Field Performance Reviews of Green and Sustainable Buildings

Catherine Turner, New Buildings Institute, White Salmon, WA

ABSTRACT

Actual energy performance feedback leads to increased commercial building efficiency, but actual building performance is rarely measured. This paper covers market research on barriers to performance evaluations, a protocol to address those barriers, and results from initial field measurements.

A literature review and market research showed that a wide variety of methods used to evaluate actual building performance, but none has been standardized and widely implemented. Well-documented barriers to achieving feedback from traditional post-occupancy evaluations include technical, cost, and timing challenges. Interviews with designers and owners identified the information most useful to them.

Based on this research, a widely used building performance protocol must gather readily available performance data from multiple sources and focus on understandable, actionable interpretations. A staged approach can permit a low initial cost and gives an informed basis for a more targeted diagnostic effort when called for. Field tests of the measurement protocol were conducted on a varied group of buildings with a mixture of ages and sustainability features. Energy usage results are presented in relation to several alternative benchmarks, ranging from existing building averages to building-specific design elements. Occupant satisfaction results are shown in areas of temperature, acoustics, air quality, and light, to help distinguish between buildings with true efficiency gains and those that merely save energy at the cost of occupant functional comfort. Consistent gathering of such information can facilitate owners' actions toward increased building efficiency as well as develop aggregate data for assessing both the energy and non-energy value of green building efforts.

Introduction

Reducing the energy use of today's buildings is essential to achieving climate change and energy efficiency goals. Commercial and residential buildings combined account for 39% of U.S. primary energy consumption. (EIA, 2006) Green and sustainable building programs often estimate anticipated savings from energy efficiency measures, but actual results are rarely measured. This lack of post-occupancy evaluation limits the ability to gauge true progress and precludes feedback to owners, operators, and designers. Such feedback could hasten the achievement of improved efficiency. To address this situation, this paper covers three facets of the New Buildings Institute's efforts to expand the use of performance reviews: market research into evaluation methods and barriers to their wide use, a protocol to address those barriers, and results from initial field measurements.

Post-Occupancy Evaluation (POE) is the general term for a broad range of activities aimed at understanding how buildings perform once they are built. Practitioners use the term with a variety of meanings, including occupant surveys, energy and water use analyses, and review of building system performance. A POE energy study may include any of the following: total building energy use intensity (EUI) compared to benchmarks, energy end-use analysis, and comparison between actual and anticipated energy use (with or without as-built calibration of the original energy model).

Time and expense requirements are often seen as prohibitive for some POE activities, especially for small buildings. Large commercial buildings may have a complex energy management system and a staff that is actively using the real-time feedback that it can provide. But nearly 90% of the nation's commercial buildings are 25,000 square feet or less (Commercial Building Energy Consumption Survey

2003, www.eia.doe.gov/emeu/cbecs) and 95% are 50,000 square feet or less. These smaller buildings typically have neither access to energy management such systems nor on-site staff to manage the buildings.

Two other activities, commissioning and building measurement and verification (M&V), have some overlap and interaction with POEs. While all have the ultimate goal of better performing buildings, they differ in their immediate objectives and level of detail. A POE typically starts with broad measures of actual whole building performance, often including occupant feedback. Commissioning focuses on functional testing of individual systems and components, to make sure that each is set appropriately and working properly. Commissioning is an essential prerequisite to achieving good performance with today's complex building systems, but it does not assure that the desired whole building performance will be achieved, nor does it typically provide a report of actual whole building performance. M&V, based on the International Performance Measurement and Verification Protocol, follows a rigorous approach to quantifying actual energy savings, at either the whole building or major system level. An M&V report can be a major component of an in-depth POE.

Market Research: Interest In, Status of, and Barriers to Building Performance Evaluation

To achieve widespread performance evaluation, the practice must extend beyond an occasional academic or efficiency program study. Market research was conducted to determine whether it would be possible to design a marketable POE protocol, one that owners and designers would purchase voluntarily. This research consisted of a literature review and a series of owner and designer interviews.

Literature Review

The literature review sought to understand current post-occupancy evaluation practices and to identify lessons learned from attempts to implement these analyses. One of the most widely known efforts of this type may be the Post-occupancy Review of Buildings and their Engineering (PROBE) work in Great Britain (Standeven, M., *et al*, 1995-2002). These reviews included analysis of actual energy usage, occupant surveys and interviews, and on-site, instrumented evaluation. They found a wide variation (by a factor of more than three) in the energy use intensity of buildings of similar types. Several of the buildings were using more energy than their design analysis predicted.

In North America, there have been a number of individual building case studies that incorporate the same depth of building systems analysis found in the PROBE work, typically requiring many hours of professional time to implement, but no standardized simple protocol is common. To gather the occupant perspective, two commonly used occupant survey tools are the Indoor Environmental Quality survey (www.cbe.berkeley.edu) developed and supported by the Center for the Built Environment at UC-Berkeley, and the Buildings in Use (Vischer, 1996) work done by Jacqueline Vischer. It appears that even these better known products have been used on at most a few hundred buildings over the last ten or more years.

Two recent books on POE have brought together many of the key lessons learned to date. (Federal Facilities Council, 2002; Vischer and Preiser, 2005). These materials describe a wide variety of POE protocols, but few focus on the immediate interests of building owners. The elements of several protocols appear to be useful, but no single protocol accomplishes the goals of meeting building owner and program sponsor needs in terms of budget, scope, and direct applicability of results. Several well-documented obstacles contribute to the current low utilization of traditional POEs. Among the more substantial barriers are:

- Responsibility. It is not clear who has responsibility to conduct POEs. The possibilities include the design team, owner, and major tenants. For any one of these potential reviewers, it may still be unclear what individual within the company should drive the review process.
- Expense. Funding for POEs is not included in design budgets;
- Timing. POE results may come too late to be perceived as useful for the design team, which has moved on to the next project, or to an owner who may not be planning any similar projects;
- Data collection. Technical and logistical difficulties often arise in obtaining even basic data; and
- Legal. A POE report may uncover problems, possibly leading to awkward questions or even liability.

POEs are potentially valuable to owners and designers, providing improved building performance and better future projects. However, for that value to be achievable, the above critical market barriers must be addressed.

Market Interviews

Ten interviews with designers and owners further helped to identify the professions most motivated to obtain building performance feedback, and the information most useful to them. All but one of the respondents were actively engaged in new construction projects, and five continue to have responsibility for managing buildings over time. Key conclusions from these interviews included the following points.

- Few owners systematically collect information on occupant satisfaction. Cost of evaluation was cited as the largest barrier, followed by logistical or time constraints.
- Energy use and occupant satisfaction were seen by those surveyed as the most important elements to include in building performance evaluation.
- Owners are the audience most immediately interested. This is particularly true for institutional owners, with multiple properties, a longer ownership time horizon, and potential public accountability requirements for new building expenditures. Similar considerations apply to evaluations in conjunction with utility or other conservation programs.
- Designers are also very interested in the general results of POEs, as a way of informing future projects. Without client/owner demand, however, they feel very constrained by the timing mismatch between project design work and the POE period.
- Both owners and design team members state they would use an *affordable* performance evaluation tool, with most suggested costs ranging from $2,000 to $10,000.

Results of this market research study are further described in Hewitt, 2006.

Energy Analysis Approaches

There is no one defined protocol for energy use analysis, either for the level of energy use detail to collect or for the comparison benchmark to use. Benchmarks range from comparison with building-specific modeling and comparison with broader classes of existing building stock or other general targets.

Comparing with Modeled Usage. When initial energy modeling has been used to select energy efficiency measures, comparing actual usage to modeled expectations can provide a seemingly direct answer to whether the building is performing as expected, reflecting the characteristics and location of the individual building. However, experience has shown that modeled and actual energy savings are frequently not well-correlated (Johnson, 2002). Models are typically prepared to estimate the value of individual energy efficiency measures, not necessarily to accurately predict the absolute level of total utility usage in a building. A more precise comparison of actual to anticipated results requires truing up the model, to incorporate differences between as-designed and as-built systems and materials. Non-conservation-related differences must also be considered, such as: actual occupant numbers, building usage patterns, building management practices, and normalization of weather-dependent loads. Such model refinement usually has a significant cost.

Despite the limitations of comparing directly to uncalibrated initial models, the actual to design-model comparison can still give a first approximation to the level of building performance, in addition to giving valuable feedback to designers and modelers. A study of eleven buildings certified by the US Green Building Council's Leadership in Energy and Environmental Design (LEED) program provided an example of this type of study (Turner, 2006). All the LEED-certified buildings were in the Portland, Oregon to Seattle, Washington region and had been occupied for at least one year by the fall of 2005. Beyond that similarity, the buildings varied widely and included office, library, and multifamily residential facilities. Sizes ranged from 12,000 to 360,000 square feet.

Figure 1 shows actual and design Energy Use Intensities (EUIs), with office and residential buildings each sorted from lowest to highest actual EUI. Despite the variety of buildings in the study, eight of the eleven have actual EUIs in the relatively narrow range of 44 to 55 kBtu/ft^2/yr. The actual EUIs were compared to the initial modeling done for the building's LEED submittal. This report uses "Design" to refer to the modeled EUI including all the anticipated energy efficiency measures. "Baseline" refers to the modeled EUI of a similar building without those efficiency measures. For this study, Baseline reflected a building just meeting ASHRAE 90.1 1999.

No single building's actual performance was within 20% of its Design model. The average Actual/Design ratio was closer than that for any individual building: 110% for all buildings and 89% if the unusual results of building O-7 are excluded.

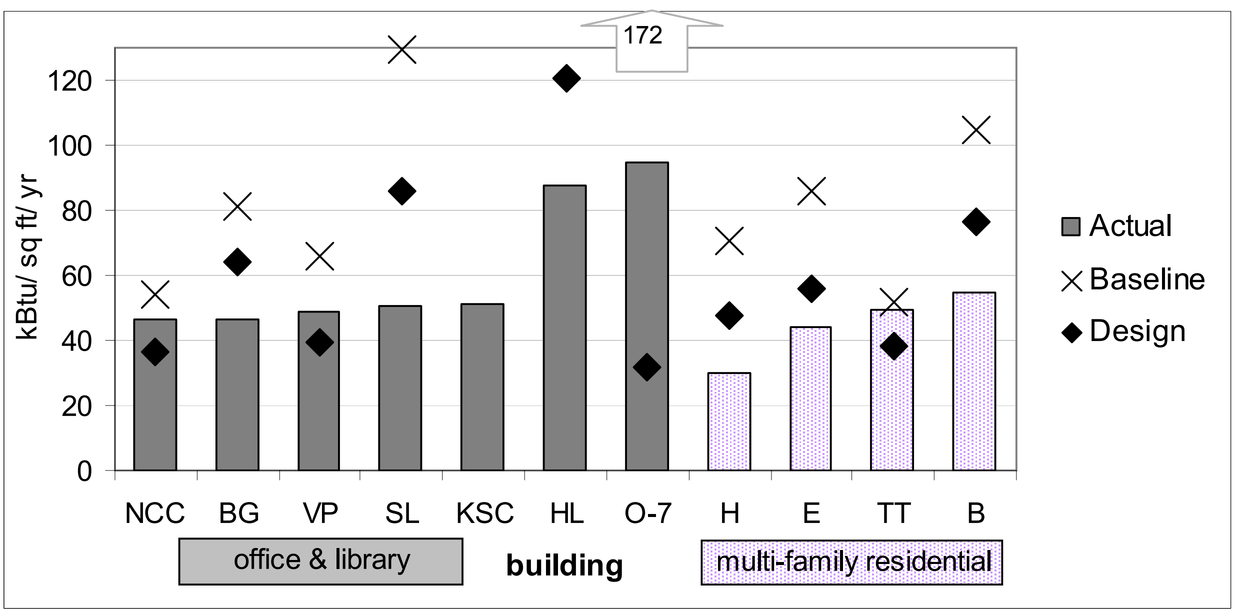

Figure 1: Actual and modeled EUIs for 11 LEED buildings in the Pacific Northwest. Baseline EUIs reflect modeling of a comparable building without optional energy efficiency measures. Design EUIs include anticipated efficiency measures.

Building O-7's actual usage exceeded its Design model by 300%. This building represents a case where the owner was aware of problems before this study was done. The facility had experienced a number of HVAC systems and lighting control problems during its first few years, and building managers felt they had finally succeeded in tuning the systems and replacing components where necessary by the end of the study period. A simple follow-up a year later would be instructive.

Building HL, which showed the highest Design EUI of the group, had a number of site constraints and design requirements that may partially explain its energy usage level. In addition, as the only single story building in this study, it has a higher surface to volume ratio than the rest of the buildings, which can also lead to greater heating and cooling requirements. Even after considering these factors, this building exemplifies a case where one would want to further investigate model assumptions before being confident that the difference between actual and Design performance reflected true efficiency savings, and not modeling anomalies.

Comparing with Existing Building Stock. An alternative benchmark is comparison with existing building stock, of a similar type. In this case, definition and identification of "similar" is one of the main challenges. The EPA has promoted for several years an approach based on the normalized actual energy use of buildings. That actual usage is corrected for weather conditions, and a few other key indicators, and then rated in comparison to other commercial buildings of the same primary activity. Over 3,000 buildings have received the ENERGY STAR label, and thousands more have taken the first step of completing the benchmarking analysis.

ENERGY STAR's Target-Finder calculation was used to provide approximate 50th to 90th percentile performance ranges for the buildings in this study, compared to buildings of comparable type and climate. Figure 2 repeats the actual performance bars from Figure 1, and adds a light blue bar with these benchmarks. According to this measure, nine of the eleven buildings were performing at levels well under that of the average building stock in the area.

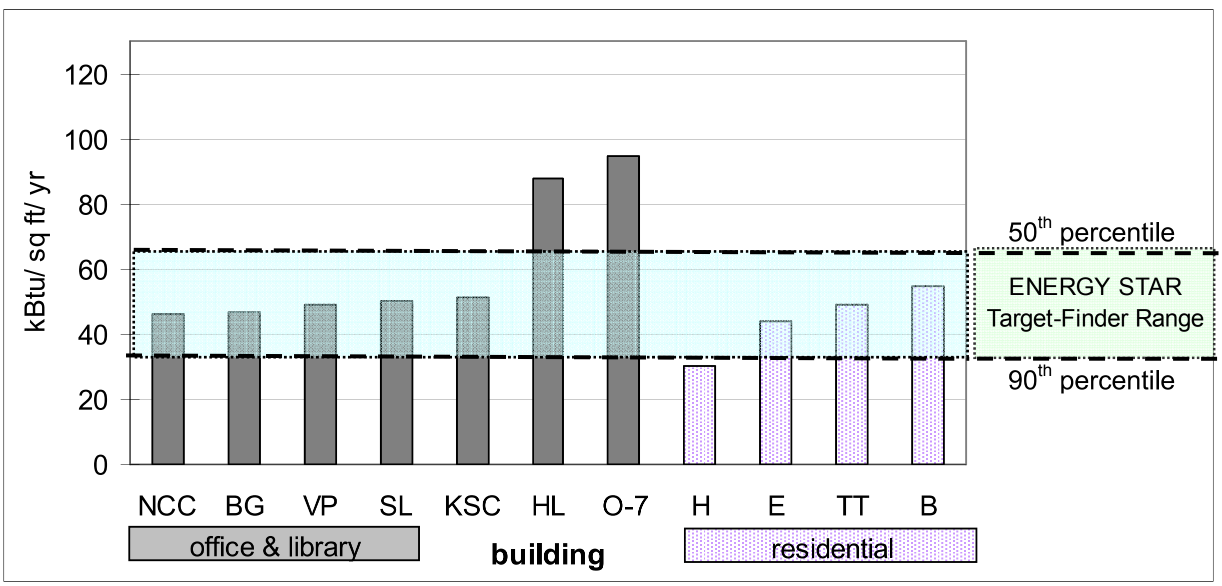

Figure 2: Actual EUIs compared to ENERGY STAR Target-Finder performance levels

The Target-Finder calculation is based only on building activity, geographic location, and fuel mix, and the percentiles are based on existing building stock of the same time and climate. The 50th and 90th percentiles calculated for the participating buildings were very similar, so a single average was shown for all. Assumed building types were "office" for the office and library group and "dormitory" for the residential group. These assumptions were accurate for most of the buildings in the study. The exceptions were two libraries (SL and HL) and one condominium (H). ENERGY STAR does not have rating categories directly applicable to either of those types.

A Market-Friendly Review: Defining an Affordable, Usable Protocol

Based on the market research results and experience with the study summarized above, we derived several prerequisites for any widely used building performance protocol. First, it is essential to start simple, gathering readily available data. Using multiple information sources can add different perspectives that facilitate more insight into true performance from this basic data. Focusing reports on actionable results at the single building level, and readily understood overviews for the institutional manager or program sponsor, increases the chances for the evaluations to be used and more widely adopted.

To respond to price sensitivities, the designed protocol consists of two levels. *Level One* contains a simple set of basic indicators: occupant survey, energy bill analysis, and a facility manager interview. These indicators reflect whether the overall building is performing to the desired level. An individual building report summarizes these indicators and can give a limited set of findings regarding performance issues: areas to address and diagnostic tools or steps that could be helpful. This staged approach permits a low initial cost. It does not attempt to pinpoint or diagnose specific problems. However, it does give an informed basis for a more targeted diagnostic effort when applicable. An optional *Level Two* review can implement the recommended diagnostics, to better identify underlying causes of, or solutions for, general issues that surfaced in Level One.

Field tests of the measurement protocol have been conducted on a varied group of LEED buildings and on K-12 schools with a mixture of building ages and sustainability features. The remainder of this report provides examples of results from these pilots and a discussion of process lessons learned.

Measured Results – Comparing Actual Energy Use to Benchmarks and Design Expectations

The following sections give examples of results from a pilot measurement program in a school district in Washington State. Four schools were included in the initial pilot, and an additional 5 schools were added to the expanded pilot program the following year.

Locally Benchmarked Energy Usage

At least one year of whole-building energy usage information is requested for a study. While summaries are typically presented at the level of whole building EUI, data are gathered by fuel and by month. Monthly usage patterns by fuel can give additional insight into the source of high energy use.

The following two figures show EUIs of recently modernized schools compared to the entire school district portfolio. In each case, modernization consisted of completely replacing a school built in the 1950s to 1960s with a new facility.

School A, (Figure 3), showed an expected pattern; the performance of the new building was much better than that of the replaced building.

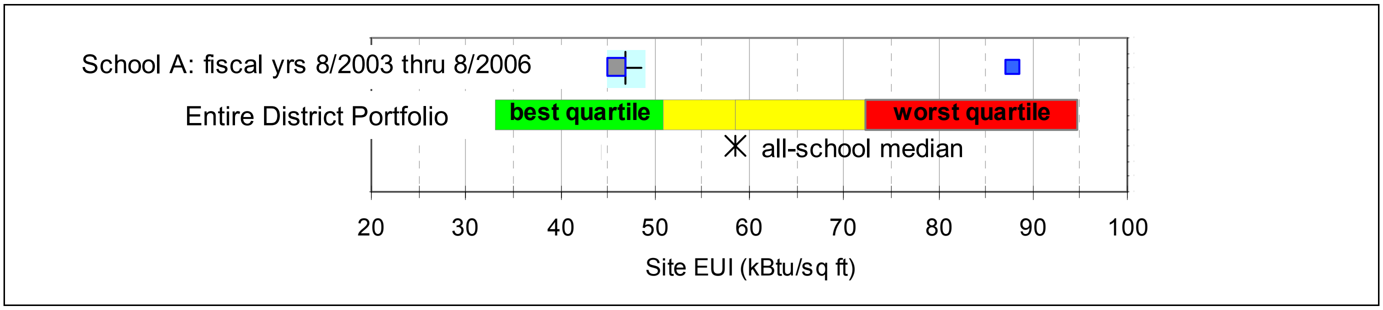

Figure 3: School A EUIs before and after modernization
School A results for 2003-2004 ■; 2004-2005 ■ ; 2005-2006 +

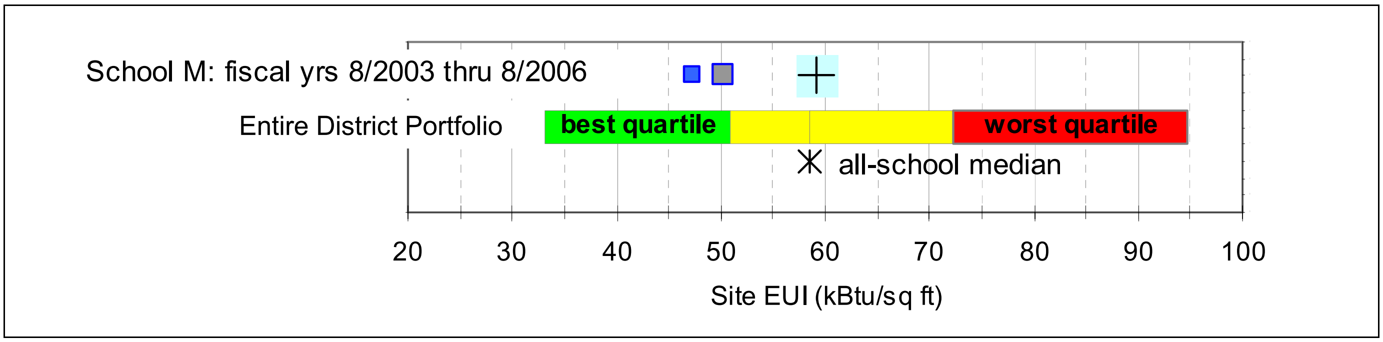

Figure 4: School M EUIs before and after modernization
School M results for 2003-2004 ■; 2004-2005 ■ ; 2005-2006 +

School M (Figure 4) shows a very different performance pattern, with the new building EUI near the overall district median, using more energy per square foot than did the prior facility. Part of the explanation is that this information on energy usage came from the building's first year, reflecting the commissioning that was ongoing during that time. Changes had been made in the course of that year to improve the airflow in the classrooms' natural convection radiators and to adjust the set-points for the CO_2 sensors controlling the rate of outside-air ventilation. Further investigation uncovered set-points for the central boiler causing it to be on when no heat was required. Follow-up monthly monitoring shows some improved performance, with one more year of experience needed to confirm the new results.

Occupant Comfort

A building with truly good energy performance must not only have a low EUI but also be functionally comfortable for those who occupy it. Level One reviews use an online survey to systematically gather feedback on the primary areas affecting worker comfort: acoustics, lighting, air quality, and temperature. This approach results in a more complete and balanced picture of comfort than simply relying on complaint reports. (An expansion of the staff survey to cover students in schools or visitors to public buildings would provide additional feedback but also require increased time and costs that may be beyond the Level One budget.)

The survey questions are based on the Buildings In Use assessment questionnaire work done by Jacqueline Vischer (1996). In a K-12 school, all teachers and staff are invited via e-mail to take the brief survey, rating various comfort conditions on a simple 5-point scale. For each of the four schools in this district's initial pilot, Figure 5 shows the average response for a question about the building overall, and the questions on each of the key comfort dimensions. Bars above the x-axis indicate positive comfort. Bars below indicate discomfort. The full survey contains several questions within each of the broad categories shown here. The individual questions, as well as write-in comments, are used to help identify the most successful aspects of each dimension and source of discomfort complaints.

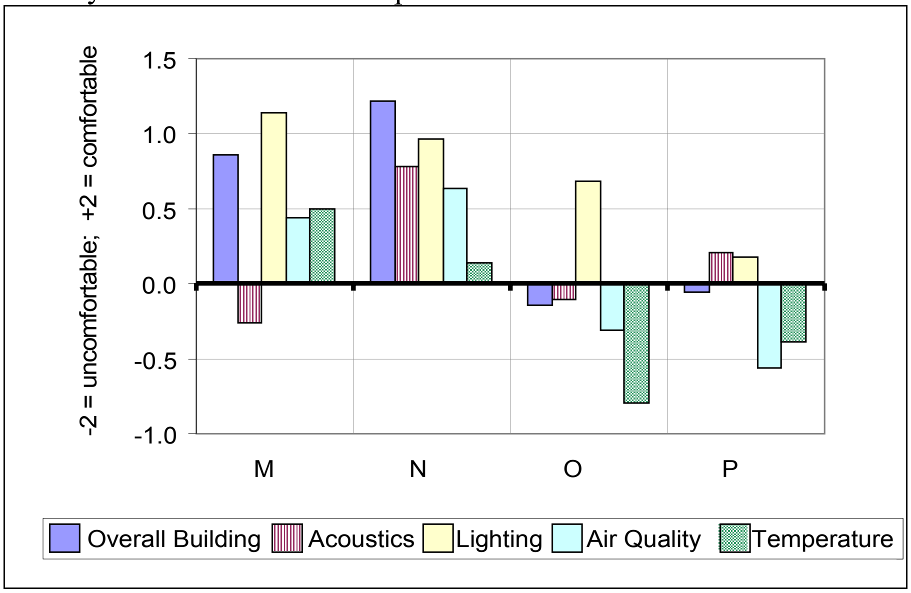

Figure 5: Functional comfort survey results for four schools

The two schools on the left in the above figure show distinctly higher comfort levels than do those on the right. The two with the higher comfort ratings were new buildings, while the other two were decades old. School M here is the building for which Figure 4 showed energy history. Adding occupant comfort scores clearly gives a more complete picture of building performance than simply looking at energy usage levels. Even though this school was no better than average in its first year energy use, the significantly higher occupant comfort shows a benefit of the new building.

The survey in building M uncovered a negative rating for acoustics, primarily associated with noise from adjoining spaces. This was a problem that had not surfaced in normal complaint channels, and that has not been seen to this degree in other buildings surveyed in this district. Write-in comments and the ability to identify the room numbers associated with strongest discomfort aid in narrowing down the possible source of problems.

Operations and Maintenance Interviews

The staff who operate and maintain the studied building provide the third source of readily available information to understand current performance. Building managers provide basic descriptive information about the building systems and are interviewed about operation practices and their observations on performance. Core interview questions cover areas such as the ease of operating controls, type and location of complaints, systems that are working well, biggest challenges, and preventive maintenance schedules. The interviews are ideally completed after the energy and survey data have been gathered, permitting inclusion of more targeted questions that may arise from review of the energy use and survey results.

Building walk-throughs have been a part of the protocol pilots, to help validate preliminary conclusions from energy and survey reviews and better identify the core interview questions that should be asked. However, in keeping with the cost constraints for Level One, the long-term objective is for this stage to be capable of completion with a phone interview only. For the phone interview approach to be effective survey results and monthly energy use by fuel must be analyzed in advance. In addition, the owner must provide the appropriate introduction and motivation for the facility manager(s) to participate in the call. The resulting report must be clear that it is a whole building view of performance, not the results of an on-site audit.

Process Lessons

As the protocol has been tested, some additional barriers to broad implementation of such reviews have become clear. Certain basic steps taken during initial design and construction can simplify later evaluation particularly in the smaller buildings that make up the vase majority of commercial building stock. The underlying theme is to plan ahead for later simple monitoring.

For example, a primary impediment to even the simplest studies can be the lack of actual utility usage information. One common problem is failure to meter individual buildings on an institutional campus. Even when a building is metered, facility managers are unlikely to have direct access to past utility bills, and accounting departments record only dollars, not usage. Gathering a few pieces of information from each past utility bill can sometimes take hours on the part of both the building staff and the study analyst. Particularly for new buildings, automatic data feeds could address this problem, either through the utility billing system for a utility-sponsored program or with the requirement of data acquisition and transmission units installed in buildings participating in other green building programs.

If initial modeling is done, a reasonability review of the resulting total EUI should always be included. Capturing key information such as the important drivers of expected performance and reasons for a particularly low or high overall Design EUI, and then passing that information along at hand-over time, can form a solid basis for monitoring against expectations.

Conclusions

The protocol described here seeks to materially increase the number of useful performance reviews by extracting performance indicators from readily available data. A staged approach creates a simple Level One report, which either shows that the building is performing well or identifies the next steps to take in diagnosing the underlying problems. Pilot tests of Level One have demonstrated that useful insights can come from combining readily available data from multiple sources: utility bills, a simple occupant survey of functional comfort, and interviews with facility managers. Aggregate data can provide overall evaluation of institutional portfolios or green building program results.

The full Level One protocol, including energy review, occupant survey, and O&M staff interviews, can be implemented easily. Various levels of self-reporting by the building owner are possible, depending on the availability of staff and accessibility of data. A simpler form of the protocol, consisting primarily of gathering energy usage data in relation to project benchmarks, is possible for aggregate evaluation of specific programs. Even in this case, however, supplementing the basic energy metrics with the occupant and O&M staff views can provide useful reporting that, if acted on, could increase the possibility of improving program performance over time.

Preliminary pilots have shown a range of owner actions based on the report results. The example in Figure 3 showed a case where the simple review indication that no priority follow-up was needed. When corrective actions are indicated, it appears that they are most likely when the next steps can be clearly identified, have a low implementation cost, and have a high chance of achieving savings. Although not all buildings have fallen into this category, Figure 4 showed a good example of a building for which further investigative and corrective steps were taken after the review, and another review is being performed to confirm progress.

References

Energy Information Agency, 2006, *2006 Buildings Energy Data Book.* US Department of Energy

Federal Facilities Council, 2002, *Learning from Our Buildings, A State-of-the-Practice Summary of Post-Occupancy Evaluation*, Federal Facilities Council Technical Report No. 145, National Academy Press, Washington DC.

Hewitt, D., 2006, *A Market-Friendly Post-Occupancy Evaluation: Building Performance Report*, New Buildings Institute contract C10091 for the Northwest Energy Efficiency Alliance, Portland, OR.

Johnson, J. (2002), *Is What they Want What they Get? - Examining Field Evidence for Links between Design Intent and As-built Energy Performance of Commercial Buildings.* Report to the Environmental Protection Agency

Standeven, M., Bordass, B., Leaman, A., Cohen, R., 1995-2002, "Probe Reports" 1 through 23, *Building Services Journal* [available http://www.usablebuildings.co.uk/, 1/3/2007]

Turner, C., 2006, *LEED Building Performance in the Cascadia Region: A Post Occupancy Evaluation Report*, Cascadia Region Green Building Council, Portland, OR

Vischer, J., 1996, *Workplace Strategies: Environment as a Tool for Work,* Chapman & Hall, New York

Vischer, J., Preiser, W., eds,, 2005, *Assessing Building Performance*. Elsevier Butterworth-Heinemann, Burlington, MA

Acknowledgements

This document draws on initial market research funded by the Northwest Energy Efficiency Alliance, a study of LEED building performance funded by the Cascadia Region Green Building Council, and pilot testing supported by several building owners. The contributions of those organizations, and the participation of owners of buildings studied are gratefully acknowledged.