	0.28	89.58	73.93
5	3-Oct	0.29	2,632.00	15.33	2.33	2,584.00	345.00	0.04	34.75	86.89

Table 5: Rainfall and discharge summary, Sept.-Oct. 2010

In addition to the above summary table, *Appendix C: Hydrographs from Rain Events* contains summary tables and flow hydrographs (plots of discharge over time) for each monitored storm event.

Based on the storms monitored, CBE determined that the site stormwater management is performing well and meeting the intent of LEED-NC SS credit 6.1, for stormwater quantity. For most storms, the percent capture was very high (more than 90%). The site performed very well even during the largest monitored storm event of 1.09 inches, when 74% of the rainfall was retained on site.

LEED-NC Version 2.1 criteria for stormwater quantity are intended to encourage site designs that manage stormwater to provide stream and channel protection. Although the credit's intent is to eliminate stormwater discharge through on-site infiltration, it only requires that the peak rate of runoff, not the volume, from a site be managed. Specifically, the credit requires, for sites that are less than 50% impervious, that the post-development peak rate for the 1.5-year, 24-hour design storm be equal to or less than the existing peak rate.

Based on the LEED-NC documentation for this credit, it is unclear whether the site is actually mitigating the 1.5-year design storm peak. The narrative indicates that the stormwater management on site was designed to capture and infiltrate runoff while providing peak rate mitigation for the 10-year storm by controlling the rate of discharge to meet Oakland County release rate requirements. It is important to note that management of larger storms does not necessarily mean that smaller storms will also be managed, and in some cases the opposite is true. However, based on the performance monitoring undertaken as part of this post-occupancy evaluation, it appears likely that the site is in fact managing the 1.5-year peak rate.

More important from a water balance perspective is the site's rainfall capture. Rainfall capture is indicative of the site's ability to "absorb" rainfall rather than discharge it as stormwater runoff. Recent guidance on stormwater management for federal facilities (U. S. EPA 2009) determines that a site can maintain or restore natural hydrologic conditions by retaining 100% of the runoff volume generated during a 95th-percentile storm. The 95^{th}-percentile event is determined on a site-by-site basis from historical rainfall records.

At the Kresge site, the 95^{th}-percentile storm event is approximately 1 inch (developed from the 37-year daily rainfall record). The stormwater flow monitoring indicates that for small storms up to 0.7-inches, the site is retaining nearly all the runoff. The flow data from the September 27, 2010, storm, in which 1.09 inches of rain fell, indicates that although the site performed very well for this storm (achieving 74% capture), it fell somewhat short of the abovementioned new federal guidelines. Even though the site did not quite meet the new guidelines for this storm, the site can manage about 64% of the total annual rainfall volume (determined by evaluating the depth of rainfall captured on site from monitoring data and comparing that to the historic rainfall records). This is very high performance for a built site; parking lots and roofs generally capture 0-1% of rainfall volume.

Water Quality

LEED-NC Version 2.1 criteria for stormwater quality specify that site designs must include stormwater treatment systems designed to remove 80% of the average annual post-development TSS and 40% of the average annual post-development TP based on the average annual loadings from all storms less than or equal to the 2-year, 24-hour storm.

Water quality samples were collected from the Kresge site on October 28, 2010, and analyzed for TSS and TP to verify removal of 80% of the average annual post-development TSS and 40% of the average annual post-development TP, as required by LEED-NC SS credit 6.2. The testing methods for both TSS and TP are standard U.S. EPA methods that are practical for surface, saline, and drinking waters, and domestic and industrial wastes applications.

Table 7 shows the results of this analysis with the concentration of each pollutant measured in milligrams per liter (mg/L) and the minimum pollutant detection limit for each test method:

Table 7: Water quality results from October 28, 2010

Parameter	Sample result	Units	Testing limit	Method
Total phosphorus	<0.1	mg/L	0.10	SM 4500P E
Total suspended solids	<4.0	mg/L	4.00	SM 2540 D

The measured pollutant concentrations of the sample were below the standard detection limit for both TSS and TP. Testing results for both Total Suspended Solids and Total Phosphorus indicated that neither pollutant of interest was detected in the sample. LEED requires that 80% and 40% of TSS and Phosphorus, respectively, be removed prior to discharge. Since the sample indicated that neither pollutant was detected, the LEED requirements are likely being met. It should be noted that only one storm was sampled for water quality and more sampling would be preferred to better assess long-term water quality performance.

This analysis is a discrete sample from one 0.5-inch storm event; therefore, it does not give a complete picture of the site's annual pollutant discharge. However, we can infer that stormwater discharged from the site is likely meeting the LEED-NC standard based on the combination of the pollutant concentration and the quantity (discharge volume) of sampling results.

Pollutant loads generated from a site are typically associated with the early part of a storm, which carries the greatest pollutant load as it washes accumulated materials (sediments and nutrients) from land surfaces. Therefore, water quality management is a function of volume capture, particularly small storm volume capture, which is designed to manage runoff volumes from small storms on site with little to no discharge. The results of the quantity analysis indicate that the stormwater measures and landscape on the Kresge site performed very well in retaining runoff volumes from small storms throughout the monitoring period. Therefore, it is highly likely that the site is providing a significant water quality benefit that meets LEED-NC SS credit 6.2 standards by reducing pollutant discharge through both quantity management and vegetative filtering by the landscape.

Data Anomalies

During the course of the monitoring, we found several data anomalies, mostly related to flow in the discharge pipe when no rainfall was recorded. In the month of October, a series of discharge surges in the pipe affected the monitoring program. Through interviews with the site manager (Grabowski 2010), we learned that these flow surges were the result of an on-site sump pump used to dewater the building foundation drains. The sump pump is directed to the cistern in warmer months and to the bioswale drainage system in the winter. The cistern was drained on October 21, 2010, for winterization, and the discharge surges began following this event.

Three rainfall events occurred following the introduction of the sump pump flow to the monitored pipe. Because it is nearly impossible to accurately separate the discharge associated with surface runoff from the sump pump discharge, our analysis did not use the flow data from the period after the sump pump discharges began. However, we can infer from the total rainfall and from the total cumulative discharge during and following these rain events that only about 13% of the total cumulative rainfall was discharged from the site. So, for small storms (under 0.5 inches), the site's percent capture was 87%.

Conclusion

Based on the performance measured in the course of this evaluation, the Kresge site is meeting the intent of LEED-NC SS credits 6.1 and 6.2. Additionally, comparison of the measured results to standard engineering stormwater methodologies, such as the USDA Cover Complex Method, indicates that the site is managing stormwater more like a "natural woodland" than a built site. This method indicates that a comparable natural woodland site would not generate runoff until approximately 0.86 inches of rain falls. The high percent capture measured to date indicates the site is performing very well. If additional and larger rainfall events can be measured, this will provide further information on the performance as the site becomes "saturated." The Complex site did not meet recent federal criteria for demonstrating "natural hydrologic conditions," which require that sites retain 100% of runoff generated during a 95th-percentile event although the site did capture 74% of the only large storm measured to date.

In sum, our analysis shows that the Complex site stormwater management is performing at a high level. Rainfall from most small (0.5-inch) storm events is completely retained on site, and 95th-percentile (1-inch) storm rainfall is also mostly retained on site. The stormwater and landscape design performs very well to provide significant water retention and reduced pollutant loads through prevention of pollutant generation, mobilization, and transport from the site. This site serves as a prototype for integrated site design techniques that meet the standards of both the LEED-NC rating system and the Sustainable Sites Initiative.

Landscape Water Use and Biodiversity

Background

The Complex site is surrounded by office complexes, retail stores, and expanses of surface parking. The site designers sought to avoid the typical landscape design of lawn, trees, and shrubs, to reduce potable water use for irrigation, and to promote biodiversity and habitat by landscaping with meadows and other native plant communities.

The Complex site belongs to the U.S. EPA's level 3 Michigan/North Indiana Drift Plains ecoregion. This area is characterized by glacial moraines and flat lake plains of oak savannah and fire-dependent prairie. The Complex site includes 1.70 acres of planted area (landscape). Local monthly precipitation averages 2.5 inches and is evenly distributed throughout the year.

Potable water is becoming increasingly valuable and expensive to provide. Utilizing other (less energy-intensive) water sources and reducing irrigation demand are two of the most effective ways of conserving potable water and the energy needed to treat and distribute it. Lawn is among the most water-intensive landscape types and is pervasive in built landscapes in the U.S. Generally speaking, native plants installed in suitable locations, accustomed to natural rainfall cycles of the region, should not require additional water inputs beyond rainfall and snowmelt. For these reasons, point-based construction and land/building management standards such LEED, the Sustainable Sites Initiative (SITES), and the Living Building Challenge value both water conservation in site maintenance and plant designs that emphasize native species either within their point-based schemes or as a prerequisite to certification.

LEED-NC has two credits for water efficiency (WE credits 1.1 and 1.2), which can be achieved in the following ways:

- Supplying 100% of irrigation with non-potable water sources and reducing water use by 50% minimum, and
- Providing no permanent irrigation system or using no potable water for irrigation.

At Kresge, a permanent irrigation system is utilized for the green roofs. Site water-reduction strategies include landscaping almost exclusively with native species found in the ecoregion. Allowing for irrigation during the first 2 years when the plants are becoming established, such a strategy might result in:

- Less potable water use than conventional landscapes (and resulting financial savings),
- Two of 14 possible site-related LEED-NC points toward the overall goal of a LEED-NC Platinum rating, and
- A lower maintenance budget than for conventional landscapes.

The landscape and biodiversity portion of this study sought to validate conformance with site LEED-NC credits; however, the intent of the site design went beyond LEED-NC conformance and included other sustainability design goals not captured by the LEED-NC points system:

- Creating a model of sustainable "green" design for grant recipients/candidates and others as a form of public awareness or outreach,

- Creating an appealing environment that attracts and retains foundation employees and welcomes visitors,
- Achieving energy use, water use, and long-term expense (maintenance) efficiencies, and
- Promoting awareness of green practices within local government.

Methodology

The CBE team evaluated the performance of the Kresge site's landscape design in the following areas:

- Potable water conservation as defined by LEED and SITES (American Society of Landscape Architects),
- Biodiversity of the site (using the Michigan Floristic Quality Assessment [FQA]), and
- Maintenance impacts of the site's sustainable design as compared to a hypothetical conventional design.

The team carried out the analysis in early 2010 by inspecting the site, including its water conservation mechanisms, and interviewing key managers and comparing water efficiency results to the criteria for LEED-NC WE credits 1.1 and 1.2.

We assessed use of potable water in the landscape by:

- Review of the water harvesting and irrigation system for the site and the green roofs,
- Observation and inquiry about any opportunity for or actual use of potable water as irrigation on site, and
- Modeling the water efficiency of the site using the LEED-NC methodology for WE credit 3.1, this method requires modeling a baseline landscape water requirement (BLWR) using an equation established by the U.S. EPA, and comparing it to the designed landscape's water requirement (DLWR). The site is compliant if DLWR is less than or equal to 50% of BLWR. Figures 5 and 6 illustrate the baseline and designed landscape, respectively.

The study of landscape-related LEED-NC designs for water-efficient landscaping (also related to WE credits 1.1 and 1.2) included the review of vegetated systems such as meadows, bioswales, green roofs, and detention basins. A site survey of the vegetation was conducted to determine whether:

- Native vegetation is dominant since installation in 2004,
- Native vegetation existing on site is used appropriately to reduce water demand,
- Bioswales and other function-driven plant communities are performing in conformance with the intent of WE credits 1.1 and 1.2, and
- Native plant communities could be providing a larger habitat value to the region.

Field investigators were on site for two days (May 12 - 13, 2010) and examined each planting zone as defined by landscape construction drawings[11] and specifications for lawns and grasses, which include seeding for meadows and erosion control. Wetland, emergent, and aquatic zone plants[12] were not investigated because of rainfall, saturated soils, and the timing of the investigation. Investigators walked the other plant zones, identifying as many plants as could be determined using their knowledge of plant species and a variety of field guides and identification tools.[13] Physical samples and photographs were taken to identify plants that could not be identified successfully in the field.

The identified plants were tabulated using a spreadsheet. Each species was tabulated according to:

- Whether it was an intended species or a volunteer (not listed in landscape construction drawings or specifications, might have been imported from other sources), and
- The floristic value of each species as determined by the Michigan FQA (Herman et al. 2001)

FQA is a tool for assessing the floristic significance or biodiversity of plants in a given area in Michigan. Floristic significance is an important measure of plants' forage and habitat value to animal species. The research supporting Michigan's FQA establishes a coefficient of conservatism ranging from 0 to 10 where each plant species is rated according to its ecological importance to pre-European settlement ecosystem conditions. An alien plant has a coefficient of conservatism of 0 while plants found exclusively in remnant plant communities (undisturbed by European settlement) have a coefficient of conservatism of 10. Using this rating system, a mean coefficient of conservatism can be established for a given site. The following excerpt from Herman et al. (2001) describes a baseline against which to compare the results from Kresge:

- Based upon recent tests of the FQA system in Michigan in a wide variety of habitats, certain patterns have emerged. The range of coefficients of conservatism (*C*) of the plant taxa found in most of our undeveloped lands is 0 - 2, whereas 85% of the total native flora has a *C* of 4 or greater. The entire native flora has a *C* of 6.5. This indicates the principal elements of our native systems are poorly represented in the landscape today. Most of the remaining undeveloped land registers floristic quality indices (FQI) of less than 20 and has minimal significance from a natural quality perspective. Areas with an *FQI* higher than 35 possess sufficient conservatism and richness that they are floristically important from a statewide perspective. Areas registering in the 50s and higher are extremely rare and represent a significant component of Michigan's native biodiversity and natural landscapes. Generally, if the *C* for the site is 3.5 or higher or has an FQI of 35 or more, one can be confident that the site has sufficient floristic quality to be at least of marginal natural area quality. If the *C* is 4.5 or higher, or has an FQI of 45 or more, then it is almost certain that the remnant has natural area potential.

We have not arrived at these threshold values arbitrarily. The best efforts of *de novo* ecosystem restoration attempts rarely achieve *C* values higher than 3.5 or FQI values higher than 35. It then follows that when an area with higher values or indices is destroyed it cannot be replaced by an area of equal value and, therefore, is an immitigable event. The difficulties in restoring areas of high quality lie in our inability to assemble the complex diversity of biotic and a-biotic factors needed in order to support a full

[11] Drawings L0.0 – L4.7
[12] Drawing L4.08
[13] Brown 1979, Embertson 1979, U.S. EPA level III ecoregions map: http://www.epa.gov/wed/pages/ecoregions/level_iii.htm, Newcomb 1977, Tekiela 2002, Tekiela 2000.

complement of species conservative to that habitat. In actuality, remnant areas with FQI approaching 60 or higher are very rare, and occupy a minute fraction of the remaining vegetated land surface of the region.

Results

Our analysis determined that the Kresge Complex landscape complies wit*h its s*tated goal of greater than 50% reduction in dem*a*nd for irrigation compared to the BLWR. The water-efficient design saves approximately 800,000 gallons of potable water each year compared to the BLWR. However, the 4-year establishment period for the site landscaping was 2 years longer than expected and, through 2009, required irrigation with potable water to levels that exceed LEED-NC Version 2.1 tolerances. We expect was compliant with LEED-NC WE credits 1.1 and 1.2 during 2010, but this needs confirmation.

Analysis of the current landscape's biodiversity using the Michigan FQI indicates that the site is a significant contributor to regional plant di*vers*ity. The site's FQI is 39.8, with a C of 3.79.However, an environmentally sensitive approach to maintaining the varied plant communities is labor intensive and effectively doubles maintenance costs compared to those for a conventional landscape of equal size maintained using conventional chemical inputs and machinery.

Irrigation

The site was built with a temporary irrigation system for the landscape and a permanent irrigation system for the green roofs. To comply with LEED-NC WE credits 1.1 and 1.2, the site design uses a stormwater cistern to capture rainwater from rooftops; this captured water is intended to meet the entire water demand for green roofs. In addition, site designers selected plants that reduce total irrigation demand by at least 50% against the BLWR. The cistern also supplies a retention basin (pond) by way of a grinder pump when the basin level is low enough to need additional water. Conversely, the pond can supply the cistern if there is irrigation demand on the green roofs. A separate potable water connection to the irrigation pump was implemented to address temporary site irrigation demand during the plant establishment period. There is no potable water connection to the cistern itself, so the only potable water source for irrigation is at the backflow preventer; this was intended to be eliminated once landscape plants were established or plants on temporary irrigation reached maturity. Site maintenance personnel explained that they did not plan to recertify the irrigation backflow preventer permit with the City of Troy and to decommission the potable water connection to the temporary irrigation system during summer 2010.

The site has approximately six potable water hose bibs located at various exterior building walls. Site inspection revealed that these six hose bibs were not actively used for irrigation in 2010. According to interviews with contractors Karl Koto and David Grabowski (Grabowski 2010), who are responsible for site maintenance, potable water was used for irrigation from 2005 to 2009. Potable water from hose bibs is also used for cleaning windows and washing the building's white, heat-reflective roof annually, which is acceptable under LEED-NC. However, use of potable water for irrigation would place the building out of compliance with LEED-NC WE credit 1.2. The reason for the potable water irrigation use is explained in the *Plantings* section, below.

Investigators computed both BLWR and DLWR according to the SITES methodology. The baseline landscape water requirement for a hypothetical conventional site is 266,946 gallons per month during the peak watering month (July) (see Figure 6: Baseline landscape design). The designed landscape water requirement (DLWR) for the actual site with temporary irrigation is within the range of 53,174 to

170,070 gallons of water per month during the peak watering month (see Figure 7: Design landscape with temporary irrigation).

The water demand of a plant species is identified as its coefficient value (K_L). Using the worst-case K_L for each plant group, the site uses 36% less water than the BLWR. However, using a more realistic K_L, for moderate water consumption by plants, the Kresge site uses 80% less water than a conventional site. It is therefore likely that the site complied with LEED-NC WE credit 1.1 and SITES 3.1 up to and including 2009.[14]

The predicted DLWR for the established site (after temporary irrigation is fully decommissioned) is approximately 23,000 gallons (assuming an average water demand among plant groups) (see Figure 8: Design landscape after irrigation). Accounting for both worst-case and realistic plant water demands, the site will use 86% to 97% less water than a conventional landscape and will therefore exceed LEED-NC standards. The hypothetical conventional landscape would use at least 228,659 gallons more water in the peak watering month than the established designed landscape at the Complex.

Planting

According to interviews with site managers Koto, Grabowski, Cynthia Powors, and Dick Rappleye, plantings at the site in 2004 did not establish well initially (Grabowski 2010). It is not uncommon for many forbs (especially native prairie forbs) to take several growing seasons to germinate and for shoot growth to remain marginal or even nonexistent during those seasons. Because plants in the frontage area and other zones did not grow and establish in a manner that was satisfactory to the owners or the maintenance contractor, those areas of the site were over-seeded with native prairie forbs in 2008.

The original design called for seeding of a checkerboard pattern of different plant communities along the property's frontage. This seeding was eliminated in the construction phase along with all bulbs. The frontage planting plan was simplified to incorporate the broad seeding of prairie species used elsewhere on the site (see Figure 8: Design landscape after irrigation). Coupled with this was a low-temperature burn of most of the planted site in 2008. This combination of activities (planting design simplification, large-scale reseeding, burning, temporary site irrigation, and regular hand weeding) is responsible for the establishment of the landscape.

Site-wide investigations found 53 of the 68 intended species on the property as well as 32 volunteer species. Although investigators sampled each plant community zone by quadrant, they concluded with reasonable certainty that the intended plant communities have established dominance, based on the overall extent of intended species and the relatively uncommon occurrence of volunteer species. Not all plants prescribed in the landscape construction drawings and specifications were found in the field; some might not have germinated or erupted at the time of inspection.

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[14] Water demand can be calculated using guidelines such as those provided by the U.S. EPA's Watersense calculator (the suggested calculator for SITES). However, one subjective variable is the landscape coefficient value. The landscape coefficient value (K_L) is a subjective determination of a plant species' water needs. The investigator is asked to provide a coefficient value based on the gross water needs of the species (low, medium, or high). There is no centralized peer-reviewed source for K_L values for different species. Moreover, the water demands of a species are difficult to generalize. Individuals within a genera or even a species can vary based on the environmental stresses to which they are subject. This study bracketed K_L by using a worst-case and best-case set of values for both the temporary and established landscapes. Utilizing the worst-case K_L for the establishment period where temporary irrigation was used would have led to the site being out of compliance with LEED-NC WE credit 1.1 and SITES 3.1.

In mid-May, 78% of intended species were present on the site, and volunteer species made up 32% of all plants species found. For the plants identified, the coefficient of conservatism among intended plants was 5.09. The mean coefficient of conservatism of the entire site (counting volunteer and naturalized plants with a 0 value) was 3.79. The FQI was 39.8.

Although intended species are numerically dominant at the site, this condition cannot be expected to persist without continued hand weeding, occasional controlled burns, and other measures. The need for persistent weeding indicates that intended plant communities do not exclude weed species and therefore cannot be truly dominant. The isolated nature of the site is such that new species will be continually introduced by birds, wind, insects, and other vectors.

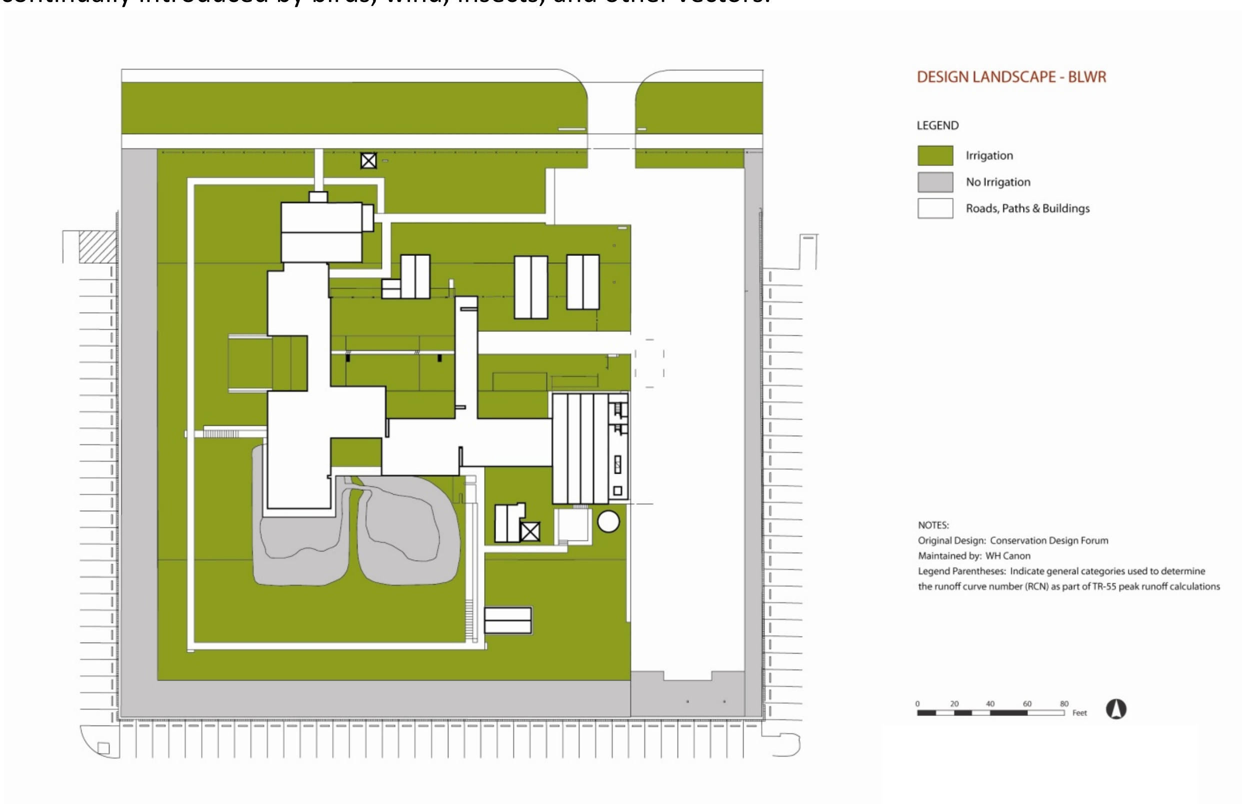

Figure 6: Baseline landscape design

Figure 7: Design landscape with temporary irrigation

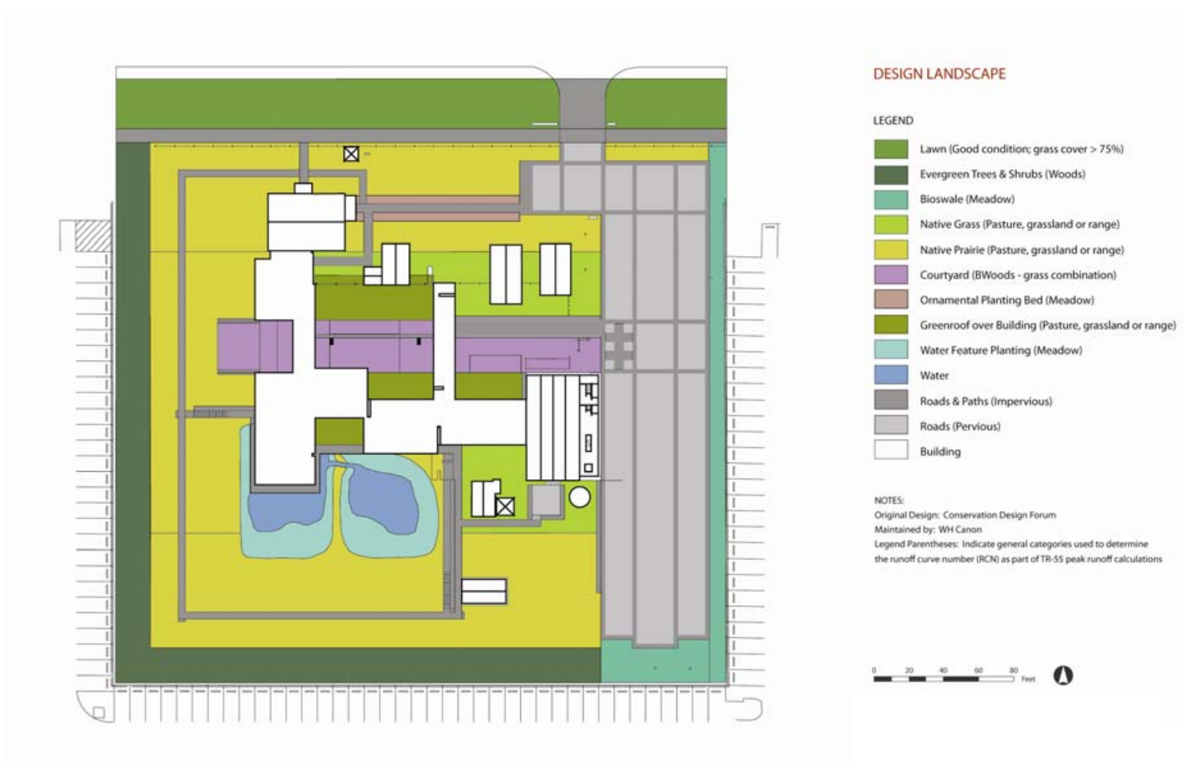

Figure 8: Design landscape after irrigation has been removed

Table 8 shows the results of the Kresge site flora survey compared to state benchmarks.

Table 8: Comparison of Kresge site to state flora benchmarks

	Statewide benchmarks	Kresge site
Mean coefficient of conservatism of intended native flora	4 or greater	5.09
Minimum FQI indicating "floristic importance"	35 or greater	39.8
Minimum site-wide coefficient of conservatism value indicating "marginal natural area quality"	3.5 or greater	3.79

Maintenance

It seems logical to assume that a sustainable landscape would not require intensive long-term maintenance, but investigation suggests otherwise, and the Kresge site exemplifies this. Annual maintenance of a hypothetical conventional site design using conventional practices and tools (herbicides, synthetic fertilizers, gas-powered mowers, trimmers, etc.) might cost half of the Complex's current annual maintenance costs. The time-intensive and somewhat skilled labor required to hand weed the Complex's 0.93 acres of herbaceous plants costs five times more than the cost of maintaining conventional lawn. The maintenance analysis, using a nationwide average cost[15], indicates that the Kresge site should have a $53,000 annual maintenance budget (see Table 9) whereas a hypothetical conventional landscape would have a $22,000 annual maintenance budget.

The cost of potable water for irrigation should be considered as well in assessing maintenance costs. The irrigation models predict that the hypothetical conventional landscape would require at least 228,659 gallons in the peak watering month, which equates to roughly $1,400 in July.[16] Total annual watering costs for the growing season could be three to four times that amount or about $5,000 (about 800,000 gallons of potable water) for a conventional landscape, compared to about $600 for the Kresge site once the native plants are established. While this constitutes a real savings, it does not significantly bridge the total landscape maintenance cost gap described above.

The current landscape maintenance contractor believes the nationwide costs used in our analysis are double the local rates in Troy but agreed that a conventional landscape of equal size and similar outdoor program maintained using conventional methods would cost 50% less to maintain.[17] Alternative landscape designs may achieve some or all of the stated goals without incurring as additional maintenance cost (see discussion). However, the size and location of the site subject it to a near-constant addition of weed and other plant species, which requires at least some degree of hand weeding and added cost.

Although conventional maintenance tools and methods appear to reduce workloads and costs associated with maintenance, they come at great expense to biodiversity, carbon footprint, and air and

[15] MEANS SiteWork and Landscape Cost Data 2010 was used. The landscape has been modified each year, so actual costs are unknown. Thus, the national average is probably the best data.

[16] City of Troy Water Department. Data retrieved by phone call (09/08/10): A unit of water consumption = 748 gallons = 100 cubic feet = $4.59

[17] Analysis includes water, gas and labor.

water quality. However, these costs/externalities are not factored into a traditional maintenance cost comparison.

Table 9 summarizes the findings of the site landscape study.

Table 9: Comparison of designed site to conventional site

Criterion	Designed site	"Conventional" site
LEED-NC compliance	No (2009) Yes (possible in 2010)	No
Annual potable water use	28,000-134,000 gallons	800,000 gallons
Annual maintenance costs (including water use)	$54,000	$27,000
Plant species diversity (FQI)	39.8	Less than 35

Discussion

This study constitutes just one approach to implementing a post-occupancy assessment of a LEED-certified site and field verification of LEED-NC performance. Landscape establishment took at least 4-5 years at this site; a follow-up assessment 5 to 10 years from now might reveal a change in landscape maintenance, costs, and the characteristics of the plant community. A quadrant study of plant frequency is necessary to meaningfully measure changes in plant community. If the numerical dominance of intended species increases, this might result in reduced maintenance.

Designers could have taken a less species-diverse approach to planting. Landscape designers used a broad range of forbs to recreate the look and ecological function of a prairie. However, the selection of fewer prairie species with an emphasis on durability, habitat, flowering sequence, and other site objectives might have resulted in earlier establishment of plants and thus might have reduced maintenance needs. This approach might not have yielded such a high FQI or coefficient of conservation, however. A smaller plant palette might also increase the likelihood of landscape failure or damage from pest infestations.

The site design and its maintenance go beyond LEED requirements. The selection of native water-efficient plants over exotic and naturalized species (which may or may not be water efficient) is laudable and serves the owners well in their outreach and education for sustainable design and land use. Although we cannot comment on the role the site landscape design might play in helping the owner retain staff (one of the owner's goals), it is evident that the site functions as an example of green design both for the owner's network of clients and for the City of Troy. There is no evidence that the City of Troy has adapted or changed any of its site-related building codes because of the Kresge design, however.

Because of the project's small size and suburban location, the site has only a minor positive impact on regional ecosystem health. Current plant communities on the site will likely act as seed banks for propagation elsewhere, but the isolation of the site from other natural or fallow areas diminishes this value to the larger ecosystem. The site's plant communities might provide forage and shelter for a limited number of other species (insects, birds, and mammals common to disturbed areas) but do not constitute refuge for significant populations. This island population of native species is subject to nearly continual import of naturalized and exotic species. The 2008 efforts to reseed and support intended plants were successful, though the landscape will likely remain dependent for the near future on hand weeding and occasional controlled burns to maintain the native species' dominance over invasive plant species.

Acoustics

Background

While the Complex's acoustics meets PMP guidelines, and the building is among the higher scoring buildings in the CBE Occupant Satisfaction database in acoustics (see *Appendix B: Survey Report*), occupants gave the Complex's acoustic quality the lowest satisfaction rating of the IEQ factors considered in the survey. Sound privacy appears to be partially responsible for this result. This section presents results from measurements of sound levels throughout the Complex as well as recommendations for mitigating acoustic issues as reported by occupants.

Methodology

The acoustic performance of the Complex was assessed through responses to the CBE occupant survey and on-site measurements. During the team's winter visit (March 2-4 and 16, 2010); measurement of a-weighted sound pressure levels (L_{eq} in dB(A)) was conducted in the occupied space according to PMP basic performance method.

The acoustic measurements were performed with rooms in three states: vacated by normal occupants, with normal occupants present (March 2-4, 2010), and with no occupants outside the room (March 16, 2010). Appendix D reports the floor area and surface characteristics of the rooms where the measurements were taken. Figures D-1 and D-4 in Appendix D show the room number assignments for the spaces that were measured. All non-HVAC-related sound-producing equipment (radios, etc.) was turned off for the duration of the measurements. The HVAC equipment or system serving the room during the measurement period was in normal operating condition, and the measurements were performed with the HVAC system operating in a steady-state condition. In selected environments, the sound pressure level was measured with private office doors open and closed.

The minimum duration of each measurement was 30 seconds. The measurement microphone was hand-held in all the measurements. A moving microphone tends to provide a sound level more representative of the room average sound level, compared to a motionless microphone, especially if the background noise spectrum contains tones. In all the measurements, the sound meter was kept roughly in the center of the room with a distance of more than 1 meter (m) from each surface and a height of roughly 1.4 m.

Measured sound pressure levels were compared with sound criteria from Table 3-10 of PMP (ASHRAE 2009). Measured sound pressure levels were compared with the recommended sound criteria reported in Table 10. The main limitation of a-weighted sound levels is that they give an overall measurement without respect to individual frequency components. Depending on the spectral characteristics (high- or low-frequency components, discrete tones, etc.), identical a-weighted sound level readings can cause significantly different degrees of annoyance. Acoustic conditions that create a high degree of annoyance are typically identified by occupant surveys and may require more advanced measurement methods (e.g., intermediate level of PMP).

Table 10: Recommended sound criteria for average sound level. This table was taken from Table 3-10 (Recommended Sound Criteria for Basic Measurements) of PMP (ASHRAE 2009).

Room types / applications		Ideal L_{eq}* (dB(A))	Maximum L_{eq} (dB(A))
Outdoor ambient	Intrusion from transportation vehicle noise	40	50
Office buildings	Executive and private offices	30	40
	Conference rooms	30	40
	Teleconference rooms	25	30
	Open-plan offices without sound masking	35	45
	Open-plan offices with sound masking	35	40
	Corridors and lobbies	40	50

*L_{eq} –= sound pressure level

Results

Acoustic quality within the Complex had the lowest ranking of any category on the occupant satisfaction survey. Only 48% of occupants were satisfied with the acoustics, giving the building a 65th-percentile ranking when compared to the CBE benchmark. Thirty percent of the occupants were dissatisfied with the noise level, and 49% reported dissatisfaction with sound privacy. The main cause of dissatisfaction was conversations in neighboring areas (76% of dissatisfied respondents), audible phone conversations (70% of dissatisfied respondents), and audible private conversations (58% of dissatisfied occupants). From the survey results, it can be deduced that even if the noise level is a problem, the main concern for the occupants is privacy. Acoustics often receive the lowest rating of any IEQ factor in office buildings, and the problem is often associated with open office plans, which do not offer sound isolation. The Complex differs from this common trend, however, because more than 50% of its offices are enclosed and private. These private offices appear to be leaking sound; occupants often described hearing sounds and voices from neighboring, private offices. Conversations in the open kitchen are also a problem.

The results of the acoustics measurements are reported in Table 11.

Table 11: Boundary conditions and average sound pressure levels for the tested rooms

Room	Office spec.	Room type[1]	Max[2] [dB(A)]	Date	Time	L_{95}[3] [dB(A)]	L_{eq} [dB(A)]	L_c[4] [dB(C)]	Door	C[5]
1.14	P02	Private office	40	16-Mar	pm	N/A	28.4	N/A	Closed	G
1.19	Conf.1	Conference room	40	2-Mar	pm	30.8	31	56	Closed	G
1.20	P01	Private office	40	16-Mar	pm	N/A	37.6	N/A	Closed	Y
1.25	P01	Private office	40	16-Mar	pm	N/A	36.8	N/A	Closed	G
2.2a	Recep.	Lobby	50	2-Mar	pm	45.1	46.7	N/A	Open	G
2.12	Conf.2	Conference room	40	16-Mar	pm	N/A	31.7	N/A	Closed	G
2.15	P04	Private office	40	16-Mar	pm	N/A	31.2	N/A	Closed	G
2.20	P04	Private office	40	16-Mar	pm	N/A	29.8	N/A	Closed	G
2.25	FH.2	Private office	40	2-Mar	pm	48.2	48.6	66	Closed	R
Barn	Open-plan offices w/o sound masking		45	3-Mar	pm	49.1	49.7	68.2	N/A	R

Barn	Open-plan offices w/o sound masking	45	16-Mar	pm	48.5	49.5	66.9	N/A	R
1.Open	Open-plan offices w/o sound masking	45	3-Mar	pm	44.5	45.5	N/A	N/A	Y
1.Open	Open-plan offices w/o sound masking	45	3-Mar	pm	43.8	44.6	N/A	N/A	Y
1.Open	Open-plan offices w/o sound masking	45	16-Mar	pm	45.5	43.4	N/A	N/A	Y
Outdoor Intrusion from transportation vehicle noise		50	3-Mar	pm	45.6	51.4	N/A	N/A	Y

[1] Room type: the office type is given according to Table 10
[2] Max: The maximum value suggested in Table 10 for the given office type
[3] L_{95}: The background noise level, 95% of the measurement had a sound pressure lower than this one
[4] L_c: c-weighting sound pressure level
[5] C: comparison between the measured L_{eq} in dB(A) and the maximum value allowed (Table 10). The color-coding is described in the text below

The last column in Table 11 gives a quick overview of the acoustic performance of the room:

- Red: the measured value is higher than the maximum value suggested in Table 11 for the considered space plus 3 dB(A),
- Yellow: the measured value is within ± 3 decibels (dB) from the maximum value suggested in Table 11 for the considered space , and
- Green: the measured value is lower than the maximum value suggested in Table 11 for the considered space minus 3 dB.

The two conference rooms analyzed (1.19 and 2.12) are good acoustical environments. They have a sound level of roughly 31 dB(A), which is below the maximum allowed. Usually, low background noise levels are preferred in conference rooms to enhance speech intelligibility. These rooms are composed mainly of hard surfaces such as glass and gypsum board. In the conference room at the courtyard level, the c-weighted sound level is 56 dB(C), indicating that a significant part of the sound is at lower frequencies. Generally, occupants cannot hear such low frequency sounds if these sounds are not vibrations, so occupants do not normally perceive these sounds as a problem.

Average sound levels in the private offices were lower than the maximum limits recommended in PMP except in the farmhouse second-level offices. Low noise levels provide a pleasant work environment; however, in private office spaces, a background noise level of 40 to 45 dB(A) improves the level of speech privacy between adjacent spaces. Thus, the low reported values have both negative and positive aspects. The survey results indicate that speech privacy is a large concern in this building, suggesting that background noise levels are too low in the private offices.

In the barn, the sound level was roughly 50 dB(A), which is higher than the recommended value for open-plan areas. The main source of the elevated noise levels is HVAC noise from the return air grille located on the west wall. According to the interviewed occupants, the background noise in the barn is not a problem. The main acoustical problem is people talking loudly in the adjacent kitchen, which is disruptive to workers in the barn. Closing the kitchen door does not reduce sound levels much because the non-structural wooden slat ceiling does not provide a sound barrier.

In the open-plan offices at the courtyard level, the sound level was roughly 45 dB(A), which is right at the maximum recommended value for open-plan areas. To achieve a satisfactory acoustical environment in open-plan areas, it is often necessary to provide sound-absorptive ceilings, sound masking, sound-absorptive treatment on the walls, and adequate distance between workstations. None of these solutions has been incorporated in the open-plan area. The cost of adding these solutions would be significant, and some solutions are likely infeasible (e.g., increasing the distance between workstations). A low-cost solution could be to define and implement a more stringent policy on occupant conduct in the open-plan areas (i.e., discouraging informal meetings in the open-plan areas while providing a private space for open-plan occupants to meet and hold conversations).

The level of speech privacy between adjacent private offices is lower in offices that were recently split (i.e., offices 1.20/1.21 and 2.14/2.15; see Figures D-1 and D-4 in Appendix D). We found that the partitions separating the newly split offices provided 5 to 10 dB(A) less noise reduction than partitions in the "non-split" offices (i.e., offices 1.24/1.25 and 2.19/2.20; see Figures D-1 and D-4 in *Appendix D: Acoustics Details*). This lower partition performance, combined with the low background noise levels measured in the private offices, results in inadequate speech privacy between adjacent offices. Although we found some acoustical leaks at the partitions separating the newly split offices (i.e., at the intersection of the partition and the exterior windows and above the perforated metal ceiling), we found that the partitions overall were acoustically "weak."

The level of speech privacy between the open-plan areas and private offices (both split and existing) would generally be considered unacceptable. The inadequate speech privacy is primarily due to leaks around the perimeters of ungasketed doors.

Based on the survey results and the acoustical measurements performed during the winter visit, we conclude that:

- The main causes of the acoustical dissatisfaction at the Complex are people talking on the phone (70% of 33 occupants who complained about acoustic quality), people talking in neighboring areas (76%), and people overhearing private conversations (58%). From the survey results, we deduce that although noise levels are a problem, speech privacy is the occupants' main concern.
- In most private offices, the measured sound levels were lower than the recommended value when the measurements were taken without people in adjacent spaces performing their usual activities. This might be a problem in a building that is not very well acoustically insulated because background noise is needed to cover private conversations. In the open-plan areas, the background noise measurements were close to the recommended limits.
- The level of sound isolation provided by the walls separating private offices was average (as-built offices) to low (newly split offices). This low-to-average partition sound isolation, combined with the low background noise level in the private offices, is the primary cause of speech privacy complaints.

Recommendations

The following recommendations could improve acoustic performance in the Complex:

- Implement a more stringent policy on conduct in the open-plan office spaces (i.e., discouraging informal meetings in the open-plan areas while providing a private space for open-plan occupants to meet and hold conversations),
- To reduce occupant annoyance in the barn, develop and implement a policy that restricts and regulates meetings and talking in the kitchen, and
- To improve the level of speech privacy between private offices:

    - Install sound masking in the private offices to provide a background noise level of 40 dB(A). The sound-masking system can be adjusted/calibrated so that it is not objectionable to the occupants. Installation strategies are available to reduce the potential for complaints about the sound-masking system. The sound-masking system should be designed and commissioned to provide uniform dispersion and conform to American National Standards Institute (ANSI) E1573. We believe that sound masking will be the cheapest solution to increase speech privacy, which is the biggest issue reported in the occupant survey. Improving the sound insulation of the walls would be more expensive. This recommendation should be implemented and its efficacy determined before moving on to the next recommendation, and
    - For split private offices, improve the noise reduction performance of the partitions used to divide the original offices by adding insulation in the wall cavity and installing an additional layer of gypsum board to one side of the wall (i.e., three total layers of 5/8-inch-thick gypsum board at each partition).
- Identify the location of and seal the leak above the demising partition (i.e., at the location of the steel beam),
- Add gasketing to the doors between private offices and open-plan areas to eliminate sound leaks at the door,
- Add carpet in the corridors where there is wood floor to reduce the noise generated by walking, and
- Improve phone equipment to help reduce noise generated by people talking on the phone. Consider prohibiting speakerphones in both the open-plan and private offices.

Lighting

Background

Lighting satisfaction in the Complex is quite high and seems to meet the needs of most occupants. Yet, during a multiday site visit, CBE staff noticed lights on in most offices even when natural light levels were sufficient. Occupants also reported not using their lighting controls. This section presents results from on-site lighting measurements and describes opportunities to reduce lighting-related energy use while maintaining the already high levels of satisfaction in the Complex.

Methodology

As specified by PMP, researchers analyzed lighting survey data and physical measurements. A general evaluation was also performed through observation of lighting system operation and informal interviews with the building engineer.

The objectives of PMP-based lighting measurements are to:

- Determine the building occupants' satisfaction with the lighting,
- Rate the building's performance against benchmarks in a database of previously measured buildings, where available,
- Identify problems with the lighting, and obtain clues to their causes using occupant responses to diagnostic questions, and
- Take spot measurements of the important photometric parameters.

The first three objectives are covered by the survey results (see *Appendix B: Survey Report*) and the overall lighting evaluation. To satisfy objective 4, the CBE team made physical measurements during two visits to the site, one in winter and one in summer. These illuminance measurements were made with the Minolta T-1H handheld illuminance meter, which has a liquid crystal display and detachable sensor that gives output in lux or foot-candles (fc). Three types of environments were tested: 1) private offices, 2) open-plan offices, and 3) corridors. The measurement procedure differed in the three cases. For the private and open-plan offices, the sensor was located at the task level, usually over the desk next to the keyboard. When the worker was in the room, illuminance at the point of work was measured with the worker in his/her normal working position. For corridors, the sensor was located at 28 inches (in.) (0.70 m) from the floor. In the private offices, three lighting levels were measured: 1) overhead lights and desk lamp switched on, 2) only overhead lights switched on, and 3) no electrical light on. In the open-plan offices, only the lighting level with the overhead light on was measured; the influence of the desk light was not evaluated. The lighting level in the corridors was measured without intervention from the operator.

Daytime measurements were conducted during the winter visit, and nighttime measurements were conducted during the summer visit. Daylight conditions, date, hour, and weather conditions were recorded because they significantly affect photometric measurements. Direct sunlight was never found at the task measuring point. If direct sunlight was present in the room, this information was reported. Measurements were compared to illuminance levels recommended by the Illuminating Engineering Society of North America (IESNA).

Results

Lighting had one of the highest satisfaction ratings among the IEQ areas studied in the Complex. Eighty-four percent of occupants were satisfied with the amount of light in their workspaces, and 71% of occupants were satisfied with the visual comfort (e.g. glare, reflections, etc.) in their workspaces. The Complex scored in the 79th percentile on overall lighting satisfaction within the CBE survey database. Only 10 of 62 occupants indicated dissatisfaction with lighting. The main causes of this dissatisfaction were insufficient light or reflections on computer screens. These complaints were not specific to a particular location in the building, so lighting issues should be addressed individually. During the two site visits, the research team noticed excessive electrical lighting use. Results are summarized below:

- Almost all the desks have one or two desk lights even if only 76% of the occupants reported that they have a desk light. Some respondents might have misinterpreted the survey question and not considered the built-in desk light in the private offices,
- The great majority of tasks undertaken in the Complex are neither small in size, nor do they require particularly short visual processing time. Thus, they do not require particularly high contrast or bright conditions,
- Occupants in private offices can control the daylighting with internal shading, the overhead lights with an on/off/dimming controller, and the desk lights with an on/off switch,
- Occupants in open-plan areas can control the daylighting with internal shading, and desk lights with an on/off switch,
- In the past, occupants had reported several problems related to light flickering. In response to these concerns, 56 faulty lighting controllers were replaced. Only one person reported light flickering in the CBE survey,
- A visual inspection of exterior light fixtures determined that lights are well located and project to the ground appropriately (not onto neighboring properties or up into the sky),
- Direct sunlight can penetrate the building and reach several office workstations. In each of these offices, the occupant can control the direct sunlight with the internal shades. According to the building engineer, there are no areas where constant exposure to daylight has caused serious deterioration,
- One set of overhead lights was placed too close to a light shelf resulting in wasted light energy being reflected outdoors (Figure 9),
- Six survey respondents reported problems related to computer screen glare. In the private offices and the open-plan space at the courtyard level, computer screens have been properly situated to avoid glare; however, the screens in the open-plan space located at the farmhouse level are not correctly positioned (Figure 8).

Figure 9: Light fixtures not far enough from the light shelf, resulting in wasted reflected light energy

Lighting Measurements

The physical measurements (taken as described in the Methodology section above and shown in Appendix E) were compared with PMP-recommended illuminance levels reported in **Error! Reference source not found.**. Appendix E lists all spot illuminance measurements taken during the winter and summer visits. Individual response to illuminance level is strongly subjective and affected by several factors, including the observer's age, surface contrast, and neighboring light sources.

We were unable to verify whether the lights were dimming properly during times of ample daylight. The building manager reported that all dimmable fixtures were controlled to turn down to a maximum of 30%; we did not independently verify these settings. Many areas throughout the building had more than sufficient daylight on a bright day, without the use of any electrical lighting. The Complex has a large window-to-wall ratio, light shelves to reflect light deeper into spaces, a narrow interior zone, and an advanced lighting system—all strategies that reduce the amount of electrical lighting needed in the space. However, the lighting system is not being used fully to save lighting energy, and daylit spaces are being unnecessarily electrically lit (Figure 12).

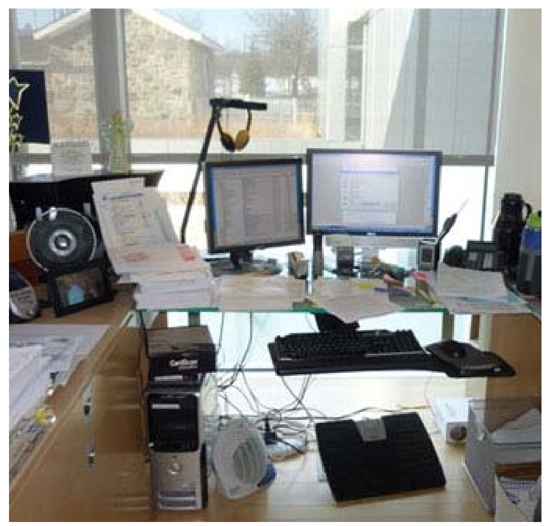

Figure 10 -- Improper orientation of computer monitor in relation to window

The recommended illuminance levels for various office tasks have changed significantly over time, indicating changing attitudes toward appropriate light levels.[18] Recent standards have provided ranges depending on computer usage (30 – 50 fc). Thus, the IESNA-recommended illuminance levels should not be taken as strict values to be met but rather as an acceptable range. Additionally, the spot measurements should be considered within the context of survey results and an overall lighting system evaluation. Room numbers were assigned according to the maps shown in Appendix E.

[18] For more information regarding the history of illuminance recommendations and how to interpret lighting levels, refer to Osterhaus (1993).

Table 12: IESNA-recommended illuminance levels

Space/task	**Horizontal or task plane illuminance – fc (lux)**
Corridors and stairs	5 (50)
Open office plan intensive video display terminal VDT* use	30 (300)
Open office plan intermittent VDT use	50 (500)
Private office	50 (500)
Meeting/conference room	30 (300)
Video conference room	50 (500)
Lobby/reception	10 (100)
Restroom	5 (50)

Winter Visits (daytime measurements)

Figure 11 displays light levels with 1: all lights off, 2: only the overhead lights turned on, and 3: both overhead lights and task light turned on in the first-floor private offices. Illuminance measurements for the other areas of the building can be found in Appendix E. There was sufficient daylight on this particular morning so that most of the office spaces did not require supplemental electrical lighting (black bars in Figure 11).

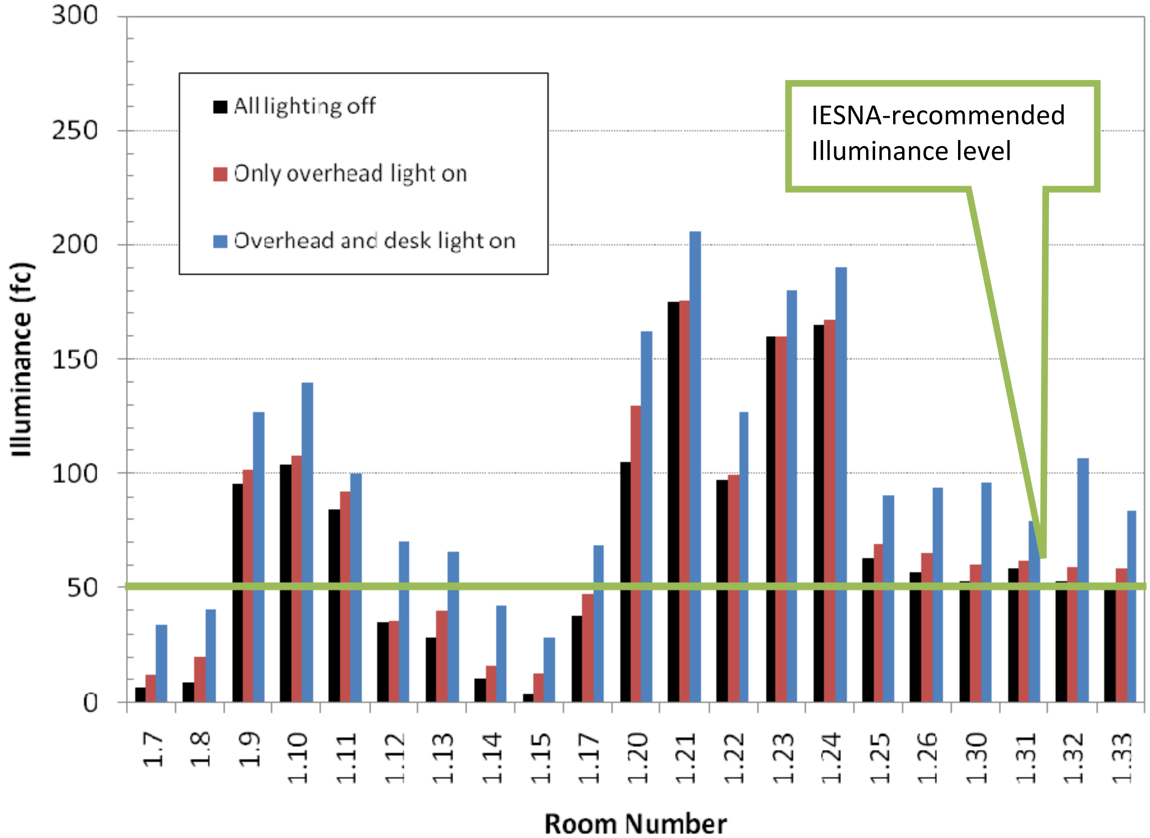

Figure 11: First-floor private office morning illuminance spot measurements (March 4, 2010 9:15 – 10:30AM)

Figure 12: Southern open office area on first floor with ample daylighting but with all light fixtures turned on

Lighting in the corridors generally far exceeded the IESNA recommended illuminance level (Figure 13). Although some corridor lights are required for emergency exit safety, most corridor lights can be dimmed or turned off during periods of adequate daylight.

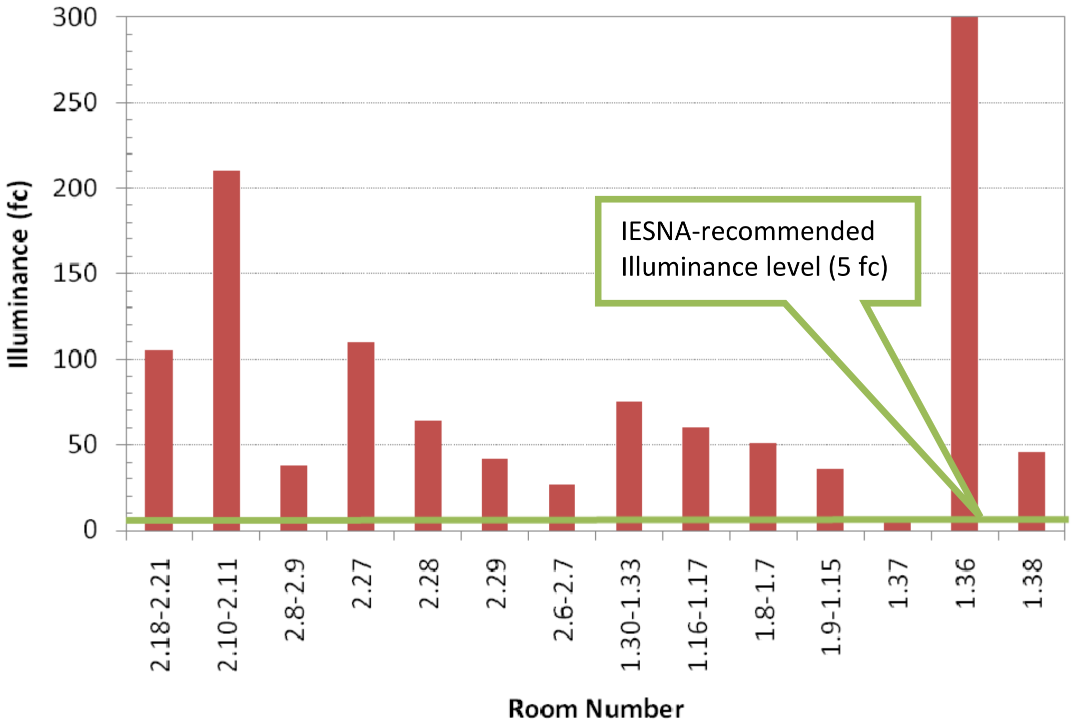

Figure 13: Corridor afternoon illuminance spot measurements (March 4, 2010 1:00PM – 1:30PM)

Summer Visits (nighttime measurements)

Figure 14 displays nighttime light levels with only the overhead lights turned on compared to light levels with both overhead lights and task light turned on in the first-floor private offices. Illuminance measurements for the other areas of the building can be found in Appendix E. The light levels measured when only the overhead lights were turned on were generally insufficient according to IESNA standards. However, when both the overhead and task lights were used, the light levels were generally sufficient. Although the light level was below IESNA recommendations in some offices, none of the measurements was low enough to cause concern unless coupled with occupant complaints.

Illuminance levels in the corridors during the evening exceeded IESNA recommendations and could be dimmed to save energy (Appendix E).

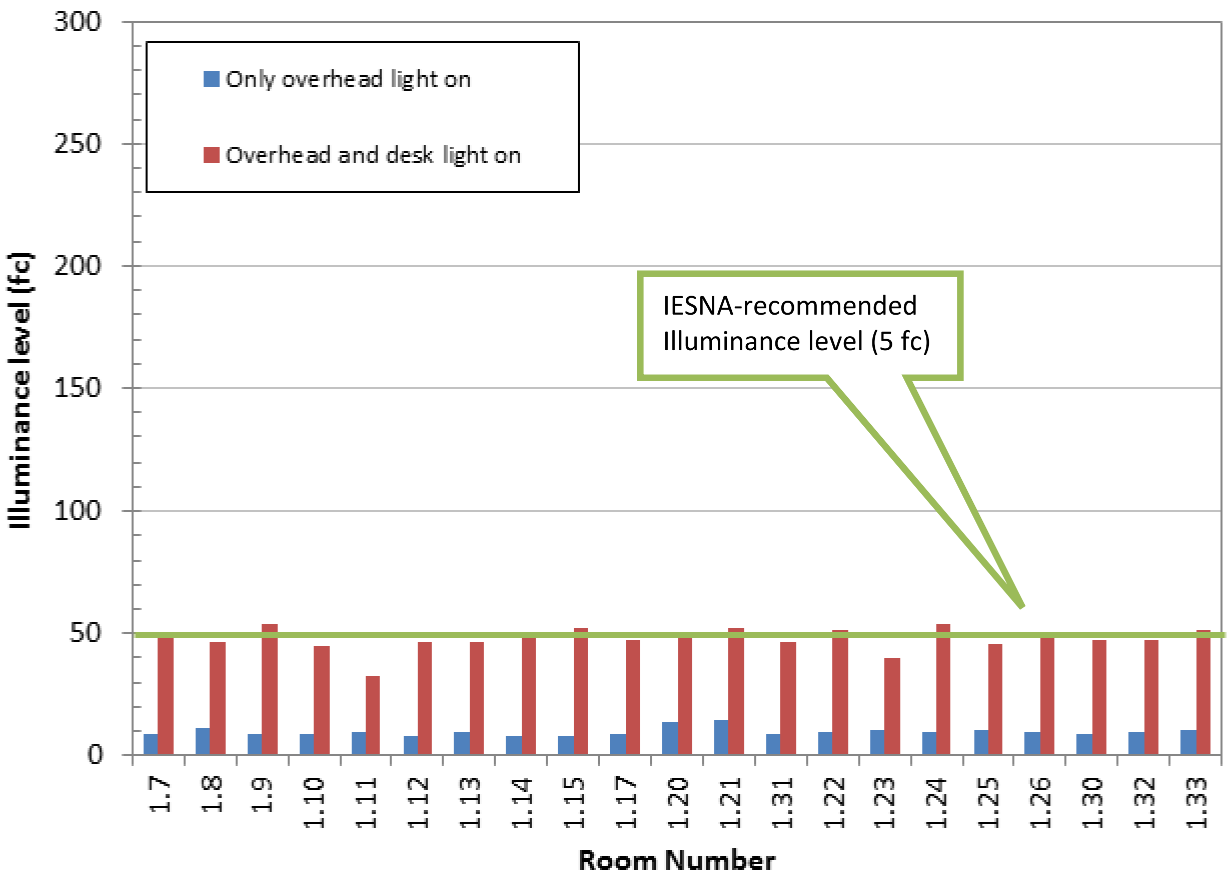

Figure 14: First-floor private office evening illuminance spot measurements (10:50PM – 11:30PM)

Recommendations

The recommendations below are based on the survey results and the lighting measurements performed during both the winter and the summer visits:

- Measured illuminance in the offices during occupied hours showed that the desk and overhead lights were switched on even when the daylighting level was higher than the IESNA-recommended level. This indicates that occupants tend not to reduce electrical lighting consumption when possible. This could be a result of: 1) the lack of knowledge regarding how to control the lighting system, 2) insufficient focus on energy saving, or 3) improper daylight harvesting system operation. We suggest the distribution of a short guide that explains how to properly regulate lighting in the office and the benefits of doing so,
- The computer screens on desks located in the open-plan space at the farmhouse level are inappropriately situated and therefore do not prevent glare. Screens should not be parallel to the windows but orthogonal to them as in the private offices. Reorientation of those screens, if the occupants agree, could solve glare problems,
- Measured illuminance levels in the corridors during the day showed that the overhead lights were switched on even if the daylighting level was higher than needed. The dimming range for the lamps controlled by ambient illuminance levels may be too small, resulting in unnecessary electrical illumination. We recommend increasing the dimming range of the overhead lamps,

- The overhead lamps located at the farmhouse level in front of the private offices close to the kitchen and the small waterfall are interacting with the light shelves. Part of the light emitted from the overhead lamps is reflected outdoors by the light shelves. This wastes energy. This series of lamps could be removed if the lighting level after removal would remain sufficient in the corridor of the floor below,
- Nighttime task illuminance levels were sufficient when the desk light was used but were not sufficient when only the overhead light was used, and.
- Occupants were largely satisfied with the lighting system and reported that it performs well. Unfortunately, the daylight harvesting system has not been tuned to achieve the desired lower energy consumption.

Indoor Air Quality

Background

Occupants' perceptions of indoor air quality (IAQ) as indicated by the CBE occupant survey were largely positive. Yet it was apparent from discussions with operations personnel that there were some questions about relative humidity, adequacy of carbon dioxide (CO_2) sensing, and other issues. In addition, Level 1 of PMP requires evaluation of ventilation performance. For these reasons, the CBE team conducted a detailed evaluation of IAQ factors.

Methodology

The IAQ assessment is based on survey results, site inspections, discussions with the building management staff, and IAQ measurements performed during winter and summer visits to the Complex. At the time of the winter visit, it was believed that trend data would be available from the BMS, so only limited IAQ measurements were performed. Subsequently trending of CO2 was started, but the capacity for capturing data remains limited overall. During the summer visit, the CBE team performed air quality measurements at the Complex. The team also collected data from the building management system (BMS), which monitors outdoor airflow, CO_2, and relative humidity. The team also took spot measurements of CO_2 and relative humidity to check the calibration of the BMS sensors. Much of the IAQ evaluation is based on visual inspections during the site visits, interviews with the building operators, and the results of the CBE survey. Radon levels measured by others are also reported.

As recognized by PMP, the number of possible chemical contaminants in indoor air is immense, and the acceptable exposure levels have been determined for only a limited number of these. PMP also recognizes that, for many chemicals, analytical measurements are prohibitively expensive whereas the human nose is a good indicator of possible concern. For these reasons, PMP stresses "perceived IAQ" (via survey and site visit results) and measurements of a few IAQ indicators (outdoor airflow rates, CO_2, and relative humidity). PMP also requires determining whether the building is in a U.S. EPA nonattainment zone (see below).

Results

IAQ was one of the highest-rated areas in the occupant satisfaction survey. One significant problem in the Complex is the location of the building exhaust adjacent to the outdoor air supply, which does not meet ANSI/ASHRAE Standard 62.1 (ASHRAE 2010). Although measured CO_2 levels were within an acceptable range during the week of measurements, this may not be true for other weather and/or HVAC operating conditions. In addition, other IAQ chemicals of concern, which were not measured, may be present at higher concentrations than would be the case with increased separation between the outdoor air supply and building exhaust. Radon concentration measurements were also well below the levels where corrective action should be taken. Summertime relative humidity measurements were also within acceptable limits; however, winter relative humidity measurements were lower than ANSI/ASHRAE Standard 55 (ASHRAE 2004) requirements. The lack of any functional way to record BMS trends is an impediment to the evaluation of IAQ issues.

Outdoor Air

The biggest potential IAQ problem observed was the location of the building exhaust and outdoor air intakes for heat pumps 1 and 2. ANSI/ASHRAE Standard 62.1 (2010) requires a separation between building exhaust and outdoor supply air. The required separation distance varies based on the type of building and various geometric factors. Section F2.4 of the standard provides for a calculation of the minimum separation distance when the supply/exhaust is located in equipment wells as is the case at

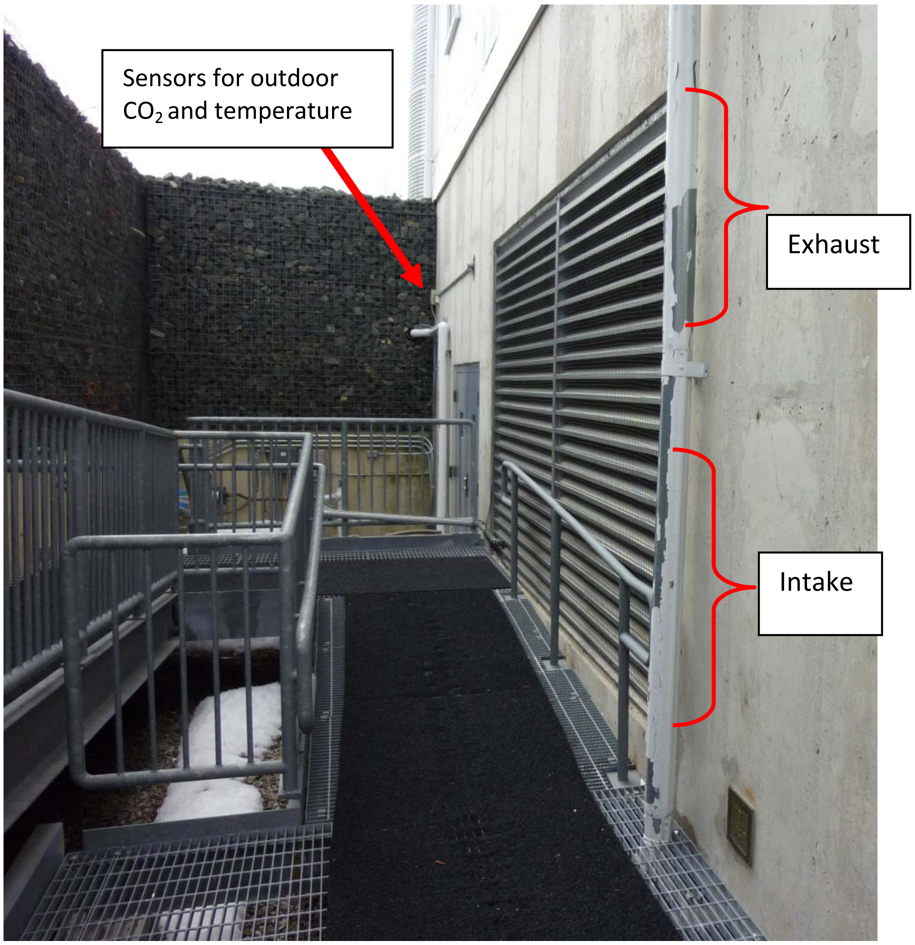

Figure 15: Locations of AHU #1 air intake and exhaust as well as temperature and CO_2 sensors

the Complex (Figure 15). Based on the observed flow rates and measured recirculation amount, the team determined that a minimum distance of 11 feet is necessary to meet the standard. CO_2 measurements made during economizer operation showed that 59% of the "outside" air that is entering the AHU is from the building exhaust. The outdoor sections of heat pumps 1 and 2 should be reconfigured to separate the two air streams.

Initially, the BMS was not configured to monitor the existing CO_2 sensors. These points are now monitored, and, for the week for which data were examined, the levels were consistently below 600 parts per million (ppm) (Figure 16). A value of 800 ppm is often used to initiate increased outside airflows, so, despite the exhaust/intake air circulation problem, it appears that building occupants are receiving adequate outside air to control CO_2. Regardless, the building may have recirculation issues with respect to other, unmeasured, chemicals. However, one of the sensors is not trending properly, and another is out of calibration and has stability issues.

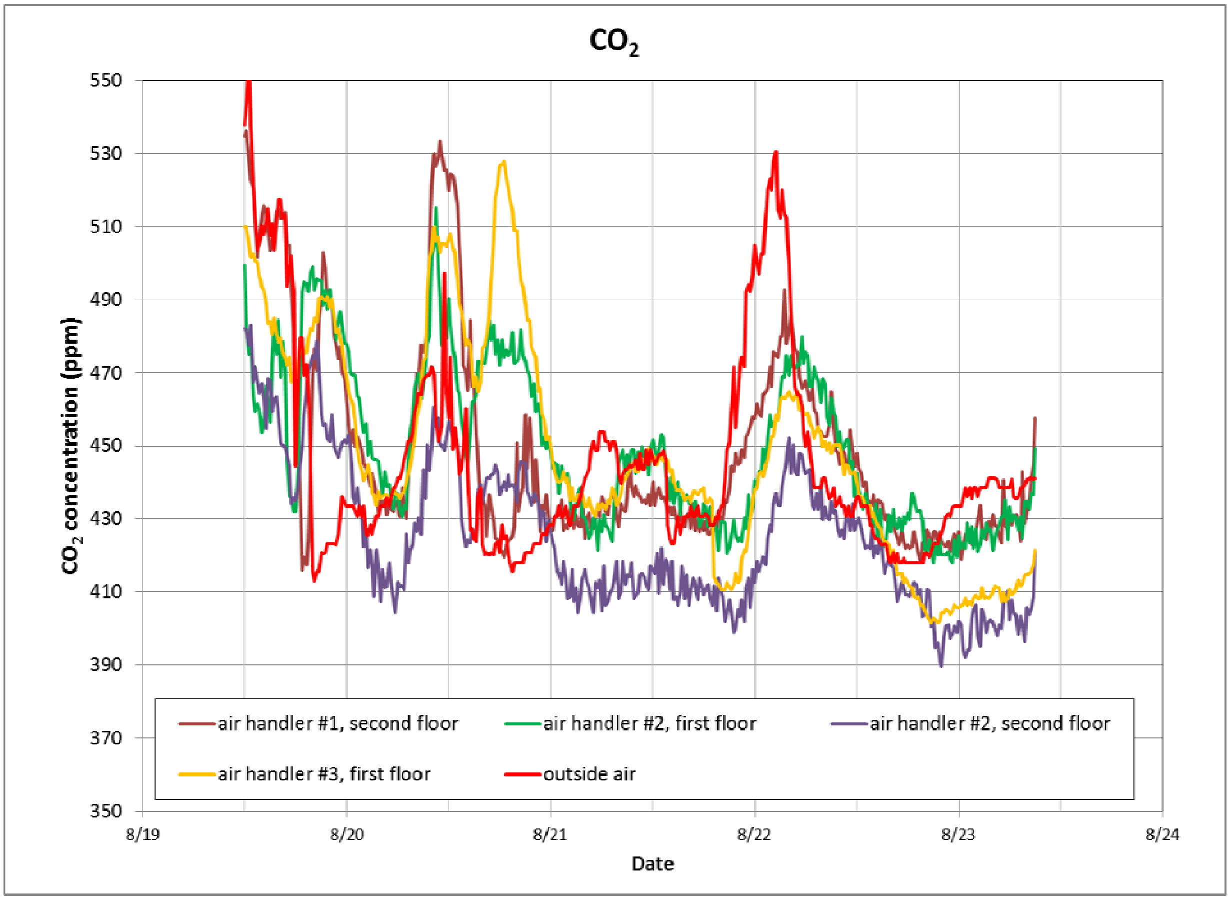

Figure 16:CO_2 concentrations for 1 week

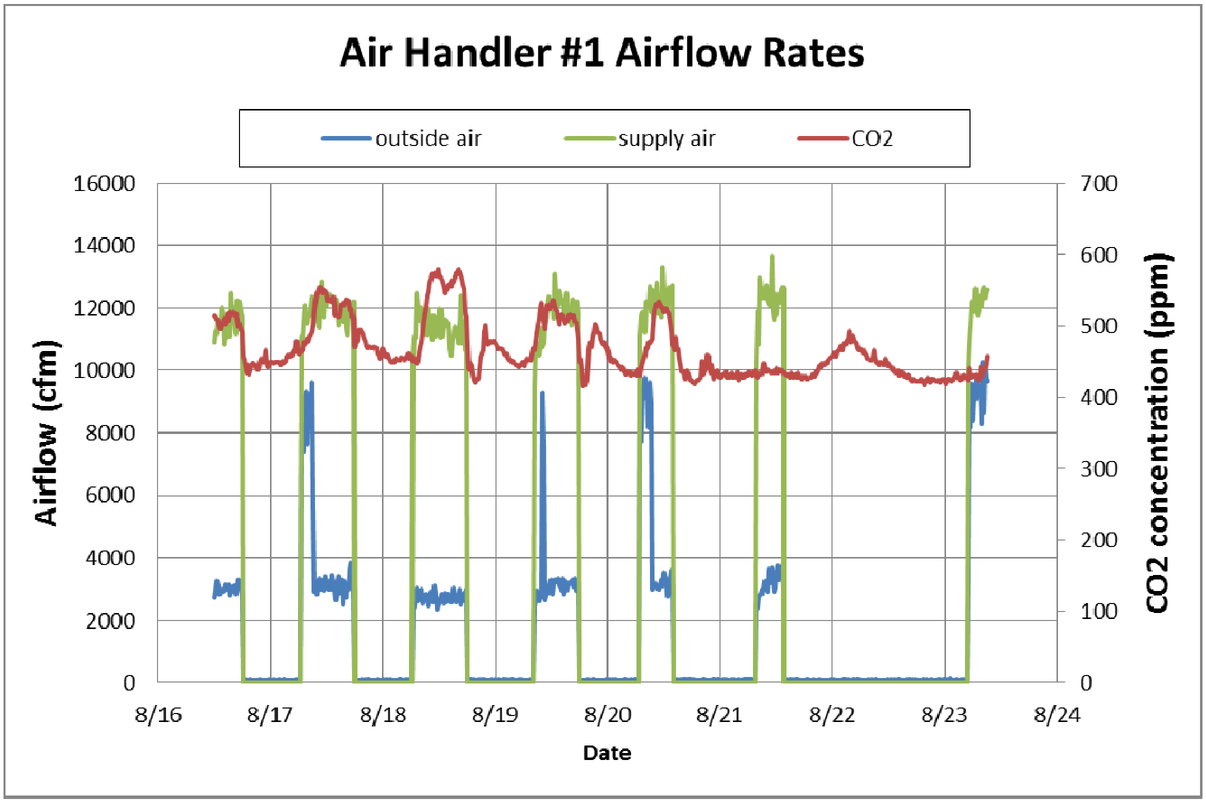

Figure 17: CO_2 variation with economizer operation

As shown in Figure 17, economizer operation has little effect on CO_2 concentrations. This is a further indication of the adjacent building exhaust and supply problem noted above. If CO_2 concentrations are to be used to set the minimum outdoor airflow, then more outside air will likely be needed than if the concentrations were obtained from "fresh air." More outdoor air means an increase in the energy used to condition and move the air. CO_2 is not the only chemical of concern. Other chemical concentrations are more likely to result from cross-contamination of exhaust and intake air; however, the survey results did not suggest any other chemical problems.

Outside Air Distribution Issues

The BMS monitors the outside airflow rate for the three larger HVAC units that serve the bulk of the 19,500 ft^2 new building. ANSI/ASHRAE Standard 62.1 (2010) suggests an outdoor airflow rate of at least 0.06 cubic feet per minute (cfm) per square foot, which is about 1,170 cfm for the entire building. The BMS measurements report outside airflow of about 6,500 cfm, well above the minimum (Figure 18). Although this flow rate is good for diluting indoor pollutants, it is probably in excess of what is needed and is resulting in energy loss as well as contributing to wintertime dry air issues.

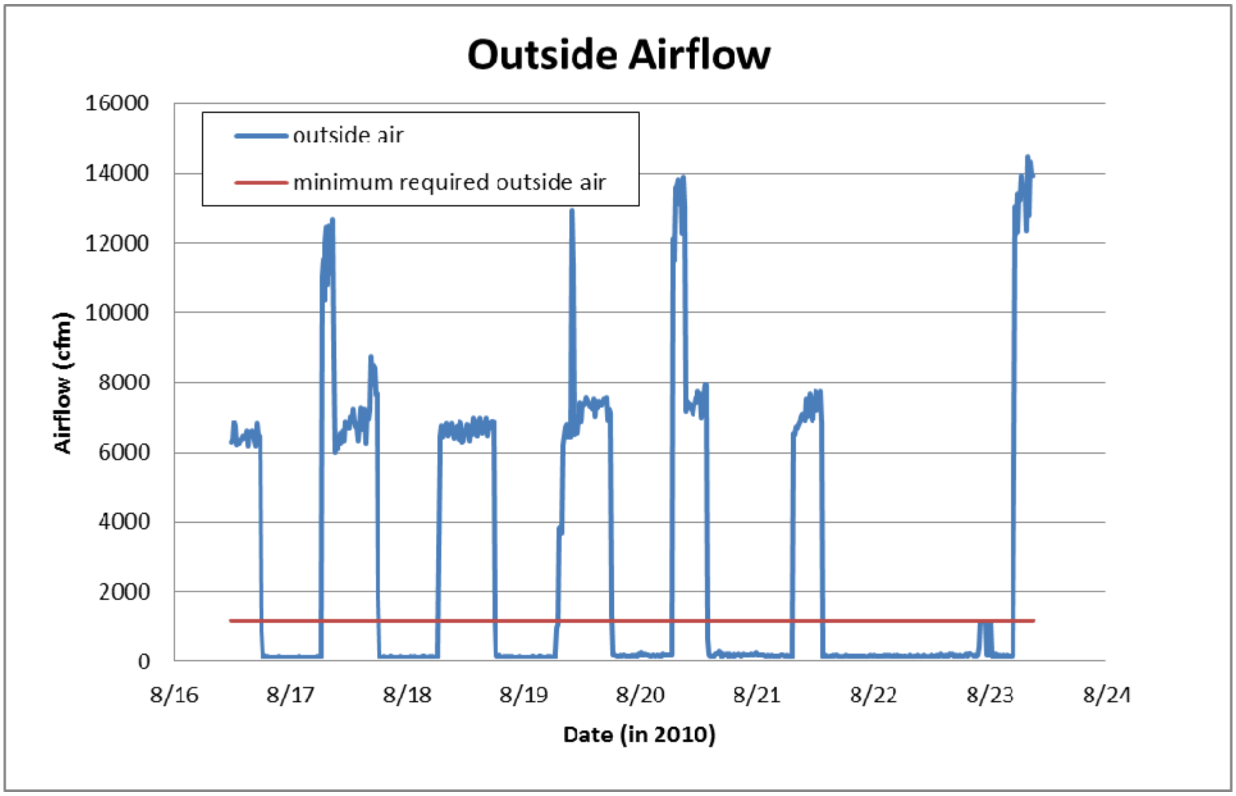

Figure 18: Outdoor airflow. Periods of outdoor airflow exceeding 9,000 cfm correspond to economizer operation of AHU #1.

Underfloor Pressures

Spot measurement of the pressure between the underfloor and the occupied zone during the team's winter site visit found some personal offices with negative pressure. This is caused by relatively high perimeter fan-box flows and inadequate underfloor supply flow. In these zones, airflow is from the office to the underfloor plenum in the interior office diffuser, which causes some recirculation of office air. These zones may not receive enough "fresh" outside air.[19] Longer-term measurements of these pressures were made (typically 1 day for an individual zone) during the summer site visit (Figure 19).

[19] ANSI/ASHRAE Standard 62.1 does not regulate individual rooms but suggests at least 5 cfm/person.

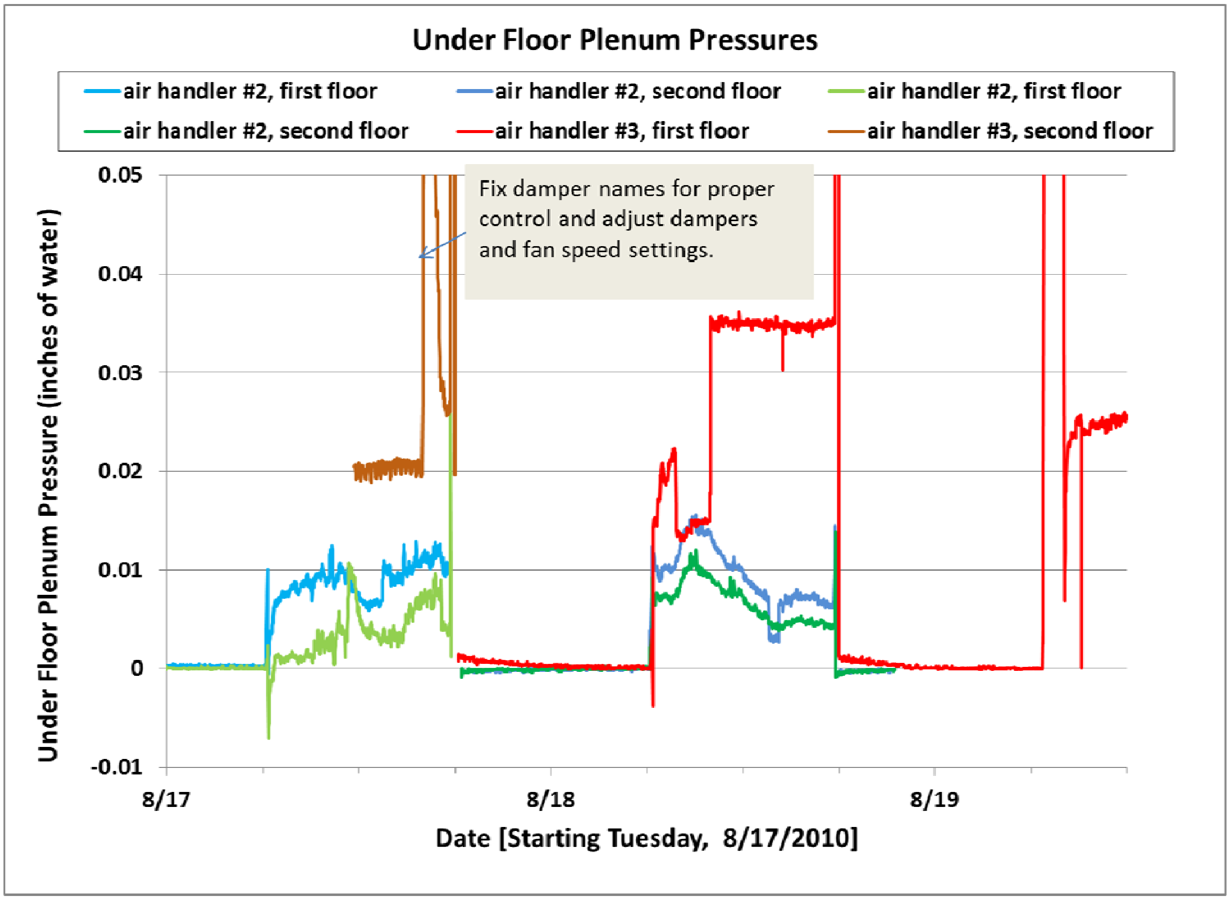

Figure 19: Selected underfloor (UF) pressures

Overall, the pressures are very low. Most underfloor systems are operated at about 0.05 inches water column (iwc) of pressure. One issue that was uncovered and resolved during the team's summer visit was incorrect labeling of the two dampers controlling the flow from AHU #3. This is likely linked to the negative pressures seen during the winter site visit, but the potential for negative pressure (which means inadequate outside air supply to occupants) still exists as long as the underfloor pressure is not controlled.

Kitchen Odors

Several occupant complaints were linked to kitchen odors. To reduce kitchen odor problems, we suggest increasing exhaust flow. This could be accomplished in three ways: using a two-speed exhaust fan in which the high speed is used during cooking (possibly triggered by an occupant sensor), increasing the flow of the current exhaust system by replacing the fan with a higher-capacity one, or enlarging the duct. If the current exhaust system serves more than the kitchen, then perhaps other areas could have less exhaust flow and more flow could be drawn from the kitchen.

Floor Diffuser Cleanup

It appears that the underfloor diffusers are not opened to have their "baskets" cleaned on a regular basis. The underfloor diffusers should be inspected and cleaned periodically, if necessary. The required frequency of inspection can be determined by experience. As we suggested after our initial site visit, the kitchen diffuser has since been removed so that the floor in the kitchen can be more easily cleaned. Floor diffusers should be cleaned every few months.

Supply Plenum Cleanup

The underfloor plenum slab was not completely cleaned before the raised floor was installed. Most of the resulting dust has likely already been blown into the building's interior space. However, occupants complained about dust, which suggests that action needs to be taken where large and obvious accumulations exist. To mitigate potential problems from dirt and debris in the supply plenum, the plenum should be cleaned where large accumulations are discovered. The dust might also come from outdoor sources, which might indicate a problem with AHU filters (see below).

U.S. EPA Nonattainment Zone

PMP requires that an evaluation determine whether the building is in a U.S. EPA nonattainment zone. Nonattainment zones are areas where the outdoor air quality does not meet U.S. EPA guidelines. Nine types of zones are defined:

- 1-hour ozone,
- 8-hour ozone,
- Carbon monoxide,
- Nitrogen dioxide,
- Sulfur dioxide,
- Particulate matter - 10 microns (PM-10),
- PM-2.5 (microns) (2006),
- PM-2.5 (2007), and
- Lead.

The Kresge Complex is located in both U.S. EPA 2006 and 2007 PM-2.5 zones. These are areas where pollution from small particulates (those less than 2.5 microns in diameter) might be high, which might warrant extra attention to filtering outside air. Likely sources of PM-2.5 are transportation, power plants (coal), industry, and wood smoke. As shown in Figure 20, PM-2.5 nonattainment areas are often urban.

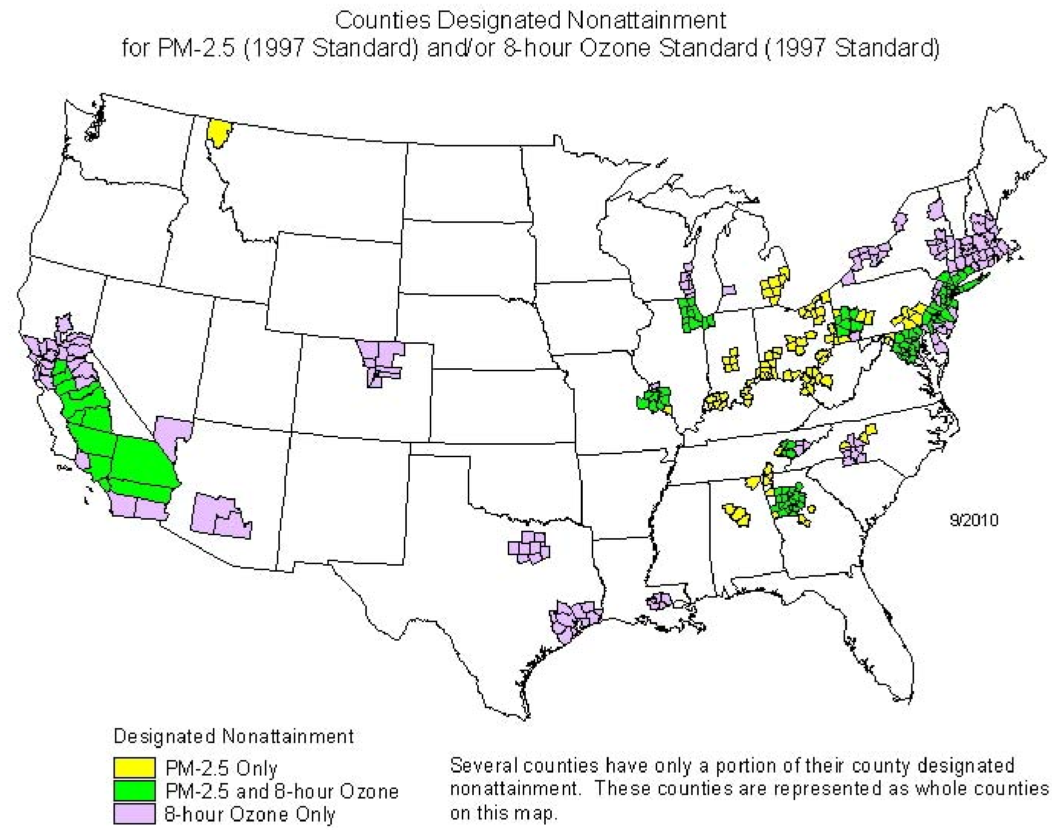

Figure 20: PM-2.5 (1997) and 8-hour ozone nonattainment zones

Inspection of the outdoor air filters at the Kresge building showed them to be in good condition. The Kresge buiding has a maintanance schedule for replacing HVAC filters and an active operations team that appears to follow the schedule. Particulate pollution from outdoors is unlikely to be a problem at the Kresge building except perhaps during fall burning of the landscaping. However, the survey found a number of complaints about dust. The source of the dust was not determined. Given the health risks associated with PM-2.5, these complaints emphasize the need to clean the underfloor plenum.

HVAC Condensate Pans

Visual inspection of the heat pump condensation pans showed no problems during either site visit. Specifically, the team noted no mold, algae growth, leakage, or plugged drains.

Indoor Humidity

Survey respondents cited low indoor humidity as a problem. Two indoor waterfalls were added as a response to this complaint in the past. During the winter site visit, the team carried a relative humidity sensor on the CBE measurement cart (see Appendix H for details about the cart) and recorded relative humidity wherever the cart was moved. These data (Figure 21) show that indoor humidity varied from 10% to 21% during occupied hours. This is lower than the ANSI/ASHRAE Standard 55 (ASHRAE 2004) values, which range from 25% to 30% (at 77°F to 68°F) for wintertime conditions in an office environment; since the measured values are not too far from this range, further remediation may not be required since humidity does not have a strong impact on comfort. The addition of a humidifier in the air handlers (or the equivalent) is recommended if this continues to be a significant problem. However, these types of humidifiers are not common in commercial buildings largely due to significant maintenance and operation problems.

Problems of low indoor humidity may also be alleviated to some extent if the AHU supply air temperature is increased to 60°F to 63°F as recommended in the energy section of this report.

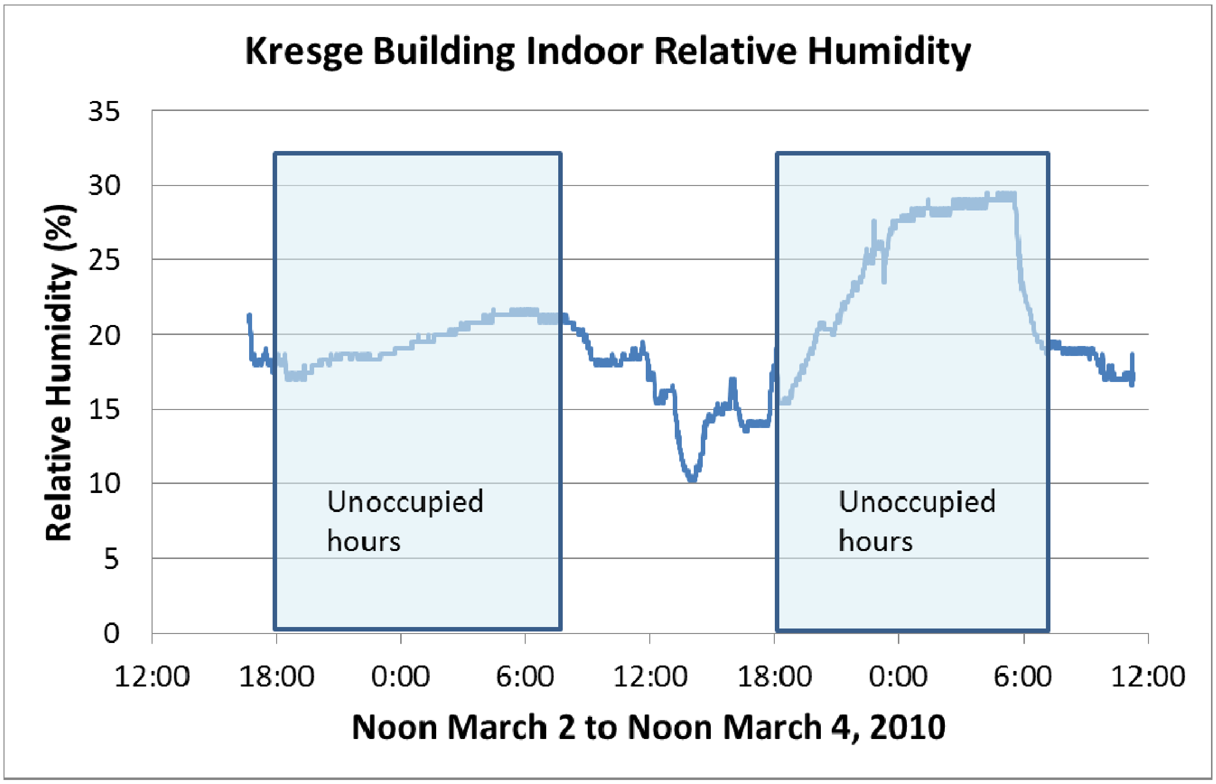

Figure 21: Wintertime indoor relative humidity conditions

BMS data were used during the August site visit to investigate summertime relative humidity conditions (Figure 22). ANSI/ASHRAE Standard 62.1 (2010) recommends that the relative humidity be less than 65% to control microbial growth but in general allows up to 80% for comfort. The data show that the summertime relative humidity at the Complex varied between 40% and 75% for the three systems for which there are data. The location of the humidity sensors was not determined, and it is possible that the higher values seen in AHU #2 are the result of a location near the larger waterfall. The ANSI/ASHRAE Standard 55 (ASHRAE 2004) summertime conditions for comfort values range from 85% to 55% (at 71.5^{o}F to 78^{o}F). The Kresge Complex is within that range. Comfort criteria other than the ANSI/ASHRAE standards that could be used to evaluate indoor relative humidity. However, given that the observed summertime values are well within the ANSI/ASHRAE comfort boundaries, it is unlikely that these values would be outside the boundaries set by other comfort determinants (see *Thermal Comfort*).

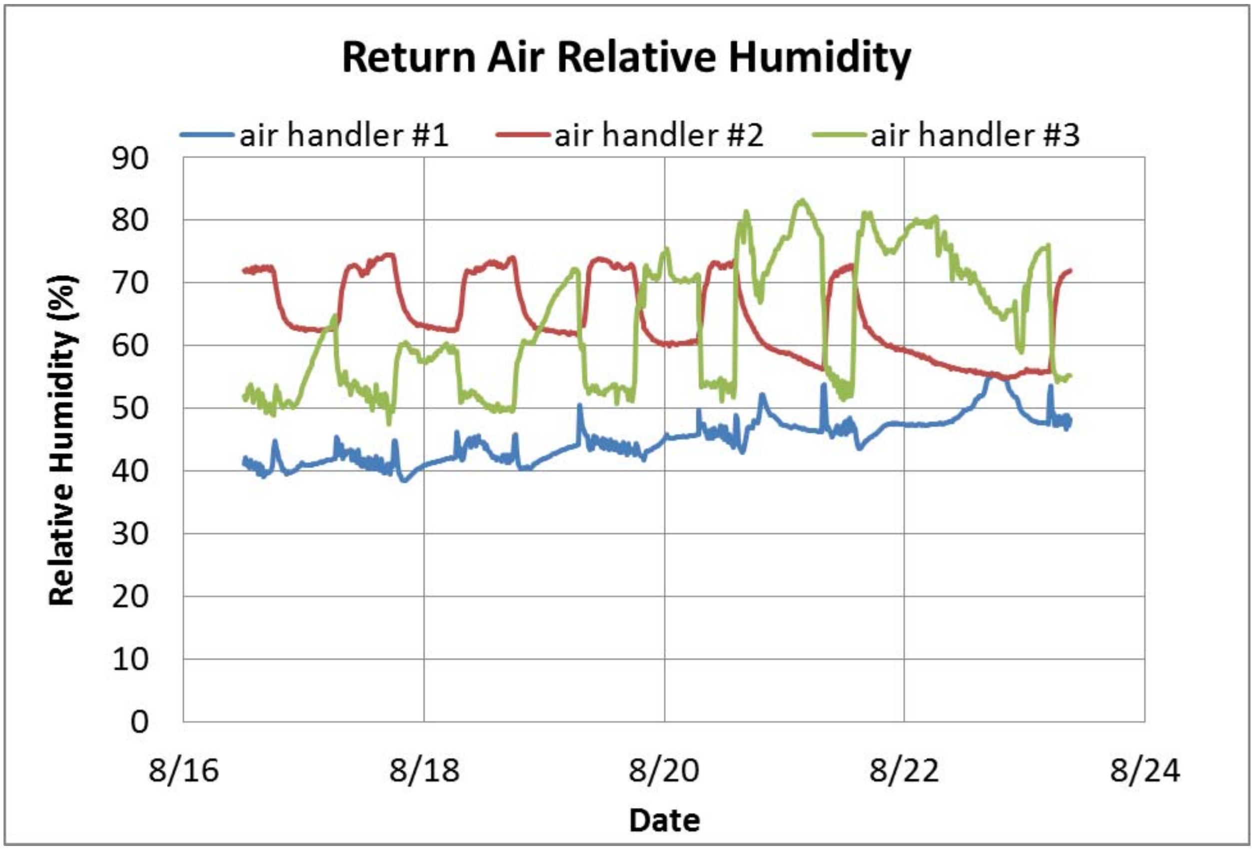

Figure 22: Summertime indoor relative humidity conditions

Moisture Mitigation

Rainwater/snowmelt drainage has caused problems with roof drains that empty onto the ground at the farmhouse level and saturate the soil. Moisture-laden soil is in contact with the partially bermed building walls at the courtyard level. At times water has either seeped through the berm wall or run over the top at construction joints, resulting in excessive moisture on the inside wall. Some of these roof drains have been retrofitted to empty away from the building. We recommend mitigating possible moisture problems inside the building and extending all remaining drains to move water away from the structure.

Outside Drainage

Another rainwater/snowmelt drainage issue arises where drainage is directed toward the building, where catch basins collect the water, which is then pumped out. These basins are approximately 2 feet in diameter and at least 6 feet deep. At the time of our inspections, there was standing and stagnant water in these basins. This could become an air quality concern if algae, mold, or other odorous agents are present although these conditions were not noted during our site visits. These basins are also possible locations for mosquito development. We recommend periodic monitoring of the catch basins for algae, mold, and mosquito larvae.

Radon

A May 2010 report from Automated Building Control Systems (ABC 2010) presents results of radon gas monitoring of eight locations in the Kresge Complex. These concentrations varied from 0.4 to 0.8 picocuries per liter (pCi/L). For long-term readings of 4 pCi/L and greater, the U.S. EPA suggests corrective action to reduce radon levels. The above readings indicate that the Complex's levels are far below the recommended action level.

Recommendations

The conclusions below are based on the survey results, inspections, discussions with the building management staff, and IAQ measurements performed during the winter and summer visits. The team recommends:

- Reconfiguring the outdoor sections of heat pumps 1 and 2 to separate the two air streams. ANSI/ASHRAE Standard 62.1 (2010) requires a separation of at least 11 feet for office buildings configured like the Kresge Complex,
- Restoring static pressure control to the supply plenums. This will improve comfort control and possibly energy performance,
- Cleaning the underfloor plenum where large dust accumulations are discovered and continuing good maintenance of air filters to address dust problems. If dust continues to be a problem after these measures are taken, measurements of PM-2.5 should be made because the building is in a U.S. EPA PM-2.5 nonattainment zone,
- Reducing problems due to kitchen odors, increasing the kitchen exhaust flow by using a two-speed exhaust fan with the high speed used during cooking (possibly triggered by an occupant sensor), increasing the flow of the current exhaust system by replacing the fan with a higher-capacity one, or enlarging the duct,
- Cleaning underfloor "baskets" regularly,
- Including observation of condensate pans and catch basins in the maintenance schedule,
- Reviewing the storm drain system, extending all remaining drains, and configuring storm drains to move water away from the structure,
- Improving the regulation of underfloor airflow by assuring a positive underfloor pressure,
- Adding a humidifier in the air handlers in the event of a significant numbers of complaints, However, this may result in increased maintenance requirements,
- Moving the outdoor CO_2 and temperature sensors out of the equipment well, and
- Upgrading BMS trending abilities.

Thermal Comfort

Background

Thermal comfort was among the lower-scoring areas on the occupant satisfaction survey. Occupants reported feeling overcooled during the summer and overheated during the winter. Factors that may contribute to occupant discomfort include the large number of diffusers and their placement in many cases directly under workstations. Thermal comfort in the building is primarily driven by exposure to conduction, solar gain through large windows, and the operation of the UFAD system. The geothermal wells, which embed the building into the ground and use super-insulation, are designed to support a comfortable low-energy building though this strategy is complicated by the large window-to-wall ratio and poorly controlled UFAD system.

Methodology

A number of thermal performance tests were conducted during both winter and summer site visits using CBE's measurement cart. The CBE measurement cart (described in detail in Appendix H) is a valuable tool for assessing UFAD system performance. It helps determine the following:

- Variability of temperature stratification profile shapes over a given area of the building,
- Floor-to-floor temperature differences,
- Supply plenum operation from temperature and pressure measurements,
- Degree of stratification in relation to location and operating conditions,
- Difference in operation of interior vs. perimeter zones,
- In conjunction with the survey results, overall comfort level of occupants, and
- Energy performance.

Cart measurements were performed in all major zones of the Complex (see Figures 23 and 24). Cart measurements take an average of all readings over a 5-minute period. The cart is moved to multiple locations within the same zone and subzone, and measurements are taken to characterize the entire area (subzones are explained in the *Room Air Stratification Profiles* subsection).

In addition to cart measurements, temperature-sensing "motes" (wireless data logging sensors) were placed in widely dispersed diffusers in the measurement zones. These motes help determine the temperature distribution in the supply plenum. Finally, BMS data were downloaded to evaluate the performance of the mechanical system further.

Figure 23: Courtyard level zone map

Figure 24: Farmhouse level zone map

Results

Despite the lack of plenum pressure control, the UFAD system is generally performing well. However, our measurements revealed several issues that are discussed in the subsections below. Although a number of measurements were conducted during the team's winter and summer visits, equipment malfunction resulted in limited cart measurement data from the winter visit. Thus, the results discussed in this section are based on data taken during the summer visit. The only winter data available in this report is presented in Figure F-4 in Appendix F: Thermal Comfort Details. Given that stratification is typically not observed in heating mode, we do not feel that the lack of winter data weakens the conclusions of this report.

Room Air Stratification Profiles

The team measured the magnitude of stratification during fully occupied operation to assess the level of comfort and identify opportunities for saving energy. UFAD systems are commonly controlled using a thermostat mounted at 4 feet. If significant stratification develops, the occupied zone, defined as the vertical region from 4 inches to 67 inches from the floor, can end up being too cool, which can result in occupant discomfort. The degree of stratification is gauged by the difference between the temperatures at 67 and 4 inches (the head-foot temperature difference). We generally consider stratification optimal when it is in the range of 2°F to 4°F. If the occupied zone is too cool, set points should be raised.

Figure 25 shows the layout of private offices in the first-floor north zone and how the zone is divided into subzones by fan-powered box (FPB) service. Figure 26 shows temperature stratification profiles for FPB subzones in private offices of the first-floor north zone. FPBs are connected to perimeter ducting and are intended to control perimeter zone temperature. They are zoned by exposure, and each FPB serves multiple offices (or a large exposure in an open-plan area), with the thermostat located in one of the offices.

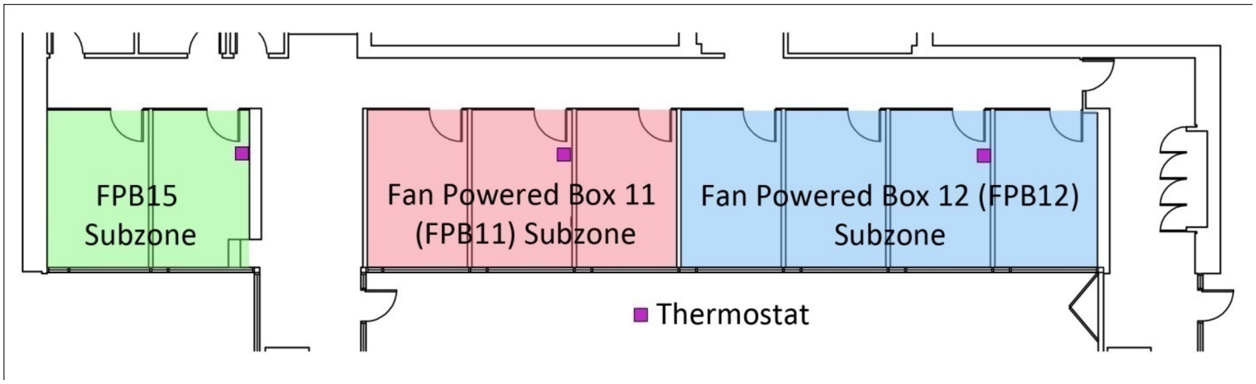

Figure 25: Fan-powered box (FPB) subzones of the first-floor north zone with thermostat locations

In addition to displaying the room air stratification, the profiles in Figure 26 highlight the difference in temperatures between neighboring private offices being controlled by the same FPB and thermostat. The solid lines indicate stratification profiles of offices with a thermostat, and the dotted lines indicate profiles of offices without thermostat control. The two private offices served by FPB11 are controlling to similar temperatures, but the offices served by FPB12 vary considerably more. This is a common problem in private office configurations; the internal loads in each office can vary considerably depending on occupant-specific loads, occupant presence, use of lighting and shading, door closing, occupant adjustment of diffusers, etc. Most areas had stratification around 4°F; however, two rooms that did not have thermostats had large stratifications in the range of 6°F to 7°F. Figure 26 also shows that the control to setpoint is relatively poor, most likely because of FPB volume settings, plenum/diffuser supply temperature, and a lack of automatic control of interior zones.

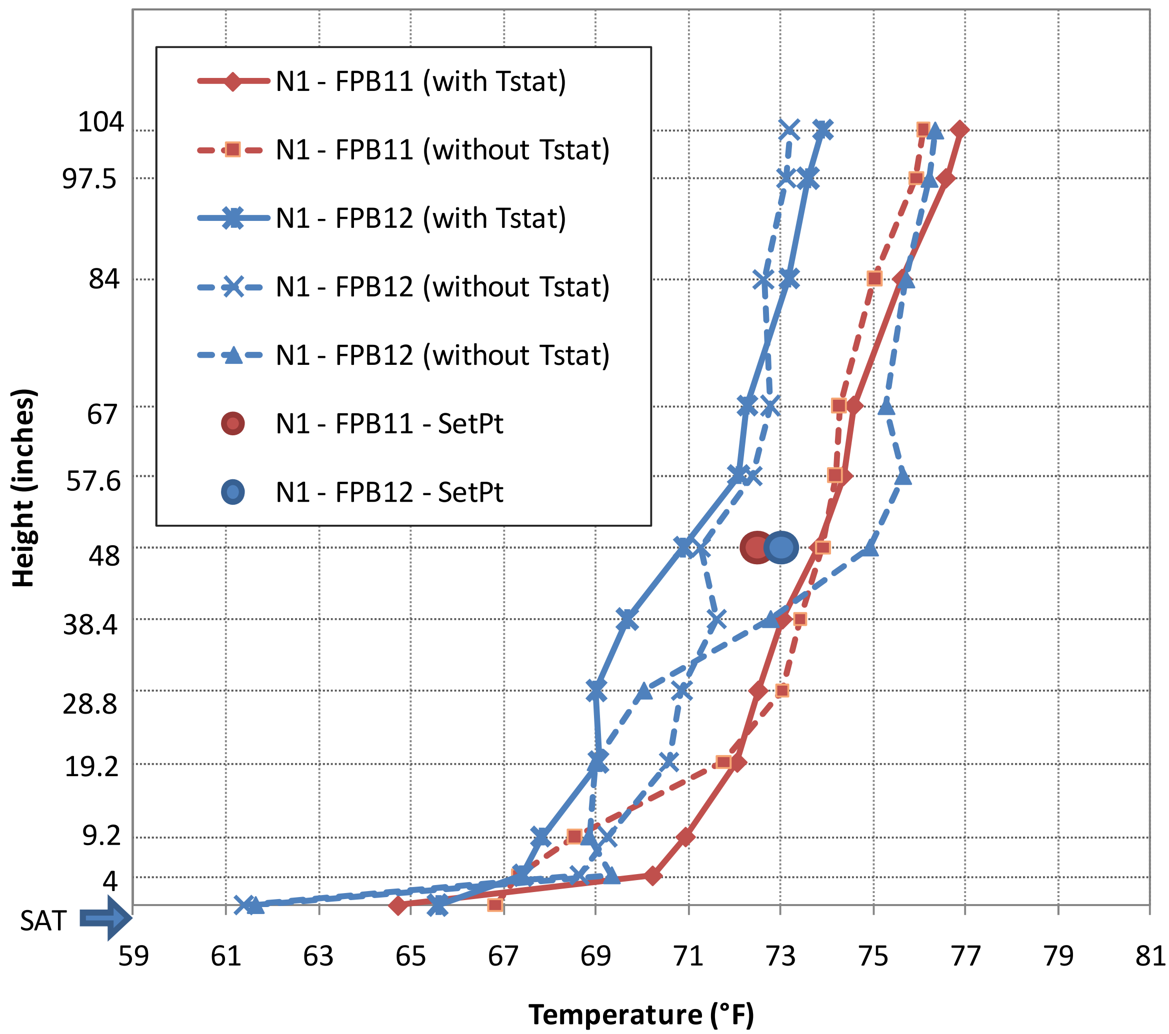

Figure 26: Room air stratification profiles for private offices in first-floor north zone

Figure 27 shows temperature stratification profiles for FPB subzones in first-floor south zone (averages of all measurements taken in those specific subzones). Most areas had stratification around 2°F with the exception of an office (FPB06) near the plenum supply that had a large stratification of 9°F. The spaces within the zone had different setpoints (see Appendix G), ranging from 74.5°F to 79.5°F. The relatively large difference in setpoint temperatures within the same open-plan space can lead to FPBs "fighting" each other—an inefficient and energy-intensive strategy. For example, FPB08 and FPB09 each serve the first-floor southern open office area but have setpoints of 75°F and 79.5°F, respectively. Two FPBs serving the same open-plan area should have the same setpoints.

Additionally, the dead band for each thermostat (the difference between cooling and heating setpoints) is set to 1°F. As expected with such a tight dead band, many of the perimeter FPBs were in heating mode during the morning, fighting the cool air from the interior plenum diffusers, or one FPB in the perimeter of an open-plan zone would be in heating mode while the other was in cooling mode. A 5°F to 7°F dead band is typical practice and provides more efficient operation. Also, note that all spaces were being overcooled by ~1°F to 2°F, largely because of the low supply-air temperature, which is discussed in the *Plenum Temperature Distribution and Decay* section below.

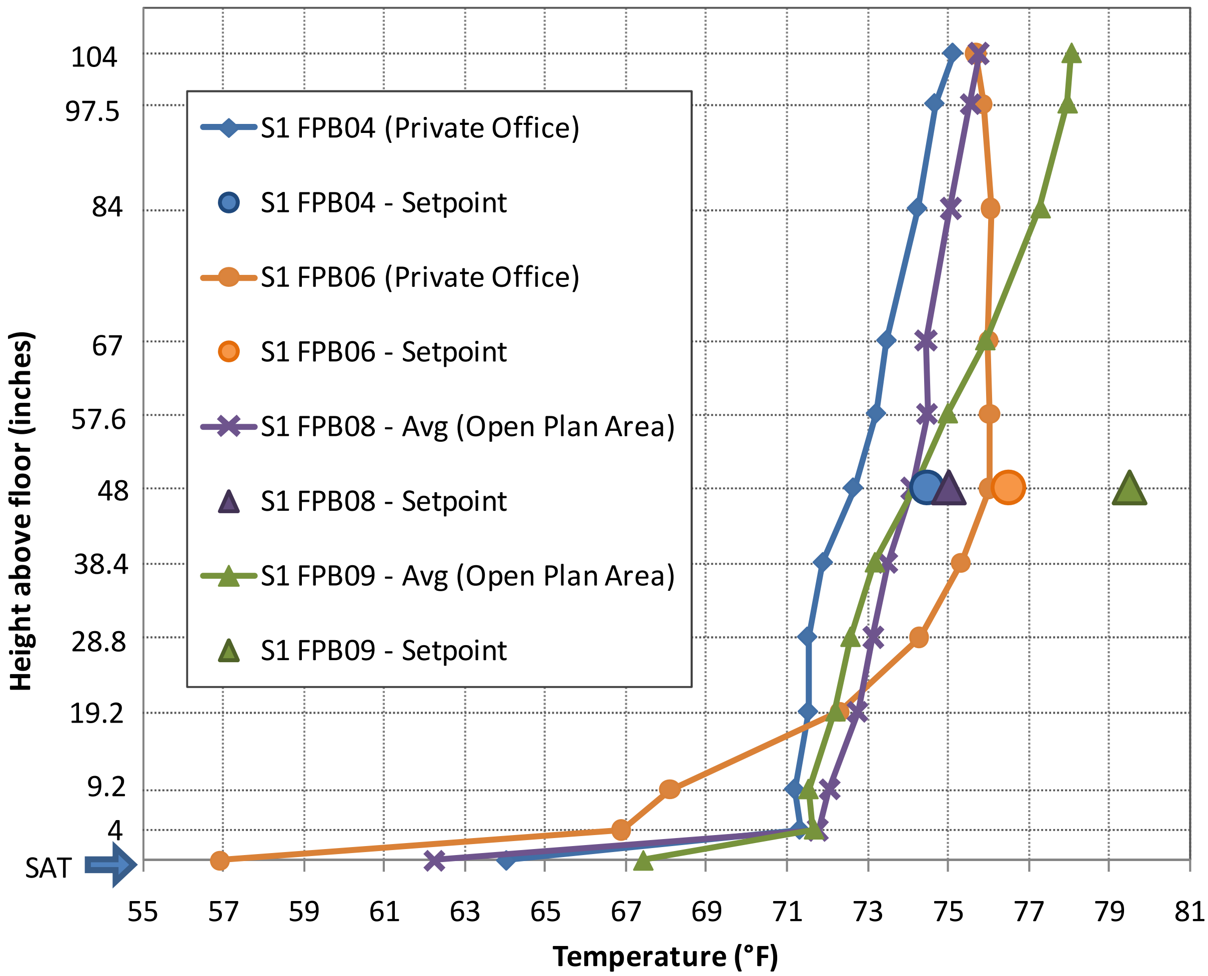

Figure 27: Room air stratification profiles for the first-floor south zone

Room Temperature and Stratification Performance Summary

Figure 28 summarizes the performance of the UFAD system in the first-floor south zone. Appendix G contains similar charts for each zone in the Complex. The chart plots average room air temperature stratification against the average occupied zone air temperature for each subzone. The error bars represent the variability in measurements in different locations within the same subzone. The color of the symbol represents the difference between the setpoint temperature and the average occupied zone temperature, which provides a quick visual indication of how well the room is being controlled. There are two shaded areas representing different "comfort zones." The beige shaded area represents the comfort zone as determined by the CBE comfort modeling study (Zhang et al. 2005). The pink shaded area represents the comfort zone as determined by ASHRAE Standard 55. The ASHRAE comfort zone was determined from operational and occupant parameters based on ASHRAE standard comfort zone models. In this case, we assumed a metabolic value of 1.2, a clothing value of 0.6, relative humidity of 50%, and air velocity at the occupant of less than 50 feet per minute (fpm.) Note that most points lie close to the lower limit of the comfort zones; this is a symptom of overcooling, which can be alleviated by raising the cooling setpoints. Additionally, most areas are being overcooled in relation to their setpoints (indicated by the shade of blue in the symbols).

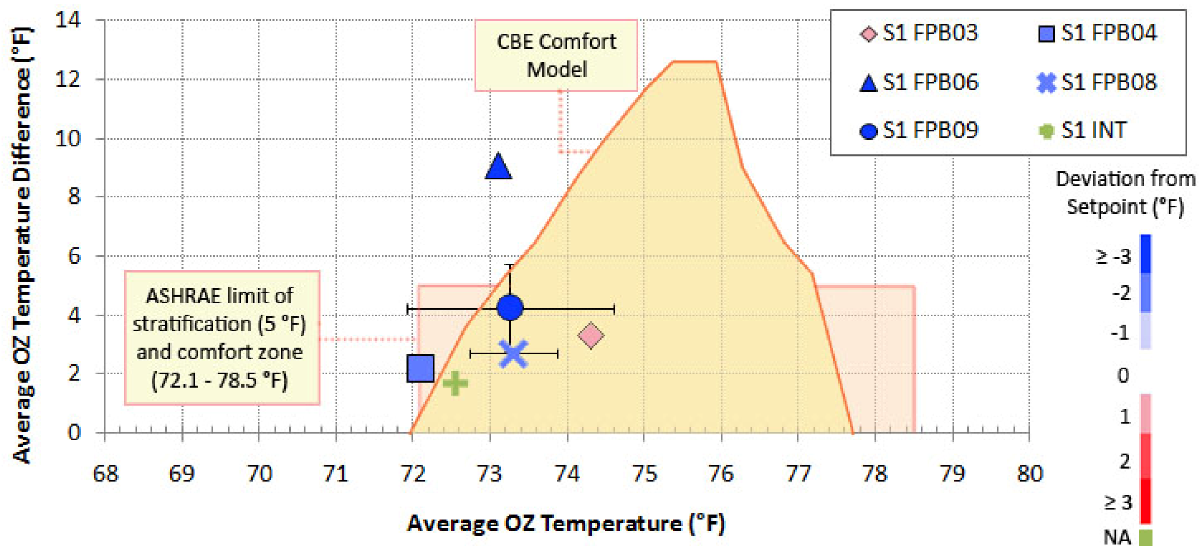

Figure 28: UFAD performance for first-floor south zone as determined by thermal stratification, occupied zone (OZ) temperature, and deviation from setpoint

Figure 29 shows a similar UFAD performance chart for the entire building. This chart does not include error bars or deviation from setpoints but shows how the building is performing as a whole. Many subzones are out of the thermal comfort zone (both ASHRAE and CBE), and, overall, the building is overcooled.

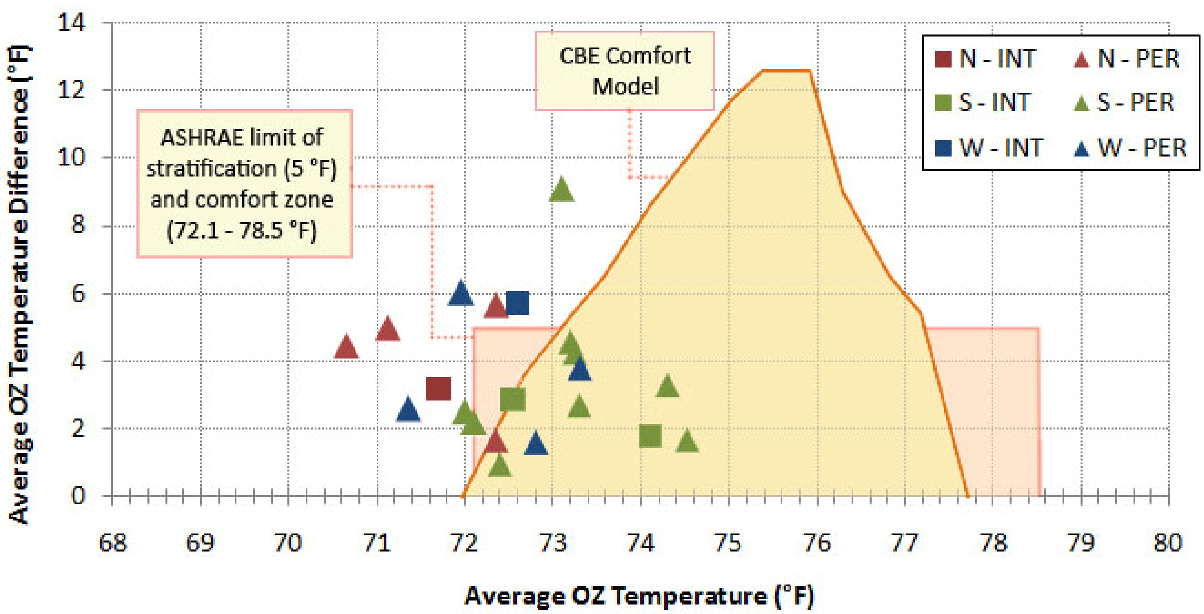

Figure 29:: Whole-building UFAD performance as determined by thermal stratification and occupied zone temperature

Plenum Temperature Distribution and Decay

Figure 30 is an illustrated thermal contour map for the second-floor southern zone underfloor plenum. The white dots represent wireless mote locations where temperatures were taken. The temperatures shown in Figure 30 represent the average temperature over the course of a 2-hour measurement period. Temperatures were linearly interpolated to provide a contour map.

Thermal decay depends on airflow rate and temperature distribution caused by how the supply airflow is delivered to the plenum. In the Complex, one air highway delivers the supply air into each underfloor plenum zone. Temperatures are typically dictated by how long the air has to travel (while picking up heat) to a particular location. The AHU supply air temperatures in the Complex averaged 54°F during the CBE team's summer visit. This temperature is lower than the 63°F specified in the design, which can lead to overcooling in the areas shown in blue in Figure 30. This low temperature also compromises the operation of the economizer, thereby reducing energy efficiency.

The plenum supply air for the second-floor southern zone comes into the space underneath the entryway to the barn (Figure 30). The thermal decay in the direction of the supply airflow (west) is relatively low (6°F), but significant decay exists in the direction toward the barn (14°F). The supply air duct is located in a narrow space in the plenum and directed away from the barn, which prevents sufficient airflow from entering the barn plenum. The underfloor pressure in the barn is very low (~0 inches water column), and an insufficient volume of cool air enters the space, resulting in dramatic thermal decay.

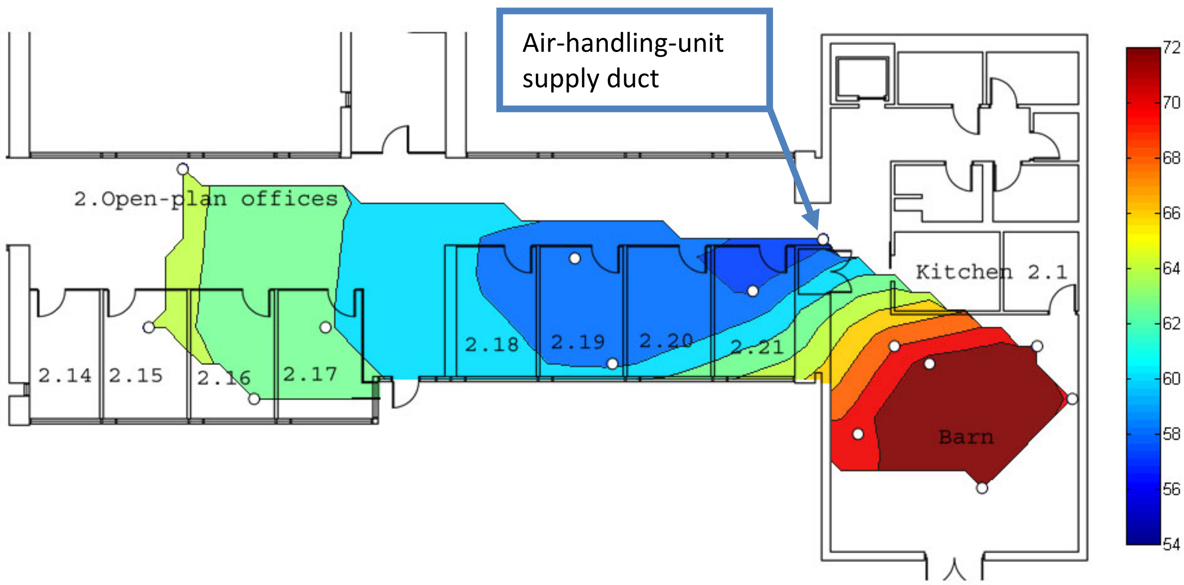

Figure 30: Underfloor plenum temperature distribution for second-floor southern zone (°F)

Appendix G contains thermal contour maps for other zones. Additionally, Figure 31 summarizes all second-floor underfloor plenums. This figure separates the wireless mote data by location within the plenum (perimeter or interior zone) and gives an average of the entire plenum space as a quick metric of thermal decay.

- The average temperature in the underfloor plenum was in the range of 60°F to 66°F, and
- The minimum temperature observed in the plenum was 57°F and the maximum was 73°F.

The average supply air temperature from the AHU was 54°F, indicating average thermal decay in the range of 6°F to 12°F. A similar summary graphic for the first-floor plenum zones is available in Appendix F: *Thermal Comfort Details*.

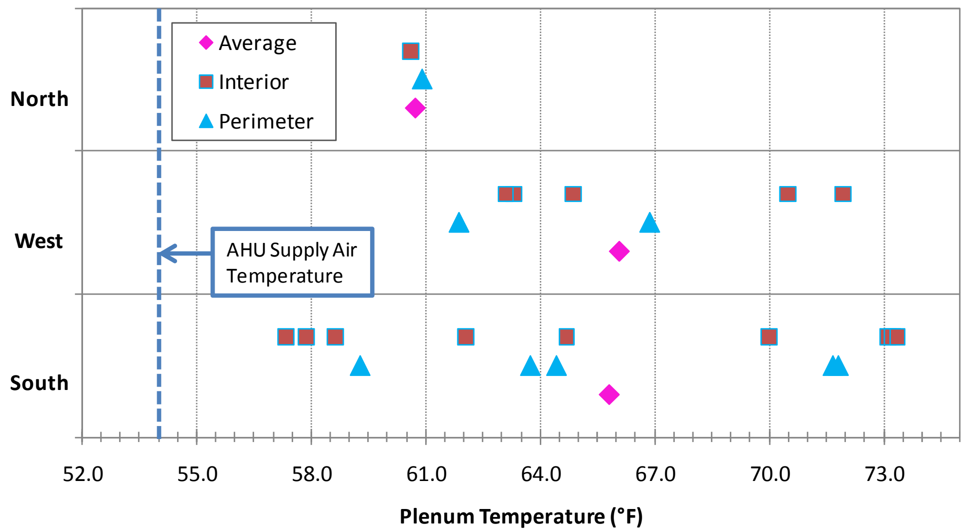

Figure 31: Temperature distributions of second-floor underfloor plenums

Observation Evaluation

In conjunction with measurements made using the commissioning cart and motes, the team analyzed BMS data and evaluated certain physical elements of the UFAD system (e.g., diffuser placement).

Currently, some interior floor diffusers are improperly located and/or adjusted. Figure 32 shows two diffusers placed too close together and Figure 33 shows diffusers placed underneath chairs. Solving these issues could improve occupant comfort and help eliminate the use of supplemental fans and electric heaters.

Figure 32: Diffusers placed too close together

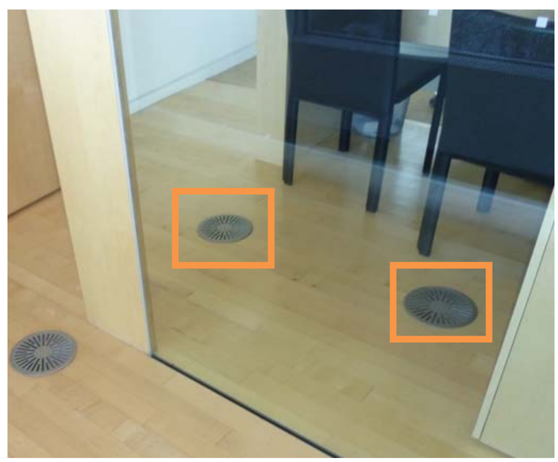

Figure 33: Diffusers placed underneath guest seating area in private offices

We also observed several poorly constructed perimeter diffuser installations (see Figure 34). There is a large gap between the hole in the perimeter duct and the floor above, creating a significant leakage path into the surrounding plenum. This problem has been remedied in a number of locations using a collar to close the gap; however, there are still areas where this solution has not been implemented. This situation resulted from lack of clear detail in the engineering documents regarding how this connection was to be made as well as poor construction practices.

Figure 34: Poorly constructed perimeter diffuser installation

While taking cart measurements in the north zone of the first floor, the team discovered that the underfloor plenum pressure was negative throughout the zone. Negative plenum pressure causes room air to be sucked into the plenum, which can reduce dilution of outside air delivered to the space and increase plenum temperatures, causing higher airflows than are needed. These higher airflows compromise energy performance. This problem turned out to be the result of a damper control naming switch in the BMS.

Recommendations

The CBE team drew the following conclusions regarding thermal comfort at the Complex and offers the following recommendations:

- Static pressure sensors and interior thermostats were found to be inoperative. Activating the sensors will provide greater control over the UFAD system and potentially increase comfort while decreasing energy consumption. Problems such as the negative pressure discovered in the first-floor northern zone would have been caught earlier and easily solved if static pressure sensors had been operational,
- Once plenum static pressure control is achieved and diffusers are relocated as necessary, occupants in private offices without a thermostat and interior-zone occupants in open-plan areas should be taught how to adjust their (interior) floor diffusers to achieve personal thermal comfort. For full automatic control of interior zone temperature, a cascaded control loop may be required,
- Performance could be improved by developing and implementing an engineered solution for resolving the design and construction problems of the poorly constructed perimeter diffusers,
- Increasing the heat pump supply temperature will mitigate overcooling in some areas, and
- Increasing the dead band to 5°F will help prevent simultaneous heating and cooling of the same zones and will save energy.

Energy Performance

Background

This section evaluates the Complex's energy use and analyzes the evaluation methods employed. An energy simulation prepared in 2005 as part of the Kresge Foundation's LEED-NC application indicated that the building envelope and mechanical and electrical systems would be 40% more efficient than a building constructed to minimum standards (i.e., following prescriptive requirements for the baseline per ASHRAE 90.1-1999). After the building was occupied, both the proposed and baseline models from the original simulation were calibrated based on actual operating schedules, occupancy, weather, and internal load estimates and comparisons to actual energy use. This was considered a way to approximate whether the building was achieving the expected energy savings over the baseline model as shown in the original design and LEED submissions. These calibrated models, prepared in 2009, indicated that the Complex's reduction in energy use was consistent with the original LEED-NC submittal's expectations. While the methods used by the energy modeler seem appropriate for updating the savings analysis, this study is focused on evaluating the comparison between the calibrated simulated results and actual energy usage and placing the actual use in context by benchmarking the actual usage.

Methods

The CBE team analyzed actual performance using utility bills and by making on-site measurements using the CBE commissioning cart. See *Cart Hardware and Specifications*, in Appendix H, for details about the cart. The team used ENERGY STAR ratings developed from the simulations and actual measured data to compare performance. The team substituted records kept by Kresge building managers to correct for errors in consumption values during the first four months of the measurement period. This period most closely covers the period used for the calibrated simulation's weather file, occupancy, etc.

Results

In general, the CBE team found that:

- Energy performance at the Kresge Complex appears to be affected by design issues and operating problems,
- Energy usage as measured by the ENERGYSTAR benchmark is higher than anticipated even though the calibrated modeling results suggest that performance is on target. This apparent inconsistency is primarily a result of fundamental differences between these two evaluation methods, the impact of unanticipated plug loads, operating conditions unaccounted for in the models, and possible inaccuracies in the underlying approximate assumptions used by both the original and calibrated energy-performance models, and
- A full analysis of energy use and differences between actual and simulated use is hampered by a lack of BMS data more detailed end use measurements, and lack of relevant details in the simulations reports. Lack of BMS data also hampered the comparisons between building operating data and CBE cart data for the UFAD system.

Because there is no perfect way to predict energy use, any approach will have shortcomings. Below we describe the issues associated with each energy use evaluation approach used to assess the performance of the Kresge Complex. The approaches discussed are:

- ASHRAE Standard 90.1, which uses the energy cost budget (ECB) method,

- The original energy model prepared for the Complex's LEED-NC application,
- The calibrated version of the original energy model, prepared by the energy modeler, and
- The ENERGY STAR Portfolio Manager benchmarking tool.

ASHRAE Standard 90.1-1999 & ECB Method

The energy code used as a base for the Complex's original energy simulation (and LEED-NC application) was ASHRAE/ANSI Standard 90.1-1999. The energy modeling protocol in this standard is called the energy cost budget (ECB) Method. It requires a simulation of lighting, service water heating, space heating and cooling, fans, and other HVAC equipment for a baseline or "budget" case (i.e., a hypothetical case of the building if all the measures listed above were designed to minimum code requirements) and a "design/proposed case" (i.e., the building as designed). The "design/proposed case" is intended as an alternative path for minimum code compliance. This methodology has been replaced in recent iterations of LEED-NC and ASHRAE 90.1 by a more rigorous modeling protocol called the "performance rating method" (see Appendix G in ASHRAE 90.1-2007 or 90.1-2010), which is intended to more accurately rate the energy efficiency of buildings that exceed the prescriptive standards. However, these newer methods still contain the inherent problems of attempting to predict actual energy usage and so may still not be adequate for "guaranteeing" good energy performance. It seems unlikely, however, that the Complex would meet these newer requirements.

Original Energy Model and LEED-NC Review

The original energy model created by Ove Arup & Partners (2005) for the Complex was based on the ASHRAE 90.1-1999 ECB method as simulated with VisualDOE, a commercial version of the Department of Energy's DOE2 simulation program. The annual energy cost for the proposed building was compared to that of the baseline case, and an energy cost savings of 40% was reported.

A number of measures were applied to the original model to account for unconventional elements of the Kresge Complex, such as the ground-source heat pumps and the underfloor air distribution system. It appears that some of these measures may have been post-processed outside of the VisualDOE software used for the modeling. Issues such as thermal decay and stratification do not appear to have been addressed in the model, so it is quite likely that the results of this model suffer from inaccuracies.

One reason this model was created was to document energy-efficiency measures to achieve LEED-NC certification. Under LEED-NC Version 2.1, energy efficiency could earn a project up to 10 points out of 69, or almost 15% of the total potential LEED-NC points. The Complex attempted and earned 6 out of 10 points after its first submission of documentation, without requirement for clarification, which is a rare circumstance.

A further issue is whether the ECB method should be considered an accurate representation of the Complex's predicted energy performance. Energy simulation software is used as a tool to compare relative effects of energy-efficiency measures on the design of a building rather than to predict absolute energy use reliably.[20] In the case of the Kresge Complex, the ECB method allowed the proposed building model to exclude items such as plug loads. Thus, the model was used only to estimate the proportion of energy saved by the Complex's alternative HVAC and envelope elements as compared to a standard

[20] "Neither the proposed building performance nor the baseline building performance (models) are predictions of actual energy consumption or costs for the proposed design after construction" (Appendix G in ASHRAE Standard 90.1-2007).

baseline case. This was all that was required to comply with ASHRAE 90.1 and to obtain a LEED-NC rating. For simulations to predict energy use accurately, many other factors must be considered; in addition, simulations can approach accuracy only if the model is calibrated appropriately (see Appendix G: *Energy Performance Analysis* for a complete discussion).

ENERGY STAR and Portfolio Manager

The U.S. EPA's Portfolio Manager is an energy-benchmarking tool that rates a building's energy performance on a scale of 1-100 relative to similar buildings nationwide. This approach is also known as a "performance rating" method. EPA developed ENERGY STAR based on an original analysis by Sharp (1996) using data from the Commercial Buildings Energy Consumption Survey (CBECS) database, but it has since refined the methods; updates are made each time a new CBECS study is released. These analyses have shown that only a few factors drive the energy performance for each specific building type. The resulting regression equations appear to explain >95% of the variance in the CBECS data. (See Appendix G: *Energy Performance Analysis*, for further discussion of this issue.).

ENERGY STAR ratings are based on normalized weather and other pertinent energy drivers, and use gross square foot (gsf)-weighted population median source energy use intensity (EUI) as the metric for the rating system. These EUIs are normalized to a scale of 0-100, which makes the rating number the preferred way to compare among buildings of any sort. All of these factors make ENERGY STAR arguably the best tool we have to date to benchmark the energy efficiency of specific buildings against the energy performance of similar facilities. See *Appendix G: Energy Performance Analysis*, below, for further discussion.

As noted and shown in Table 13, which summarizes the energy use of the Complex, the Complex did not perform as well in ENERGY STAR's Portfolio Manager as indicated by the calibrated simulations. The Complex's energy use, according to this benchmark, is approximately 15% above the national average.[21] (See Appendix G*: Energy* Performance Analysis for a more detailed discussion of this issue.)

Table 13: Portfolio Manager energy use summary for the Kresge Complex[22]

Time period	ENERGY STAR rating (1-100)	Site energy intensity (kBtu/ft^2)	Source energy intensity (kBtu/ ft^2)
November 2008 through October 2009	31	80.2	266.6

Table 13 shows that actual energy usage for 2008 and 2009 are higher than the calibrated proposed by 10% and 12% respectively.[23] Also shown for reference are the results for the average office building rating for ENERGY STAR.[24]

[21] See http://www.energystar.gov/index.cfm?c=assess_performance.normalize for more information about the parameters used to determine this national average. ENERGY STAR uses normalized parameters for comparison.

[22] The figures reported here in Table 13 are based on the square footage values created by the architect and used in the energy simulations (26,757 square feet). However, a revised square footage value based on more recent information (28,883 square feet), using the same actual energy data, results in an ENERGY STAR score of 40.

[23] The EUI and ENERGY STAR ratings for the calibrated proposed model would be slightly different (higher and lower, respectively) if the small amount of gas actually consumed in 2008 and 2009 was modeled.

[24] This rating is for the total of 498 buildings in the ENERGY STAR Office database.

It should be noted that the Complex uses all-electric energy, so it could be "penalized" under ENERGY STAR. ENERGY STAR rates based on source energy; all-electric buildings like Kresge have a source to site ratio of ~3.3, whereas the average ENERGY STAR building has a ratio of ~2.6. Thus, if the Complex had used the same total energy but with a normal mix of gas vs. electric (i.e., if the heat-pump hot-water generator were replaced with a boiler, possibly a high-efficiency condensing boiler) it would score ~25% higher. However, using gas would also be less efficient because the system would not enjoy the heat pump coefficient of performance. It would be interesting to know the actual average coefficient of performance that the ground-source heat pump system delivers to see how the performance compares to using an alternative means of heating.

Table 14: Performance analysis summary, energy usage (site and source) and ENERGY STAR ratings

	Calibrated baseline	Calibrated proposed	Actual 2008	Actual 2009	ENERGY STAR average
Floor area (ft^2)	26,757.0	26,757.0	26,757.0	26,757.0	
Number of people	62.0	62.0	49.0	58.0	
Number of PCs	59.0	59.0	49.0	58.0	
Weekly operating hours	65.0	65.0	68.0	68.0	
Total annual energy (kWh)	1,340,933.6	558,554.0	610,181.5	626,040.0	
ENERGY STAR site EUI (kBtu/ft^2/yr)	171.0	70.8	77.3	80.2	67
ENERGY STAR source EUI (kBtu/ ft^2/yr)	401.6	236.4	257.2	266.9	222
ENERGY STAR score	6.0	41.0	31.0	31.0	50

Calibrated Energy Model

In 2009, the energy modeler created a calibrated energy model for the Complex, with parameters largely based on the original Arup model but using actual monthly energy data from utility bills, corresponding weather data, actual occupancy schedule/building operation hours, and estimated receptacle loads (also called plug loads or unregulated loads). The energy modeler calibrated model has both baseline and "proposed" cases, parallel to those in the original Arup energy model. Table 15 shows energy by end use for the "proposed" cases for both the original Arup and calibrated the energy modeler models.

The inclusion of the receptacle loads in the energy modeler's calibrated model was the largest adjustment made from the original Arup energy model; the inclusion of parking lot lighting was the second largest. In general, the energy modeler calibrated proposed case results showed lower end-use energy consumption than the original proposed case (except for service water heating and plug loads); the 5.8% (Table 15) increase in annual energy use in the calibrated model was due primarily to plug loads and miscellaneous equipment differences. (See Table 15 and Figure 35.) These results raise a number of issues. For example, if the plug loads and occupancy are higher, why is the cooling and fan energy lower? In addition, the original proposed model results were post-processed to account for the addition of return fans and to correct energy consequences of using electric baseboards in the model for perimeter zone heating; it is unclear if the calibrated model was post processed as well. The energy modeler may have simply taken the original model and applied updated schedules, weather, internal loads and possibly external shading devices to it.

Table 15: Percentage difference between proposed energy use in the original and calibrated energy models for the Kresge Complex

	Energy use (kWh*)		
	Original /LEED-NC proposed (2005) (Arup)	Calibrated proposed (2009) (Energy modeler)	Percentage change
Lighting	80,557	56,068	-30.4%
Miscellaneous equipment	36,069	37,313	3.5%
Space heating	90,991	73,228	-19.5%
Space cooling	26,625	22,293	-16.3%
Pumps	10,740	9,891	-7.9%
Fans – interior ventilation	110,621	67,021	-39.4%
Service water heating	120,146	136,668	13.8%
Receptacle loads	52,375	146,216	179.2%
Parking lot lighting	0	9,855	100.0%
Total	528,124	558,553	5.8%
Average monthly consumption	44,010	46,546	5.8%

* kilowatt-hours

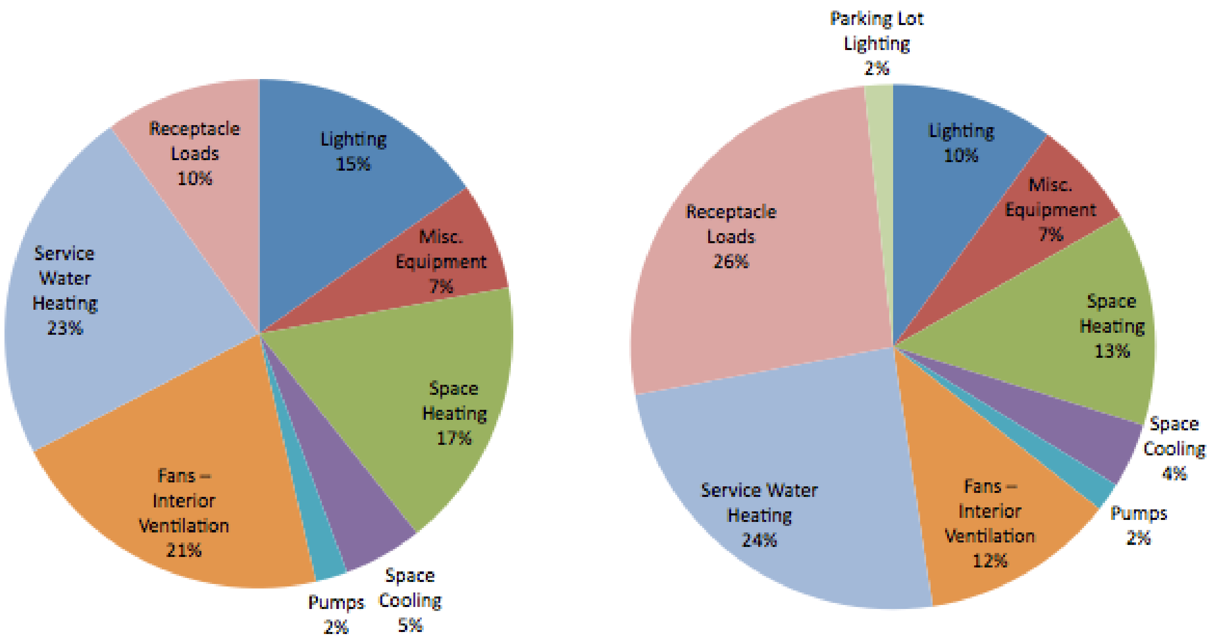

Figure 35: Left: Simulated proposed energy by end use, original Arup/LEED-NC Model (2005); Right: Simulated proposed energy by end use, the energy modeler/Calibrated Model (2009)

Figure 35 compares end-use breakdowns from the calibrated baseline and "proposed" energy use cases. These results show that HVAC energy is ~55% (including service water heating) of the total building energy use. This chart clearly shows that the Complex's major savings are due to fan and heating energy savings. Heating energy is reduced dramatically due to the coefficient of performance of the heat pump service water heater[25] used for perimeter fan coil heating as opposed to the gas and electric heat used for the baseline. Although the simulated baseline case assumed a gas boiler as backup for the heat pumps, the proposed models had no gas usage since it was replaced by a water-to-water heat pump, which we assume is included under service water heating. Actual energy use of gas, while not zero, is small. Simulated fan energy is reduced between the two proposed models presumably due to changes is schedules and weather as discussed in the energy modelers report.

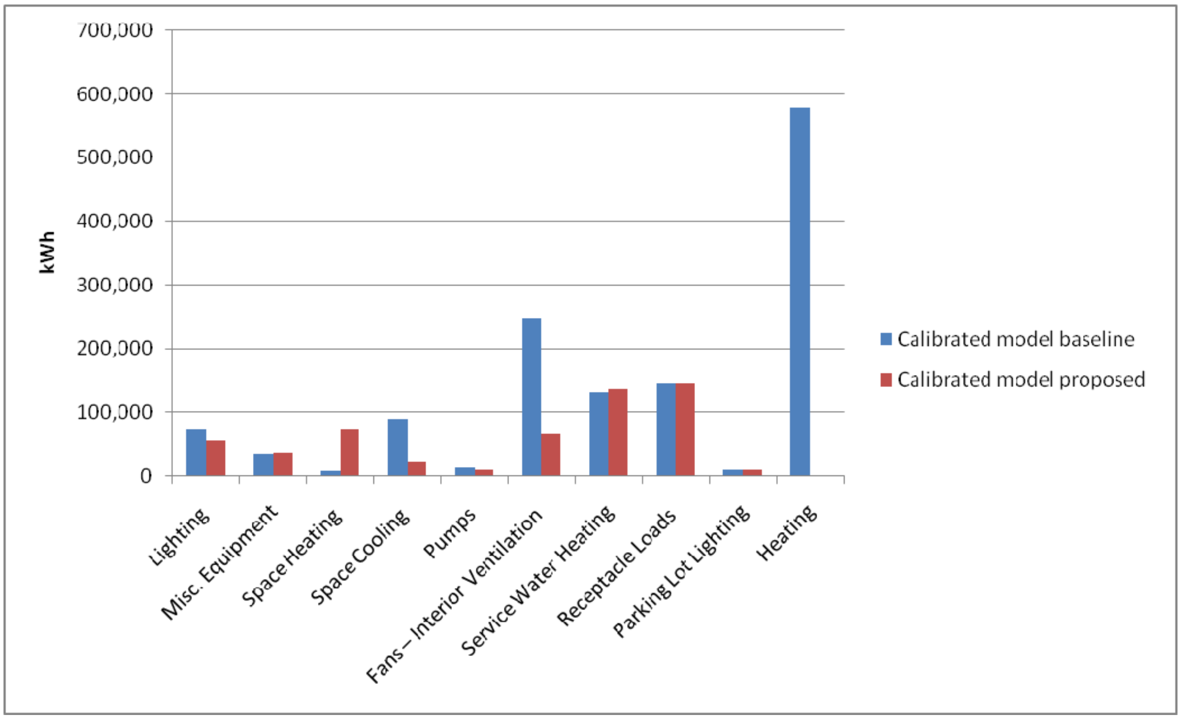

Figure 36: Calibrated modeling end-use breakdown comparison

Table 16 shows the difference in rate structures applied to the original and calibrated models as well as the average energy rates applied to the Complex in 2009. Table 17 shows the difference in simulated energy cost in the calibrated model when the three different rate structures are applied. Finally, Table 17 compares site energy, source energy, and cost savings between the baseline and proposed cases for both the original and calibrated models.

Table 16: Kresge Complex modeled and actual energy rates

	Electricity ($ per kWh)	Gas ($ per kWh)
Original model	0.0800	0.0166
Calibrated model	0.1082	0.0342

[25] Water-to-water heat pumps use ~20-30% as much energy to generate hot water as boilers do.

Actual rates (2009)[26]	0.1146	0.0970

Table 17: Calibrated energy model energy costs per rate

	Using original model energy rates	Using calibrated model energy rates[27]	Using actual 2009 energy rates
Baseline energy cost	$70,407	$102,049	$143,288
Proposed energy cost	$44,684	$60,436	$63,984
Percentage improvement	37%	41%	55%

Table 18: Energy use, cost, and percentage improvement of simulated and actual energy

		Energy use and cost				Percentage improvement		
		Annual site energy use (kWh)	Annual source energy use (kWh)	Cost	Cost savings	Site energy	Source energy	Cost
Original energy model[28]	Baseline	1,302,918	2,971,318	$66,057	$23,864	59%	40%	36%
	Proposed	527,418	1,761,577	$42,193				
Calibrated energy model[29]	Baseline	1,339,747	3,145,083	$102,049	$41,613	58%	41%	41%
	Proposed	558,554	1,865,570	$60,436				
						% difference from calibrated model @ calibrated model rates		
Actual energy use, 2008	Actual	610,182	2,084,357	$71,664		9%	12%	18%

The difference between energy savings and cost savings is due to the mix of fuel types. Although the energy savings look dramatic, they are relative to a prescribed model with very low performance potential. The calibrated baseline building to which the (calibrated) proposed case was compared has a source EUI of 171 kBtu/ft^2/year, qualifying it for an ENERGY STAR rating of only 6. (See Table G-1)

Accuracy of Calibration

Table 19 shows the comparison between actual utility data and the proposed calibrated simulation. The difference of 8.5% (noted as mean bias error [MBE]) is the same as that shown in the energy modeler's report (ENERGY MODELER 2009). Although this appears to be close, it is not sufficient to gauge the accuracy of the calibration. ASHRAE Guideline 14-2002 (ASHRAE 2002) specifies that MBE does not adequately represent accuracy without adding the coefficient of variation of the root mean square error (CVRSME), a measurement of the variance in the results. Guideline 14 also specifies that MBE and CVRSME based on monthly data be within ±5% and ±15%, respectively. Furthermore, we know that there are a number of factors that might contribute to uncertainty of the calibrated simulation and contribute to differences from actual energy usage (see Appendix G:

[26] Blended rate from two separate meters

[27] These values were based on those reported in the calibrated energy report produced by the energy modeler, but corrected for errors we found (see footnote 31, below).

[28] The cost savings in the original Arup/LEED-NC report were reported to be 40%. The difference here is due to the inclusion of a "miscellaneous loads" value in the calibrated report produced by the energy modeler. Because this load was a byproduct of the VisualDOE program and not assigned to any specific load in the building, the same load value was applied post-hoc to the original LEED-NC model's baseline and proposed energy use totals to produce a more even comparison.

[29] The energy use and cost are adjusted in this report due to the apparent miscalculation of the cost of natural gas in the energy modeler's calibrated energy model report.

Energy Performance Analysis, below). Yet, the calibrated model is useful as a starting point for analyzing the Complex's performance, and could be used to explore the reasons why there appears to be a discrepancy between the proposed calibrated simulation and ENERGY STAR results.

Table 19: Calibration performance comparison

	Actual total 2008 [kWh]	**Calibrated proposed total [kWh]**	**Percent difference (actual – calibrated proposed)**
Nov 07	58,491.1	56,389	4%
Dec 07	55,821.0	70,170	-26%
Jan 08	61,381.4	41,926	32%
Feb 08	65,431.3	38,823	41%
Mar 08	54,891.1	44,625	19%
Apr 08	52,301.0	38,068	27%
May 08	50,581.4	49,430	2%
Jun 08	38,381.0	43,122	-12%
Jul 08	40,070.5	41,796	-4%
Aug 08	48,760.4	45,380	7%
Sep 08	39,240.4	40,119	-2%
Oct 08	44,830.9	48,706	-9%
MBE	610,181.5	558,554	8.5%
CVRSME			23%

MBE = mean bias error; CVRSME = coefficient of the root mean square error

All of these factors will affect the calibrated simulation results. Some will increase energy use, and some will decrease it. The only way to determine the overall impact is to include them in the simulations where possible using the most sophisticated tools available. Because the building has a UFAD system, this would require using a more advanced modeling program such as EnergyPlus. In summary, the primary purpose of listing these issues is to indicate how uncertain simulation results can be when it comes to comparing to actual measured performance.

Factors affecting Kresge Complex Energy (and Comfort) Performance

The analysis above provides some insights regarding why the Complex performs as it does. Below, we summarize those factors we believe contribute to the Complex's measured energy performance. As discussed above, attributing a magnitude to these would require a more in-depth study focused on energy and comfort issues.

<u>Building design</u>

- Size and aspect ratio – The Complex consists of low-rise, slender sub-buildings, resulting in a perimeter-dominated building, which is known to increase energy use.
- Window-to-wall ratio – It is not entirely clear how much this ratio impacts the overall performance because the windows were designed according to ASHRAE 90.1, which should allow larger ratios without having an undue impact. The high-performance glazing is some of the best on the market. However, the major zones have ratios of nearly 100% even though the

overall ratio is in the range of 30-50%; undoubtedly, smaller windows in these area using the same glass would result in lower energy use. Still, the tradeoffs among heating and cooling and daylighting are not obvious without further study and of course, smaller windows might compromise important esthetic effects.

- More robust comparisons could have been facilitated by using EPA's Target Finder (U.S. EPA 2010a) program during design. This tool allows designers to compare simulation estimations with ENERGY STAR ratings in a similar way that Portfolio Manager does for actual energy use. Using this method may have added context about how this building would compare to other buildings in operation versus hypothetical ones early in the design process.

<u>HVAC</u>

- Geothermal piping insulation affects heat pump performance.
- Return fans were used on AHUs instead of relief fans.
- Outside air minimum rates appear too high

<u>Controls</u>

- Thermostat setpoints vary widely or are too low for cooling, and there is no dead band.
- Supply plenum pressure control is insufficient. Pressure sensors and a control loop are suggested.
- The air handling unit (AHU) supply air temperature is possibly too low.
- Lighting controls are needed to turn off electric lights when daylighting is adequate.
- There are no reset strategies for AHU pressure and temperature control.

Recommendations

A number of actions could reduce energy use and increase thermal comfort at the Complex. Table 20 highlights the most important recommendations to achieve these goals. However, to estimate the magnitude of these effects would require more detailed analysis and simulations than those that were undertaken in the study described here.

Table 20: Summary of recommended actions

Item	Description of issue	Impact on performance
Thermostat setpoints	Settings vary widely, and there is no dead band.	Correcting this issue might help resolve simultaneous heating and cooling problems, reduce energy use, and increase thermal comfort (by increasing cooling setpoints to ~76°F to 78°F). See the *Thermal Comfort* section.
Control of supply plenum pressures	Control loops are not implemented, which results in negative pressures and a lack of control in interior zones.	Correcting this issue would reduce fan energy consequences associated with sucking room air into supply plenum. Better control of interior zones would help reduce simultaneous heating and cooling and disparities in zone temperatures, reducing energy use and increasing comfort.
Geothermal field	Piping to building is too	Correcting this issue would reduce energy use and

Item	Description of issue	Impact on performance
piping insulation	exposed to environmental conditions.	maintenance and operation problems (and perhaps increase the equipment life) of the water-source heat pumps and multi-stack unit. Evaluation of this impact would best be done based on detailed performance measurements for the heat pumps.
Perimeter-zone floor diffuser installation	A number of floor diffusers have yet to be repaired.	Correcting this issue could reduce energy use and improve comfort in perimeter zones.
Outside air intake configuration	Outside and return air mixes at air intake louvers.	Correcting this issue could improve economizer performance and thus reduce energy use.
AHU supply air temperature	Supply air temperature is too low.	Increasing supply air temperature might improve economizer performance and thus reduce energy use, but because this is climate dependent, the effect should be evaluated first. Increased supply air temperature might mitigate comfort problems in certain areas.
Lighting system controls	Many areas have sufficient daylighting, so overhead lights could be turned off.	See *Lighting* for more detail. Reduced lighting would reduce energy use.
Morning warm-up	The use of electric heaters for morning warm-up uses more energy than is necessary.	Minimizing the use of electric heaters for warm-up and spot cooling could reduce energy use. However, in some instances this may not be possible without substantive changes to the building (e.g., in the entryway).
BMS upgrade	Currently, the BMS allows for only limited data logging and analysis of operations and control.	This upgrade might make it easier to accomplish the controls revisions outlined above as well as to facilitate more efficient monitoring and analysis to assist operators in understanding performance and comfort issues.

Conclusions

Many ambiguities surround the issue of building performance benchmarking. This report provides context for this debate and makes apparent that there is no clear way to determine how well a building is performing. The analysis of the Kresge Complex contributes to this discussion.

The discrepancy between simulated and actual energy use —as shown in Table 14—is not a new issue in the industry; a number of studies (see *Appendix* G: Energy *Performance Analysis*) indicate that building energy models do not, and may not be intended to, accurately predict energy use. Furthermore, there are discrepancies between the certification methods and actual performance as exemplified by the improvement over baseline shown in Table 14 relative to the low ENERGY STAR score for the proposed design. Methods used by LEED-NC and ASHRAE used to evaluate performance of a design are intended to foster good actual energy performance, but not for developing a *rating* per se (also known as an “asset rating”)[30] for a building, or for accurately predicting its energy use. The LEED-NC and ASHRAE approaches use a “comparison to alternatives,” for which simulations are best suited. Additional studies (Bordass 2004, Diamond 2006, GSA 2008) examine the gap between simulated low energy use of so-called high-performance buildings and the actual energy use of the building stock as a whole. Clearly, LEED and other organizations need better methods for estimating performance during design that can ensure good performance during operation.

Other ad hoc methods that might be conceived such as comparing the Complex to other LEED-NC buildings and/or the CBECS database would likely result in a skewed result due to selection bias and other issues. Incorporating all known operating and design factors into a simulation would most likely bring the simulated performance more in line with actual results but would not change the fact that a building is operating more or less efficiently than might be expected as indicated by its LEED rating. The results of this study highlight that calibrated simulation is best used as a tool for understanding how energy is used, why performance is what it is, and how and by how much it might be improved by making changes.

Determining how well the building is *actually* performing is best done by benchmarking. There needs to be a well-established standard against which to compare. Currently we believe that ENERGY STAR is the best standard available. There are logical reasons that a building performs the way it does and varies from the standard. Some of these can be the result of design decisions made to accommodate the building’s desired overall program and aesthetics, its relation to nature, and the intent of providing a superlative environment for the occupants. These goals appear to have been largely achieved at the Complex. See Appendix G: *Energy Performance Analysis*, for more detail.

[30] Currently, this approach is not technically an asset rating because ASHARE 90.1 does not with provide a rating score, (see Appendix G in ASHRAE 90.1-2007), but it is now being considered as the basis for such a system. As implemented by LEED-NC, the approach comes closer to producing an asset rating because LEED-NC credits are awarded based on its findings.

First, Operational, and Life-Cycle Costs/Benefits

Background

This section discusses the financial implications of the Foundation's design choices. The analysis takes a long-term perspective, as it is likely the Complex will serve its occupants for many decades. Construction cost data is based on estimates from the design development stage of the project. No other data is available.

Methodology

The cost analysis is based on a comparison of construction costs for the Complex and those of comparable buildings without the high-performance features incorporated into the Complex. It includes savings as identified in the energy use models and water use predictions. Still, the results are more indicative of overall costs and benefits than a definitive study. Because of the integrated nature of the Complex's design and the constraints imposed by the site, it is not possible to attribute costs to specific sustainability or energy-saving measures. Similarly, it is difficult to establish what other design strategies might have been adopted in lieu of the present design in areas such as building massing and orientation. Further, the project spent $144,000 removing existing buildings; although this made an appreciable contribution to the sustainable character of the project, it is likely that this would have been undertaken for historic preservation purposes regardless of sustainability goals. For this reason, it was not included in the analysis.

No information is available regarding current operating costs for maintenance and repair of facility equipment. There are, nevertheless, specific strategies that can be broadly measured and evaluated, recognizing that comparison to a “conventional” design is, at best, both subjective and hypothetical and relies heavily on professional judgment.

Life-cycle costs are estimated using net present value calculations where the value of the construction costs is compared to the savings (benefits) they offer over time. The benefits analyzed are limited to the direct cash benefits and do not include intangible benefits like employee productivity. In addition, this section uses the building energy model because it most closely reflects the specific strategies incorporated in the building.

Results

Table 13: Kresge Complex first and operational costs/benefits summary

First and Operational Costs/Benefits Summary

Costs		
	All Sustainable Strategies	$1,300,000
	Energy only	$900,000
Benefits (Annual Savings)		
	Energy	$41,600
	Water	$1,000
	Operating	$8,000

Taken together, the cumulative construction cost premiums, including fees and overhead, are in the range of $1,200,000 to $1,300,000. Of this, roughly $900,000 is attributable to energy-use reduction.
Overall, we would expect the combined annual and annualized periodic costs (replacement and major repair) to be moderately less for the Complex than for a conventional building, with a net operating

cost reduction of approximately \$0.30/ft^2, or \$8,000 per annum. Most of this reduction is in the form of reduced replacement costs. We would expect the annual operating cost to be higher than that of a conventional building by approximately \$26,000. It is worth noting that the majority of these increased maintenance costs relate to site measures; when energy-only measures are evaluated, the annualized operating cost reduction is in the range of \$22,000.

The calibrated energy model prepared by the energy modeler, dated January 19, 2009, indicates an estimated energy cost saving of \$41,613. This is larger than the \$23,864 estimated in the original model prepared during design.[31]

The recorded water usage for the past 2 years appears to include start-up irrigation for the landscaping. Excluding the extra water used for irrigation, the current usage is lower than baseline standards. Although this is a significant reduction, water costs are very low, and the anticipated annual saving is in the range of \$1,300 per year. These costs and benefits were used to produce the life-cycle cost analyses.

Figures 37 and 38 show the life-cycle cost outcomes for all measures and for energy-only measures, respectively. The outcomes are highly sensitive to real discount rate selection, which in turn reflects the selection of both nominal rate and escalation rate.

If the project is funded from foundation resources – i.e., if we treat the project as a grantee of the foundation – the effective rate on funds spent is zero. Looking at the funding differently, however, it is common to apply an opportunity cost to the funds, reflecting the fact that the funds would have been used for other purposes that would have an effective return to the foundation, whether in income or in charitable impact. The real discount rate used in the analysis is the discount rate after adjusting for inflation. It is equal to the nominal discount rate minus escalation. We used a range of nominal rates in the analysis to show the impact of the discount rate options on the cost effectiveness outcome, -3%, 0% and +3%. These represent reasonable points within the overall range of possible actual rates.

The -3% rate reflects a scenario where inflation runs 3 percentage points higher than the foundation's cost of money. This is realistic if the nominal rate is set at 0% and inflation averages 3% per annum, or if the foundation rate is set at a "low risk" rate, similar to the federal cost of money, and inflation runs at a higher rate, around 6% to 7%. Although this is possible for a short period, it is unlikely to be the case over the term of the analysis.

The 0% rate reflects a scenario where inflation and the cost of money offset each other. This is realistic if the foundation cost of money is set at the federal cost of money, and inflation returns to a moderate long-term trend of 3% to 4% per annum. It also would remain realistic if inflation rises, and federal rates rise in line with inflation. This scenario probably most closely matches current economic conditions.

The +3% rate reflects a scenario where inflation remains below the nominal discount rate. This is realistic if the foundation sets a nominal rate closer to a commercial rate of 6% to 7% while inflation

[31] We use the difference between baseline and calibrated models since they likely contain the same assumptions. The measured energy data and simulations do not. A comparison against measured costs savings requires a measured baseline, which we do not have. Further, the difference between the calibrated and actual usage is small, so the simulated difference is likely close to the actual energy difference.

remains low at 3% to 4%. It also would remain realistic if inflation rises, and commercial rates rise in line with inflation.

The analysis has been performed for a 50-year period because the building is intended to be a long-term asset for the foundation. The input costs and benefits are based on the estimates included in this report. For simplicity, the term was not varied for sensitivity analysis although there is uncertainty in these costs and benefits.

When considering all measures and the middle scenario of 0% real discount rate, the net present value (NPV) of the investment in all strategies, over 50 years, is around $1,300,000, with a discounted payback period of roughly 24 years. At -3% real discount rate, the NPV increases to almost $4,600,000, with a discounted payback period of almost 19 years. At a +3% real discount rate, the NPV is only $125,000 with a discounted payback period of over 40 years.

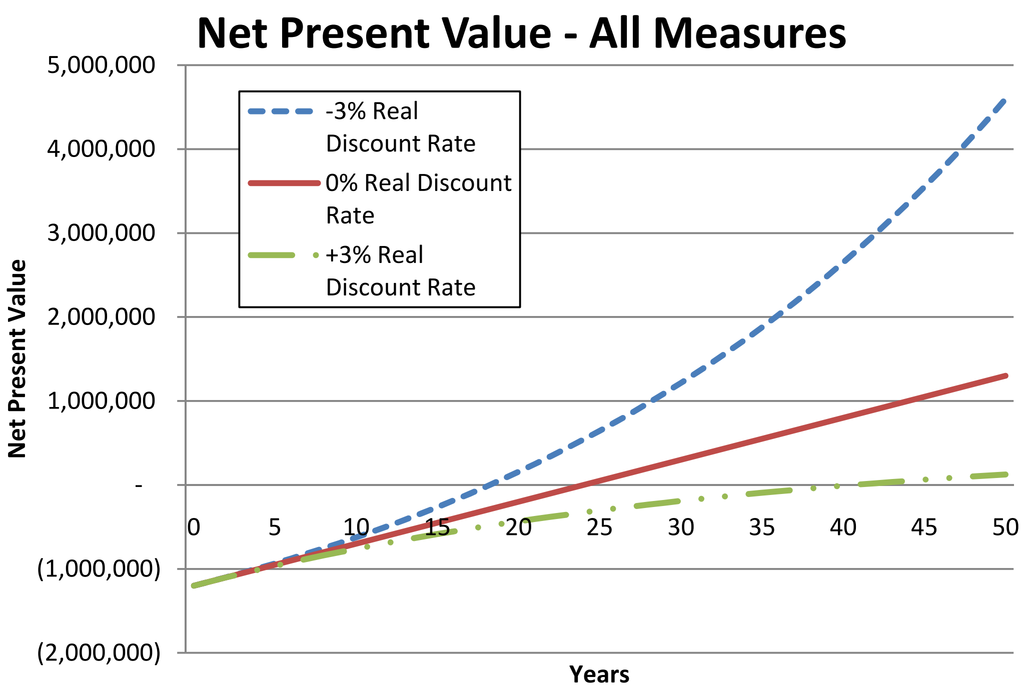

Figure 37: Life-cycle cost outcomes for all measures

When considering energy strategies only, the middle scenario of 0% real discount rate, the NPV of the investment in energy-only strategies, over 50 years, is $2,300,000, with a discounted payback period of roughly 14 years. At -3% real discount rate, the NPV increases to over $6,500,000, with a discounted payback period of almost 12 years. At a +3% real discount rate, the NPV remains negative for 17 years with a final NPV of around $800,000.

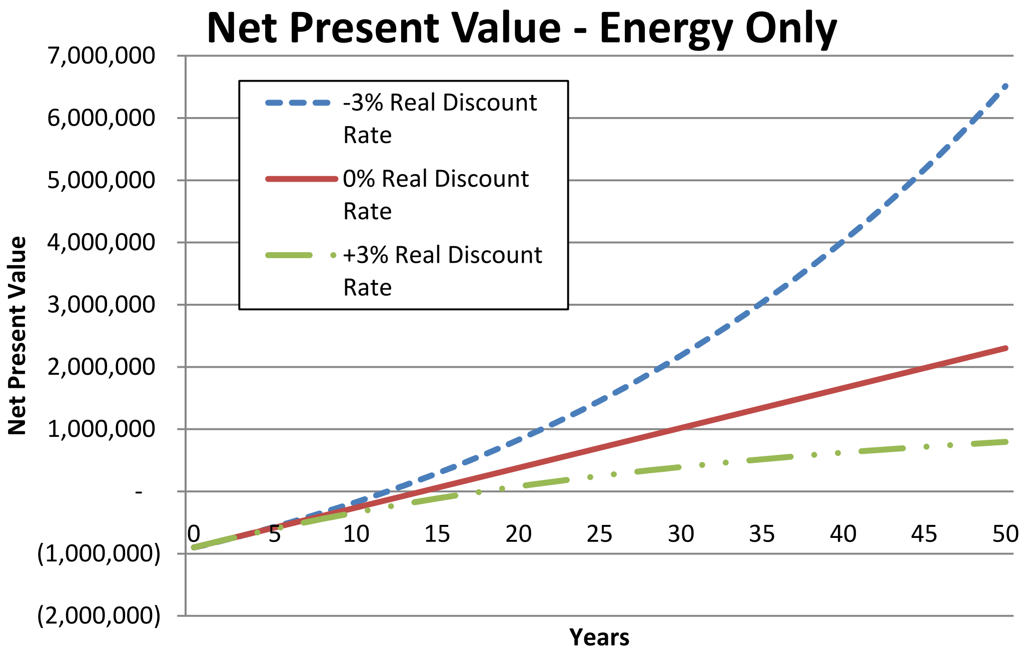

Figure 38: Life-cycle cost outcomes for energy strategies only

Findings by System/Strategy

Based on an overview assessment of the selected systems, we would expect the maintenance and construction costs to differ from those for a conventional building as follows:

Air Conditioning Systems

Ground-Source Heat Pumps

The heating and cooling for the project is provided by a ground, coupled, closed-vertical-loop system comprising both water-to-water and water-to-air heat pumps connected to a series of 40 wells, each approximately 400 feet deep. The conventional approach for a building of this size would be either direct expansion (DX) or compressor-based cooling, and gas-fired heating. The DX system would have the lowest first cost but the highest energy and operational cost. The baseline used in the design energy model was a DX system.

Underfloor Air Distribution System (UFAD)

The UFAD system functions integrally with the ground-coupled heat pump system in that the water-to-air heat pumps also serve as the predominant air supply and circulation fans. The conventional approach for a building of this size would be a ducted, overhead air distribution system supplied by roof-mounted air handlers with either constant volume or variable air volume zone controls.

The combined cost of the HVAC and raised floor system included in the project guaranteed maximum price contract (GMP) was $1,465,474, or $52.61 per gross square foot (gsf). A conventional system would be expected to cost in the range of $30.00/gsf to $35.00/gsf for a building of this type. The overall cost for the baseline system would therefore be in the range of

$830,000 to $970,000, giving a premium cost for the selected air-conditioning strategies of between $500,000 and $600,000.

Lighting Controls and Daylight Harvesting

The Complex makes extensive use of daylight and lighting control as an energy-saving measure. The building configuration is designed to provide a very high level of daylight penetration through both the layout and the use of light shelves. As discussed earlier, the building configuration is not considered a cost factor for this analysis.

Light Shelves

The building has approximately 300 linear feet of sunshades and light shelves on the south façades. The cost for these is not segregated in the GMP, but we estimate it to be in the range of $25,000.

Daylight Controls

The building has a sophisticated lighting control system to provide for a high level of user control and daylight dimming. The cost for this is not segregated in the GMP, but we estimate it to be in the range of $75,000 for the control system and the associated ballasts and fixture enhancements.

The combined cost of the daylight strategies is in the range of $100,000. The baseline building would have neither of these, giving an overall premium cost of $100,000 for these strategies.

Envelope Thermal Performance

The Complex has added insulation in both the walls and the roof. In addition, it has a high-performance glazing system with both improved glass and thermally broken frames to provide significantly better energy performance than the baseline system.

Wall Insulation

The walls are designed with an additional layer of rigid insulation at all opaque surfaces. The cost for this is not segregated in the GMP, but we estimate it to be in the range of $25,000.

Roof Insulation

The Complex has significantly more roof insulation than a conventional building. In addition, the Complex has approximately 2,700 ft^2 of green roofs, which also provide higher levels of insulation than in the baseline model. The green roofs do not, however, provide higher levels of insulation than the enhanced insulation in the non-green portions of the roof. As such, the planting is not a premium cost related to the improved insulation. The cost for the enhanced roof insulation is not segregated in the GMP, but we estimate it to be in the range of $33,000.

Enhanced Glazing Systems

The glazing systems incorporate both high-performance glass and thermally broken frames to increase their energy performance. While the glazing system has an appreciably higher performance and cost than code-minimum systems, typical comparable buildings use reasonably high-performance glass as a matter of course. Thermally broken frames are not common, however. The cost for the exterior glazing systems is not segregated in the GMP, but we estimate it to be in the range of $400,000. A code-minimum system would cost in the range of $275,000, and a typical building system would cost in the range of $330,000.

The combined premium cost for the enhanced envelope thermal performance is, therefore, in the range of $128,000.

Roofing

The project incorporated two strategies to improve the roofing performance: vegetated (green) roofs and high-albedo ethylene propylene diene monomer (EPDM) roofs. Both reduce the urban heat island effect, and the green roofs also contribute to stormwater management (both slowing the rate of flow and improving the water quality).

EPDM Roofing

The EPDM roofing is carried in the GMP at approximately $\$10.50/ft^2$ of roof area. A conventional roof in the same configuration would cost in the range of $\$7.00/ ft^2$ of roof area, for a total cost difference of $50,000.

Green Roofs

The cost for the green roof is not segregated in the GMP, but we estimate it to be in the range of $80,000, excluding the insulation and membrane, which are addressed above.

The combined premium cost of the roofing enhancements is in the range of $90,000.

Low-emitting Building Materials

The project incorporated several low-emitting materials, including linoleum in lieu of vinyl flooring, milk paint in lieu of conventional paint, and wood products with no added formaldehyde. (Cleaning products used both during and after the construction are specified to have low levels of volatile organic compounds (VOCs), but these are not considered in this analysis because they are not part of the first cost of the project.) There is insufficient information in the GMP and available design documents to generate an accurate estimate of the cost, if any, of the low-emitting materials. In many cases, the materials selection is based not only on the chemical properties but also reflects appearance and other performance choices. For example, the perforated metal ceilings may have lower-emitting properties than conventional lay-in tile ceilings, but it is unlikely that their selection was based solely on environmental considerations.

Based on our review of and experience with other projects, it is very difficult to estimate the premium cost of low-emitting materials, except in very specific cases. In general, it is possible to select acceptable products with little or no premium over less environmentally appropriate materials. Where a more expensive low-emitting material is selected, it is normally a result of other considerations, as described above. We therefore conclude that there is no premium cost resulting from the incorporation of low-emitting materials into the project.

Forest Stewardship Council Certification of Wood Products

The project incorporated Forest Stewardship Council-certified wood into the construction. The extent and cost of the Forest Stewardship Council wood is, however, not identified in the available design documents or the GMP. The total cost of finished carpentry in the GMP is $447,213. Given this cost, we estimate that the premium cost is likely to be, at most, in the range of $10,000 to $25,000.

Plumbing Systems
The Complex incorporated a series of water-use reduction strategies including low-flow fixtures and waterless urinals, in addition to the use of landscaping designed to require no permanent irrigation. Overall, the cost premium of the indoor plumbing strategies is insignificant, and the elimination of landscape irrigation can lead to overall cost savings because it eliminates a complete system. These savings may be partially offset by increased plant materials costs. In reviewing the GMP planting budget, we find that the overall cost is comparable to the cost of a conventional construction of this nature, so we conclude that there is no premium or savings associated with the irrigation system.

Site Construction and Landscaping
The Complex incorporated several sustainable features into the site development, including permeable paving, gabion retaining walls, stormwater management, and native planting.

Permeable Paving

Permeable paving is used for both vehicular and pedestrian areas. For the purpose of this analysis, only the vehicular paving is considered because the design choices for pedestrian paving are relatively cost neutral for a building of this character. Although it would be possible to select lower-cost pedestrian paving, it is unlikely that the design would be suitable within the context of the project. The permeable paving contributes to the Complex's sustainability for both stormwater management and reduction of the heat island effect of asphalt.

The project has approximately 17,500 ft^2 of permeable vehicular paving. The cost for this is not segregated in the GMP, but we estimate it to be in the range of $260,000 compared to conventional asphalt parking at $100,000, for a premium cost of approximately $160,000.

Gabion Retaining Walls

The gabion retaining walls reuse construction waste and reduce off-haul and dumping. In addition, because concrete manufacturing contributes significantly to greenhouse gas emissions, it is desirable to avoid using new materials for the walls. The cost difference for the gabion walls is difficult to assess because the cost of the walls is very dependent on the availability of suitable materials and the willingness and ability of contractors to incorporate the material into gabions. Where the reclaimed material can be readily used, the cost of the gabion walls should be comparable to conventional cast-in-place concrete walls.

Stormwater Management

The stormwater management system comprises piped collection of roof and site stormwater, constructed wetlands, and a storage cistern. The piped component is not appreciably different from what would be expected in a conventional stormwater collection system. The constructed wetlands and cistern are added costs. The GMP budget identifies the cistern cost at $20,000. The cost for the constructed wetland is not separately identified in the GMP, but we estimate it to be a minimal premium over the cost of comparable landscaping, $10,000 or less.

Therefore, these site construction strategies collectively have a premium cost in the range of $190,000.

General Contractor Costs
Overall, the general contractor costs for contingency, overhead, and fees are not appreciably different from those we would expect for a conventional construction project. The GMP does, however, identify

certain costs associated with the implementation of the sustainable strategies. These include construction air quality management at $30,000, mechanical peer review at $10,800, and geothermal testing at $22,500, for a total of $63,300. Of these, it is possible that the mechanical peer review would have been required for conventional construction, although this is not common.

Cost Premiums by System	
Ground-source heat pumps and UFAD	$600,000
Lighting controls and daylight harvesting	$100,000
Added insulation (wall and roof)	$58,000
Enhanced glazing systems	$75,000
Roofing (EPDM and green)	$90,000
FSC wood	$25,000
Site construction and landscaping	$180,000
General contractor	$63,000

Repair and Maintenance Costs

Based on an overview assessment of the selected systems, we expect that maintenance and repair costs for the Complex would differ from those for a conventional building as follows:

<u>Ground-Coupled Heat Pumps</u>

The ground-coupled heat pump system should be easier to maintain than a conventional system of cooling tower and chillers, or DX cooling units.

<u>Underfloor Air Distribution System (UFAD)</u>

Although raised floors offer a benefit in life-cycle cost related to churn and office reconfiguration, this is unlikely to be a significant factor for the Kresge Complex because the office areas are relatively small and not suited to large-scale reconfiguration. The Kresge air distribution system using heat pumps is comparable to a conventional air handling system, and there is no appreciable cost difference expected in operating cost for the raised floor or the UFAD.

<u>Daylight Controls</u>

The daylight controls moderately increase the cost of maintenance and operations in that they introduce new elements to be maintained compared to a conventional lighting system (without controls).

<u>EPDM Roofing</u>

The EPDM roofing should have a better life-cycle performance than a conventional built-up roof, both because of better material characteristics and because of the solar reflectance.

<u>Green Roof</u>

The green roof has higher routine maintenance than a conventional roof, with annual burns and regular plant management, but it should have better life-cycle performance because the membrane is protected from direct solar exposure and from impact or penetration.

Permeable Paving

The permeable paving will require slightly more routine maintenance to address weed growth and potential paver displacement, but it should require significantly less periodic maintenance and less frequent resurfacing or replacement than conventional paving.

Stormwater Management

The constructed wetlands and cistern will require more maintenance than a conventional piped system.

It is difficult to quantify the overall impact of the changes in operating cost from all of the above; Table 22 shows an estimate of likely cost differences:

Total repair costs

Table 22: Total repair costs

	Annual cost $/ft^2	**Annualized periodic cost** $/ft^2
Ground-source heat pumps	(0.10)	-
Underfloor air distribution	-	-
Daylight controls	0.05	-
EPDM roofing	-	(0.75)
Green roof	0.25	-
Permeable paving	0.25	(0.50)
Constructed wetlands	0.50	-
Total	0.95	(1.25)

Acknowledgements

We would like to thank the Kresge Foundation for the financial support to complete this project. We would also like to thank the many persons whose knowledge and expertise made this report possible. We sincerely appreciate the support and guidance of Jessica Boehland, Richard Rappleye and Cynthia Powors from the Kresge Foundation. We are grateful for the assistance and information provided by David Grabowski of Larson Realty Group and Karl Koto of WH Canon. We also thank Nan Wishner for her editorial expertise.

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Appendix A: Performance Scorecard Details

Table 1 provides an overview of the performance of the Kresge Complex as described in the Executive Summary to this report. The Center for the Built Environment (CBE) team used evaluation criteria drawn from industry standards, guidelines, best practices where available, and professional judgment where standards were not definitive or required interpretation. The (+) sign indicates conformity with these criteria and performance consistent with what the authors consider appropriate for high performance buildings. The (-) sign indicates nonconformity with relevant criteria or other causes for concern.

Table A-1: Scorecard with detailed criteria citations

1) Occupant survey	**+/-**	**Evaluation reasoning**
Office layout	-	In top quartile of CBE survey database
Office furnishings	+	Not in top quartile of CBE survey database
Thermal comfort	+	In top quartile of CBE survey database
Air quality	+	In top quartile of CBE survey database
Lighting	+	In top quartile of CBE survey database
Acoustic quality	-	Not in top quartile of CBE survey database
Cleanliness	+	In top quartile of CBE survey database
2) PMP [1]		
Lighting	+	IESNA (2000)
Acoustics	+	Table 3-10 (Recommended Sound Criteria for Basic Measurements) of PMP (ASHRAE, 2009)
Thermal comfort	-	ASHRAE Standard 55-2004 – Thermal Environmental Conditions for Human Occupancy (ANSI Approved) (ASHRAE 2004)
Air quality	-	ANSI/ASHRAE Standard 62.1-2004, Ventilation for Acceptable Indoor Air Quality (ASHRAE 2004a)
Energy	-	ENERGY STAR rating system
Indoor H_2O	+	U.S. 1531 Department of Energy Federal Energy Management Program Federal Water Use Indices, which is based upon American Water Works Association table 1996. Also based on Verein Deutscher Ingenieure VDI 3807 Blatt 3 (Association of German Engineers VDI 3807 Part 3)
3) LEED-NC		
Landscape H_20 reduction	+	LEED-NC credit WE 1.1 – Water Efficient Landscaping Reduce by 50%
Landscape H_20 use	-	LEED-NC credit WE 1.2 – Water Efficient Landscaping No Potable Use or No Irrigation
Storm H_20 quantity	+	LEED-NC credit SS 6.1 – Stormwater Management Rate/Quantity; Oakland County Drain Commissioner (2007)
Storm H_20 quality	+	LEED-NC credit SS 6.2 – Stormwater Management Treatment
4) Others		
Biodiversity	+	Plant species diversity (FQI)
Life-cycle Costs	+	Professional judgment
Operations Costs	+	Professional judgment

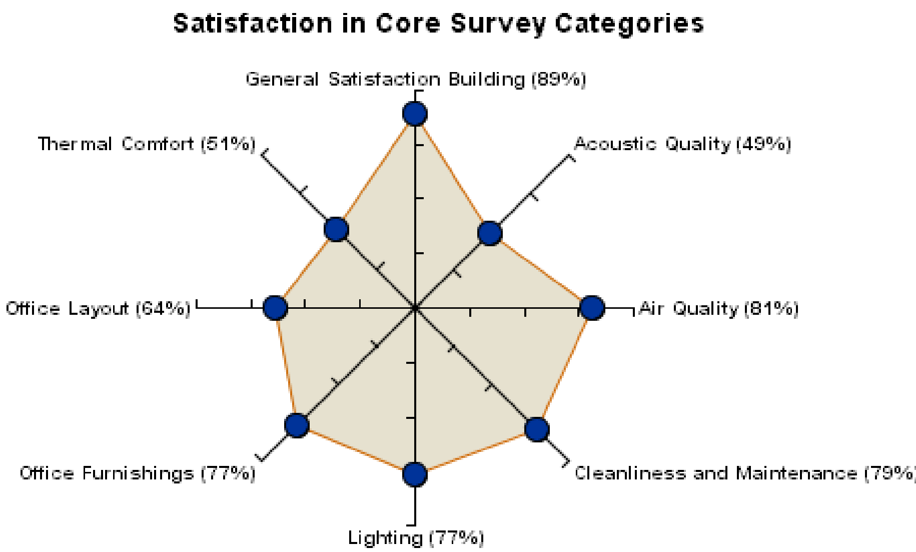
Appendix B: Survey Report

Kresge Office Building

Occupant Survey Report

Survey Dates: 2/1/2010 through 2/12/2010

Center for the Built Environment
University of California, Berkeley



C B E

Table of Contents

3.3 Occupant Survey Methodology

3.4 How to Get the Raw Data

1.1 How to Use This Report

This report contains a lot of detail about this building. You can use this report in different ways depending on the level of detail you need. The first section, the executive summary, is a high-level overview of the building's performance. It contains basic metrics by category. Read this section if you need a general understanding of the building's performance or its relationship to other buildings. This section answers 'how.' How is the building performing from the occupants' perspective.

Section two contains information at the question level. Here you can get specific information about the drivers behind the building's score in a particular category. You can also find information about occupant responses to a particular question. This section answers 'what.' What is contributing to this level of perceived performance?

Section three contains information from and about the occupants. This is where you look for demographic information and information about how occupants use the building. You can also find comments from occupants in this section. This section answers 'who.' Who is using the building?

One of the most powerful uses of this report is diagnostic. The survey report gives you information about what's going right (or not so right) in your building. With this information you can make informed decisions about how to improve your buildings performance.

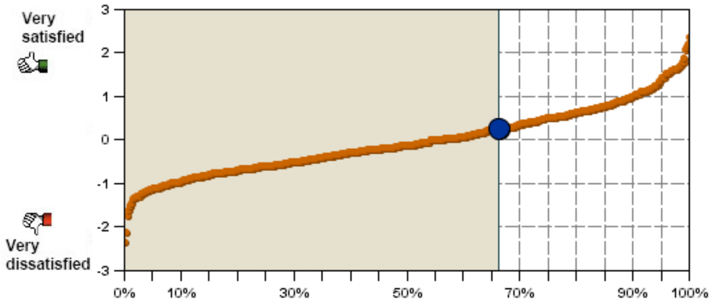
1.2 Building Scorecard

Performance of Kresge Office Building in core survey categories

Acoustic Quality

66%

Percentile



0.26

Mean Response

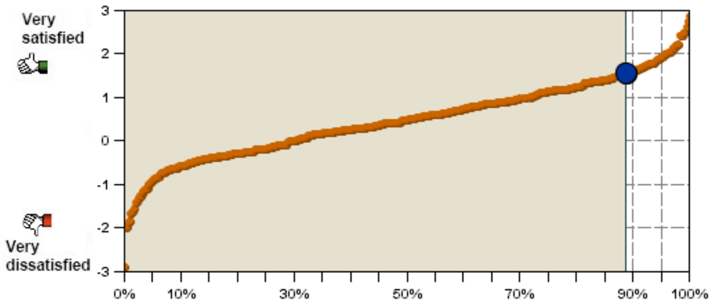
49%

Satisfied

Air Quality

89%

Percentile



1.56

Mean Response

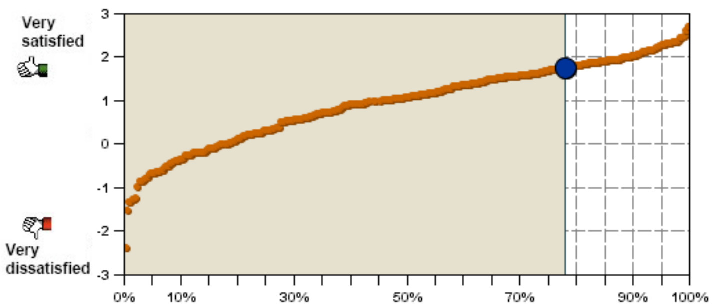
81%

Satisfied

Cleanliness and Maintenance

78%

Percentile



1.76

Mean Response

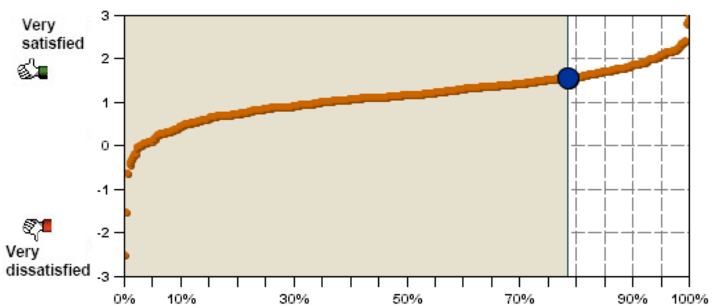
79%

Satisfied

Lighting

78%

Percentile



1.57

Mean Response

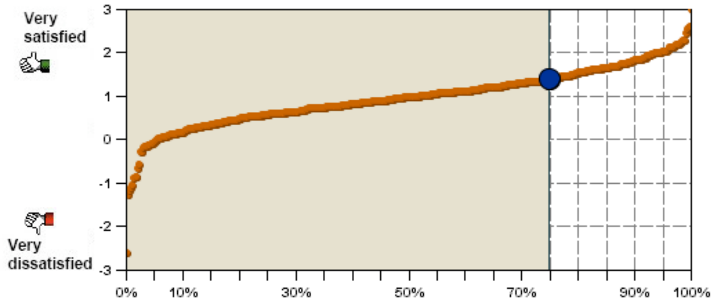
77%

Satisfied

Performance of Kresge Office Building in core survey categories

Office Furnishings

75%
Percentile

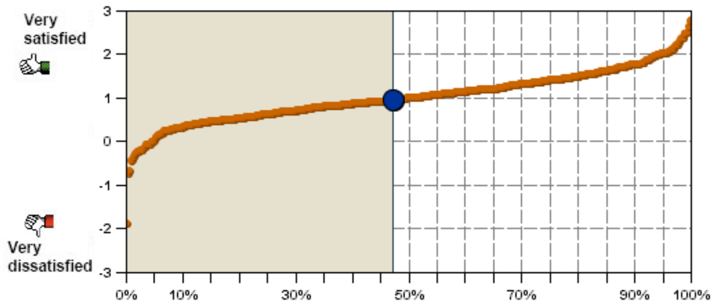


1.41
Mean Response

77%
Satisfied

Office Layout

47%
Percentile

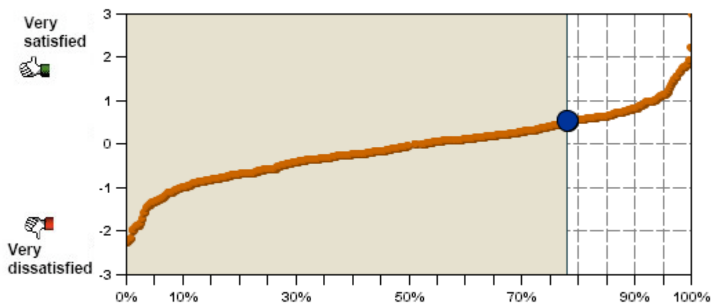


0.98
Mean Response

64%
Satisfied

Thermal Comfort

78%
Percentile



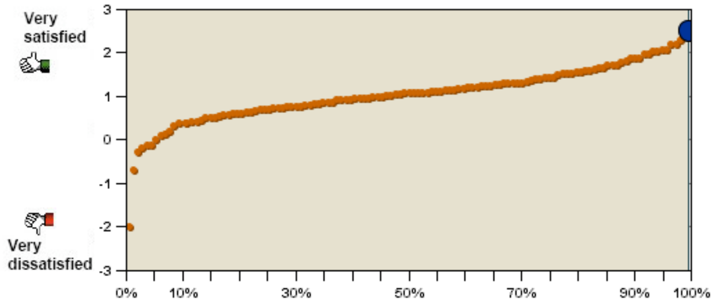
0.54
Mean Response

51%
Satisfied

Performance of Kresge Office Building in additional survey categories

Building Management Staff

100%
Percentile

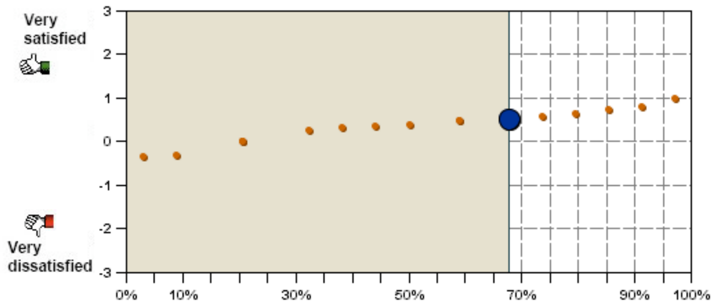


2.52
Mean Response

95%
Satisfied

Floor Diffusers

68%
Percentile

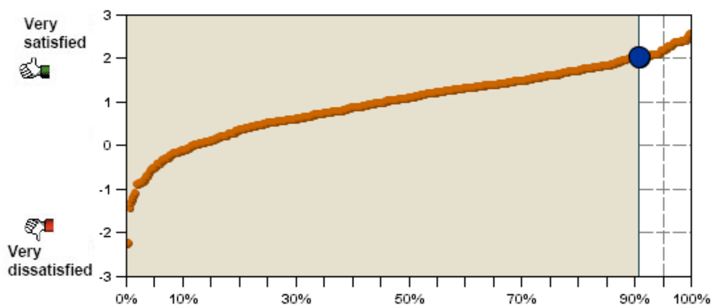


0.54
Mean Response

40%
Satisfied

General Satisfaction-Building

91%
Percentile

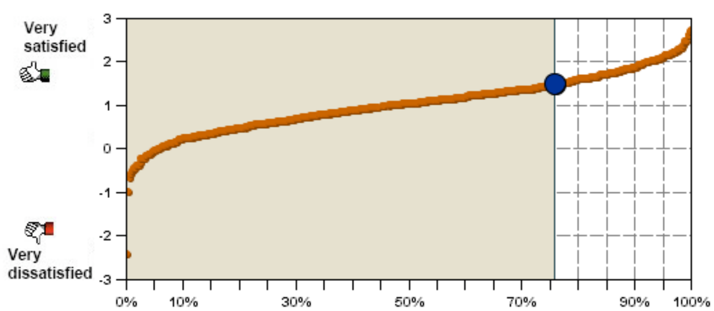


2.04
Mean Response

89%
Satisfied

General Satisfaction-Workspace

76%
Percentile

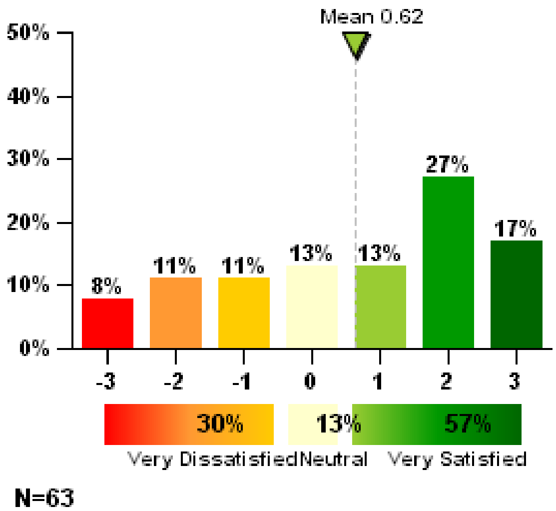


1.51
Mean Response

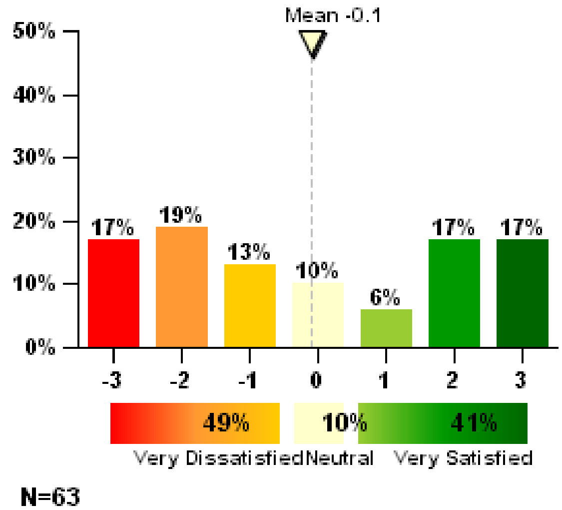
72%
Satisfied

2.1 Acoustic Quality

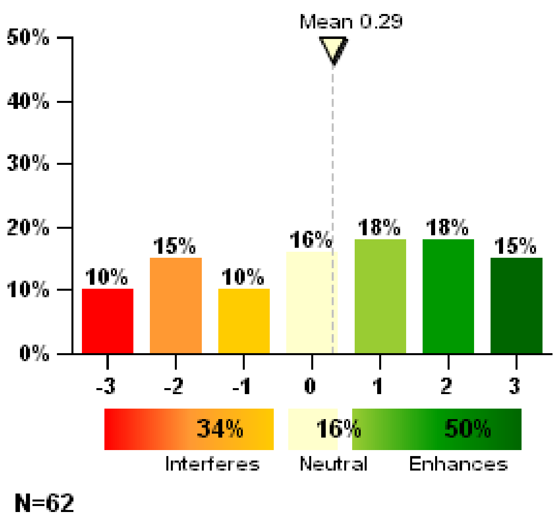
How satisfied are you with the noise level in your workspace?



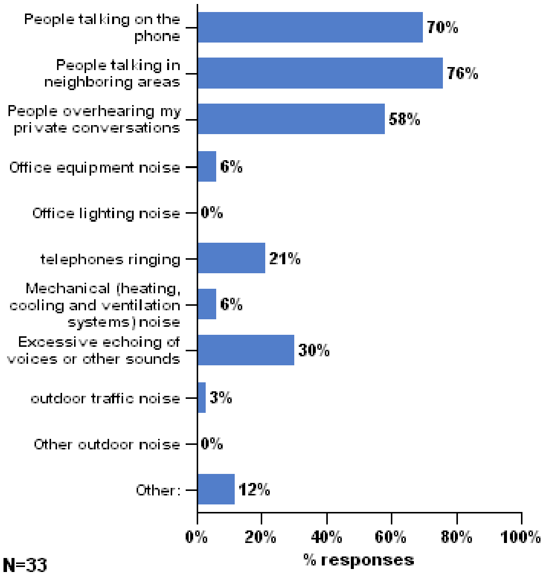
How satisfied are you with the sound privacy in your workspace (ability to have conversations without your neighbors overhearing and vice versa)?



Overall, does the acoustic quality in your workspace enhance or interfere with your ability to get your job done?



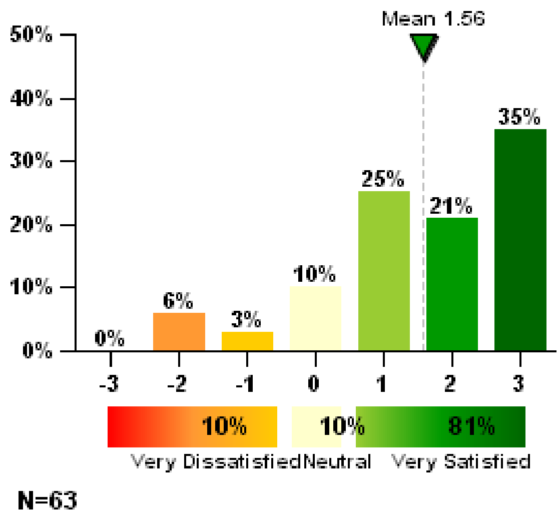
You have said you are dissatisfied with the acoustics in your workspace. Which of the following contribute to this problem? (check all that apply)



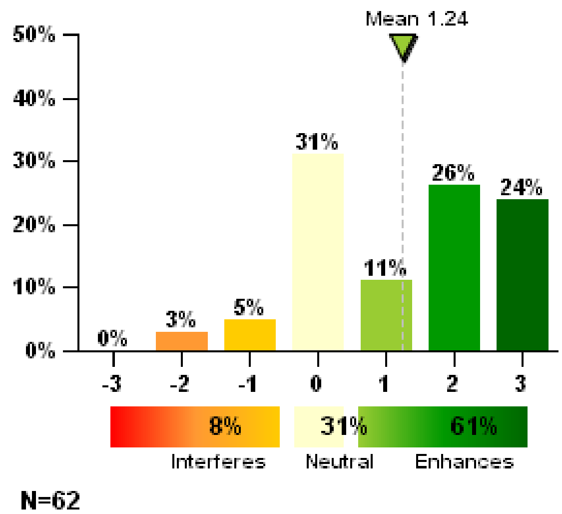
N=33

2.2 **Air Quality**

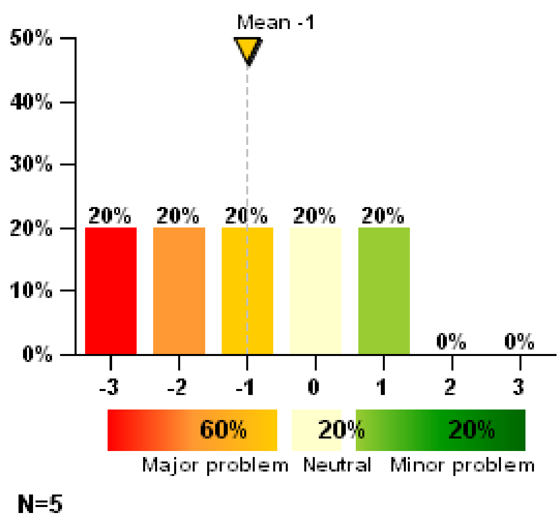
How satisfied are you with the air quality in your workspace (i.e. stuffy/stale air, cleanliness, odors)?



Overall, does the air quality in your workspace enhance or interfere with your ability to get your job done?



Air is stuffy/stale



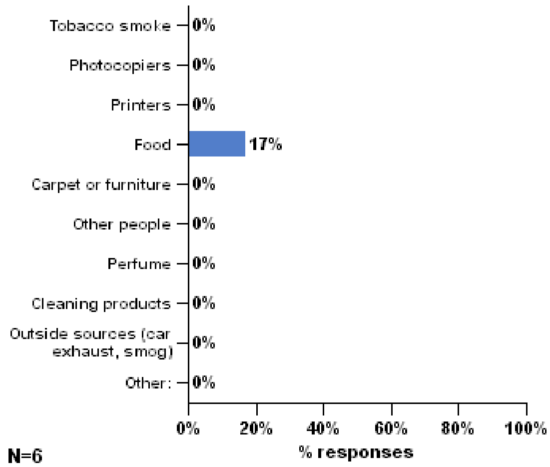
Air is not clean

Due to the limited number of responses to this question, its chart is not displayed

Air smells bad (odors)

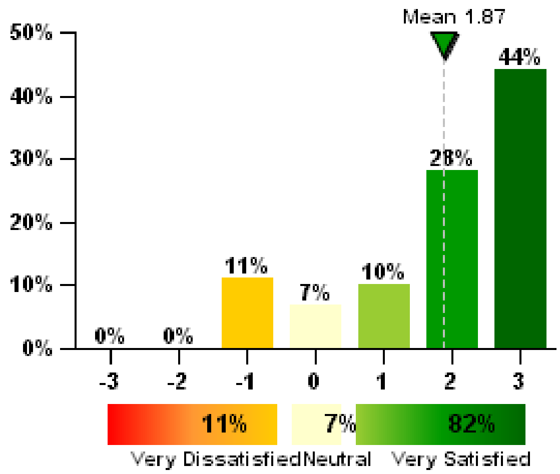
Due to the limited number of responses to this question, its chart is not displayed

If there is an odor problem, which of the following contribute to this problem? (check all that apply)



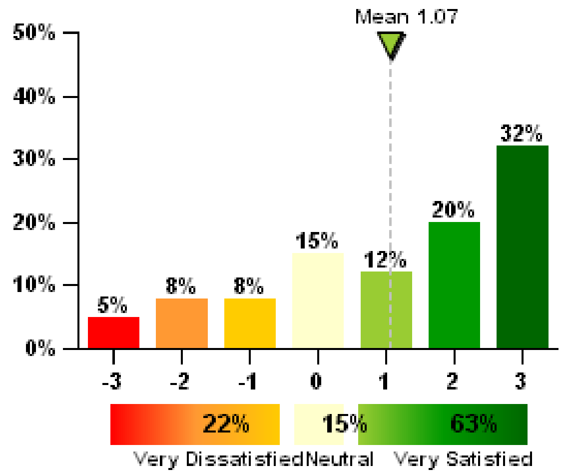
2.3 Cleanliness and Maintenance

How satisfied are you with general cleanliness of the overall building?



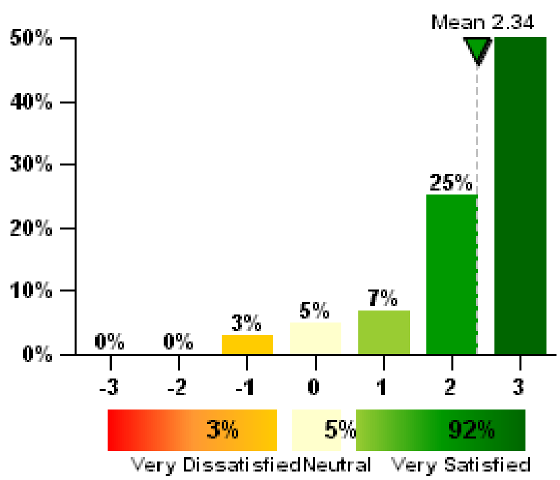
N=61

How satisfied are you with cleaning service provided for your workspace?



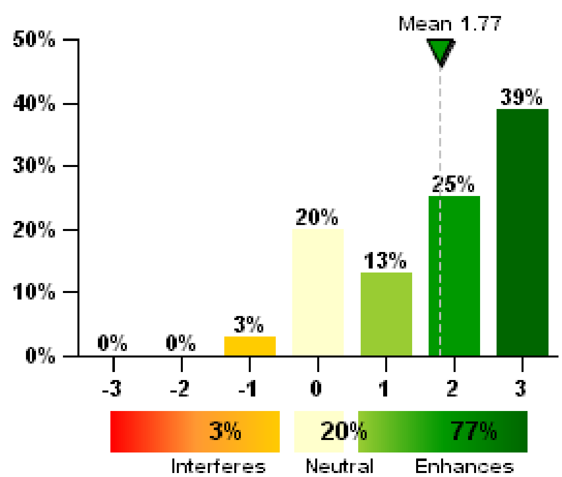
N=60

How satisfied are you with general maintenance of the building?



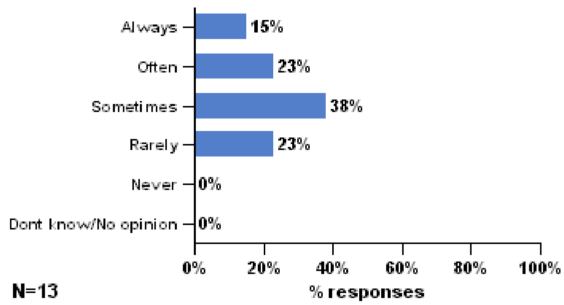
N=61

Does the cleanliness and maintenance of this building enhance or interfere with your ability to get your job done?

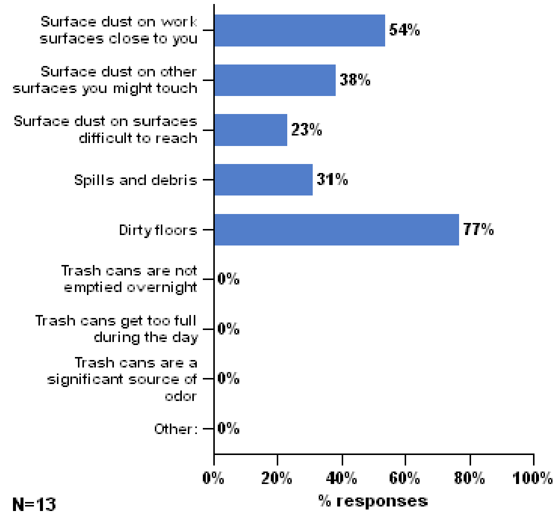


N=61

You have told us that you are dissatisfied with the cleaning service provided for your workspace. How often do you have significant problems?

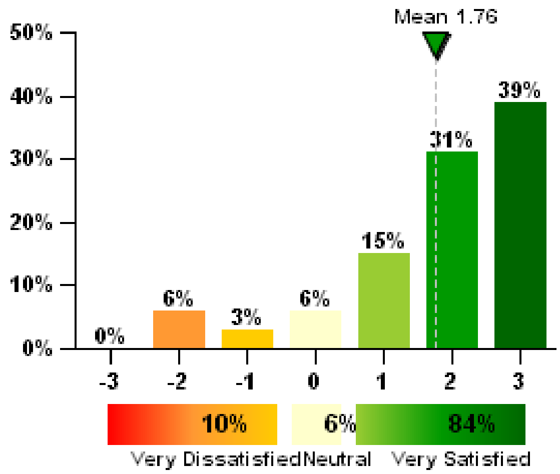


Which of the following contribute to this dissatisfaction? (check all that apply)



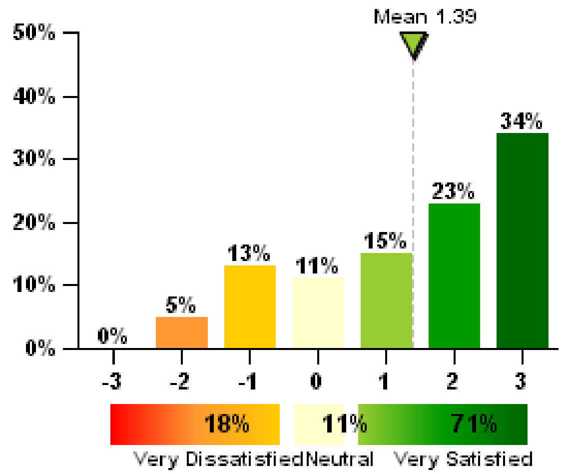
2.4 Lighting

How satisfied are you with the amount of light in your workspace?



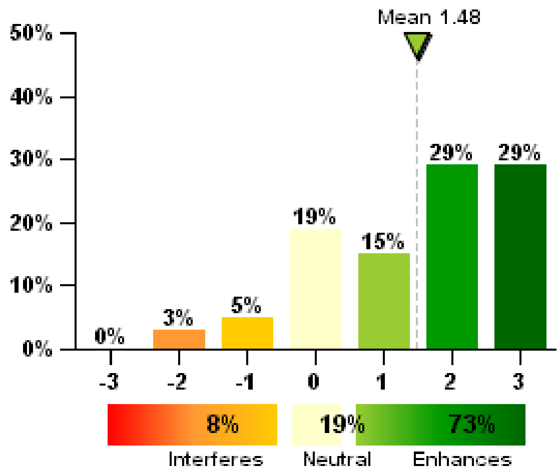
N=62

How satisfied are you with the visual comfort of the lighting (e.g., glare, reflections, contrast)?



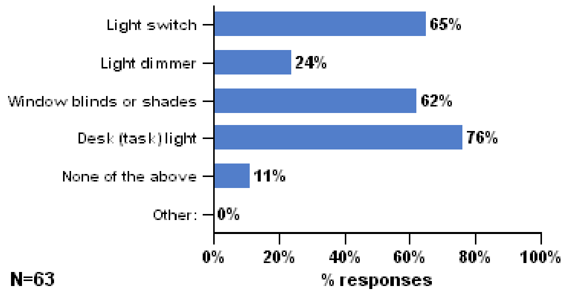
N=62

Overall, does the lighting quality enhance or interfere with your ability to get your job done?

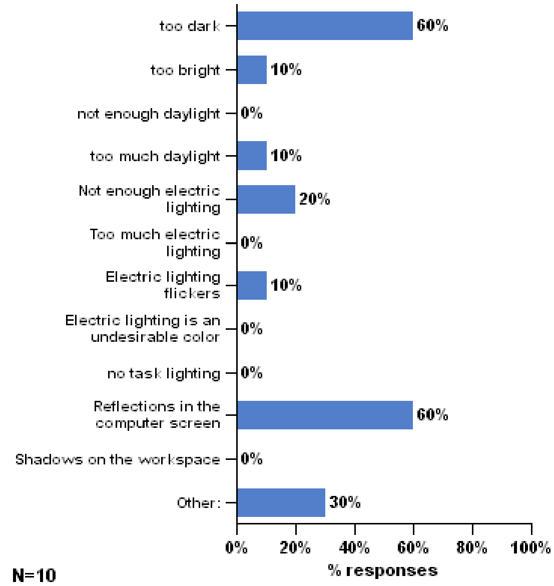


N=62

Which of the following controls do you have over the lighting in your workspace? (check all that apply)

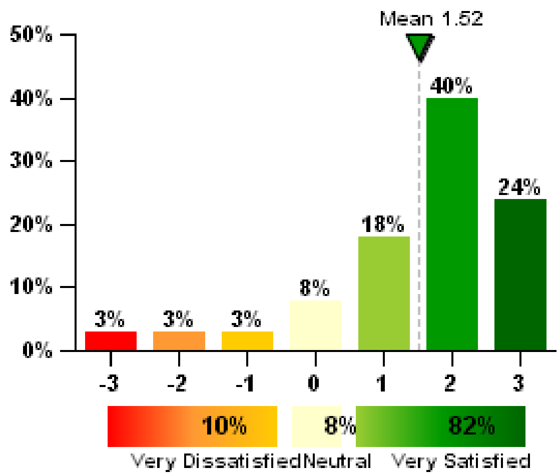


You have said that you are dissatisfied with the lighting in your workspace. Which of the following contribute to your dissatisfaction? (check all that apply)



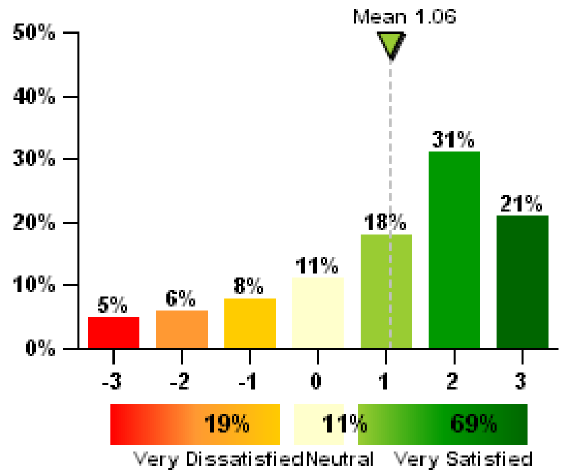
2.5 Office Furnishings

How satisfied are you with the comfort of your office furnishings (chair, desk, computer, equipment, etc.)?



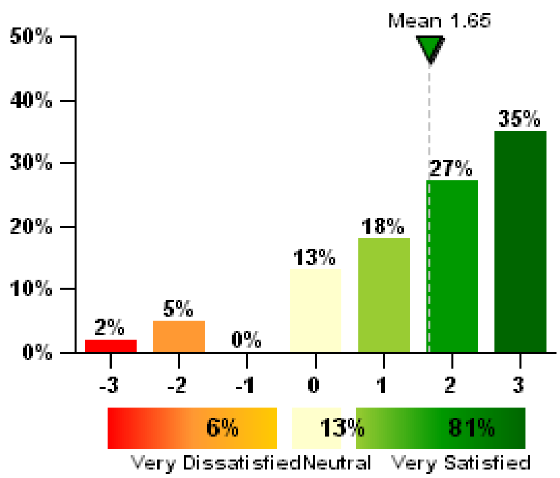
N=62

How satisfied are you with your ability to adjust your furniture to meet your needs?



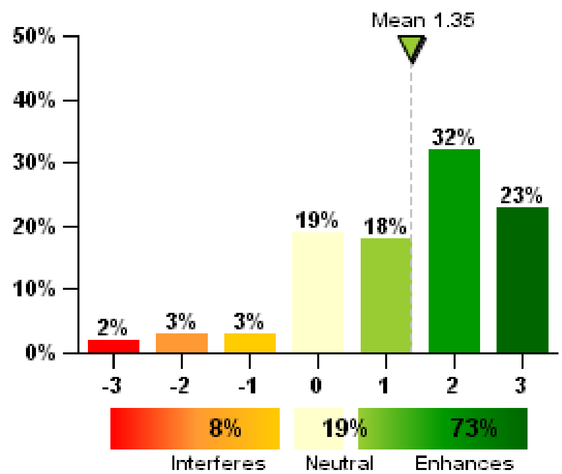
N=62

How satisfied are you with the colors and textures of flooring, furniture and surface finishes?



N=62

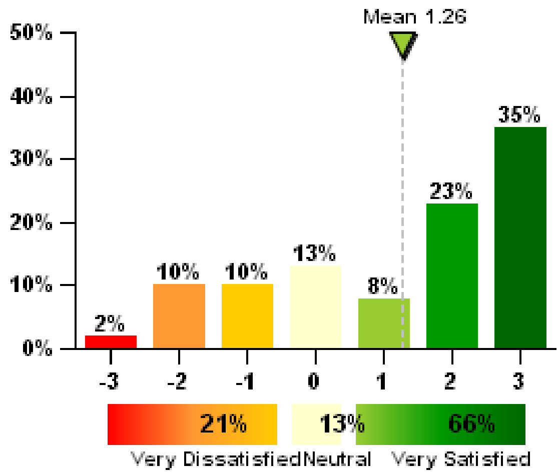
Do your office furnishings enhance or interfere with your ability to get your job done?



N=62

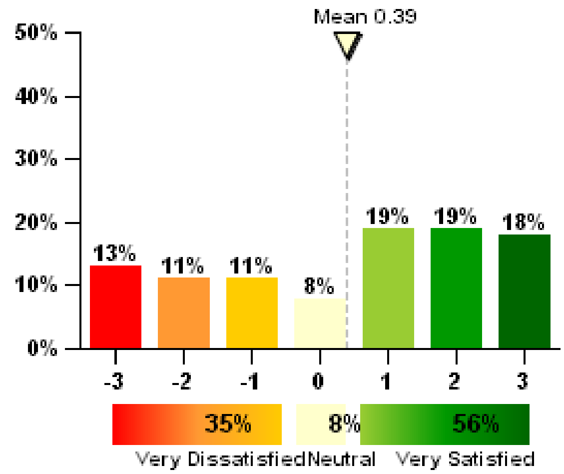
2.6 Office Layout

How satisfied are you with the amount of space available for individual work and storage?



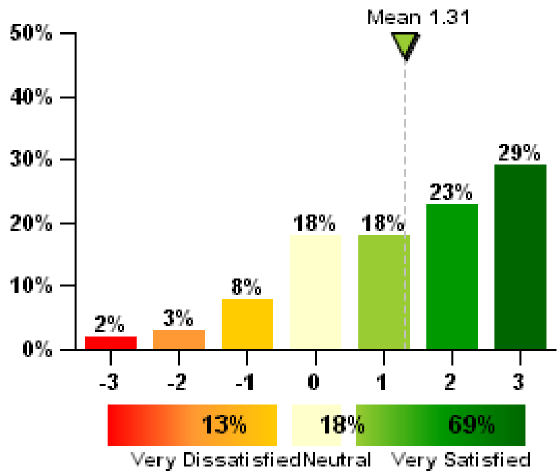
N=62

How satisfied are you with the level of visual privacy?



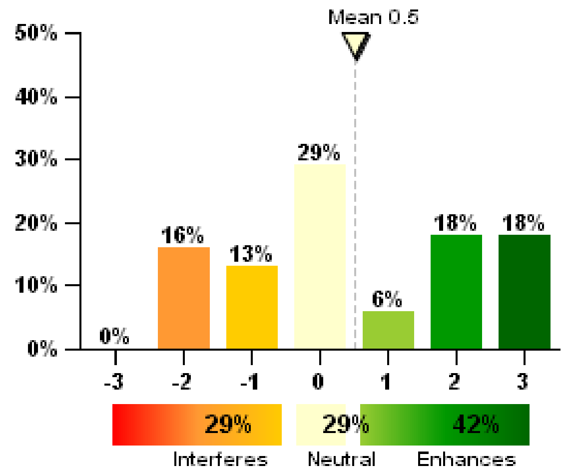
N=62

How satisfied are you with ease of interaction with co-workers?



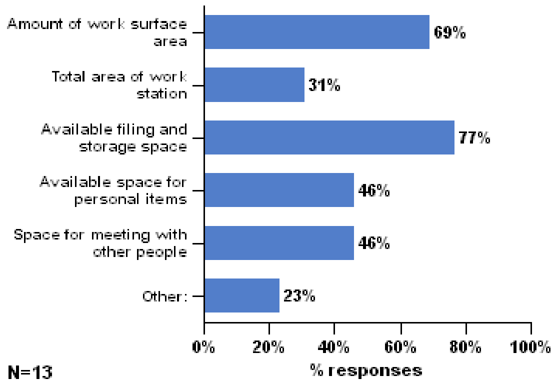
N=62

Overall, does the office layout enhance or interfere with your ability to get your job done?

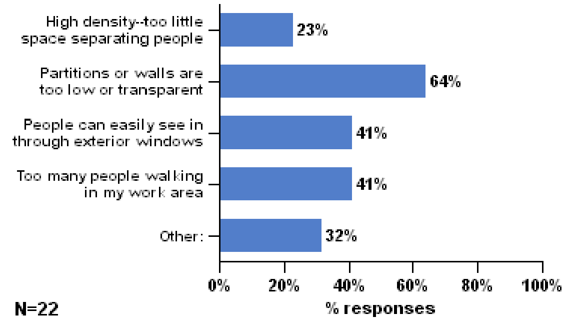


N=62

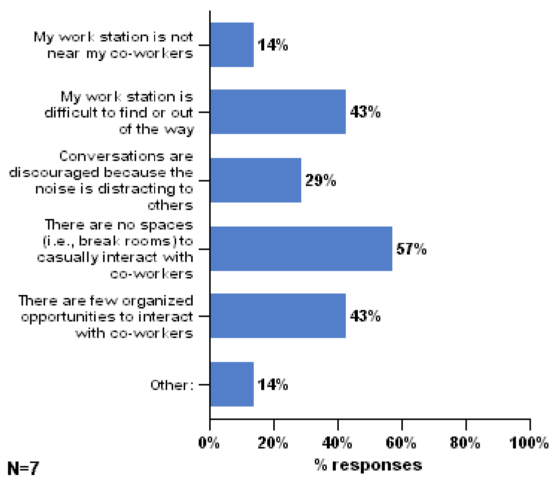
You have said that you are dissatisfied with the amount of space available for individual work and storage. Which of the following contribute to your dissatisfaction? (check all that apply)



You have said that you are dissatisfied with the level of visual privacy. Which of the following contribute to your dissatisfaction? (check all that apply)

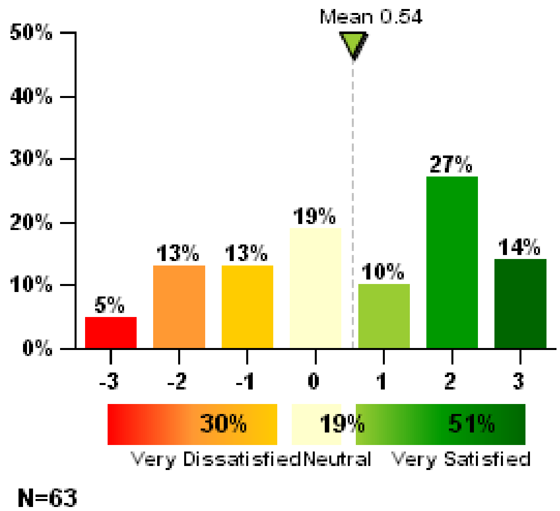


You have said that you are dissatisfied with the ease of interaction with co-workers. Which of the following contribute to your dissatisfaction? (check all that apply)

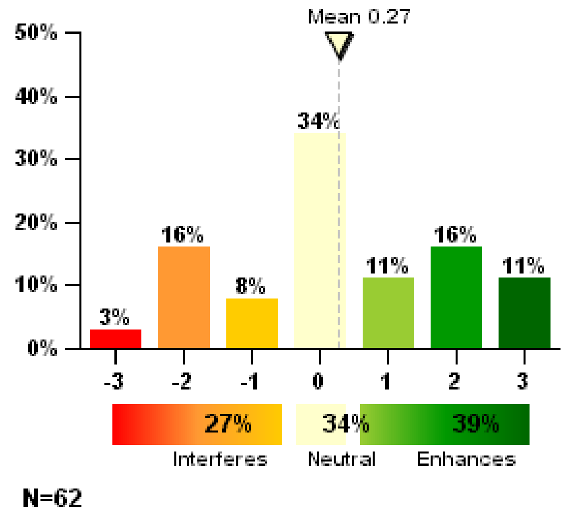


2.7 **Thermal Comfort**

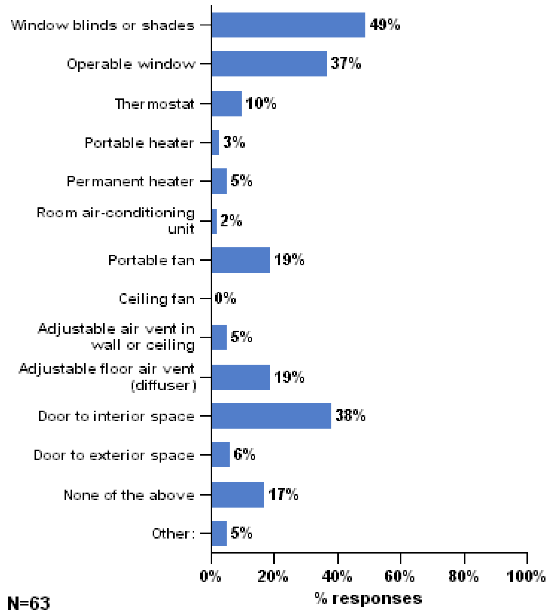
How satisfied are you with the temperature in your workspace?



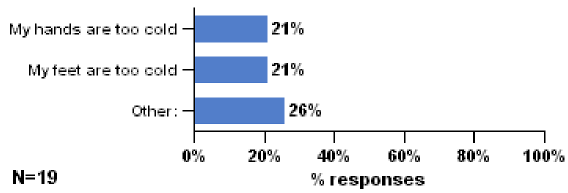
Overall, does your thermal comfort in your workspace enhance or interfere with your ability to get your job done?



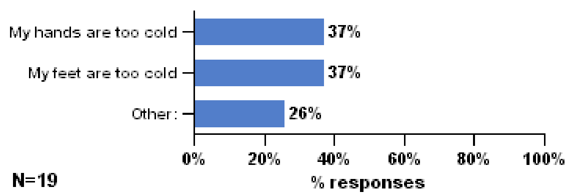
Which of the following do you personally adjust or control in your workspace? (check all that apply)



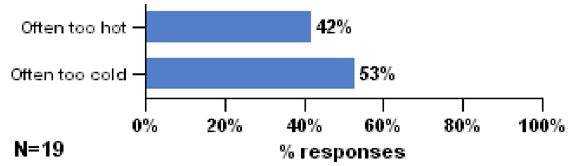
In warm/hot weather... (check all that apply)



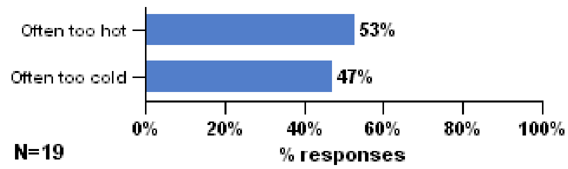
In cool/cold weather... (check all that apply)



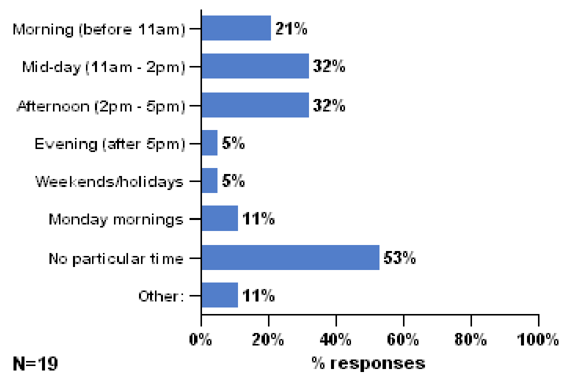
In warm/hot weather, the temperature in my workspace is: (check all that apply)



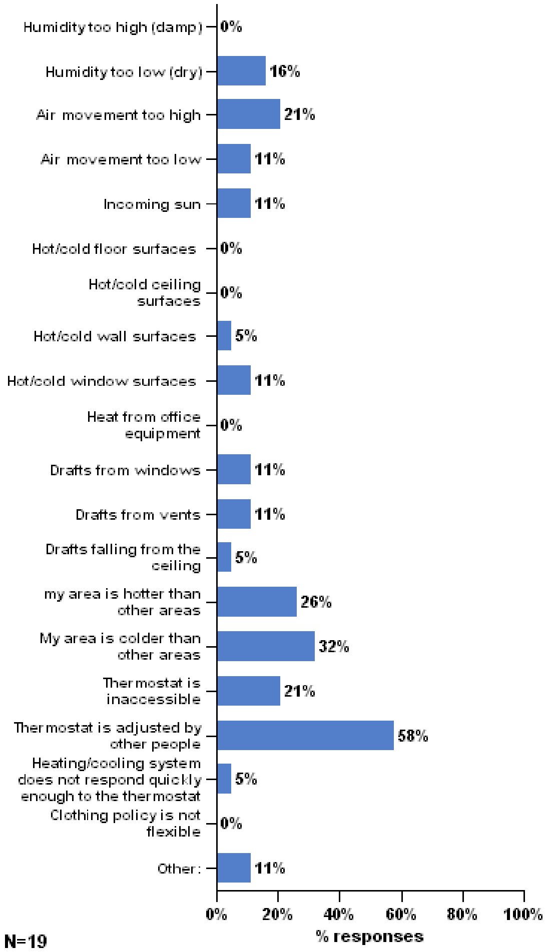
In cool/cold weather, the temperature in my workspace is: (check all that apply)



When is this most often a problem? (check all that apply)



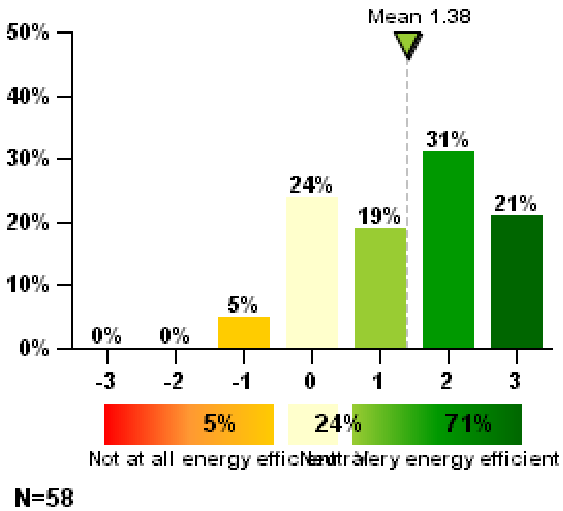
How would you best describe the source of this discomfort? (check all that apply)



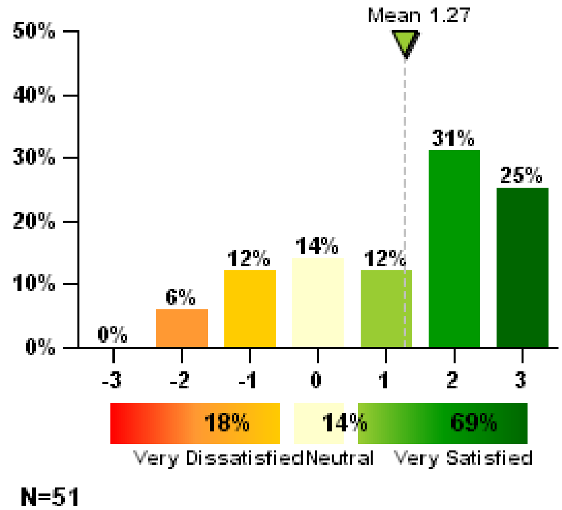
N=19

2.8 Building Features

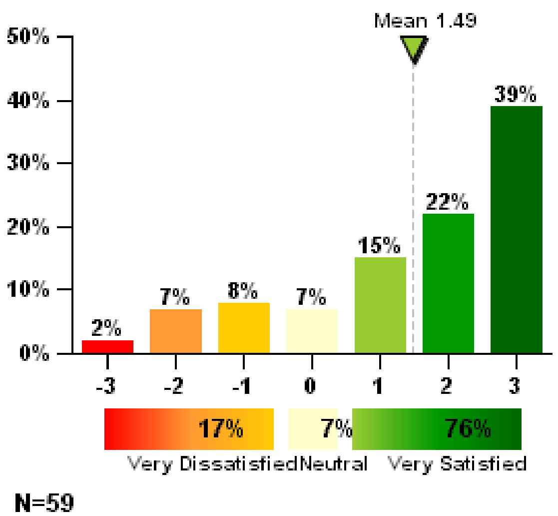
Considering energy use, how efficiently is this building performing in your opinion?



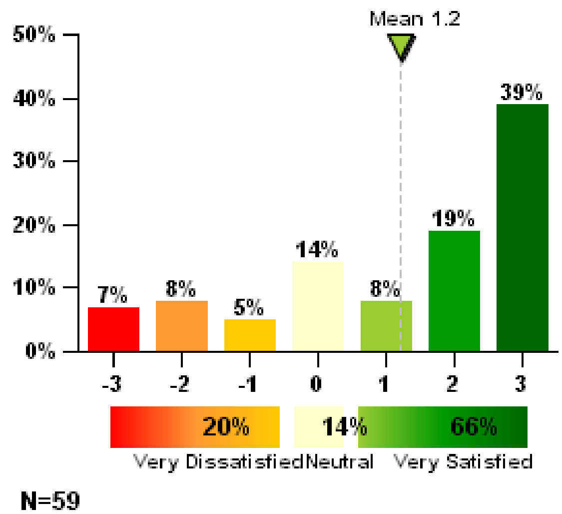
Automatic daylight controls



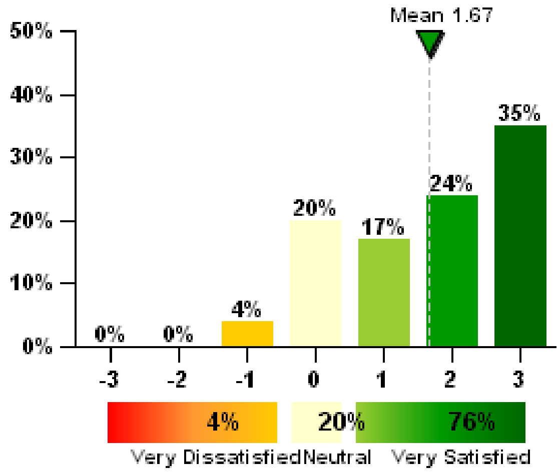
Restrooms



Nearby restaurants or shopping

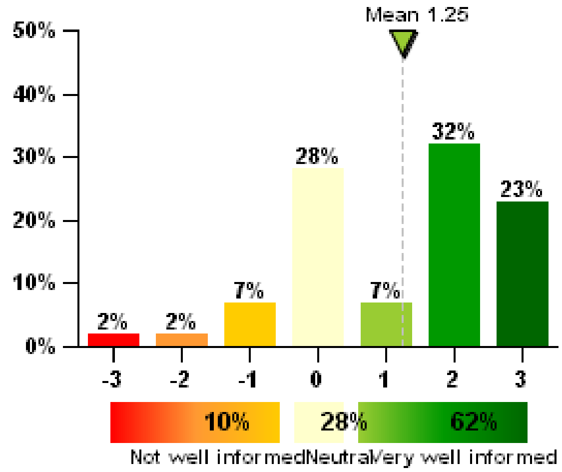


Recycling systems



N=54

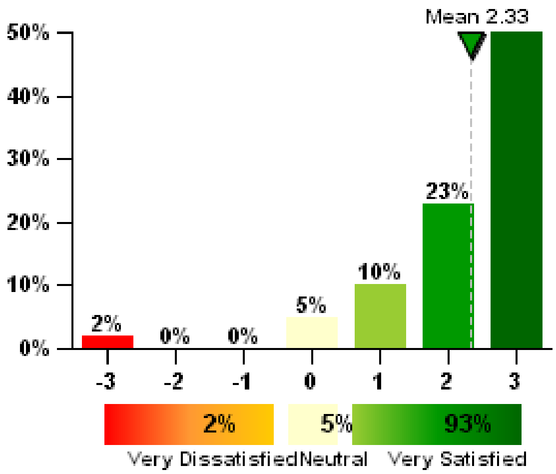
How well informed do you feel about using the above mentioned features in this building?



N=60

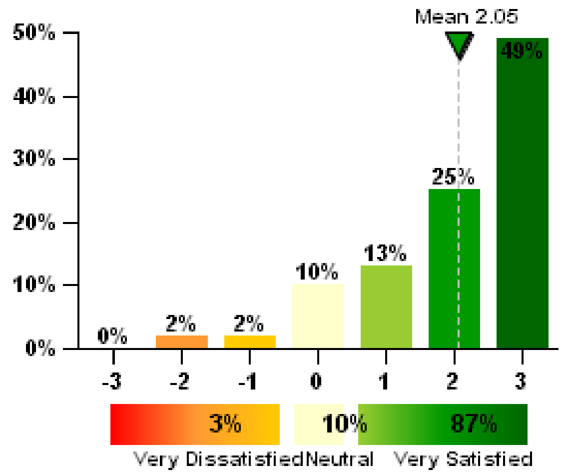
2.9 Building Grounds and Lobby

How satisfied are you with the exterior appearance of the building?



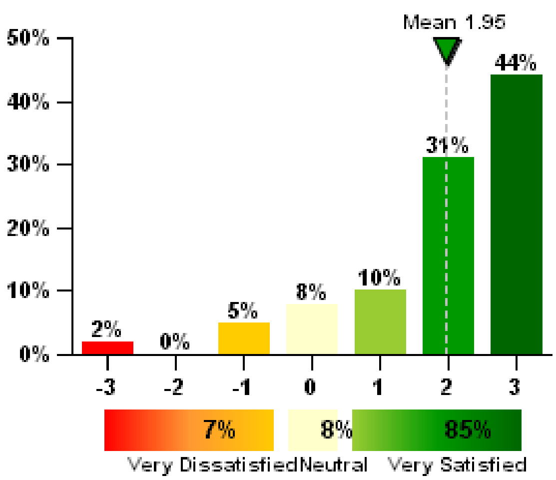
N=61

How satisfied are you with the design of the buildings exterior grounds, including its plazas, landscaping, and outside seating areas?



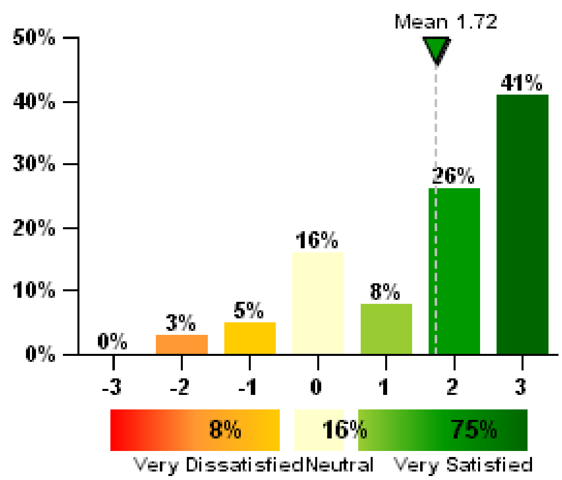
N=61

How satisfied are you with the attractiveness of the main lobby of the building?



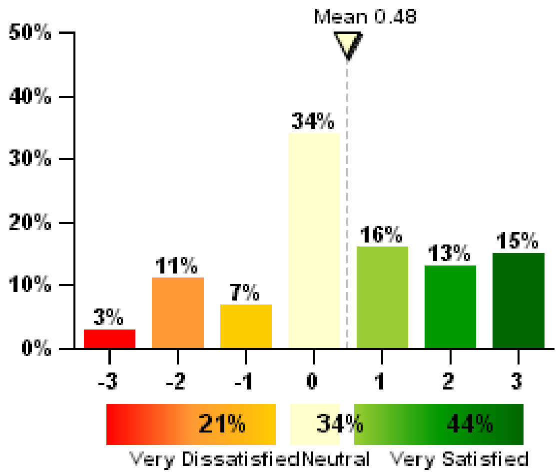
N=61

How satisfied are you with the functionality of the main lobby of the building?



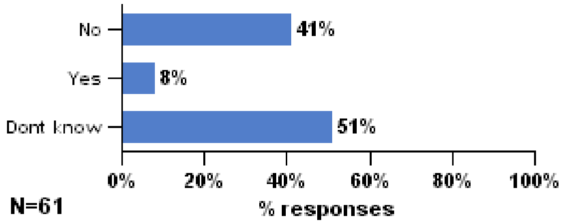
N=61

How satisfied are you with the artwork in the building?

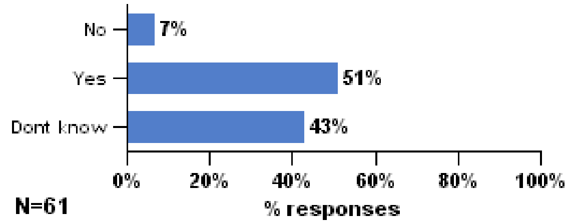


N=61

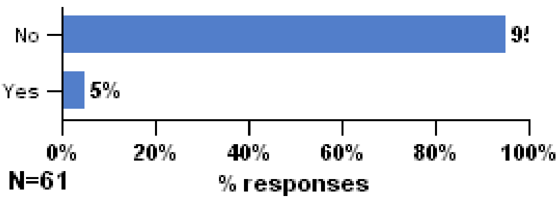
Is public transportation available to commute to this building?



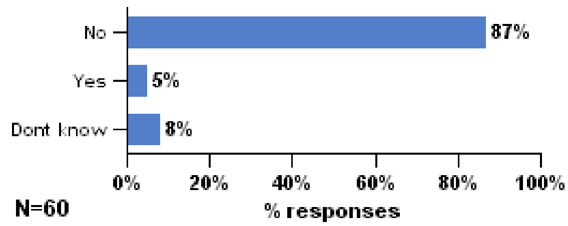
Are there adequate provisions to park bicycles at this building?



Do you ride a bicycle to work?

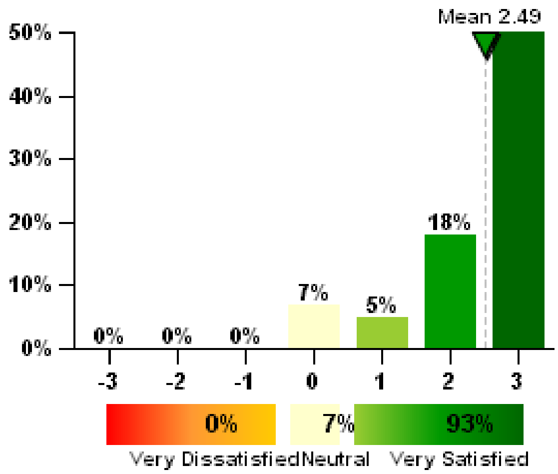


Have you received any printed materials or read any informational signage that helps you interpret the form and meaning of the artwork?



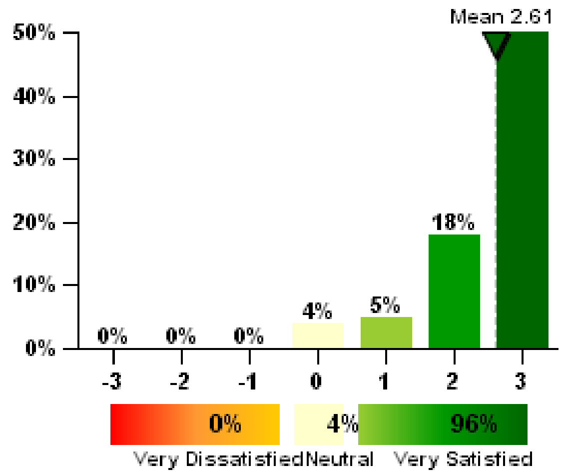
2.10 **Building Management Staff**

How satisfied are you with the availability of building management staff?



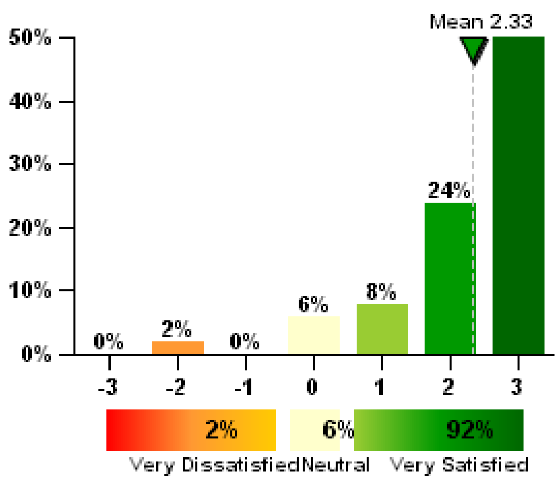
N=55

How satisfied are you with the appearance of building management staff?



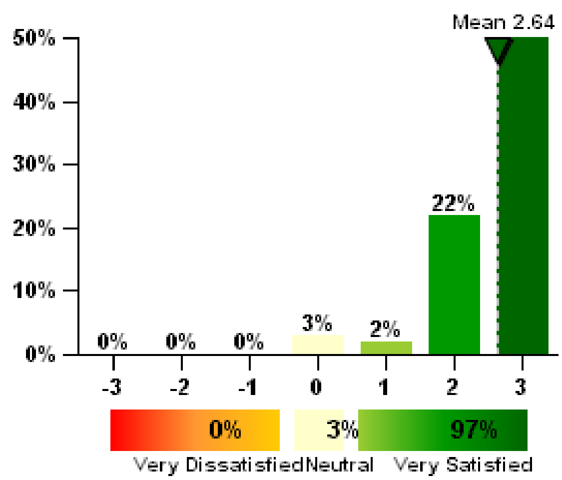
N=56

How satisfied are you with the procedures required to get service from building management staff?



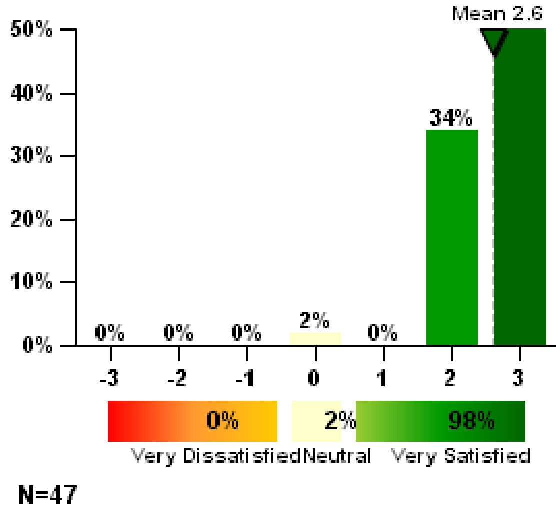
N=51

How satisfied are you with the courtesy of building management staff?

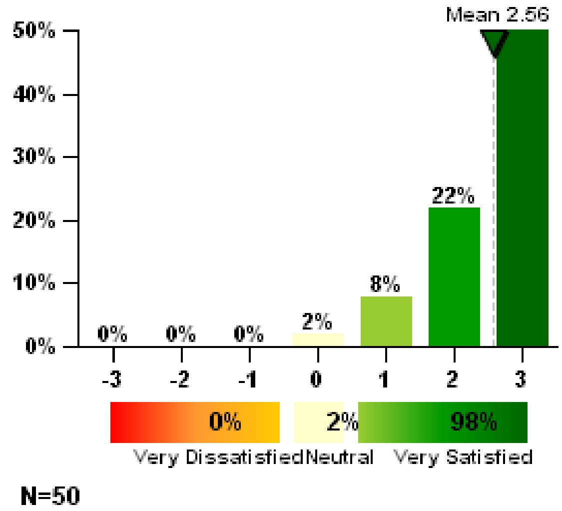


N=58

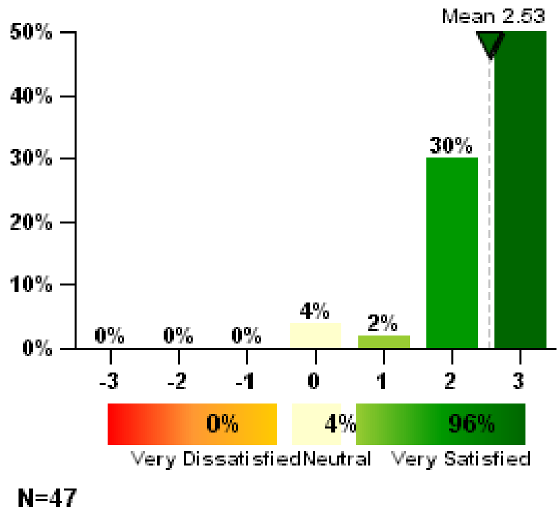
How satisfied are you with building management staffs knowledge of the building and systems?



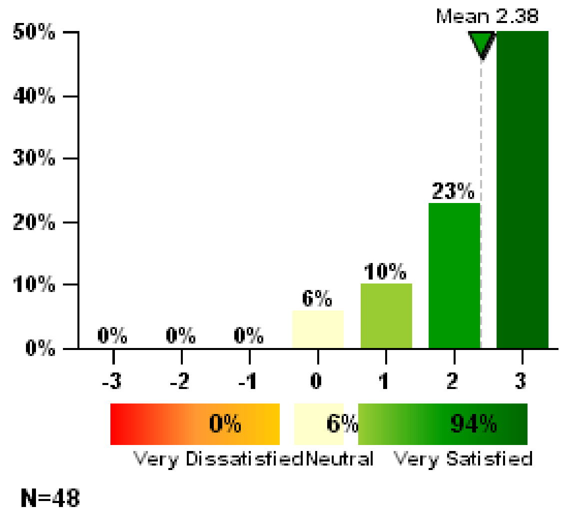
How satisfied are you with building management staffs timeliness of response?



How satisfied are you with building management staffs follow-up communication?



How satisfied are you with building management staffs understanding of your needs and requirements?



2.11 Exterior Appearance

You have indicated that you are not satisfied with the exterior appearance of the building. Why? (check all that apply)

Due to the limited number of responses to this question, its chart is not displayed

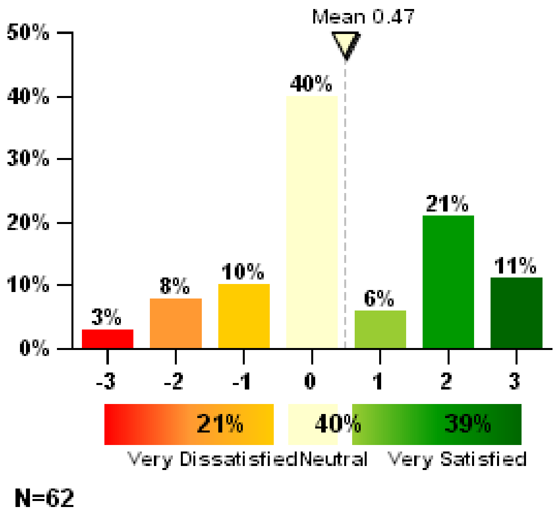
2.12 Exterior Grounds

You have indicated that you are not satisfied with the buildings exterior grounds. Why?
(check all that apply)

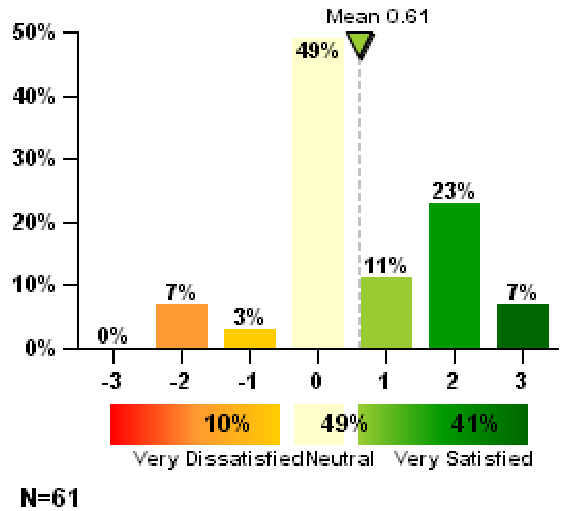
Due to the limited number of responses to this question, its chart is not displayed

2.13 Floor Diffusers

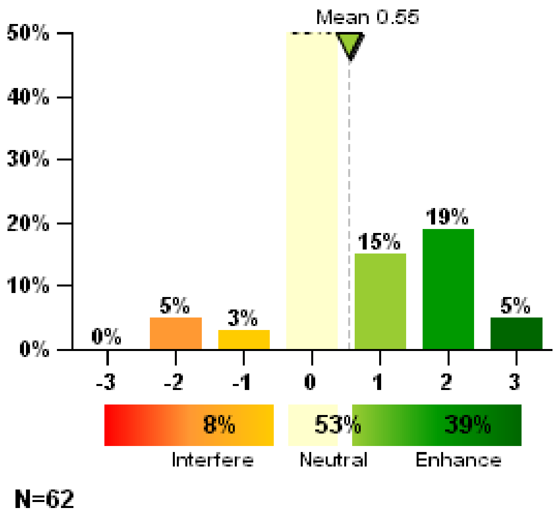
How satisfied are you with the location of the floor diffusers in your workplace?



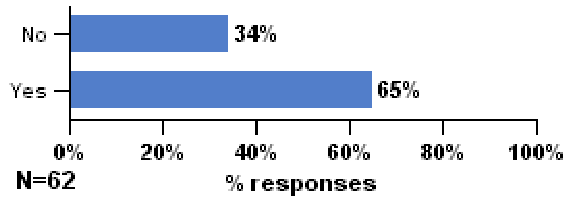
Overall, how satisfied are you with the floor diffusers in this building?



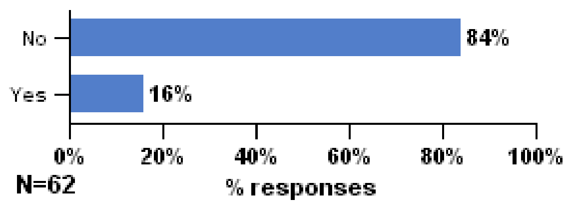
Do the floor diffusers in this building enhance or interfere with your ability to get your job done?



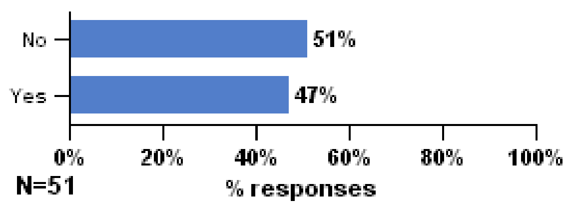
When seated at your desk, are you in close proximity (within 3-4 feet) to a floor diffuser?



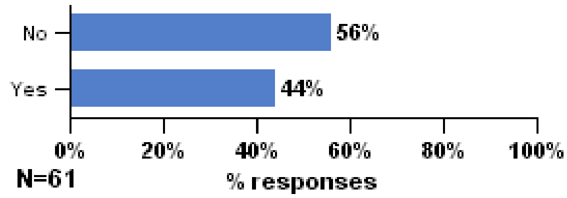
Have you ever requested the relocation, removal or addition of a diffuser within the proximity of your workspace?



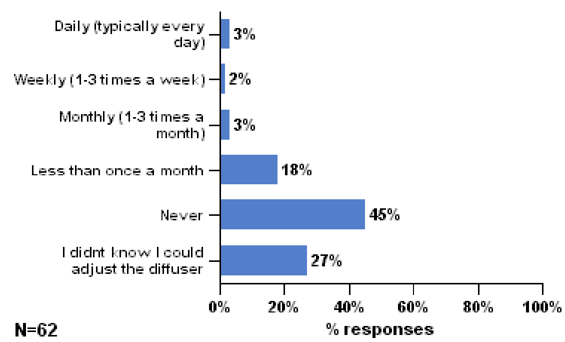
In your opinion, does adjusting the airflow through your floor diffuser improve your thermal comfort?



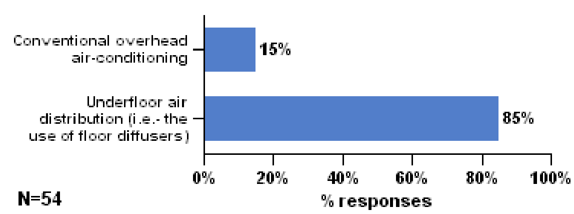
Have you received any information on how to use your floor diffuser from management, facility staff, coworker or other source?



How often do you adjust the airflow through floor diffusers located within the proximity of your workspace?

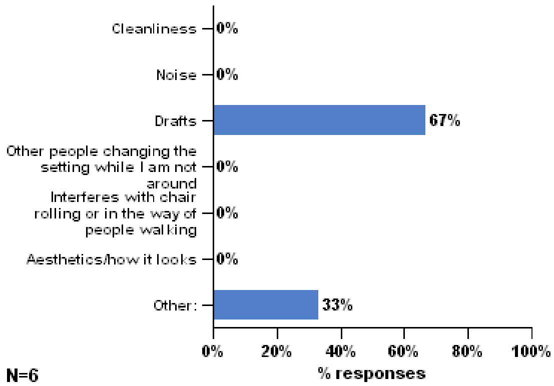


In your experience with this and other buildings, which of the following air distribution systems would you prefer to have in your workspace?



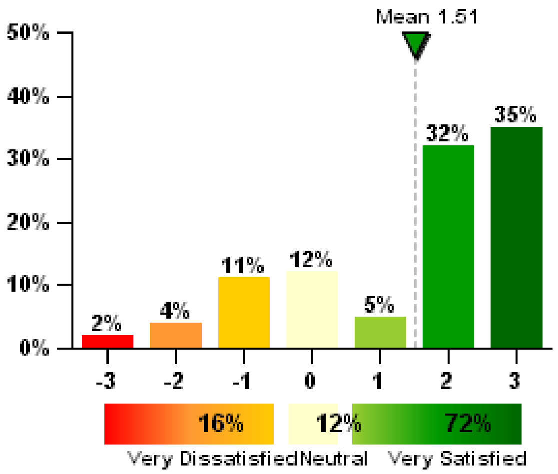
You have said that you are dissatisfied with the floor diffusers in this building. Which of the following contribute to your dissatisfaction?

(check all that apply)



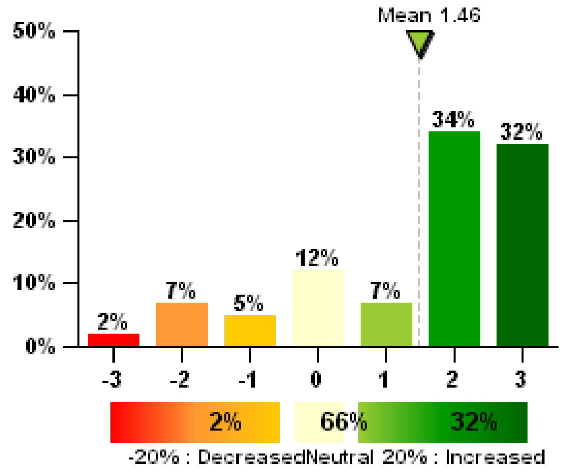
2.14 General Comments

All things considered, how satisfied are you with your personal workspace?



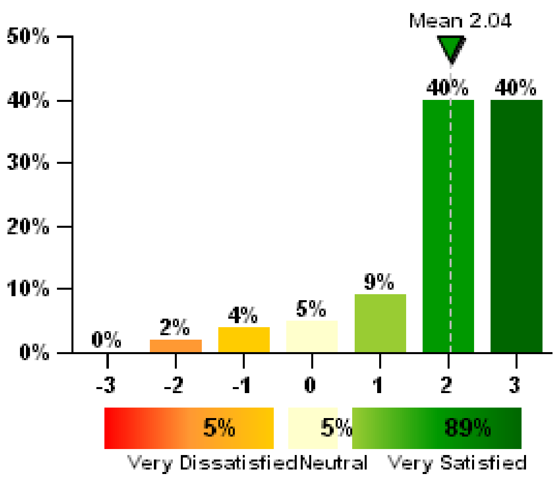
N=57

Please estimate how your productivity is increased or decreased by the environmental conditions in this building (e.g. thermal, lighting, acoustics, cleanliness):



N=56

How satisfied are you with the building overall?



N=57

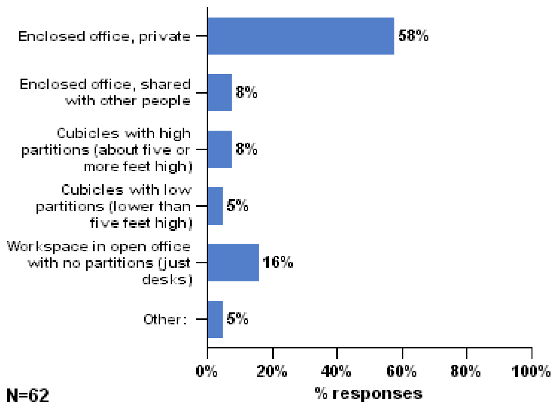
2.15 Lobby

You have indicated that you are not satisfied with the functionality of the buildings lobby. Why? (check all that apply)

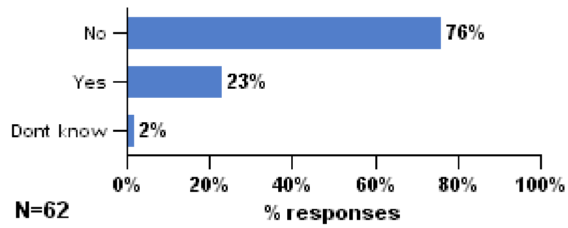
Due to the limited number of responses to this question, its chart is not displayed

2.16 Personal Workspace Description

Which of the following best describes your personal workspace?

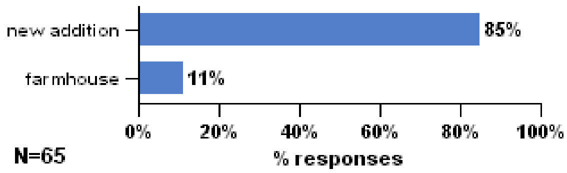


Are you in an area that was redesigned as office space (i.e. barn, farmhouse, other)?

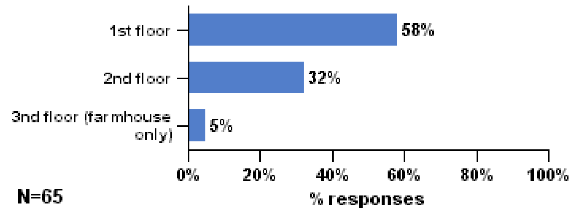


2.17 Personal Workspace Location

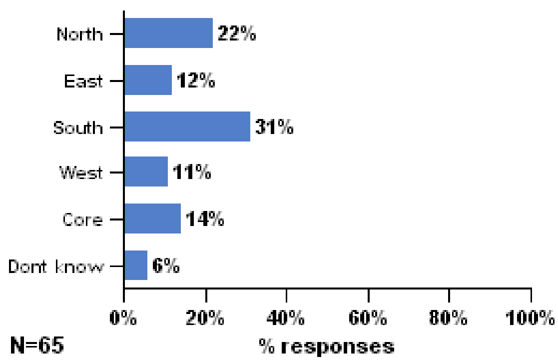
In which building is your workspace located?



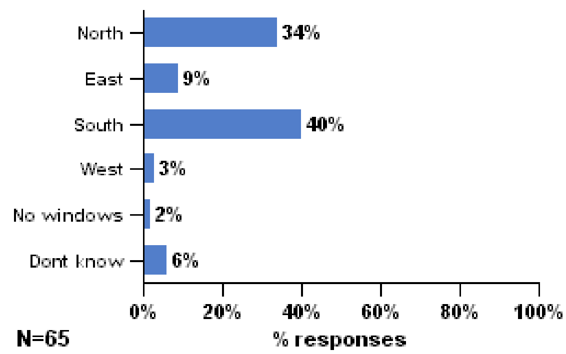
On which floor is your workspace located?



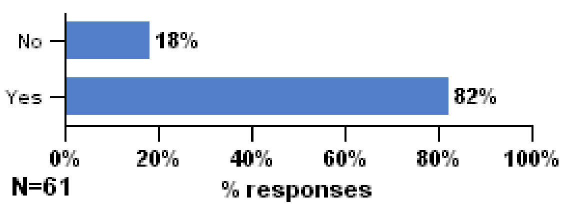
In which area of the building is your workspace located?



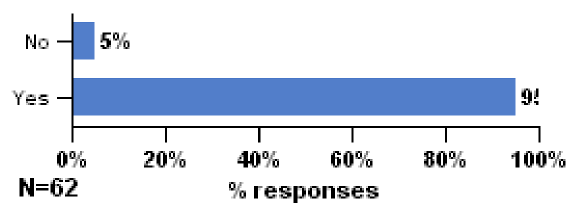
To which direction do the windows closest to your workspace face?



Are you near an exterior wall (within 15 feet)?



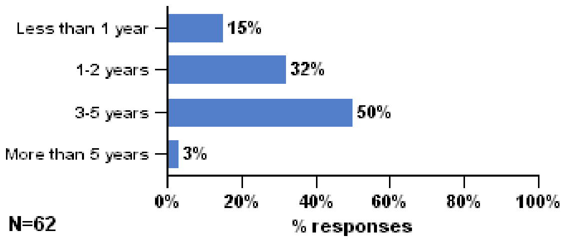
Are you near a window (within 15 feet)?



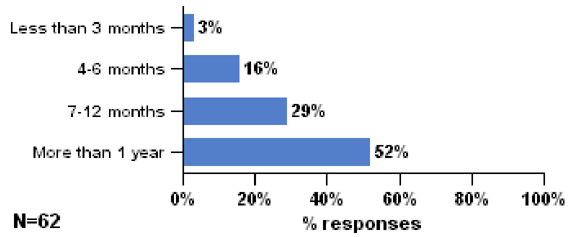
2.18 Workspace Use

3.1 **Background**

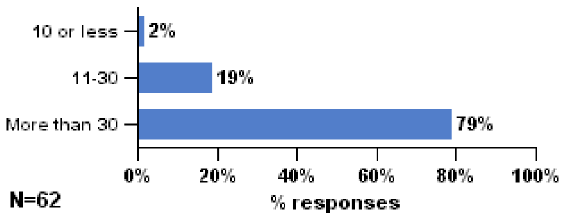
How many years have you worked in this building?



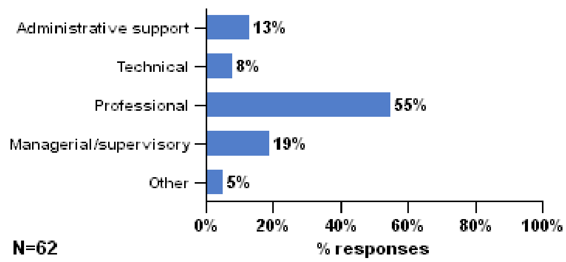
How long have you been working at your present workspace?



In a typical week, how many hours do you spend in your workspace?

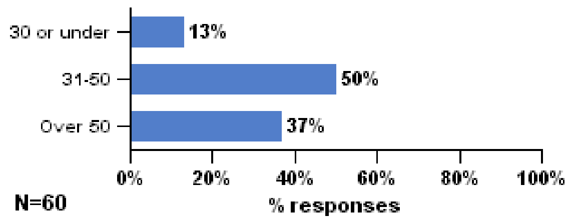


How would you describe the work you do?

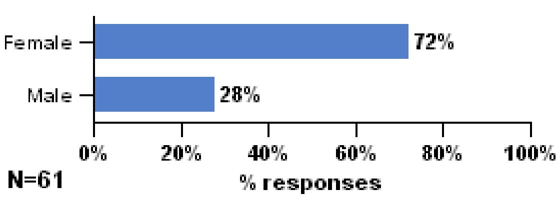


Which department do you work in?

What is your age?



What is your gender?



3.2 Summary of Comments by Question

You have said you are dissatisfied with the acoustics in your workspace. Which of the following contribute to this problem?

- Traffic noise
- Front door slamming!
- Cannot talk on the phone without everyone hearing everything
- You can hear things from both the 1st level and 2nd level
- see comment below

Please describe any other issues related to acoustics that are important to you.

- It's not so much noise her and there, as it is the level of noise. At times things can get excessively loud. The sound in the barn reverberates when alot of things are all going on at once(groups of people talking, copy machine running, phones ringing or conversations, etc.); You lean to adapt to a point, plus I try & use my music to drown out the sounds when they get excessive or I put on my headphones.
- Again, it is like working in a bowling alley. I often wear headphones (& so do others) just to dull some of the constant noise.
- See note in previous section about noise from the kitchen.
- using speaker phones in next door office w/loud voice-coworker
- The office next to mine was originally a file room. It is now an office and I can often hear conversations taking place in that office. I worry that people can hear my conversations as well. I often hear mechanical noises from the heating/cooling system as well - when the cooling fan is on the diffuser makes a lot of noise in my office.
- Walls are too thin...can hear neighboring offices' conversations almost unabated.
- When the walls were built between offices, they were not well-insulated. It is virtually impossible to carry on a private conversation. I can hear every word my neighbor speaks when we both have our doors shut.
- When you are in offices, you can hear your neighbor's conversations and they can hear your conversations - there is not a lot of privacy.
- My office, while a private office, has tile floor. Conversations outside of my office can be heard with the door closed. Those outside my office can hear conversations inside my office with the door closed.
- I'm grateful I have a door. We have a lot of people in an open work environment. They have zero privacy, and some of them have very loud voices and/or talk a lot.
- Voices really carry, the walls are paper thin so even if you shut your door to make a quick private call seems like neighbors can still hear it.

Please describe any other issues related to the air quality in your workspace that are important to you.

- The humidity often does not appear high enough, resulting in dryness associated with the eyes.

- The only thing I'd say about the air quaility is that it is very dry & dust collects constantly; so I guess perhaps its the air filtration that isn't good. And as far as the odor, being that the kitchen isn't inclosed, you can smell food as all times of the day which at times can be very distracting.

Which of the following contribute to this dissatisfaction?

- bathrooms aren't cleaned very well

Please describe any other issues related to cleaning and maintenance that are important to you.

- I'm not sure that vacuuming is done on any regular basis.
- The cleaning company does not vacuum under our desks each night. It would be nice if they could.
- My issue is with the cleaning service. Since we no longer have an eating area within the building sometimes eating at your workspace can bring about crumbs/debris on the floor. The cleaning service never sweeps nor do they dust. And as I mentioned, the barn (not sure on other areas in the bldg) has a dust issue. Again, I've adapted by dusting my area myself 1-2x's a week & I'll ask Kirby for a broom to sweep but he ends up sweeping my area for me. Kirby's the Greatest!!!

You have said that you are dissatisfied with the lighting in your workspace. Which of the following contribute to your dissatisfaction?

- lots of shadows - kind of weird
- sun reflection from building is blinding
- Light sensor turns light off often while sitting at my computer

Please describe any other issues related to lighting that are important to you.

- The lighting is too dark so I always have my overhead lamp on. When the sun comes out, it shines right on my computer screen so I can't see it so I have to lower the shade due to the glare.
- Motion sensor is not in a good spot - lights often go out when I am working and i have to get up and wave my arms to turn them back on. Very frustrating (and time waste).

Please describe any other issues related to office furnishings that are important to you.

- More fluid telephone system would help
- floor area between desk and counter too small -- some other offices are larger, but mine is tiny (and I am big and also have a lot of books, etc.) Laptop computer is too large and heavy for travel. docking system and monitor are great. lighting is annoying -- motion detectors switch off too quickly. workspace is either too warm or too cold. building managers cater to individual's needs. should just set whole building at 70 degrees and recommend sweaters.
- The chair is uncomfortable and the chairs do not slide on the floor. A lot of wasted space, too.
- There are the crazy things: screens that do not really screen (they are not sealed) and are hard to open or close. My current office allows me to walk to my window, but other offices I've had in this building had desks that wen tthe length of the office, thus creating a 2 X 12 foot "no man's land" of empty, lost space that only has heating vents and can't be accessed unless you crawl under your

desk. The rumor is that Valerio made some miscalculations in the built-in furniture design and the placement of vents that created this problem. It's not horrible, but it's a stupid waste of space in a building that is already packed to the gills.

- Would prefer a laptop rather than desktop.
- Previously mentioned the ergonomics and comfort of my workstation are disatisfactory.
- Keyboard on pull out tray and mouse is an uncomfortable set up. Guest chairs are uncomfortable. Tables for meeting in offices would be nice, esp for higher level individuals who meet often with a group of staff, this would free up some conference room space which is at a premium right now.
- They're visually beautiful.
- I would like some ergonomic training on how to adjust our chairs for proper workstation posture. I would also like options for seating (inflatable ball) or standing work stations--or even treadmill stations. Our office is beautiful but could use more splashes of color, like colorful works of art or photos of the work of Kresge grantees.
- I wonder about the amount of time and labor required to keep the glass surfaces clean. I also wonder what types of chemicals are used for this purpose.
- I am in a temporary workspace in the farmhouse. Most of my office furniture has been rented, and it doesn't quite function well in the space, nor is there much storage availabe. Chairs and a table have been borrowed to create a meeting space in my office, and coworkers/visitors are unable to adjust chair height without a screwdriver. Desk chair, on the other hand, is very comfortable and adjustable.
- The carpeting in the offices are very unattractive. It is worn out and stained. When carpet cleaners clean the carpets, there is never a difference. It always appears old and used.
  The wood flooring is not very durable. There are marks and small holes and the finish looks dull.
- Please see previous comments about personal lateral files.
- Extensive use of glass internally is a plus and windows to outside always maintain a feeling of being outside and in nature.
- I need two chairs in my office for guests, which I have, but they cannot be placed properly so that visitors face me for a conversation. My computer, phone, printer and files are not in workable locations for my work comfort.
- Desk drawers do not fit file folders, and there is not a comfortable spot to do projects.
- The light color wood and carpet and reflective ceiling are beautiful, warm, contriuting to a lightness that contributes to the pleasant environment. It would be an improvement to add some color to the chairs -- too much black.
- I find the chair to be very uncomfortable at times. But I am extremely satisfied with all of the other office furnishings (desk, computer, etc.).

Please describe any other issues related to the office layout that are important to you.

- Though I do not sit in an open area, the open areas tend to be noisy and make any conversation difficult and I am sure the staff in those areas have a difficult time focusing.
- The private office are more conducive to work. The open areas are quite noisy and make it difficult for staff to concentrate.

- Regarding individual space for work & storage -- lateral file drawers are too shallow to hold files correctly, cannot be correctly reconfigured to hold 3 rows of files and file/storage drawers cannot be moved to the other side of "cubicle" to allow for right vs left-handed usage.
- Very conducive to working together and provides access to people, facilities, and supporting equipment (copiers,conference rooms, etc.)
- Important to have individuals you interact with the most nearest to your office
- Insufficient meeting areas and space
- There is not enough storage for files
- It's hard to be so far from my administrative assistant. With so many meetings in downtown Detroit, it would be helpful to have an office there.
- Too noisy, several times a week there is cold air blowing down on me and cannot be resolved, my work is spread out over a large part of the building.
- Layout of file storage area prevents easy access to windows. Considerable amount of space wasted behind the file storage area.
- No issues, really. This is a fabulous palce to work -- so much natural light, good work space for the kind of work I do. I guess the only thing to complain about is that the temperature is not as controlled as I would like and it is often on the edge of being out side my comfort zone on both ends of the scale -- too warm - too cold. The one other thing that I couipd compain about is that while the windows do open it is difficult and dangerous to try and stretch over the glass desk top to reach the handle and dangerous to crawl under the desk through a maze of computer wires and connections; the window could help with optioins to manage temperature.
- Better access to window would be helpful--have to go under glass desk to get to window.
- The layout of the desk was designed to look nice, but it does not function well. I do not have enough workable file storage space. i do not have enough space on my desk for my everyday files. My equipment is not placed correctly.
- noise level from co-workers can be an issue when on a call.
- Noise level is high from coworkers, even w/closed door.
- Cleanliness, windows, modern furniture
- Our HR offices are furthest away from all the people in the building which requires a lot of walking and less time working.
- Noise level from kitchen is frequently disturbing to my ability to concentrate.
- Because of noise issues, many coworkers close their doors all day. This makes it more difficult to know if the coworker is still available for work-related matters or if they would like to not be disturbed.
- Staff placement was thoughtfully determined by function and interaction.
- It is very hard to have phone conversations or do any reading because of noise and lack of privacy
- Lack of Privacy
- interruptions, distractions, noise level
- Would be nice to have some privacy sometimes vs. window viewing for all to see. Would be nice to see departments located more together, but layout isn't conducive to it and seems like there is alot of wasted space. Carpeted 2nd floor would be nice & make it less loud, drafty & less dangerous walking. Voices seem to really carry down the hall & from upstairs to downstairs.

- I like how natural light flows through the building -- it's wonderful. I like being able to see colleagues. I don't like the noise level. We have more people crammed into the space than it was designed for. I don't like that there isn't an area where we can gather informally, such as a lunch room. It would be nice to have additional private spaces/conference rooms.
- It woud be good if there was more visual privacy.
- The building is beautiful, but the office layout means that I am quite a distance from people who work with me. I can see people, but the distance means that we are not necessarily aware of what we are all doing. I think for managers, it makes it hard to know if people are on task and can sometimes undermine general teamwork. I think it would be more efficient if the PD, POs, PAs, GMAs and admin. for a team were all fairly close to each other instead of separated by a courtyard. Some people could be moved from offices to be closer to colleagues, but since there are no workstations for admins, GMAs or PAs in the North and East wings, the building's physical layout cannot accommodate this. I would have rated this lower, but the fact we can see each other does help somewhat.
- office space is small, inefficent use of space (loss of sq. footage by windows in offices) poor drawer/shelf spaces. cabinets over desk useless. no room for guest to sit in office.
- There are times when the lack of privacy and/or noise level interferes with concentration. Unfortunately, the thing I like most (lots of windows) can also be the thing I like least at times because there is no privacy.
- No privacy for conversation and limited workspace. For conference calls or call with grantees, potential grantees, must find an empty office or go to a meeting room (that is if one is available).
- No privacy and very loud - it is nice that we all can see outside, but it is hard to work here because of the noise, lack of privacy, and the workstations - they are pretty but are not efficient.
- The ergonomics of my work station are very poor. My work station and seating are not functional. There isn't any place for filing or storage at all.
- The glass box that two of my staffers have to work in makes accomplishing their work very difficult. One staffer's job is to be on the phone most of the time and the other requires significant amounts of quiet for quality control work associated with the content on the Web and in print publications.

You have said that you are dissatisfied with the amount of space available for individual work and storage. Which of the following contribute to your dissatisfaction?

- no place to hang notes, not enough file space, can't even hang my coat except in a freezing closet
- no privacy or quiet space for working
- physical space for moving around, bookshelf space

You have said that you are dissatisfied with the level of visual privacy. Which of the following contribute to your dissatisfaction?

- it is like working in a bowling alley
- No walls leads to more interruptions
- Location of desk
- Everyone walking by the office is distracting

- It's an open area; overall, if anyone wants to stop me in the middle of something, they can.
- Walls are non-existent in my area
- noisy

You have said that you are dissatisfied with the ease of interaction with co-workers. Which of the following contribute to your dissatisfaction?

- I don't like the open floor plan, my work and co-workers are all ove rthe building
- My workstation is a long distance from the Finance Dept. where most my interoffice communications occur.

Which of the following do you personally adjust or control in your workspace?

- Because of the open floor plan cold air blows down from the upper level
- use blanket
- humidifer

In warm/hot weather...

- generally temperature is okay - somedays cooler than others
- Don't Know yet...
- Because of the open floor plan temerature control has always been an issue
- Southern exposure "cooks" the office, needs better UVB blockage in window film
- too hot

In cool/cold weather...

- Because of the open floor plan temerature control has always been an issue
- Heating from southern exposure worse than summer months as the sun's angle is below roof overhang
- too hot
- My body is too cold

When is this most often a problem?

- Completely unpredictable
- Unpredictable, all of the above
- inconsistently

How would you best describe the source of this discomfort?

- Open floor plan is a problem

Please describe any other issues related to being too hot or too cold in your workspace.

- It's always hot, but seems to get more and more hot throughout the day. Not sure if someone else is in charge of thermostats or if it's just HOT!

- It's frequently too cold in the winter. I feel a draft from the window area. The window in my office is hard to reach and nearly impossible to open/close. The building staff are great about trying to adjust the heating/cooling system, but it's a fickle beast. Also, there's a challenge in that some individual staff members want heating/cooling specifically tailored to their spaces.
- Can't seem to get it right, some offices are warm, some are cold.
- Some of my colleagues are always cold so Larson raises the temperature for them and my office is usually very warm.
- building management has decided to respond to individual staff complaints about temp and adjusts the system accordingly. however, the system is interconnected, and this causes others to be affected. this approach is inefficient in the extreme (from an energy standpoint) and inconvenient. if i had a window, i would open it to breath when it gets to 78 degrees, but cannot. policy should be one temp for all areas: 72F.

Considering energy use, how efficiently is this building performing in your opinion?

- Not sure. Will be curious to find out.
- Don't have access to the bills so don't know
- I know the latest light bulbs and technology are in place, but the policies governing employee usage (supplies, copies,lights, hours heat required, etc.) could be improved.
- Difficult to say. have not received any information regearding performance.
- I see the electric bills every month and think them quite high, although building maintenance staff assure me that I am incorrect.
- I really have no idea.
- see temp comments.
- unsure
- You can smoke a ham in here it is so hot in the winter.
- I've heard it is doing very well. We are probably using more energy and water now than when we opened in 2006 because we started with about 28 staff and now have more than twice that number.
- I don't really know
- Not sure, but i do like all the natrual light we get (particularly in the winter). I assume that allows us to use less electricity for overhead lighting.
- I know they've worked hard on the lighting, but I think too much still lights up at night/on weekends. I really wonder how efficient the heating system is. I wonder how much heat we lose due to all the windows.
- It seems as though the building isn't turned back much on weekends. I expect it to be cold in the winter on the weekends, but it's not. Also, large banks of lights are on even if I'm the only one in the building. I wish there were a manual override for open-space lighting.

Automatic daylight controls

- I wish lights dimmed or turned off more often. It seems like my office lights never turn off due to bright sun. Also, I wish lights turned off more quickly when we left the room--very few of us manually shut them off when we leave.

- lights don't stay on long enough when working late or on weekends
- My office motion sensor is problematic (not aimed correctly therefore does not sense motion at my desk)
- lights often go out if I am sitting quietly and not moving in my office
- Mine go off and on by themselves at times
- building is too dark on cloudy days, need to use supplemental lighting in my cubicle especially during winter months

Restrooms

- With increased staff, it would be nice to have additional restrooms.
- same as above regarding lights not staying on long enough
- Not enough restrooms
- Decore a little sparse - reminds me of an old gas station
- Too few.
- grout in floors of restrooms need some better maintenance and cleaning
- Rooms are cold because there are no heat vents
- water in sink runs very slow
- The restrooms themselves and the toliet seats can be VERY cold!
- Thank God they finally put heat in the ladies Room - we are in Michigan!
- I used to use a restroom in the lower west wing. It was freezing. The one I use most often now is great.
- Slow drains and trash cans are too small so people just leave trash on the floor. Not enough counter space.
- the ladies room off the main lobby needs a table or shelf to hold the purses, notebooks etc. of the women in the restroom.
- I'm glad that the temperatures in the restrooms are allowed to drift outside normal parameters. I love the dual-flush toilets. Not so keen on the chemical air-fresheners.
- It's nice to have private restroom stalls.
- The bathroom with an exterior wall is freezing in the winter, and the water is cold. The slow-draining sinks are horrible.

Nearby restaurants or shopping

- We're not really in walking distance of anything.
- No time to take advantage of these resources
- Unless you bring a lunch, you pretty much have to drive to go get food.
- Annoying not to have much within safe and easy walking distance.
- There's really no place to walk to for lunch.
- Yes, we're near an impressive mall, but it is a real schlep to get there to make use of restaurants or shops. I am a very fast walker and it takes me at least 12 minutes to walk from the office to the mall. Driving is not much faster because of the time it takes to go through lights and park. I have worked in downtown areas and have enjoyed the proximity of shops, restaurants, gyms and public transit that this site does not offer. We are a little green island in an ugly see of empty parking lots

next to empty buildings.
- Would like to walk to them
- Little within walking distance

Recycling systems

- Hard to find for bottles/cans/plastic
- We should have cans/bottles recycling on site
- Would like more spaces to recycle plastic
- While I appreciate the availablity of recycling bins in the building, I wish they were larger - I typically go to put things in them only to find them full.
- I only recently learned where to recycle glass and plastic.

Please describe any other issues related to the design and operation of the above mentioned features that are important to you.

- There is a lack of parking, and because of the lack of lines in the parking lot people use the space very poorly. It also increases the chance of vehicles "bumping" into each other.
- I think we should do a better job of informing new hires of the green features within their control. I really wish the bathroom sinks would drain more quickly; we could control water use better by limiting the flow from the faucet. It takes forever for the sinks to drain, and so you either have to wait a long time to leave a clean sink or you leave and the next person finds a scummy sink.
- The building is gorgeous--it is definitely a pleasure to work in such a lovely and environmentally friendly space. As a new staff member, it was a big selling point. I would like a bit more continuing education on how to use and appreciate the facility.
- The parking lot is inadequate for the number of individuals working and visiting the building.
- I really don't have any input about the building, workspace, etc. It just is what it is.
- We could do a better job of recycling.
- This relates to building management -- the ergonomic set up of the front desk area needs attention and reconfiguration. I have requested this months and months ago and no real changes have been made yet.
- The paving system is problematic for women and shoes with heals. It would be nice to have more paved paths to utilize, especially in the winter. The stones on the paths also are difficult to maneuver.
- Staff sometimes don't seem to understand how good they have it. Visitors continue to rave about the building and say how they wished they could work in these surroundings. I agree - it's both enjoyable and exciting to try to enhance our green efficiencies.
- I consider working in this building a benefit with regard to the overall employment package.

Is public transportation available to commute to this building?

- Not from where I live
- We're in a location that is not at all pedestrian friendly.
- There are reserved spaces for hybrid vehicles but many non-hybrid drivers park in them.

- suburban transportation options stink
- I do not know how available however.

Are there adequate provisions to park bicycles at this building?

- the bike rack is hidden near a door that we have been asked not to use to come in/exit out of
- I would be interested in bike parking as I live close enough to bike to work in warmer weather.
- There are bikes rakes for a couple of bikes only.
- Have to drag bike down stairs, park on rough rocks, in the way of the service doors - I don't ride my bike here anymore because of that - i tried leaving my bike out of the way in the back of the parking lot but that is verboten!

Do you ride a bicycle to work?

- not anymore - see above
- in approp weather
- I might this summer.
- In winter...in Michigan?

How satisfied are you with the artwork in the building?

- I do not find all of it visually appealing. It would look nicer to 2-3 art themes or types of art throughout the building that are more appealing to the staff in the building.
- Need more Notre Dame Memorabilia
- Most of the artwork was purchased in teh 80's for the previous building and for the most part is nto very interesting. What we do have is inadequate and of the wrong type for the space (works on paper don't survive well in an abundance of sunllight. There is space for much more art and an appreciation (and expectation) of a higher quality and significantly more interesting art work.
- old and tired for the most part. Definitely not up to the architecture of the building.
- The artwork really needs updating. We could use better art, vibrant photos, feature and support local artists, etc.
- We have an art committee that is currently involved in assessing the current artwork and selecting new pieces.
- boring
- Definately could be updated & use more
- Would love to see more. Perhaps from KAID artists.
- I wish I had something on the wall in my office
- I think the placement of the art is very nice, but there is not much and it's not that great. There is no outdoor sculpture in the courtyard, which seems like an obvious opportunity, and most of the art was just pulled from the old building. I would like to see see art from some of our grant focus areas (Detroit, Africa, etc.) and maybe more artful versions of program work (like mounting the covers of books or posters the teams are producing from their work). Finally, the art in the lobby, which focuses on the marketing strategy that occurred just before Rip came, should be changed. It's no longer relevant and is misleading to visitor since it reinforces their perceptions of Kresge's old grantmaking programs. I really like the green displays, though.

You have indicated that you are not satisfied with the exterior appearance of the building. Why?

- The grounds look sloppy and unkept especially in late summer and fall. The overgrown weeds and grasses are not that attractive.
- The meadows and landscaping looks very sloppy and untended.

You have indicated that you are not satisfied with the buildings exterior grounds. Why?

- I like the ponds and grasses in the rear of the building, but I think the front landscaping should be more conventional and professional looking.
- I think the praire and trees on the property need work
- The grasses and weeds are unattractive especially when they grown beyond 3 feet. There is an overall sloppiness in the landscaping.

Please describe any other issues related to the floor diffusers that are important to you.

- Quality of heating and cooling definitely seems better with floor diffusers. When adjustments are needed for people with apparent problems, the attention and response time from management services and staff is remarkable - quick, thoughtful and considerate - with the concern and comfort of total staff being the guide.
- I used to be in an office with floor diffusers for almost 2 years. They blew cold air on you when you were already cold, they emitted bad smells that maintenance could not pinpoint, and they were not easily adjustible by the office occupant.
- They were very well for me.
- Removed baskets to maximize airflow, but still feel qunatity of air flow is inadequate as is the temperature (air is too warm). Other offices nearby enjoy much stronger and cooler air flow. Stronger and cooler air flow is particlarly needed to offset strong radiation heating coming through the windows facing the South.
- The air flow is very strong and this is not a conventional conventional air distribution system
- I am rarely cold. Sometimes when the sun is out it warms up but is not something that I'd raise to the building manager.
- No access to the diffusers behind the file cabinet near the windows. Unable to tell if they would make a difference in the overall comfort of the space.
- They stick and often require tools to adjust them - it should be easier to do so, and if it were, I would probably adjust them more frequently, which in turn would improve my comfort.
- My diffusers have reequired qite a bit of manipulation in order to work properly, to cut down on the level of noise, and to provide the right level of heating/cooling in the office.
- I've never heard about them.
- too hard to control and I feel air moving even if I close the diffusers that are in my space. I do NOT enjoy feeling cold air blowing on or around me, even in warm weather.
- I had property mgmt shut two off in my office due to being cold, one of the other ones blows into my eyes but if I turned it off then I would get no heat or air. I often cover it up when it is really bothering me.

- My office doesn't have a floor diffuser, rather a wall vent. There is only one, and it is located near my door. Most of the heat escapes out the door and into the hallway if I don't partially or completely close my door.
- When I have meetings in my office, especially in the summer, my colleagues are very uncomfortable because the cold air diffusers are by the guest chairs (which makes it extremely cold for guests) so I have to cover the diffusers with books or binders to block the air. I mentioned earlier that I'm usually warm in my office. If I do close the doors, then it does get a little cooler in my office because of the diffuser that are located closer to my office door.
- Too close to desk top workspace. Constant blowing directly onto face and upper torso.
- I knew we had them but I don't know where mine is or how to adjust it. The temperature at my workstation is fine but the temperature in conference rooms seems to vary significantly.
- The air flow out of them is very strong. It makes a nice white noise. I wonder how much energy is expended moving that much air around. The diffusers in my office are very inconveniently located with respect to the furniture. You must crawl underneath a portion of the credenza to reach them!
- Most of my floor diffusers are near the window and access is blocked by the file credenza that runs the length of the wall.
- The problem is not with the floor diffusers, per se. The problem is that they are placed on the other side of a built-in credenza and next to a window, so they are hard to manipulate. This is not a design flaw iin floor diffusers, this was a design flaw in the built-in office furniture.
- No floor diffuser in my office
- Sometimes there is a sever, freezing draft on my feet (summer & winter) - told there is nothing that can be done "That's how the difusers work" - I keep a shawl to cover my feet and ankles with.
- Sometimes I cover up the floor diffusers, depending on if I'm hot or cold. I know you should be able to open & close the diffusers without covering them up but they are very difficult to move.
- best way to adjust floor difusers is to block and unblock. i use books for this because the vents dont work.

You have said that you are dissatisfied with the floor diffusers in this building. Which of the following contribute to your dissatisfaction?

- They are separated from many people's primary workspace.
- Effectiveness, mainly in my office space

Any additional comments or recommendations about your personal workspace or building overall?

- I'm very proud to work in a green building. The building's architecture is gorgeous. I love all the natural light. The pond makes us a little oasis in the desert of sprawl. Cynthia, Kirby, and Dave work very hard to make us comfortable here. I wish we could get the heating/cooling to work better; the temperature really varies throughout the building, without much rhyme or reason.
- It is very cool to tell people that I work at an LEED certified building and it has a unique look in this business area.
- I absolutely love the large windows and abundant daylighting. I feel that these features make me more productive, calm, and happy. I also love looking out onto a natural landscape and wildlife. It

feels like an oasis in the suburban desert.

When I first started this job, I was excited to learn that the building had operable windows. They're sort of operable in name only, however. They're very difficult to access, and then don't open far.

I wish that staff knew more about the building's green features and how to operate them. Very few staff ever manually shut off lights, for example, and I wonder if everyone knows how to operate the dual-flush toilets. I'm not sure that the staff understands that the restrooms/atrium/elevator are intentionally allowed to get hotter or colder than the rest of building--and why. I don't think very many people turn off their computers or monitors at night or over the weekend. Maybe helping staff understand how much energy/money these things save would help motivate people to turn off their computers, take the stairs instead of the elevator, avoid the side door (with no vestibule) in the winter, etc.

Thank you!

- This building is pleasing both aesthetically and environmentally. Visitors are consistently amazed by the amount of daylight in the workspace and the general beauty of the site. It is evident that staff comfort and satisfaction is important to the building management staff.
- I found that when I moved from an office with glass walls to a more private workspace in the farmhouse with meeting space available in it, that my productivity increased - it was quieter and very beneficial to have adequate meeting space directly in my office.
- It is a beautiful building to work in and I am proud to show it off to others.
- It's a fine place to work as a facility. The amount of natural daylight is very nice, but I don't know if I could confidently state that the building contributes to greater productivity. I just need lights and the internet and I'll get by. I will say, the chairs are not particularly comfortable after prolonged periods of time.
- I like working in this building due to all of the windows, daylight, and nature. No building is perfect but this is a very unique and appealing building so it makes it nice to come to work everyday. One issue that is very negative, it that there is limited parking. We need to expand the parking lot due to the expansion of our staff and the increased number of visitors.
- I like my workspace and I like the building, but think the exterior grounds design detracts from the building's appearance. It would look better to me if the grasses were kept to a semi-uniform lenth of about 2 to 3.5 feet especially in the front of the building along W. Big Beaver Road and on some of the green roofs.
- temperature and noise main points decreasing productivity.
- The building was not designed to handle 60+ employees. We are too crowded and using spaces (like the barn) that were not designed or intended to be used as office area. If you aren't lucky enough to be assigned a private office, there is no space available to eat lunch or to make a private phone call. Plans to expand have been put on hold due to economic conditions, so there is no end in sight to the overcrowding. If we are really committed to "being green", I think we should be creative about telecommuting opportunities and locating nearer to public transportation.
- Spectacular space--never take it for granted.

- We routinely receive compliments on the appearance and functionality from the many asset managers who visit us each year.
- Would be helpful to know if we are able to change furnishings or equipment such as chairs (e.g., annual survey of personal needs).
- The amount of light in the building is phenomenal and contributes greatly to the working environment. The amount of nature on the property is wonderful and helps staff who work long hours have some enjoyment from time to time as they look out windows.
- It is typically either very hot in the building - however, it can fluctuate to very cold - especially in the conference rooms (Board room). I find it hard to be productive when it's so hot.
- The building was designed with modest staff growth (FTEs) in mind. Staff growth since we moved in, however, has been explosive. The open, light, airy, bathed in natural light feeling of the space has been assualted be the need to shoe horn bodies into every availale space, including hallways and meeting rooms. In one sense it is a testament to the building that in can absorb so many people -- but it does so at a price. The related issue is parking, there simply is not enough.

  That said -- it is the finest work space I have ever had the pleasure to work in.
- Nicest physical environment I've worked in. Hope we can continue to improve and incorporate new green technology, and be a model of green for others.
- The stairs are difficult to navigate, especially with full hands -- perhaps because they are all stone? It would be helpful to have some type of "grip strip" to keep from slipping.
- Overall, this is a wonderful space to work in. The natural light and openness, though bothersome from a noise perspective, increases job satisfaction. The only major change that would be nice is to have departments more physically aligned with one another.

  Thank you.
- Ability to cool my office only significant issue, otherwise terrific space.
- Just to recap:
  1. The ladies room off the lobby needs some sort of table or shelf to hold women's purses, notebooks etc. A coat tree also would be beneficial. This restroom is used primarily by visitors and they have to juggle all their belongings while they try to wash their hands.
  2. The set up of the front desk is not ergonomically correct. An analysis has been done but no action has been taken to resolve the issues with the desk and the actual workspace area.
- It is pretty but not at all a easy building to actually work in - loud and inefficient. I know traditional offices are ugly - but they are set up for work.
- We have a beautiful, energy efficient building that is a delight to work in and visit. I love the way the green roof looks in the snow, or seeing foxes or herons from our conference rooms during a meeting. As a major funder of environmental programs, we are living the world we hope to help to create.

  Unfortunately, despite these wonderful virtues, the building is now way too small (it was originally designed for about 50 people). We have run out of offices, conference and meeting rooms, kitchen spaces, and parking.

In addition, despite the building's beauty, we are an isolated green island in a sea of half empty parking lots and emptier buildings. We are far from colleagues, public transit and other people. Although shopping and some restaurants are in the nearby mall, they are actually less convenient than a casual observer might think: at least 12 minutes away if you're walking (across several lanes of traffic) and often no quicker if you drive.

Basically, it's a great building that's too small and in the wrong place.

- It would be nice if their was more visual privacy. However, the building overall does look very nice.
- More humidity in the air so that it's not so dry; I don't see that the waterfalls are helping in the barn. And just better air filtration so that there isn't so much dust. Over all I love the concept, design, asthetics, and function of the space. I am particularly satisfied with my work area. There is great natural lighting and privacy! We could use a runner down the center to help difuse the noise as well a few buffers/baffles in the ceiling of the kitchen. Also the kitchen could use a vent to route food smells outside the building. Again over all I am very pleased with my work area and the building as a whole!

You have indicated that you are not satisfied with the functionality of the buildings lobby. Why?

- I just think the unutilized space & flow of the lobby needs so attention.
- We need to reconfigure the entrance and reception.
- Dark and Dingy....
- Front desk is dirty and a mess

Which of the following best describes your personal workspace?

- Open with 1 divider between the desks
- Open with 1 low partition
- 1 partition about 5' high

During a typical week, what percentage of your time do you spend working in the following locations?

- supervisor's office
- Supporting other users in individual and shared workspaces
- no such thing as a typical week
- travel
- outside office
- server room
- Boss's office
- Switchboard

Considering only your working time in your building, please estimate the percentage of that time you spend on the following activities.

- email
- Switchboard
- Doing Maint

3.3 Occupant Survey Methodology

This report presents the results of an Occupant Satisfaction Survey. Occupant responses are collected via the Internet and recorded to a secure server database using SQL technology (SQL is a standardized query language used for requesting information from a database). To protect the confidentiality of participants, the online report contains only aggregated, anonymous results.

The survey is comprised of a core survey and optional survey modules. The core survey includes modules for office layout, office furnishings, thermal comfort, air quality, lighting, acoustics, and building cleanliness and maintenance. This survey report includes information for the optional commute and daylighting modules. Core questions are the same across surveys and are used for benchmarking and trend analysis.

The survey has been extensively tested and refined. An established in-depth pre-testing method called cognitive interviewing was used by the Survey Research Center at the University of California, Berkeley to assess how well respondents were able to comprehend and accurately report answers to survey questions (Eisenhower, 2000). Cognitive interviews allowed researchers to examine the thought processes that affect the quality of answers provided to survey questions. The primary technique used was “concurrent think aloud” where respondents were asked to comment out loud about the thoughts that crossed their mind as they read, interpreted and answered each question. This technique was supplemented with paraphrasing (asking the respondents to put something in their own words) and systematic probing. Seven people participated in this testing. Results were used to refine the survey organization, question text, graphic design of the scales, and the process required to access the survey website.

The time to completion has been monitored, and occupants have evaluated the length of each section of the survey. Approximate time to completion for the core survey is 5-12 minutes; time to completion varies depending on the number of branching questions and comments answered. This length of time has not been regarded as an impediment to completion in most (but not all) of the buildings surveyed to date. Surveys that include several customized modules in addition to the core survey have had completion times of up to 20 minutes. Organizations that choose to implement longer surveys are briefed regarding the potential negative effect that longer time to completion can have on response and completion rates.

The survey implementation process typically begins with an email informing building and sent either by CBE or the sponsoring agency. Subjects can open the survey at their convenience. After linking to the survey, respondents see a welcome screen informing them of the purpose of the survey. The welcome page also advises them of the amount of time it should take to complete the survey, and their rights as a research participant. Participation in the survey is voluntary and anonymous. Upon starting the survey, participants click through a series of questions asking them to evaluate their "satisfaction" with different aspects of their work environment. Satisfaction is rated on a 7-point scale ranging from "very satisfied" to "very dissatisfied" (see Figure 1). In most cases, respondents who indicate dissatisfaction (the lowest three points on the scale) with a particular aspect of their work environment are branched to a follow-up screen probing them for more information about the nature of their dissatisfaction. Respondents who indicate neutrality or satisfaction (the upper four points on the scale) move directly to the next survey topic. When applicable, respondents are also asked to assess the impact of environmental factors on their effectiveness in getting their job done.

A survey typically stays open for 1-2 weeks. The rate of participation is monitored; if few have responded, reminder emails may be sent. After the survey is closed, the data is cleaned. The responses of participants who answer less than 15 questions are removed from the final data set.

Satisfaction ratings are tabulated for each point on the scale, and are also summarized into three categories: satisfied (top three points), neutral (middle point) and dissatisfied (bottom 3 points). This summary is particularly useful to managers that need to see a top-level overview of occupant feedback. Comments are also listed in totality for each question.

For more information, please send us an e-mail or contact us at (510) 642-4984.

3.4 How to Get the Raw Data

CBE can provide you the raw data for your survey in a tab delimited or comma delimited format. This will include the question text and answer text for each response. Each user is assigned a unique user ID so that you can rectangularize the data if you so choose. The data files can be quite large, too large for Microsoft Excel. You will need a robust statistical package (e.g. SPSS or Stata) or a database package (Microsoft Access or MySQL) to use these files.

Appendix C: Hydrographs from Rain Events

Monitored Event #1 – September 11, 2010

Total precipitation (P), in inches	0.31
Total Q*, in gallons	2.10
Total Q, in inches	0.00
Percent of rainfall captured	99.99%

Table C-1: Summary table for precipitation event on September 11, 2010

Q is discharge

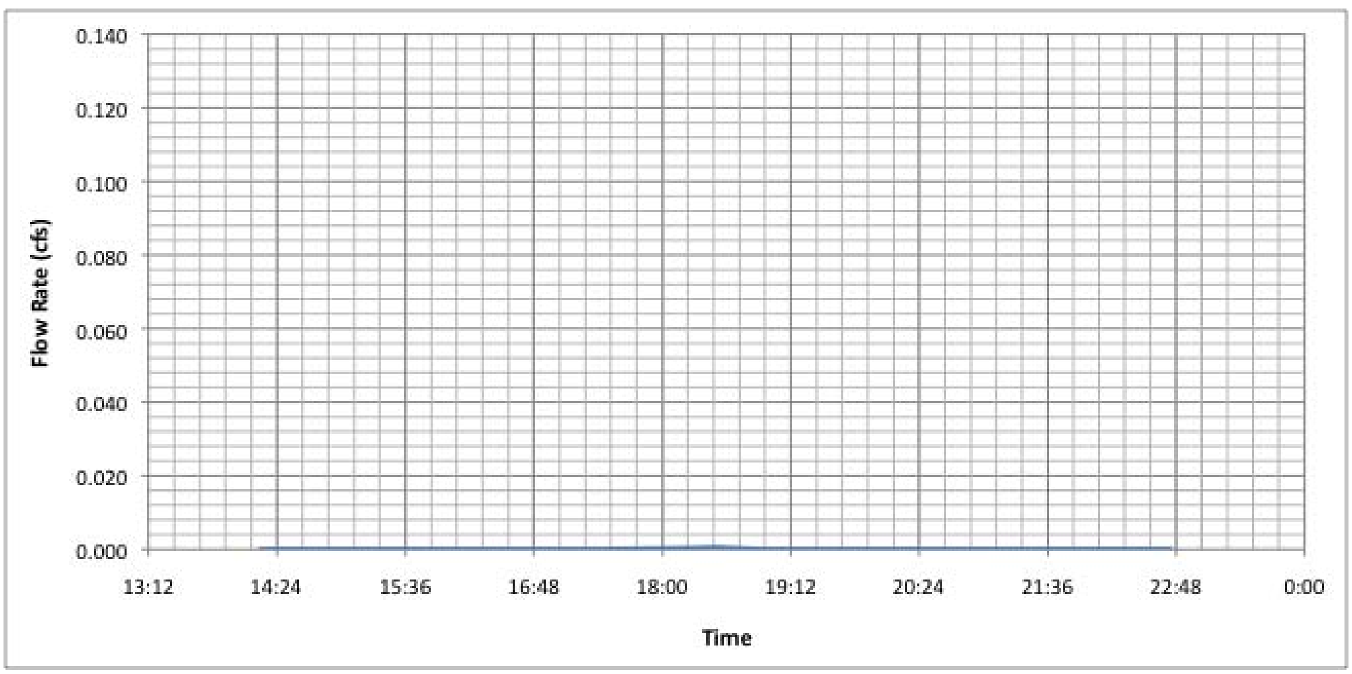


Figure C-1: Hydrograph (flow rate vs. time) showing total discharge from precipitation event on September 11, 2010

Monitored Event #2 – September 16, 2010

Total precipitation (P), in inches	0.69
Total Q, in gallons	2,348.30
Total Q, in inches	0.03
Percent of rainfall captured	94.99%

Table C-2: Summary table for precipitation event on September 16, 2010

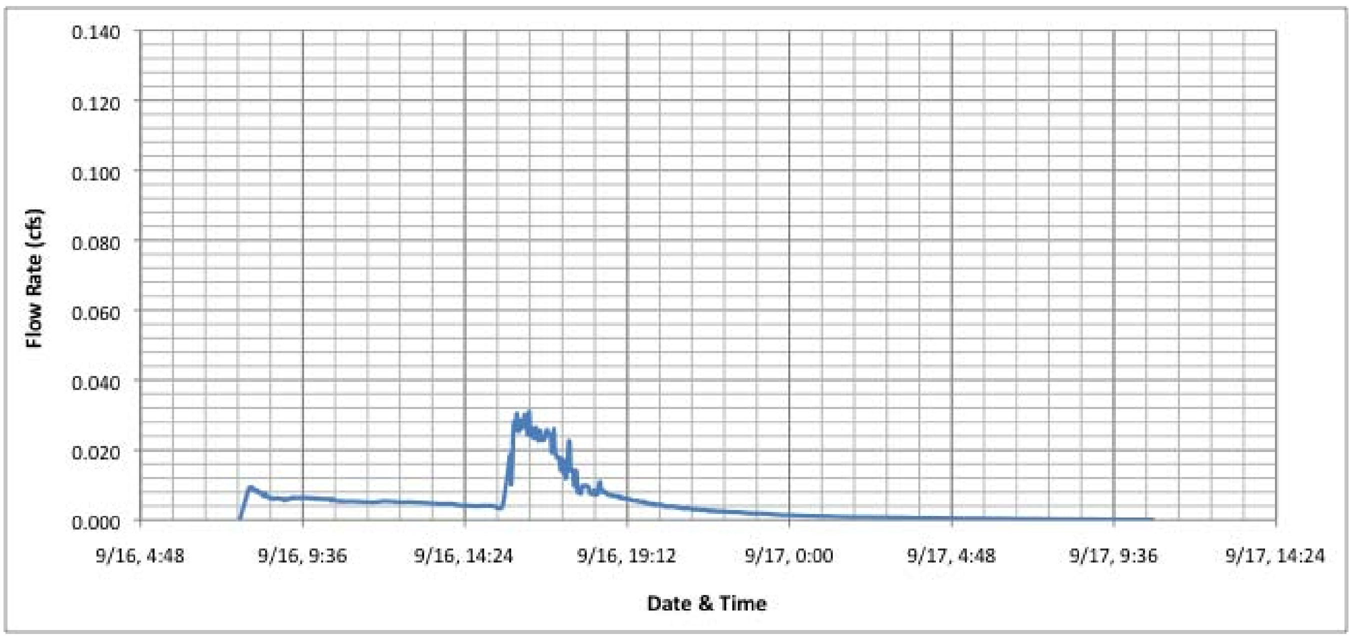


Figure C-2: Hydrograph (flow rate vs. time) showing total discharge from precipitation event on September 16, 2010

Monitored Event #3 – September 22, 2010

Total precipitation (P), in inches	0.22
Total Q, in gallons	1,021.20
Total Q, in inches	0.02
Percent of rainfall captured	93.16%

Table C-3: Summary table for precipitation event on September 22, 2010

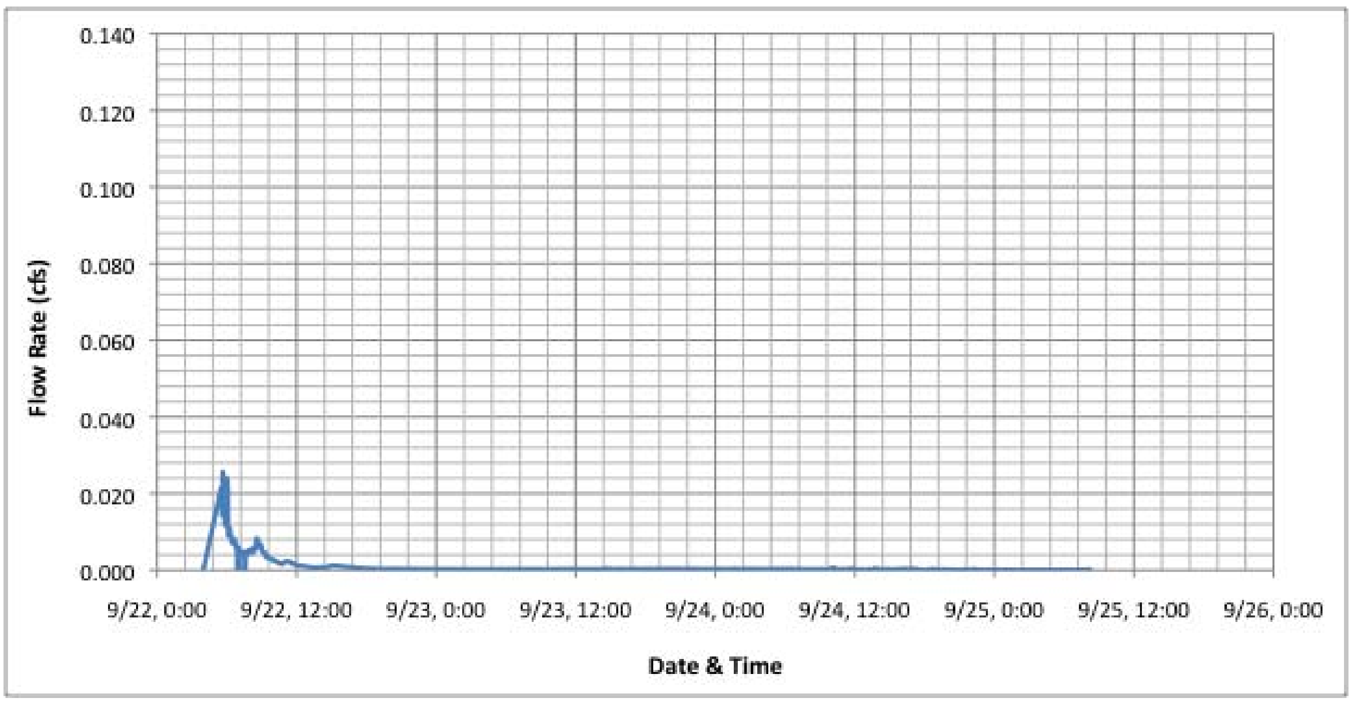


Figure C-3: Hydrograph (flow rate vs. time) showing total discharge from precipitation event on September 22, 2010

Monitored Event #4 – September 27, 2010

Total precipitation (P), in inches	1.09
Total Q, in gallons	19,291.00
Total Q, in inches	0.28
Percent of rainfall captured	73.93%

Table C-4: Summary table for precipitation event on September 27, 2010

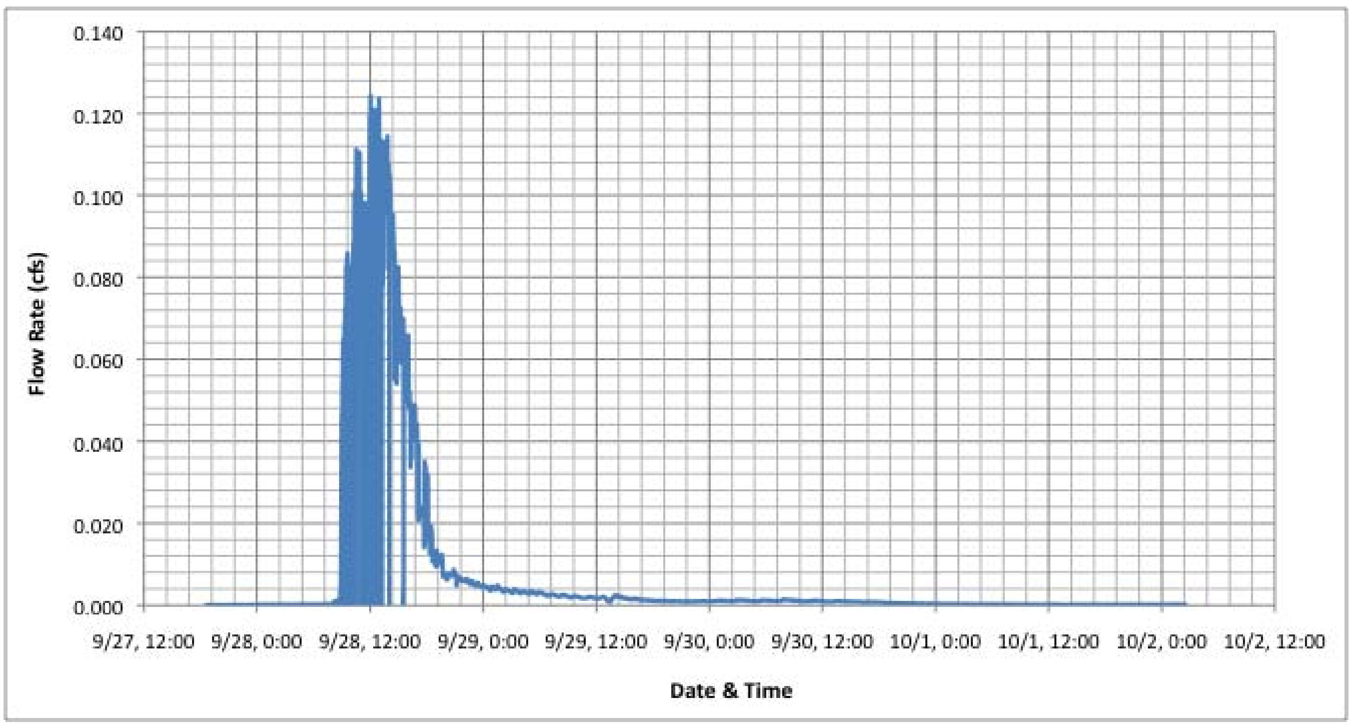


Figure C-4: Hydrograph (flow rate vs. time) showing total discharge from precipitation event on September 27, 2010

Monitored Event #5 – October 2, 2010

Total precipitation (P), in inches	0.29
Total Q, in gallons	2584.00
Total Q, in inches	0.04
Percent of rainfall captured	86.89%

Table C-5: Summary table for precipitation event on October 2, 2010

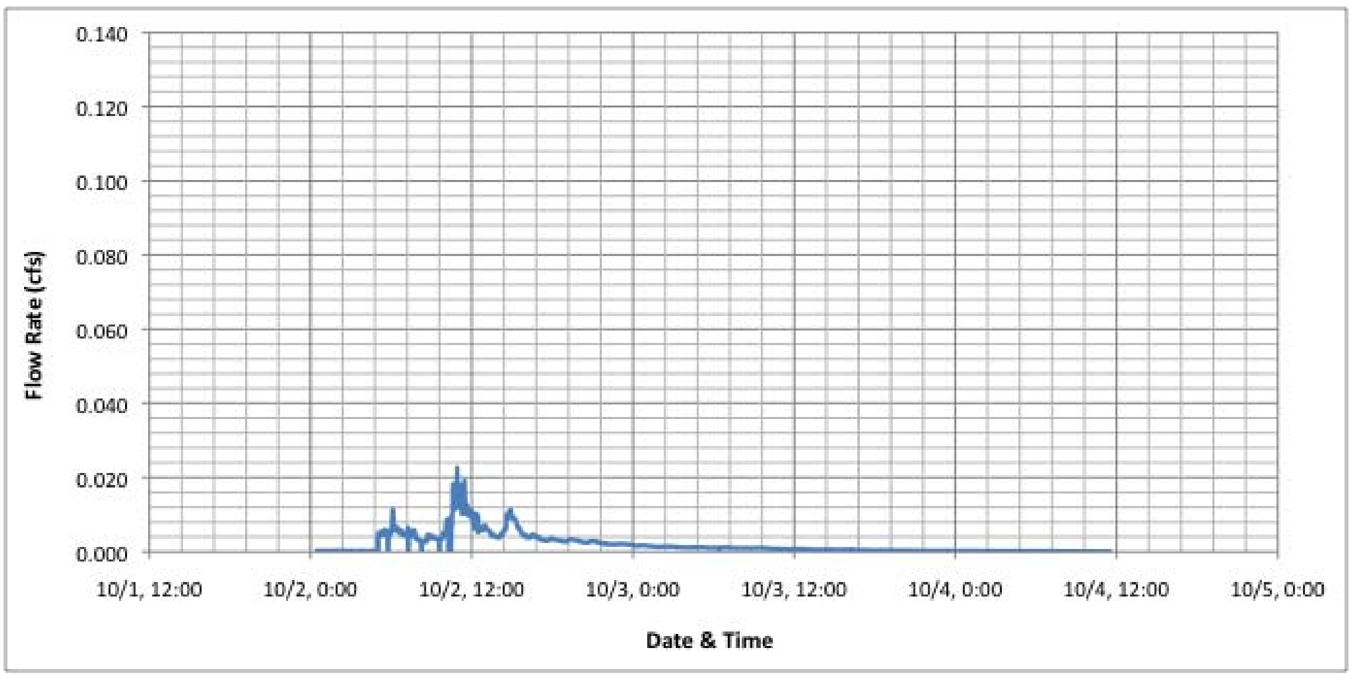


Figure C-5: Hydrograph (flow rate vs. time) showing total discharge from precipitation event on October 2, 2010

Appendix D: Acoustics Details

Description of the Spaces

Figures D-1 and D-4 show floor plans of the courtyard level and farmhouse level, respectively, with the corresponding room numbers. Figures D-2 and D-3 show the courtyard-level open-plan offices and the courtyard-level conference room, respectively. Table D-1 describes the areas where the team performed acoustic or lighting measurements and characteristics of the surfaces in each area.

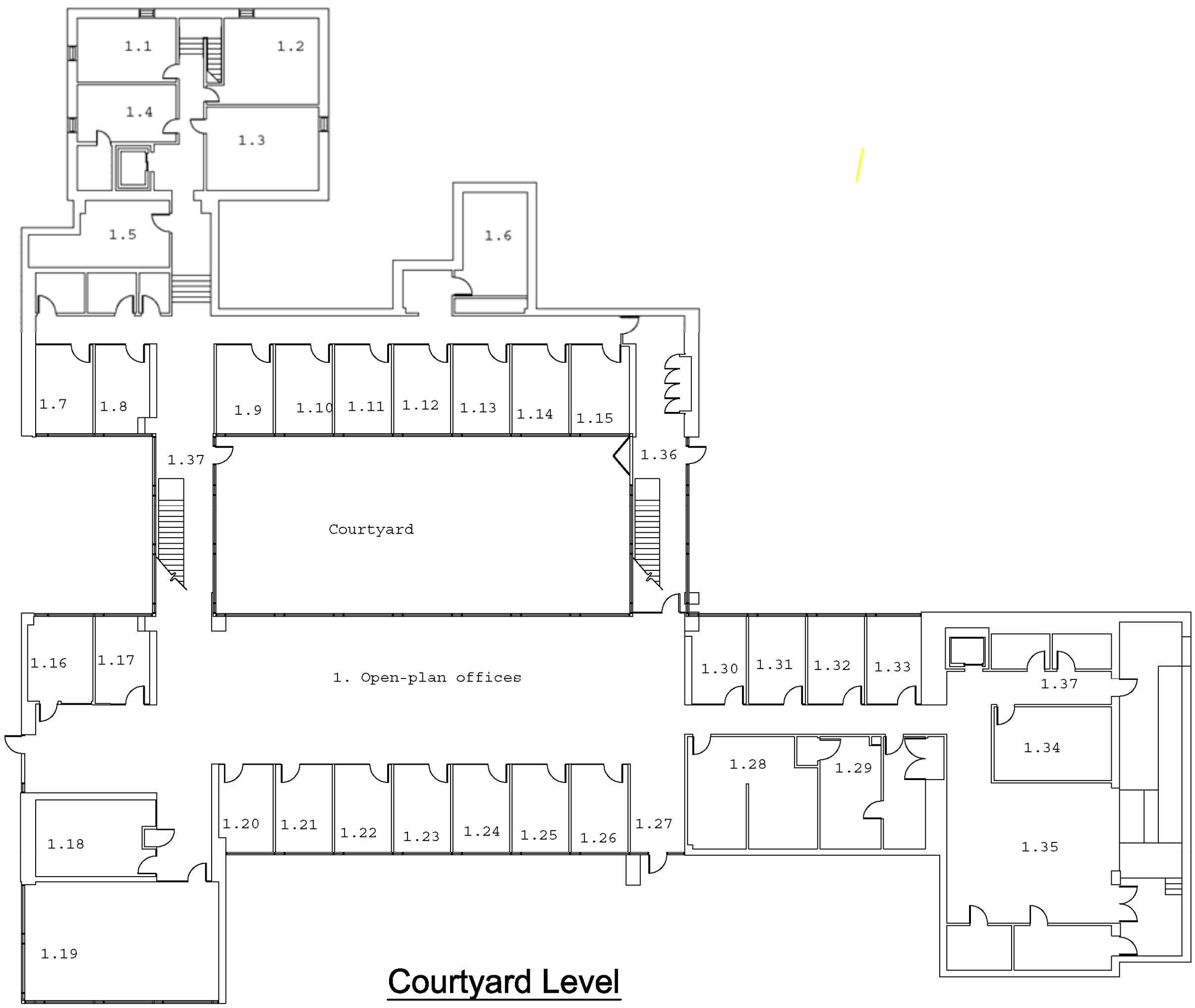


Figure D-1: Plan of the courtyard level with room numbers used for referencing the locations of the acoustic and lighting-level measurements

Figure D-2: Open-plan offices at the courtyard level

Figure D-3: Conference room (1.19) at the courtyard level

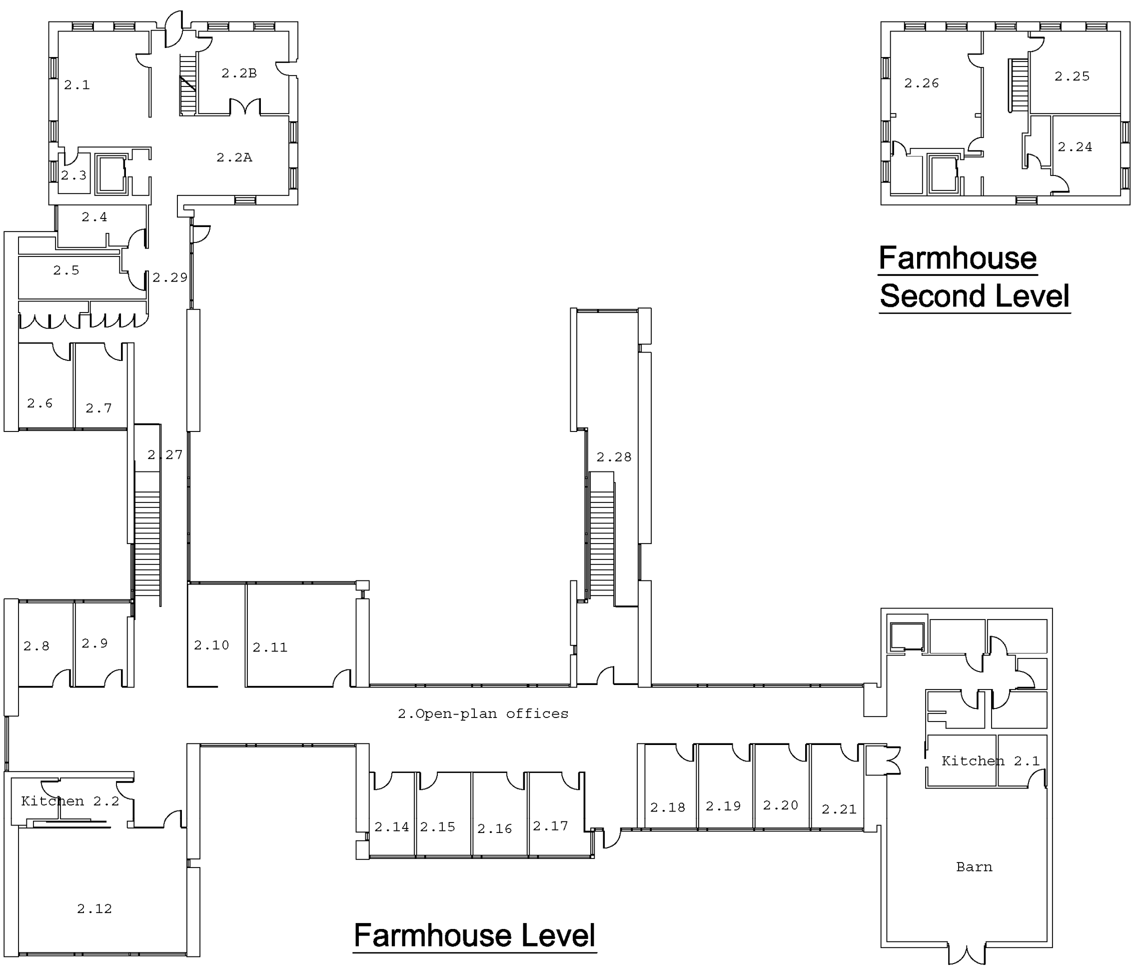


Figure D-4: Plan of the farmhouse level with the room numbers used for referencing the locations of the acoustic and lighting-level measurements

Table D-1: Area and surface treatments of the areas where the acoustical and lighting measurements were performed

Office specification	Room number	Figure	Surface treatments
PO1	1.8,1.20	N/A	Metal perforated ceiling. One light-color wood wall. One white drywall. Two full glass walls (one on the exterior and one on the corridor). Light-brown carpet floor.
PO2	1.12, 1.14, 1.21, 1.24, 1.25, 1.31, 1.7	Figure D-7	Metal perforated ceiling. Two white drywalls. Two full glass walls (one on the exterior and one on the corridor). Light-brown carpet floor.
PO3	2.14, 2.18	N/A	Metal perforated ceiling. One wood wall. One drywall. Two full glass walls (one on the exterior and one on the corridor). Wood floor.
PO4	2.6, 2.9, 2.15, 2.19,2.20	Figure D-5	Metal perforated ceiling. Two drywalls. Two full glass walls (one on the exterior and one on the corridor). Wood floor.
PO5	2.10	Figure D-6	Metal perforated ceiling. One drywall. Three full glass walls (one on the exterior and two on the corridor). Wood floor.
PO6	1.1	Figure D-8	Dry wall ceiling. Two drywalls. Two stone walls. Linoleum floor.
PO7	2.17	N/A	Metal perforated ceiling. One drywall. Three full glass walls (one on the exterior and two on the corridor). Wood floor.
PO8	2.11	N/A	Metal perforated ceiling. Two drywalls. Two full glass walls (one on the exterior and one on the corridor). Wood floor.
Conf.2	2.12	N/A	Metal perforated ceiling. Two drywalls. One glass wall. Wood floor.
Video.1	1.18	N/A	Metal perforated ceiling. Four drywalls. Carpet floor.
Conf.1	1.19	Figure D-3	Metal perforated ceiling. One wood wall. Three full glass walls. Wood floor.
FH.2	2.25	N/A	Drywall ceiling. Four drywalls. Wood floor with large Persian rug (roughly 70-80% of floor area). Several wood furniture items. Two desks.
Recep.	2.2a	N/A	Drywall ceiling. Four drywalls. Wood floor with three Persian rugs. Several wood furniture items. One receptionist desk. Five doors always open.
Barn	Barn	N/A	5-8m not flat ceiling with acoustical panels (many complains of noise level in the past). Four dry wall, one door to the kitchen always open. Linoleum floor.
1.Open	1.Open-plan offices	Figure D-2	Metal perforated ceiling. Two short drywalls. One full glass exterior wall. Glass and wood wall to the private offices. Carpet floor. Roughly 14 desks.
2.Open	2.Open	N/A	Metal perforated ceiling. Two short drywalls. One full glass exterior wall. Glass and wood wall to the private offices. Carpet floor. Roughly 4 desks.

Figures D-5, D-6, D-7, and D-8 show photos of office types PO4, PO5, PO2, and PO6, respectively.

Figure D-5: Office type PO4

Figure D-6: Office type PO5

Figure D-7: Office type PO2

Figure D-8: Office type PO6

Instrumentation

For measurements, the team used an NL-06 integrating sound-level meter equipped with an omnidirectional condenser microphone (UC-52) and preamp NH-19 from Rion Co., Ltd. The meter met Type 2 specifications (see ANSI S1.4) and was capable of digitally displaying the A-weighted equivalent sound level (L_{eq}) to the nearest decibel. The manufacturer's stated noise floor for the sound-level meter is typically 18 dB(A). The meter can display the equivalent continuous sound pressure (L_{eq}), the maximum (L_{max}) and minimum (L_{min}) level for the recording time used (30 seconds), and five percentile levels (L05, L25, L50, L75, and L95.) A handheld Type 1 portable acoustic calibrator was used to check the sound-level meter calibration before and after each measurement session. Both the meter (including the microphone) and the portable acoustic calibrator were certified to have been calibrated by an independent testing agency that is traceable to the National Institute of Standards and Technology.

Appendix E: Detailed Lighting Results

Instrumentation

Illuminance measurements were conducted with the Minolta T-1H, which is a handheld illuminance meter with a liquid crystal display and detachable sensor with output in lux or foot-candles (fc). The sensor is cosine corrected and self-calibrates before use. The sense range is 0.001 to 9,990 fc with a declared accuracy of ± 2% + 1 digit of displayed value. The spectral response is 400 to 760 nanometers (nm). The calibration of the sensor was verified before use. The instrument complies with PMP requirements.

Measurements

Tables E-1 through E-3 show summer measurements at the site, and Tables E-4 through E-6 show winter measurements. A map of room number assignments is available in Appendix D, Figure D-1, and Figure D-4.

Table E-1: Illuminance measurements during evening of August 17th for private offices

Room	Time	IESNA-recommended value (fc)	Only overhead light on (fc)	Overhead and desk light on (fc)
1.1	11:33 PM	50	N/A	28.4
1.7	11:25 PM	50	9.19	48.9
1.8	11:24 PM	50	11.70	46.7
1.9	11:17 PM	50	9.02	53.9
1.10	11:18 PM	50	9.30	45.2
1.11	11:19 PM	50	10.1	32.5
1.12	11:20 PM	50	8.23	46.3
1.13	11:21 PM	50	9.63	46.8
1.14	11:22 PM	50	7.80	48.3
1.15	11:23 PM	50	8.47	51.9
1.17	11:27 PM	50	9.18	47.0
1.20	10:51 PM	50	13.8	49.5
1.21	10:53 PM	50	14.9	52.6
1.22	10:54 PM	50	9.38	51.7
1.23	10:55 PM	50	10.90	39.7
1.24	10:57 PM	50	10.10	54.3
1.25	10:58 PM	50	10.5	45.9
1.26	10:59 PM	50	9.70	48.5
1.30	11:02 PM	50	9.04	47.5
1.31	11:03 PM	50	8.71	46.7
1.32	11:04 PM	50	9.90	47.7
1.33	11:05 PM	50	10.50	51.3
2.60	10:46 PM	50	8.24	48.8
2.70	10:48 PM	50	7.85	38.4
2.90	10:24 PM	50	9.52	52.0
2.10	10:26 PM	50	14.30	22.1

Room	Time	IESNA-recommended value (fc)	Only overhead light on (fc)	Overhead and desk light on (fc)
2.11	10:28 PM	50	7.74	38.9
2.14	10:29 PM	50	15.10	49.3
2.15	10:32 PM	50	17.30	N/A
2.16	10:31 PM	50	7.20	55.2
2.17	10:30 PM	50	7.37	51.1
2.18	10:34 PM	50	9.50	52.9
2.20	10:37 PM	50	8.70	48.6
2.21	10:46 PM	50	10.60	54.9

Table E-2: Illuminance measurements during evening of August 17th for open-plan offices

Room	Time	IESNA-recommended value (fc)	Only overhead light on (fc)	Overhead and desk light on (fc)
Open Office Plan - Flr 1	11:06 PM	30	19.8	31.5
Open Office Plan - Flr 1	11:07 PM	30	13.4	24.1
Open Office Plan - Flr 1	11:08 PM	30	13.8	28.3
Open Office Plan - Flr 2	10:45 PM	30	8.25	19.3
Open Office Plan - Flr 2	10:46 PM	30	8.85	N/A
Open Office Plan - Flr 2	10:47 PM	30	21.7	N/A
Barn	11:42 PM	30	14.4	33.2
Barn	11:43 PM	30	10.4	42.2
Barn	11:45 PM	30	11.0	27.4

Table E-3: Illuminance measurements during evening of August 17th for corridors

Corridors	Time	IESNA-recommended value (fc)	Illuminance level (fc)	Overhead lights
2.18-2.21	10:40 PM	5	24.3	ON
2.10-2.11	10:45 PM	5	27.6	ON
2.8-2.9	9:25 PM	5	13.4	OFF
2.27	9:27 PM	5	21.0	OFF
2.28	9:28 PM	5	16.9	OFF
2.29	9:30 PM	5	38.5	OFF
2.6-2.7	9:32 PM	5	10.6	OFF
1.30-1.33	9:34 PM	5	4.42	OFF
1.16-1.17	11:30 PM	5	20.9	ON
1.8-1.7	11:30 PM	5	23.2	ON
1.9-1.15	11:32 PM	5	13.9	OFF
1.37	9:36 PM	5	19.1	OFF
1.36	9:37 PM	5	9.7	OFF
1.38	9:38 PM	5	22.6	OFF

Winter Measurements

Table E-4: Illuminance measurements during morning of March 4th for private offices

Room	Time	IESNA-recommended value (fc)	All lighting off (fc)	Only overhead light on (fc)	Overhead and desk light on (fc)	Blinds position	Direct sun?
1.1	12:10 AM	50	1.77	26.5	N/A	N/A	No
1.7	10:00 AM	50	6.65	11.9	33.7	N/A	No
1.8	9:58 AM	50	8.94	19.8	40.6	N/A	No
1.9	9:57 AM	50	95.3	102.0	127.0	N/A	Reflection from snow
1.10	9:54 AM	50	104.0	108.0	140.0	N/A	Reflection from snow
1.11	9:31 AM	50	84.3	92.3	100.0	N/A	Reflection from snow
1.12	9:28 AM	50	34.9	35.6	70.3	N/A	No
1.13	9:25 AM	50	28.8	40.0	65.9	N/A	Yes
1.14	9:23 AM	50	10.4	15.6	42.5	N/A	No
1.15	9:15 AM	50	3.7	12.4	28.8	N/A	No
1.17	10:25 AM	50	37.9	47.5	68.8	N/A	No
1.20	10:07 AM	50	105.0	130.0	162.0	N/A	Yes
1.21	10:09 AM	50	175.0	176.0	206.0	N/A	Yes
1.22	10:11 AM	50	97.0	99.0	127.0	N/A	Yes
1.23	10:12 AM	50	160.0	160.0	180.0	N/A	Yes
1.24	10:15 AM	50	165.0	167.0	190.0	N/A	Yes
1.25	10:16 AM	50	63.0	69.0	90.6	N/A	Yes
1.26	10:26 AM	50	56.7	65.5	93.9	N/A	No
1.30	10:31 AM	50	52.4	60.1	95.9	N/A	Reflection from snow
1.31	10:32 AM	50	58.8	61.7	79.2	N/A	Reflection from snow
1.32	10:34 AM	50	53.0	59.0	107.0	N/A	Reflection from snow
1.33	10:35 AM	50	52.0	58.3	83.7	N/A	Reflection from snow
2.6	12:04 AM	50	108.0	118.0	155.0	Up	Yes
2.7	12:02 AM	50	141.0	150.0	166.0	Up	Yes
2.9	11:42 AM	50	30.4	43.6	59.8	N/A	No
2.10	11:41 AM	50	80.5	86.1	N/A	N/A	No
2.11	11:40 AM	50	93.5	94.1	111.0	N/A	No
2.14	11:27 AM	50	86.7	92.5	131.0	Down	Yes
2.15	11:26 AM	50	150.0	155.0	185.0	?	Yes
2.16	11:25 AM	50	210.0	210.0	257.0	?	Yes
2.17	11:23 AM	50	140.0	142.0	181.0	?	Yes
2.18	11:21 AM	50	84.2	93.4	118.0	Down	Yes

Room	Time	IESNA-recommended value (fc)	All lighting off (fc)	Only overhead light on (fc)	Overhead and desk light on (fc)	Blinds position	Direct sun?
2.19	11:19 AM	50	84.3	84.3	118.0	Down	Yes
2.20	11:17 AM	50	201.0	203.0	228.0	?	Yes
2.21	11:15 AM	50	108	117	162	?	Yes

Table E-5: Illuminance measurements during morning of March 4th for open-plan office spaces

Room	Time	IESNA recommend ed value (fc)	Only overhead light on (fc)	Overhead and desk light on (fc)	Blade position	Direct sun?
Open-Plan Office - Flr 1	10:38 AM	30	64.1	N/A	N/A	No
Open-Plan Office - Flr 1	10:40 AM	30	75.1	N/A	N/A	No
Open-Plan Office - Flr 1	10:42 AM	30	82.2	N/A	N/A	No
Open-Plan Office - Flr 1	10:44 AM	30	53.4	N/A	N/A	No
Open-Plan Office - Flr 1	10:46 AM	30	90.5	N/A	N/A	No
Open-Plan Office - Flr 1	10:48 AM	30	85.3	N/A	N/A	No
Open-Plan Office - Flr 1	10:50 AM	30	76.0	N/A	N/A	No
Open-Plan Office - Flr 1	10:52 AM	30	27.1	N/A	N/A	No
Open-Plan Office - Flr 1	10:54 AM	30	34.4	N/A	N/A	No
Open-Plan Office - Flr 1	10:56 AM	30	33.9	N/A	N/A	No
Open-Plan Office - Flr 1	10:58 AM	30	48.1	N/A	N/A	No
Open-Plan Office - Flr 1	11:00 AM	30	59.3	N/A	N/A	No
Open-Plan Office - Flr 1	11:02 AM	30	110.0	N/A	N/A	No
Open-Plan Office - Flr 1	11:04 AM	30	112.0	N/A	N/A	No
Open-Plan Office - Flr 2	11:06 AM	30	49.2	N/A	Down	No
Open-Plan Office - Flr 2	11:08 AM	30	88.7	N/A	Up	No
Open-Plan Office - Flr 2	11:10 AM	30	56.7	N/A	Up	No
Open-Plan Office - Flr 2	11:12 AM	30	88.7	N/A	Up	No
Barn	11:52 AM	30	40.5	57.1	Half	No
Barn	11:54 AM	30	36.8	86.5	No	No
Barn	11:56 AM	30	118.0	34.2	N/A	No

Table E-6: Illuminance measurements during afternoon of March 4th for corridors

Corridors	Time	IESNA recommend ed value (fc)	Illuminance level (fc)	Overhead lights	Lighting sensor
2.18-2.21	1:06 PM	5	105.0	On	Motion sensor
2.10-2.11	1:10 PM	5	210.0	On	No sensor
2.8-2.9	1:12 PM	5	37.8	On	Motion sensor
2.27	1:14 PM	5	110.0	Off	Motion sensor
2.28	1:16 PM	5	64.2	On	Series of illuminance sensors

Corridors	Time	IESNA recommended value (fc)	Illuminance level (fc)	Overhead lights	Lighting sensor
2.29	1:18 PM	5	41.3	On	Illuminance sensor
2.6-2.7	1:20 PM	5	27.0	On	No sensor
1.30-1.33	1:22 PM	5	75.6	On	No sensor
1.16-1.17	1:24 PM	5	60.1	On	No sensor
1.8-1.7	1:26 PM	5	51.0	On	No sensor
1.9-1.15	1:28 PM	5	35.9	On	No sensor
1.37	1:30 PM	5	5.9	On	No sensor
1.36	1:32 PM	5	301.0	On	Series of illuminance sensors
1.38	1:34 PM	5	45.5	On	No sensor

Appendix F: Thermal Comfort Details

Thermal Contour Maps

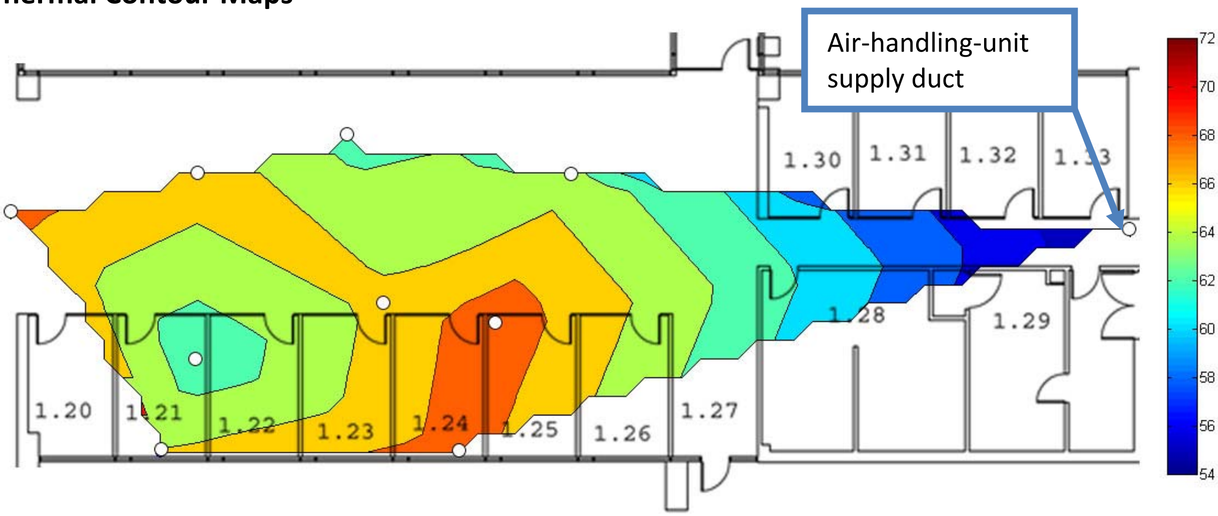


Figure F-1: Thermal contour map of first-floor southern zone

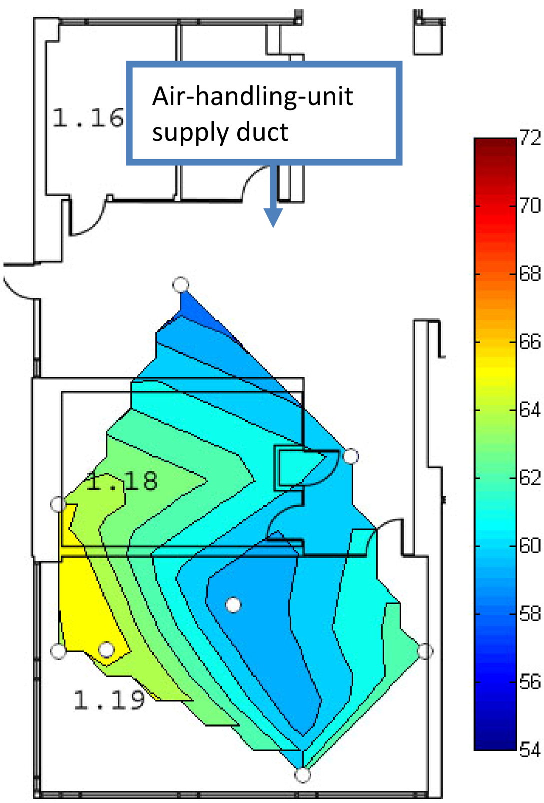


Figure F-2: Thermal contour map of first-floor western zone

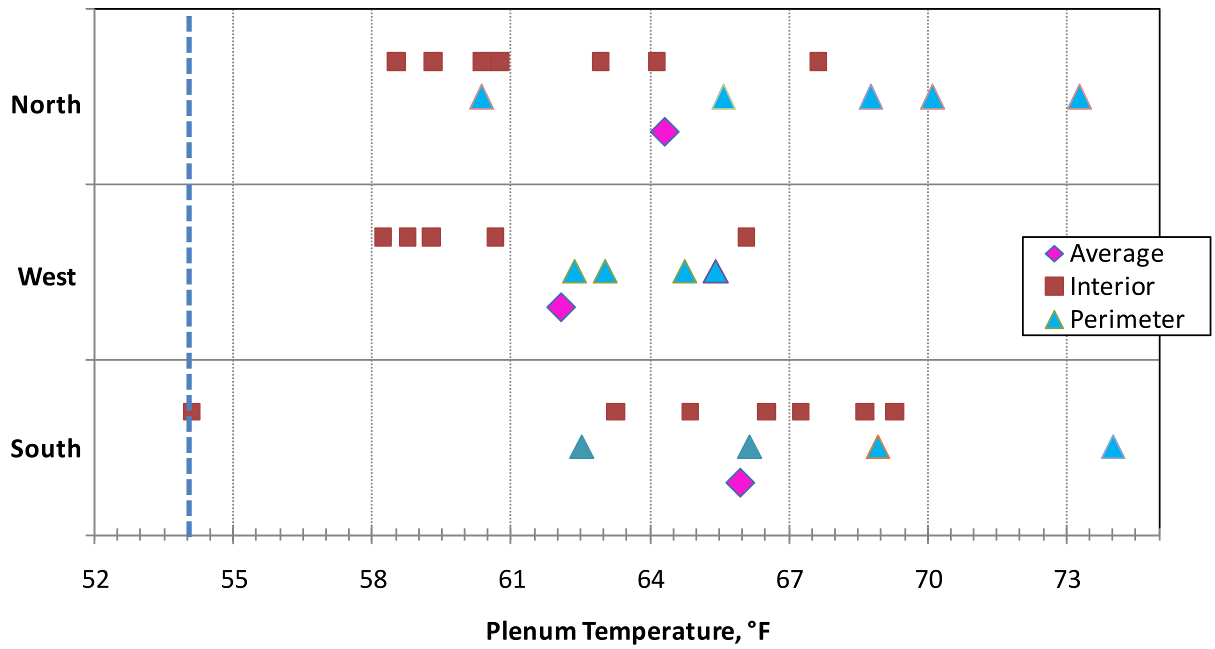


Figure F-3: Temperature distributions of first-floor underfloor plenums

UFAD Performance Charts

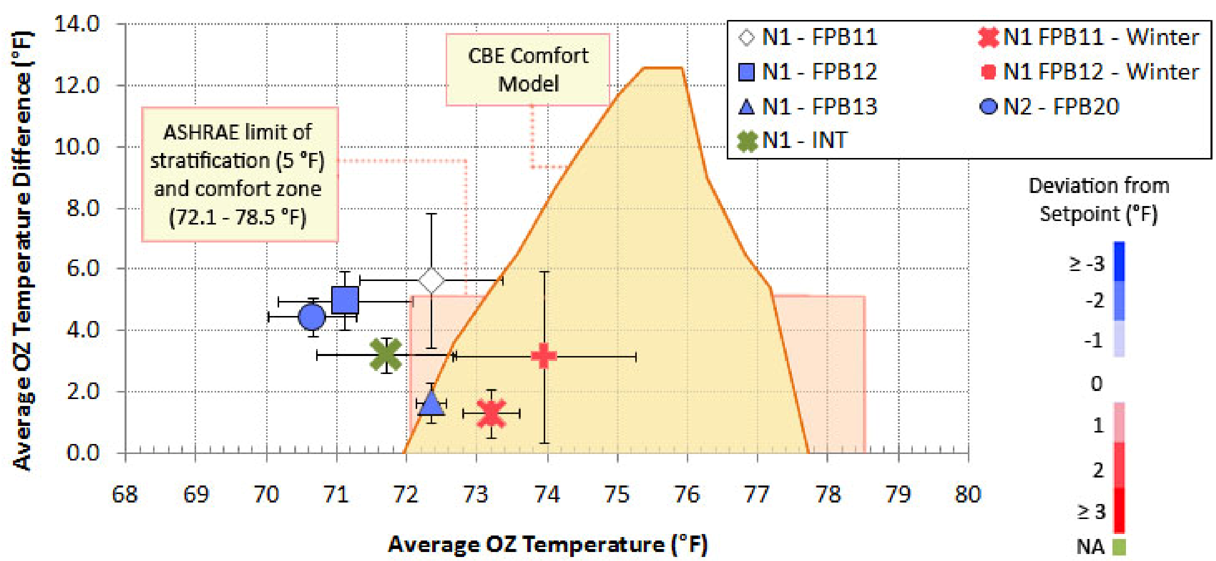


Figure F-4: UFAD performance for first- and second-floor north zones as determined by thermal stratification, occupied zone temperature, and deviation from setpoint (note: comfort zone not valid for winter measurements)

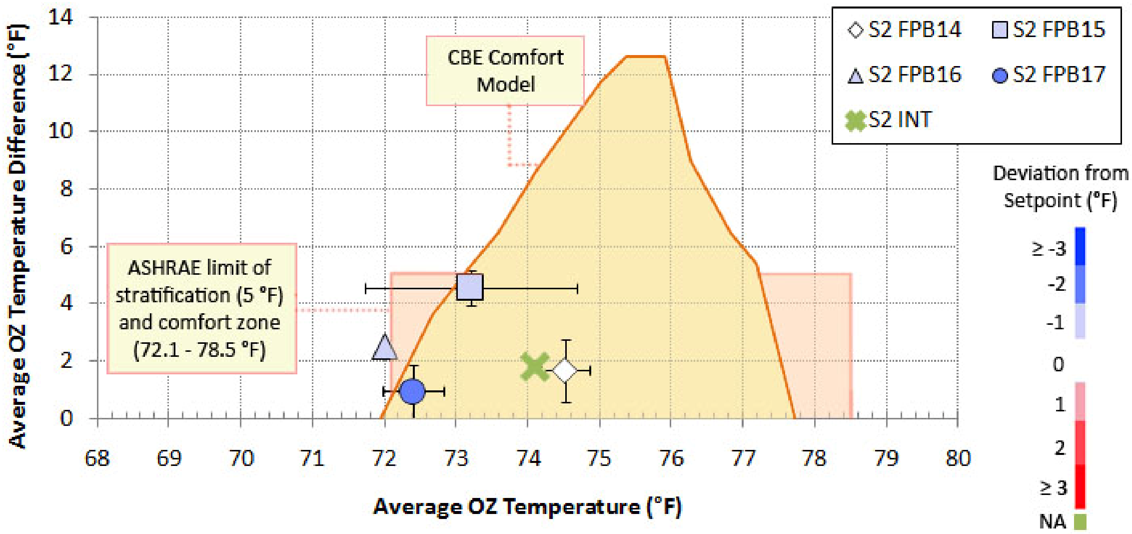


Figure F-5: UFAD performance for second-floor south zone as determined by thermal stratification, occupied zone temperature, and deviation from setpoint

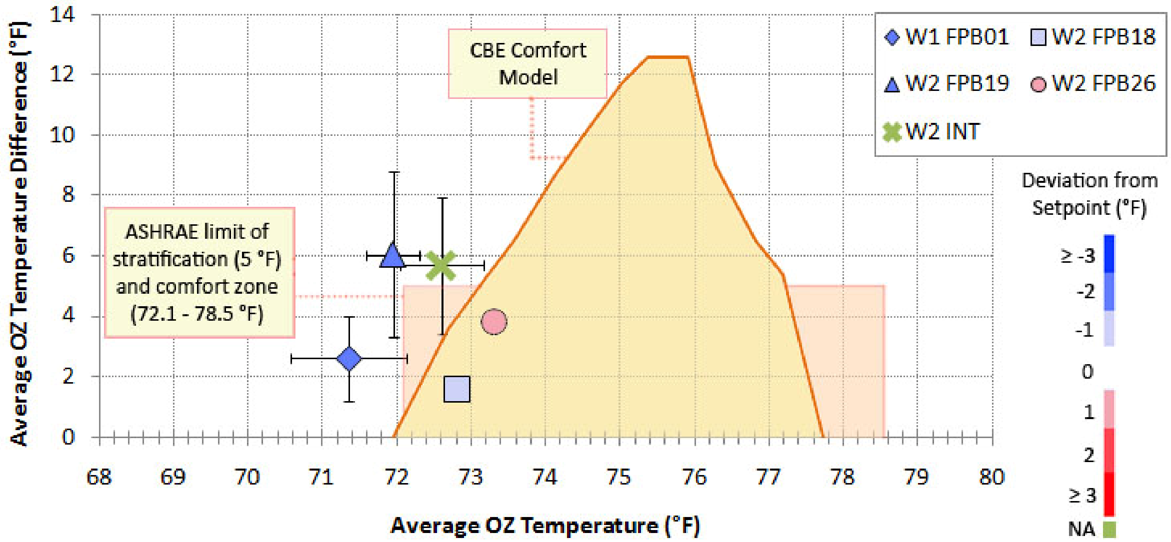


Figure F-6: UFAD performance for first- and second-floor west zones as determined by thermal stratification, occupied zone temperature, and deviation from setpoint

Thermostat Setpoints

Table F-1: Thermostat setpoints for fan-powered boxes (°F)

FPB	Zone SP	Heat SP	Cool SP
1	73.5	72.5	73.5
2	73.0	72.5	73.5
3	73.5	72.0	73.0
4	74.0	73.5	74.5
5	77.0	76.5	77.5

FPB	Zone SP	Heat SP	Cool SP
6	76.0	75.5	76.5
7	78.0	77.5	78.5
8	74.5	74.0	75.0
9	79.0	78.5	79.5
10	72.0	71.5	72.5
11	72.0	71.5	72.5
12	72.5	72.0	73.0
13	74.0	73.5	74.5
14	74.0	73.5	74.5
15	73.5	73.0	74.0
16	72.5	72.0	73.0
17	73.0	72.5	73.5
18	73.0	73.3	74.3
19	72.5	72.0	73.0
20	72.5	72.0	73.0
21	78.0	77.5	
22	80.0	78.0	
23	71.5	70.4	
24	72.0	71.5	
25	72.0	52.0	
26	72.0	71.5	
27	72.0	71.4	
28	74.0	73.5	

Appendix G: Energy Performance Analysis

Energy performance simulations

Simulation is best used for evaluating design alternatives while calibrated simulation is best used for determining savings associated with retrofits. Calibrated simulation is not usually considered a benchmarking method. For the Kresge Complex, the energy modeler used calibrated simulation to validate initial saving estimates compared to the original minimum-code baseline with actual operating conditions and loads incorporated. Thus, that analysis only indicates savings compared to how the building would have performed if it used the budgeted building design and does not tell how the building compares with other similar buildings that were designed using same standard. Furthermore, this type of comparison depends strongly on the depth and accuracy of the calibration.

Calibrated simulations issues

There are many factors to consider when conducting calibrated simulations. Among the issues that have a significant impact on performance, results are the following:

- HVAC equipment energy estimates are only as good as the modeling capability of the simulation program. It is critical that the program be able to model the type of equipment being used accurately, and that actual performance characteristics of HVAC equipment (i.e., rated capacities and part-load performance curves) be incorporated into the models. This requires detailed performance measurements of actual equipment. Sometimes a newer system such as UFAD cannot be modeled explicitly, so "workarounds" are used to estimate its performance. The accuracy of these methods is always in question,
- Internal load inputs (including those from people, lighting, and plug loads) must be based on actual measured usage,
- Any known problems with controls, setpoint differences, economizers, supply air temperature control, etc., must be accounted for and simulated properly,
- End-use breakdowns are needed to ensure accuracy of calibration, and
- ASHRAE Guideline 14 describes methods to determine the accuracy of calibrated simulations and uncertainly of savings estimates when compared to measured data.

Kresge calibrated simulation issues

This list summarizes possible factors that may help explain differences between actual and simulated results. These factors were could have been ignored (possibly because of difficulties in modeling them in VisualDOE), not modeled correctly (due to incomplete information), were unknown at the time that the calibration was performed, or are different now than when the calibration study was conducted (so could be misconstrued by the CBE team). These factors indicate the difficulty of developing an accurate calibrated model. In particular, calibrated modeling without validation against detailed end use measured data is inherently problematic.

Shading: As shown in Figure G-1, the Kresge Complex has both external shading devices and internal light shelves. External shading reduces cooling loads, and internal light shelves reduce lighting energy use (and possibly cooling) by distributing the daylight throughout the upper regions of the space. (See *Lighting*, below, for more information on this issue). It is not clear which of these were modeled; it appears that neither of these was in the original model but both were in the calibrated model; daylighting, however, was simulated in both. This may result in overstated differences between the original and calibrated model, but if it is true that shading devices were included in the calibrated model it would help narrow the differences between simulated and actual performance.)

Figure G-1--: External shading and internal light shelves

In addition to external shading, internal roller shades used for comfort and glare control do not appear to have been modeled. This is a very difficult aspect to simulate since they are occupant controlled in highly unpredictable ways. In addition, simulation algorithms that attempt to account for their thermal effects are complex and still being developed. Furthermore, for UFAD systems, research has shown that blinds (roller shades have not been studied) can have a significant impact on stratification under cooling load conditions. The overall impact of shading devices is to reduce cooling loads but depending on how they are used, could actually increase heating load in winter by reducing solar gain; therefore the effects on the difference is not intuitively apparent.

Glazing: Stated averages of window-to-wall vary between 30 and 50%. The energy model shows 30% and we assume that this is the overall building average derived from a detailed fenestration breakdown for the spaces. However, the larger new building spaces with the highest loads and occupancies have south and north facing glass close to 100%, although with good window thermal properties. We expect that these spaces are the drivers of the overall energy use (we do not have a breakdown of load distribution) and as such may help explain why the energy use is so high for both the models and the actual building. If these WWRs were applied correctly in each area of the building, there should be minimal impact on the differences between actual and simulated.

Operable windows: The effects on performance of natural ventilation – i.e., occupants opening windows in private offices – were not simulated. However, because the windows in the Complex are difficult to operate, they appear to be seldom used. In addition, they may not be of sufficient size or configuration to provide a significant benefit on energy but could potentially improve local comfort conditions.

Heat pump performance problems: As discovered during commissioning of the Complex, the piping between the building and the geothermal field was placed too near the surface and inadequately insulated. This resulted in operational and performance problems with the water-source heat pumps (numbers 1, 2, and 3) and the multi-stack hot water generator. This situation most likely results in lower heat pump performance (at both peak and part loads) than expected (and simulated), especially in winter.

UFAD system: It appears that only one parameter was adjusted to simulate the UFAD system: the supply air temperature for the UFAD systems was set at ~61°F. It is difficult to simulate these systems using DOE2[32] programs, which do not account for supply plenum thermal decay and stratification in the room. However, since this is a heating climate, the impact might be relatively small since UFAD systems behave similar to overhead systems when in heating mode; i.e., no stratification.

[32] DOE2 is the building energy analysis program that was used to create the Complex's energy simulations. See http://doe2.com/DOE2/index.html for more information.

It is unclear whether the modelers used measured outside air rates; we estimate that minimum outside air rates are greater than required. Greater rates would result in greater energy use for the real building.

Supply air temperature: Another issue that affects the energy performance of UFAD systems is the supply air temperature setting. Normally these systems use a setting of ~63°F, which leads to economizer savings in more temperate climates. Complex BMS data show that supply air temperatures were set at ~53°F during the summer visit, apparently to manage comfort problems. It is not clear when this setpoint was changed but it is likely to have an impact on cooling (higher) and fan energy (lower) use relative to the calibrated simulation.

Room setpoints: The setpoints were changed between the original proposed and calibrated proposed model based on a study of actual setpoints by the energy modeler. These setpoints were also used in a brief study by the energy modeler to determine the impact of using a dead band, which resulted in about a 5% decrease in HVAC energy consumption. Actual energy use would be reduced if wider deadbands and higher cooling setpoints were used, but to the degree that they were the same for the model and actual building during the 2009 period, there should be no impact on the difference between the two. However, simulation models assume that all zones are in perfect control, which is not the case in a real building, as shown in Figures 26 and 27. This would cause simulations to over-predict cooling energy use relative to real systems. Furthermore, real controls are subject to calibration and location issues that are not easily (or usually) captured in simulations.

Warm-up electric heaters: During commissioning, a number of electric baseboard (e.g., electric baseboards in the entryway) and zone heaters (not personal heaters, many of which had been removed) were installed by the operations staff at the Complex to mitigate morning warm-up and cold-day comfort problems. These heaters were apparently not included in the calibrated model and would add to the total electric energy use (relative to the model), although they might also offset normal heating supply to some extent.

Fan performance: Medium-efficiency variable-speed vane axial fans were modeled for the heat-pump air handler supply fans and for baseline system return fans for some systems. Return fans were accounted for in the original model via post processing adjustments; it is unclear if they were included in the calibrated model proposed cases. Actual fan energy use would increase relative to the model. Uncertainties in simulation can be introduced with the part load performance is not modeled as it actually occurs; a better BMS along with additional measurements would allow this to be determined.

Miscellaneous equipment loads: It appears that VisualDOE assumes some auxiliary equipment loads that are not explicitly specified and were not possible to eliminate for these simulations; this accounts for 37,315 kWh/year. For the sake of clarity, we included these loads post-hoc in the original Arup/LEED-NC model results, which is why the results in this report are slightly different from those in the Arup energy model and summary report. However, they are likely to cause greater energy use by the simulation (since there appears to be no actual equivalent) by either adding electrical load or heating and cooling energy or both causing the model to have greater energy use than actual.

Control and installation problems: We observed control problems that might affect energy performance. Among these are simultaneous heating and cooling, negative supply plenum pressures, poorly installed floor diffusers, poor outdoor air configuration, and higher than necessary outside airflows. These are the kinds of issues that differentiate actual vs. simulated performance; simulations assume all controls are operating perfectly.

Plug loads: the energy modeler surveyed plug-load connected devices in 2009 and cataloged their number and nameplate power requirements, which resulted in a breakdown similar to Table 15. The numbers in bold are those that differed from the original estimates. It should be noted that these are peak power ratings and that the actual energy use represents diversified load that results in the simulated value of 146,220 kWh/year. These devices add connected load as well as heat gain to the space, which increases air-conditioning load.

Table G-1 was derived from the original table included in the ENERGY MODELER REPORT when it was discovered that the server room power was included in the PC category. As shown in ASHRAE *Handbook of Fundamentals*, Chapter 18, Tables 8-9 (2009), nameplate ratings rarely correspond to actual energy and heat production for many devices, throwing doubt on the reliability of using manufacturers data. We have revised these estimates accordingly, as shown in Table 15. The result is a power consumption estimate 18% lower than simulated.

At the bottom of Table G-1 we have estimated the average power derived from the reported annual diversified plug load energy usage from the simulations reports, divided by an estimated total annual number of hours for these loads provided by the energy modeler; this yields a value of 1.78 W/sf. Likewise, the peak power density is 2.11 W/sf. Although these are imprecise estimates, they indicate unusually high plug load power on both a peak and average basis.[33]

This issue of plug loads is an important issue (currently being researched due to its recognized significance) since it can skew the results of a simulation as shown below (Table G-1) where the revised plug loads account for 26% of the building consumption. This has a major impact on the difference between simulated and actual performance that can only be resolved by using measured data.

Lighting loads: Lighting loads were not measured. Therefore, we assume the same lighting power densities were used in both the original and calibrated models; differences between the two were attributed to differences in operating schedules in the energy modelers report.

“Workarounds”: There appear to be a number of workarounds in the program that may add additional uncertainty some of which may have been handled with post-processing (at least in the original model). All of these may in fact be explainable and produce a reasonable simulation but it is less than clear and somewhat confusing when looking at the reports. The following are a few examples:

- In the output summary report (PS-E), the Misc. Equip. category that was unexplained is supposed to be the plug loads; the estimated plug loads were actually added under the Ext. Equip. category which is supposed to be external (to the building) loads. This suggests that these loads did not contribute to internal heat gain in the simulation.
- The space heating is zero for the winter months, with no explanation.
- Domestic hot water shows a very high-energy use and is shown in the report summary tables as Service Water heating which implies it is simulating the GSHP hot water generator, which may explain why no Space Heating is reported. However, electric baseboards were used to simulate UFAD terminal units, which would require post-processing to be done to account for the COP of the hot water generator; it is unclear if this was done in the calibrated model case.

[33] Simulated high performance buildings generally use peak power densities in the range of 0.8-1.3 w/sf. Anecdotal information indicates that average annual plug load power in modern buildings can be as low as 0.6 w/sf.

- Infiltration: Although Kresge uses fan tracking to maintain building pressure control, it is not apparent how well it was working overall. Since there are multiple units in these interconnected building sections as well as operable windows, it may be difficult to control and maintain the positive pressure assumed (and therefore no infiltration during operation) in the simulations.

Table **G-1**: Internal load estimates

	Energy Modeler Estimate			Revised estimate	
Office equipment	**Quantity**	**Watts (each)**	**Total energy (W)**	**Watts (each)**	**Total energy (W)**
Server room			10500		10500
Subtotal			**10500**		**10500**
PC	50	90	4,500.00	**65**	3,250.00
Monitor	65	57	3,705.00	**30**	1,950.00
Laptop	40	65	2,600.00	**25**	1,000.00
Tasklight	50	18	900.00	18	900.00
Under cabinet/tasklight	31	18	558.00	18	558.00
Printer	11	176	1,936.00	**110**	1,210.00
Multi-function printer	4	171	684.00	**135**	540.00
Copier	2	1,440.00	2,880.00	**800**	1,600.00
Refrigerator	3	1,265.00	3,795.00	1,265.00	3,795.00
Mini-fridge	3				
Water cooler	1	90	90.00	90	90.00
Television	1	71.6	71.60	71.6	71.60
Digital projector	1	250	250.00	250	250.00
Smartboard	1	1.5	1.50	1.5	1.50
Postage machine	1	36	36.00	36	36.00
Electric heater	1	500	500.00	500	500.00
subtotal			**22,507.10**		**15,752.10**
Kitchen equipment					
Microwave	3	1,600.00	4,800.00	**400**	1,200.00
Oven	1	5,200.00	5,200.00	5,200.00	5,200.00
Coffee maker	4	1,750.00	7,000.00	1,750.00	7,000.00
Toaster oven	1	1,500.00	1,500.00	1,500.00	1,500.00
Toaster	1	1,100.00	1,100.00	1,100.00	1,100.00
Dishwasher	3	1,300.00	3,900.00	1,300.00	3,900.00
subtotal			**23,500.00**		**19,900.00**
Total			**56,507.10**		**46,152.10**
Total power density, W/sf			**2.11**		**1.72**
% Difference					18%
			Hours/wk		
Hours/week - office			54.5		
Hours/week - kitchen			15		
Hours/week - server			168		
Load weighted hours			59.2		
Total diversified loads, kWh/yr			146200		
Average annual power, W			47521.8		
Average power, W/sf			1.78		
Full load equivalent hours			2587.29		
Estimated total operating hours, load weighted			4412.1		
Diversity factor			0.59		

Benchmarking

Benchmarking methods are used to assess how well a building performs relative to other similar designs. Because no two buildings are alike, it is virtually impossible to compare two buildings one to one, so statistical methods must be used to compare against a population of other buildings.

One could argue that the baseline budget model for ASHRAE 90.1 represents a sort of "benchmark." However, while the comparison of the budget and proposed models use many of the same features, actual buildings built to the same standard might have widely divergent characteristics (e.g., variance in window-to-wall ratio or different actual HVAC systems could be used). These differences are mitigated to some extent by the prescriptive requirements of the standard. However, some factors are limited for the budget model (e.g., window-to-wall ratio cannot be above 40% for the budget model).

Further complicating this issue is the treatment of plug loads. LEED-NC procedures based on ASHRAE 90.1–1999 specified that plug loads be ignored in the simulation comparison (they are standardized at 25% in the newer versions of ASHRAE 90.1 and LEED-NC). This creates a serious challenge for any comparison to actual data because not only is the connected energy ignored in the models, but the corresponding load on the HVAC equipment is also ignored. Calibration must accurately account for these loads if there is to be any hope of making a comparison.

The only reasonable way a "simulation benchmark" could be created would be to run a whole range of designs[34] that are possible under the budget model assumptions. Another problem with using 90.1 methods as a benchmark is that the system choices for the baseline may not make sense. To its credit, 90.1 attempts to make somewhat logical choices for the budget system depending on the choices for the proposed system. But this seems to be a somewhat artificial constraint because there are other options for a baseline that could be conceived that would be higher performing than that prescribed by 90.1. This raises the question: what is a valid baseline – one that sets a lower bar or one that sets a higher bar? Furthermore, alternatives for the proposed system could change the whole comparison, and the same building could end up with a number of different system choices, which would affect as-built performance. These are issues being hotly debated today.

Statistical Benchmarking

Benchmarking methods predominantly use one of three possible techniques: 1) filtering an existing set of buildings to try to find ones as similar as possible, 2) regression-based benchmarking using statistics, or 3) "simulation-based" or "technical" benchmarking in which the actual performance is compared to an "ideal" (i.e., best of the best practices) simulation based on the major energy-related characteristics of the actual building. The third method is somewhat like that used for the Complex, but it evaluates "how much worse" the actual performance is compared to the "best possible" baseline rather than the ASHRAE 90.1/LEED-NC method of evaluating "how much better" the building is anticipated to perform compared to a minimally code-complaint building. With statistical benchmarking, a single building is compared to the mean (or median) of a population of a similar class of buildings.

Benchmarking is more useful and accurate when the major energy-performance factors are normalized to get as close as possible to an apples-to-apples comparison. A building compared to a "similar" benchmark derived in this manner should perform within the range of these statistically similar

[34] In newer Appendix G specifications for ASHRAE 90.1, some attempt is made to run a whole range of designs by requiring that multiple building orientations be modeled.

buildings. One issue is the age of the database population; because CBECS, for example, represents a mix of older buildings, they are likely to exhibit poorer performance than newer buildings built to better standards. Using a database such as this sets the bar for high-performance buildings lower than might be appropriate. Buildings that are intended to be "high performance" should certainly perform better than the average of such a database.

Performance of LEED-NC buildings

One of the most recent well-known large studies that attempted to evaluate the performance of LEED-NC buildings is the New Buildings Institute (NBI) study (Turner and Frankel 2008). In this study, measured energy use data from a selected set of LEED-NC buildings were compared to the predictions of three different rating/modeling approaches:

- CBECS,
- ENERGY STAR, and
- Proposed simulation models.

CBECS Comparison

CBECS is the most comprehensive database of existing buildings available and is used for many evaluation purposes. NBI compared LEED-NC buildings to this database and attempted to filter the CBECS data set to correspond to the LEED-NC building set. Their conclusion was that LEED-NC buildings on an aggregate basis perform better than existing buildings by 25%-30%. However, Scofield (2009) and Newsham et al. (2009) conducted critical evaluations of this study and found the following problems:

- The selected LEED-NC buildings were not a random set; they were solicited from projects willing to submit their data, which has the potential for self selection based on "good" results,
- NBI compared the median EUI of LEED-NC buildings to the mean EUI of the CBECS buildings; this is a fundamental statistical error,
- The mean was calculated on a building basis rather than on an area-weighted basis, another fundamental error,
- The results were not tested for statistical significance,
- Source energy was not used as a metric, and
- The CBECS dataset was not adequately filtered to include principle building activities most similar to LEED-NC dataset buildings.

Newsham et al. (2009) attempted to correct the errors in the NBI study using a different approach in which the CBECS dataset was filtered to find buildings with energy-related design characteristics most like those of the LEED-NC dataset. However, these researchers also erred by not using area weighting for the means. Scofield then reanalyzed both the NBI data and Newsham data, correcting the above factors, and found that although the NBI and Newsham results based on site energy and building weighting were statistically significant, when area weighting is used, the differences are in the 4%-10% range and are not statistically significant on either a site- or source-energy basis.

In general, CBECS comparisons like those above must be done carefully, and the datasets need to be randomized, normalized, and/or filtered properly to reduce the variance in the results.

ENERGY STAR Comparison
U.S. EPA developed ENERGY STAR Buildings & Plants based on original analysis by Sharp (1996) of the CBECS database; methods have been refined since then. These analyses have shown that only the following few factors drive the energy performance for each specific building type:

- Gross area,
- Operating hours,
- Occupant density,
- Number of computers, and
- Source energy use intensity.

The resulting regression equations appear to explain >95% of the variance in the CBECS data. However, there are still questions, for example:

- Why are economizers or chillers not significant drivers?
- Are there other parameters relative to HVAC systems that are not captured because they are not available in the database?

ENERGY STAR ratings are based on normalized energy drivers and weather, and use gsf (gross square foot) weighted, median source energy use intensity (EUI) as the metric for the rating system. These EUIs are normalized to a scale of 0-100, which makes the rating number the preferred way to make comparisons between buildings of any sort. All of these factors make ENERGY STAR arguably the best tool we have to date to compare performance between buildings.

The NBI study and Scofield found that the ENERGY STAR scores for LEED-NC buildings on average were in the range of ~60, not much different than those for the non-LEED-NC buildings (by definition, 50 is the national average). However, they found that half of the sample had scores of 75 and above, but also 15% of the sample was below 30.

Simulated Comparison
The NBI study showed that there are wide variations in the comparisons between simulated and measured results. This is understandable because the comparison was made based on *proposed* models, not calibrated models.

Table G-2 summarizes the Kresge Complex energy performance analysis, comparing the Complex baseline and proposed modeling results to actual performance for two years as well as to results from benchmark simulations for a comparable climate of Duluth, Minnesota. The benchmarks have been created by the National Renewable Energy Laboratory (NREL) to represent performance of various building types generally conforming to ASHRAE Standard 90.1–2004 and CBECS 2003 and other studies (Torcellini 2006) as simulated by EnergyPlus, one of the most up-to-date simulation programs available. The results for a medium office building located in Duluth, Minnesota, are included here to provide a rough reference point for the Kresge baseline and proposed models. Although the DOE benchmark represents a larger building and a different aspect ratio, and the vintage of the ASHRAE code differs; this does indicate what can be achieved when ASHRAE 90.1 is closely followed.

Table G-2: Kresge Complex energy performance analysis summary

	Kresge								Duluth		
	Calibrated baseline, electricity (kWh)	Calibrated baseline, gas (kWh)	Calibrated proposed, electricity (kWh)	Calibrated proposed, gas (kWh)	Actual 2008, electricity (kWh)	Actual 2008, gas (kWh)	Actual 2009, electricity (kWh)	Actual 2009, gas (kWh)	Medium benchmark (90.1 -2004), electricity (kWh)	Medium benchmark (90.1 -2004), Gas [kWh]	Energy Star average, offices
Floor area (ft^2)	26,757		26,757		26,757		26,757		53808		
Number of people	62		62		49		58		268		
Number of PCs	59		59		49		58		268		
Weekly operating hours	65		65		68		68		86		
	Monthly total kWh										
Nov_07	57,602	61,237.0	56,389	0	58,160	331.1	57,760	361.2	31610.8	101574.3	
Dec_07	60,706	97,627.6	70,170	0	55,520	301	70,800	361.2	31610.8	88361.2	
Jan_08	62,590	103,809.9	41,926	0	60,960	421.4	66,160	270.9	28653.7	52033.8	
Feb_08	57,810	98,125.7	38,823	0	65,040	391.3	44,800	391.3	33506.4	22596.3	
Mar_08	67,476	83,827.3	44,625	0	54,560	331.1	54,560	0	30493.8	10848.6	
Apr_08	61,135	32,405.8	38,068	0	52,000	301.0	46,800	331.1	32558.6	3780.2	
May_08	62,212	24,787.8	49,430	0	50,160	421.4	46,400	511.7	32204.7	2092.3	
Jun_08	67,925	11,192.6	43,122	0	38,080	301.0	37,600	270.9	32204.7	3630.0	
Jul_08	67,274	8,321.2	41,796	0	39,920	150.5	55,120	150.5	32558.6	14270.9	
Aug_08	72,473	10,372.2	45,380	0	48,640	120.4	50,400	90.3	30493.8	25043.8	
Sep_08	63,073	14,327.7	40,119	0	39,120	120.4	44,800	120.4	33506.4	54926.2	
Oct_08	59,580	35,042.8	48,706	0	44,560	270.9	47,920	60.2	28653.7	77539.4	
Total annual	759,856	581,077.6	558,554	0	606,720	3,461.5	623,120	2919.7	378055.7	456697.0	
Grand Total, kWh	1,340,933.6		558,554		610,181.5		626,040		834752.7		
ENERGY STAR Score	6		41		31		31		99		50
ENERGY STAR site EUI, kBtu/sf/yr	171		70.8		77.3		80.2		53.1		67
ENERGY STAR source EUI, kBtu/sf/yr	401.6		236.4		257.2		266.9		110.8		222

Appendix H: Cart Hardware and Specifications

Cart Functional Description

The development of a stratification measurement cart was supported by a contract with the *New York Times*, which was seeking a tool to commission its new 52-story headquarters building in New York City, NY. Twenty-four floors of the new building use UFAD. The cart was conceived to be used for both pre- and post-occupancy testing. For pre-occupancy testing, artificial loads were created to provide a means for generating thermal stratification.

The cart uses sensors attached to a converted hand truck converted and was adapted to measuring indoor environmental parameters for UFAD systems. It includes the following components:

- Computer: A laptop computer is equipped with Labview software suitable for logging and presenting data; the laptop is also equipped to write data to media for remote storage,
- Power supply: The entire cart system is powered by a 12-volt direct current (VDC) battery. A battery charger allows rapid recharging of the battery at the end of a day of testing,
- Stratification profile tree: The tree consists of a series of rapid-response thermocouples mounted on a telescoping pole that can extend to 13 feet. Stratification to 6 feet is measured in increments of 9.6 inches and above 6 feet in increments of 12 inches. Thermocouples are also mounted at 4 inches from the floor and the ceiling. One additional thermocouple is available for insertion into floor diffusers to measure supply air temperature. The setup and takedown at a given measurement location is quick, requiring only the time to expand or retract the telescoping pole and initialize the data acquisition system for that location,
- Plenum pressure measurement: An accurate low-pressure-measuring transducer measures plenum-to-room differential pressure,
- Radiant temperature: Two infrared (IR) temperature detectors are oriented to measure ceiling and floor surface temperatures,
- Relative humidity (RH): Relative humidity is not measured because a building will not be occupied during commissioning, so realistic data cannot be obtained, and
- Instrumentation system interfaces: Data acquisition boards collect analog sensor data and convert it to digital input signals to Labview data acquisition and analysis software.

The cart can be moved freely around a room and takes up a minimum of horizontal space.

Cart Hardware and Specifications

Figure H-1 shows an annotated photo of the fully assembled cart with its major components labeled.

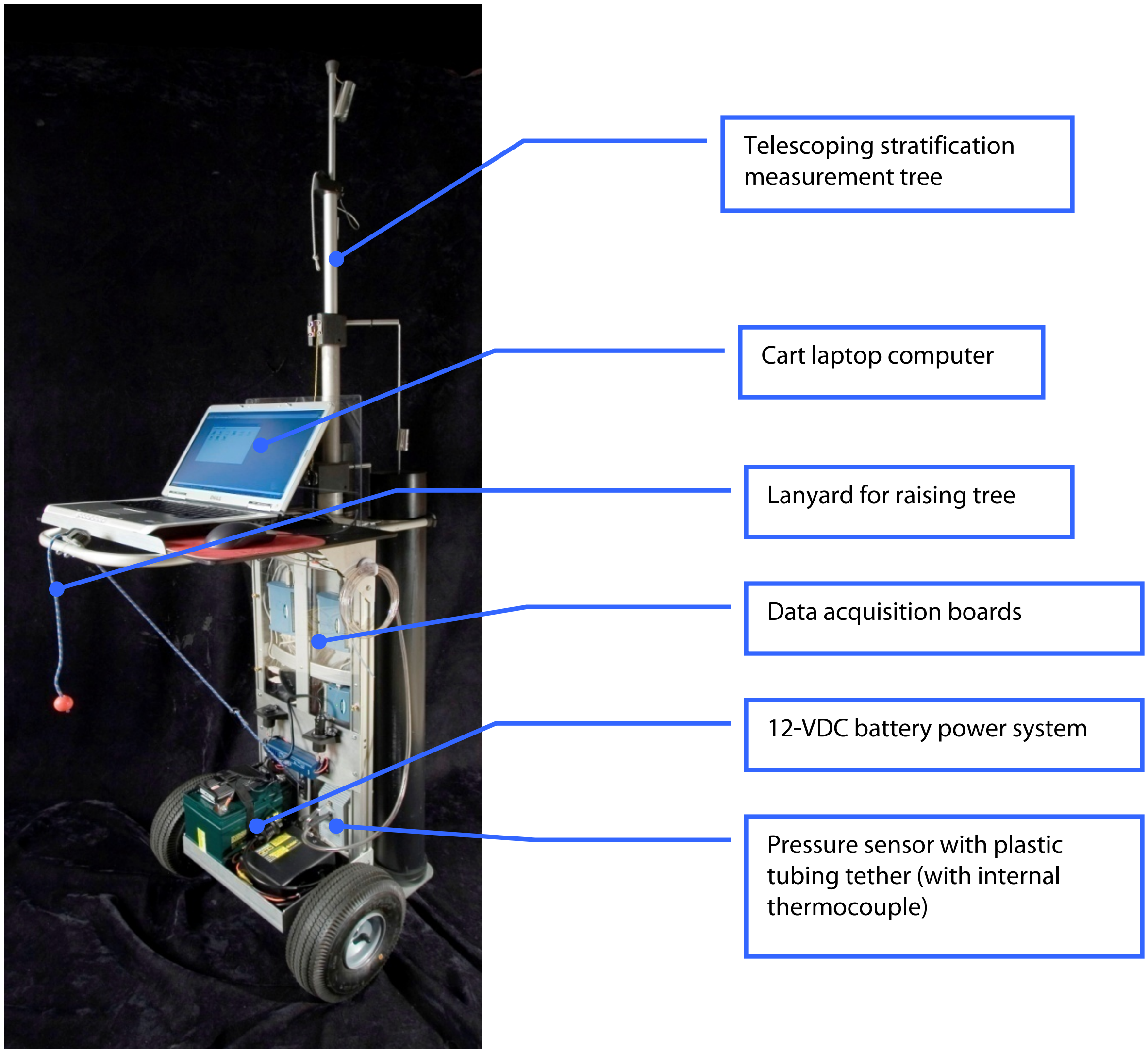


Figure H-1: CBE measurement cart

The Labview software platform is divided to support three functional modes: 1) setup and configuration; 2) data acquisition, in which real-time data are displayed, a test of any length can be initiated, and data from each test are logged into an on-board database; and (3) analysis, in which previously stored test data can be retrieved and used to compare test-to-test (e.g., before and after remediation) results.

The cart includes wireless sensing capabilities intended to capture detailed measurements of supply-plenum thermal decay. These data are stored with each test and can be analyzed via various displays and metrics using the analysis software. Supporting these functions is a data management system.

Motes are small devices that use a new wireless technology called mesh networks to communicate data collected from on-board sensors back to a base station that communicates to the cart laptop via Wi-Fi. The cart hardware (and software) system supports data acquisition of up to 70 motes that can be deployed over a broad area in the building. Although motes can be deployed in many places, they are primarily designed to measure and report the following parameters:

- Zone temperatures at thermostat locations,
- Diffuser supply temperatures in air super highways,
- Diffuser supply temperatures in low-pressure plenums, and
- Perimeter diffuser temperatures at the linear bar grilles.

Appendix I: Acronyms and Abbreviations

AHU	air handling unit
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BLWR	baseline landscape water requirement
BMS	building management system
C	coefficient of conservatism
C	comparison between measured and maximum allowable sound level
CBE	Center for the Built Environment
CBECS	Commercial Buildings Energy Consumption Survey
cfm	cubic feet per minute
CO_2	carbon dioxide
CVRSME	coefficient of variation of root mean square error
dB	decibel
dB(A)	a-weighted decibel
dB(C)	c-weighted decibel
DLWR	designed landscape water requirement
DOE	U.S. Department of Energy
DX	direct expansion
ECB	energy cost budget
EPA	U.S. Environmental Protection Agency
EPDM	ethylene propylene diene monomer
EUI	energy use intensity
fc	foot-candle
FPB	fan-powered box
FQA	floristic quality assessment
FQI	floristic quality index
ft^2	square foot
gal	gallon
GMP	guaranteed maximum price (contract)
gsf	gross square foot
HDPE	high-density polyethylene
HVAC	heating, ventilation, and air-conditioning
IAQ	indoor air quality
IEQ	indoor environmental quality
IESNA	Illuminating Engineering Society of North America
in.	inch
kBtu/ ft^2/yr	thousand British thermal units per square foot per year (units for EUI)
K_L	landscape coefficient value (gross water needs of a plant species)
kWh	kilowatt-hour
L_{95}	95^{th} percentile of the a-weighted sound pressure level
L_c	median c-weighted sound pressure level
L_{eq}	median a-weighted sound pressure level
LEED-NC	Leadership in Energy and Environmental Design Rating System for New Construction and Major Renovations
m	meter

MBE	mean bias error
mg/L	milligrams per liter
NPV	net present value
pCi/L	picocuries per liter
PM-10	particulate matter (10 microns)
PM-2.5	particulate matter (2.5 microns)
ppm	parts per million
Q	H_20 discharge
SITES	Sustainable Sites Initiative
SS	Sustainable Sites category in LEED-NC
TP	total phosphorus
TSS	total suspended solids
UF	underfloor
UFAD	underfloor air distribution
VDC	volt direct current
VDT	video display terminal
VOC	volatile organic compound
WE	Water Efficiency category in LEED-NC