EVALUATING ACTUAL PERFORMANCE OF NEW COMMERCIAL BUILDINGS: THE ENERGY EDGE DEMONSTRATION PROGRAM

Rick Diamond, Jeff Harris, Odon de Buen, Bruce Nordman,
Lawrence Berkeley Laboratory
Bruce Cody, Bonneville Power Administration

The 28 Energy Edge buildings are part of a multi-year effort to assess the conservation potential for new commercial buildings in the Pacific Northwest. Our work focuses on evaluating the measured energy performance of the buildings and the cost and savings of individual measures. The goal of the analysis is to compare each Energy Edge building with other new buildings in the region, and with simulated performance of the same building without the energy-saving features. We also compare the design-stage performance predictions with the results of computer simulations where the model has been "tuned" using monitored data from each building. This paper reports results from the first year of performance analysis. Pending availability of detailed monitored data for most of the buildings, we have analyzed utility billing data for 26 buildings, hourly monitored data for four buildings, and the detailed "tuned model" results from one pilot study building. Preliminary findings are that, as a group, the Energy Edge buildings use less energy than other new commercial buildings in the region, although more precise comparisons require additional data on energy by end use, operating conditions, and weather. The Energy Edge buildings typically use about 11% more energy (based on utility bill data) than was predicted at the design stage. For individual buildings, however, there are significant discrepancies between design predictions and whole-building energy use. Most of this variation appears to be due to changes in building design, operating characteristics, and imperfect performance prediction for individual measures. Understanding these differences will require detailed monitoring data and additional computer modeling. Although the results are still incomplete, the program already points to useful lessons for updating the Northwest energy codes, as well as for other commercial building research, demonstration, and design-assistance programs.

INTRODUCTION

The Energy Edge project was initiated by the Bonneville Power Administration (BPA) to develop the expertise necessary to implement full-scale new commercial conservation programs in the northwest region of the United States. By focusing on the construction of new commercial buildings, Energy Edge meets the region's goal of capturing otherwise lost opportunities to accomplish energy conservation.

The specific goal of the Energy Edge project is to redesign new commercial buildings to achieve energy consumption that is at least 30 percent below a base level of energy use. The base energy use was determined by applying the Model Conservation Standards (MCS) for energy performance to each building. MCS is similar to the ASHRAE 90 standard, with more stringent requirements for lighting. The MCS requirements apply only to electrical energy usage, although some of the Energy Edge buildings use natural gas for "non-MCS" end uses (such as commercial cooking) or for back-up heating. Certain miscellaneous energy end-uses (food preparation, office equipment, spas, etc.) found in commercial buildings are not subject to MCS requirements, and were excluded from the 30 percent savings target.

OBJECTIVES

The reliability of "conservation resources" in the commercial sector needs to be documented, so that decision makers can make appropriate choices to meet the region's electricity needs. Energy use in the commercial sector is difficult to describe, let alone predict. Buildings and occupancy requirements are idiosyncratic, and these differences are often important in understanding their energy use. While the number and types of buildings in the Energy Edge program are not large enough for statistical inferences, the program seeks to document case studies that will provide reliable information on measured costs and savings for a variety of measures and building types. The specific goals of the metering and data analysis are to determine:

- The effectiveness of modeling and its limitations in energy-efficient design of commercial buildings and prediction of program-wide savings.
- Levelized costs of energy savings for individual energy conservation measures (ECMs) that might be installed in typical commercial buildings in the region.
- Customer satisfaction and acceptance of the measures, especially lighting measures.
- The applicability of ECMs to new commercial buildings, and their value to owners and occupants.
- The cost-effectiveness of using detailed monitoring and "tuned" simulation models to assess building performance.

We are ultimately interested in the net effects of Energy Edge, beyond what might have occurred in the absence of the program. Arriving at an estimate of net impact is often difficult, especially for programs implemented without an explicit control group. One approach is building-by-building comparisons of the actual building with a conventional design, either hypothetical (using computer modeling) or actual, using data on real buildings that are "similar." To establish a broader context for Energy Edge, however, we also need to examine regional trends in new commercial construction, energy-related code enforcement, and other programs--as well as market forces. For example, we would interpret Energy Edge results differently if typical performance of a new, non-Energy Edge building represented a 20% shortfall--or a 20% improvement--compared with MCS code requirements.

An important reason for doing a thorough technical analysis as part of the program evaluation is to be able to use experience with Energy Edge to guide future technology choices and the design of programs for new commercial construction. Some building features or operating practices that are observed in the Energy Edge buildings, but were not designated as energy-saving measures, may nonetheless be very important for future buildings. A prime example, illustrated repeatedly in the Energy Edge buildings, is the importance of construction quality control and proper "commissioning" and operation of mechanical systems.

The rest of this report presents our preliminary findings from analyzing the Energy Edge technical data available through early 1990. A separate report (Harris et al., 1990) provides additional information on the Energy Edge buildings, including the four "Phase 1" buildings examined in detail.

WHOLE-BUILDING PERFORMANCE

A primary goal of the Energy Edge program is to demonstrate that new buildings can be designed and built, cost-effectively, to use no more than 70% of the energy specified by the Model Conservation Standards (MCS). Our analysis uses two complementary approaches: (1) comparing energy use of the Energy Edge buildings with groups of "similar" commercial buildings designed to meet the MCS code requirements; and (2) comparing the actual performance of each building, individually, with a computer simulation of how that building would have performed if constructed to just meet--rather than exceed--the MCS standard. This second approach uses detailed monitored data to "tune" the computer model to actual operating conditions, calibrating each end-use energy prediction to recorded values. The first approach can be undertaken with only whole-building energy consumption, readily available from billing data, although more careful inter-building comparisons can be made where end-use data and other building characteristics are known. At present, the limited availability of on-site monitored data for many of the Energy Edge buildings has led us to focus on the first approach, although results from a pilot study for one building, using a tuned computer model, are also presented.

Comparison Buildings and Regional Trends

Figure 1 compares annual billing data for the 12 Energy Edge office buildings with annual energy use for other actual or hypothetical office buildings in the Pacific Northwest. The comparisons are expressed as Energy Use Indices (EUIs), in kilowatt-hours per square foot (kWh/sq.ft-yr). The average predicted EUI for the twelve Energy Edge office buildings was 15.9 kWh/sq.ft-yr for the base (MCS) design and 11.0 kWh/sq.ft-yr for the buildings with efficiency measures included. Billing data for these buildings showed actual EUIs averaging 12.7 kWh/sq.ft-yr. Once again, we should note that the billing data do not yet account for differences, unrelated to measure performance, between the design-stage predictions and the actual building. Future analyses, with more detailed data, will explore factors such as weather, operating schedules and setpoints, and miscellaneous loads, that should help to better characterize the energy-saving impact of specific measures.

For comparison, Figure 1 also shows EUI estimates by the Northwest Power Planning Council for prototypes of newly constructed office buildings (based on computer modeling results, not measured data). These EUIs range from 21 kWh/sq.ft-yr for the "baseline" current practice (prior to MCS) to 17 kWh/sq.ft-yr for a new office building that conforms with MCS. The Council also cites a small sample of current-practice buildings (n=14) for which the measured EUIs averaged 19 kWh/sq.ft-yr (Council 1986). Thus, the estimated EUI for the base (MCS) design of the Energy Edge offices is slightly lower than the Council's predicted value for new buildings that conform with the regional standards.In another study of six new, large office buildings in the Seattle area, the predicted mean EUI was 11.7 kWh/sq.ft-yr (slightly higher than the predicted value for the Energy Edge office buildings) but the actual EUIs for these buildings averaged around 20 kWh/sq.ft-yr (Momentum Engineering 1988). This doubling of the predicted EUI was due in large part to more intensive building occupancy, longer hours of operation, and increased equipment loads compared with assumptions in the original model. We should also note that these buildings are an order of magnitude larger than the Energy Edge office buildings for which we currently have billing data.

Also shown for comparison in Figure 1 is a recent survey of the commercial building stock in the Pacific Northwest (not limited to new construction). The average EUI for the 14 office buildings studied was 19 kWh/sq.ft-yr, with smaller offices using only about 13 kWh/sq.ft-yr (BR Associates 1988).

Design Predictions vs. Billing Data

While we ultimately plan a detailed analysis using hourly, sub-metered data, some interesting initial comparisons can be made for the 26 Energy Edge buildings for which we have whole-building (utility bill) data. Figures 2 and 3 show the predicted vs. actual (utility-billed) annual energy use for each building, normalized by floor area. Figure 2 includes small and medium-sized offices; Figure 3 shows the other building types in Energy Edge (note the different scale in Figures 2 and 3).

Actual energy use (billing data) for eight of the 26 buildings was within ±15% of the predicted annual predictions for six buildings, and more than 15% high for 12 buildings. When we calculate the ratio of billed energy use to design-predicted energy use, the median value for these 26 buildings is 1.11, i.e., the typical building used 11 percent more energy

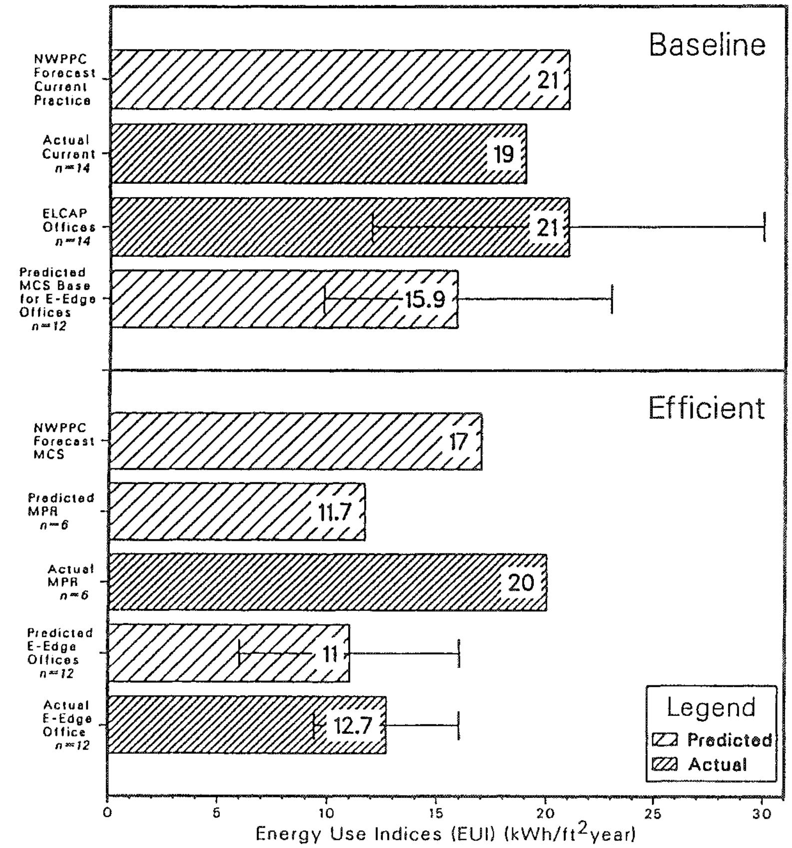

Figure 1. Comparison of Energy Use Intensities (EUIs) for Office Buildings of Existing Stock, Forecasted MCS, Energy Edge, and Other New Buildings

than originally predicted, at the design stage.[1] The mean value of these ratios was 1.23, but because there are a few outliers (see Figures 2 and 3) we prefer to use the median.

Once again, when interpreting these numbers it must be kept in mind that the actual Energy Edge buildings, as built and operated, may differ significantly from the specifications used for the initial computer modeling at the design stage. First, the energy-saving measures actually installed--as well as other important building features--were changed in several instances between the design stage and final construction. Some of the buildings in Figure 2 were only partly occupied during the billing periods shown. And third, actual weather conditions, operating hours, and miscellaneous equipment loads all may differ from the standard assumptions used in the design-stage modeling. Efforts will be made to account for all of these factors, as the required monitoring data and simulation model outputs become available.

The pilot study of one building (see below) showed that preliminary values such as those in Figures 2 and 3 may change significantly, or be re-interpreted, on the basis of site-monitored data and the completed tuned-model analysis. For the pilot study

[1] *Note that the values given here, for both Energy Edge billing data and baseline estimates, include the buildings' total consumption, including end-uses such as plug loads, cooking, and refrigeration that are not covered by the MCS requirements, nor used in calculating the 70% target levels at the building design stage. In buildings where some end uses are served by natural gas (or in one case, steam) rather than electricity, the values in Figures 2 and 3 for both predictions and billed energy use include all fuel types, except where noted.*

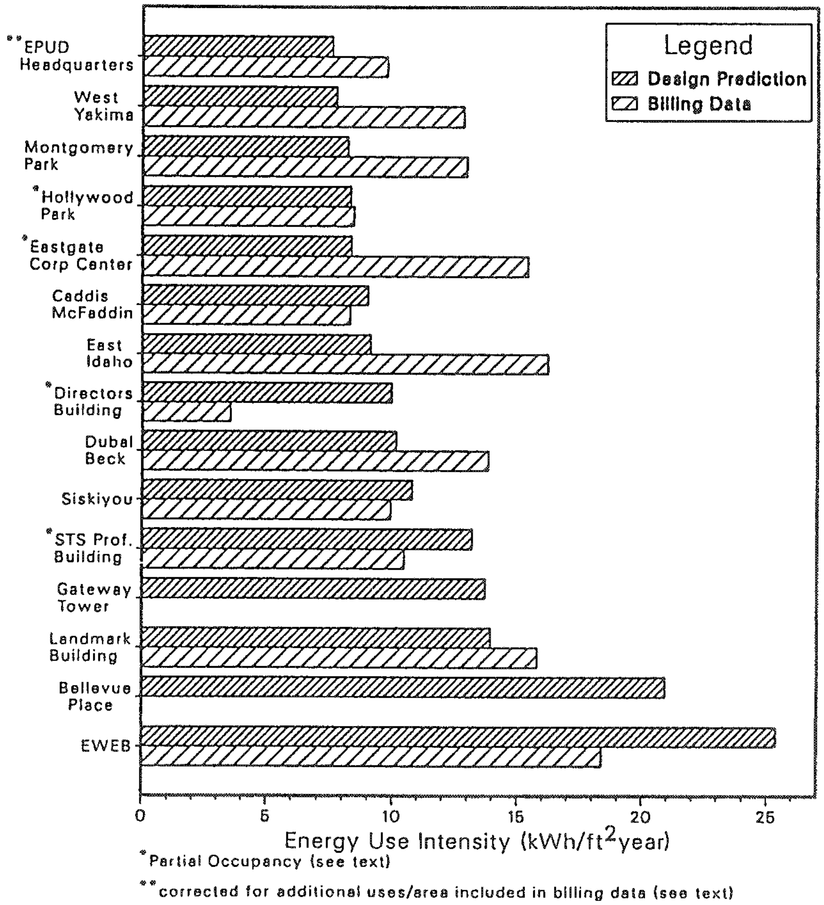

Figure 2. Predicted vs Actual Energy Use for the Energy Edge Office Buildings for Which Billed and Design-Estimated Data Are Available

building, estimated whole-building energy savings changed only a little between the design-stage prediction and the tuned-model results, but there were major differences in the estimates of energy consumption by end-use and of estimated energy savings by measure.

Long-term Tracking

Although it is very important to track building performance over a multiyear period, this has rarely been done in previous field demonstration projects. The value of long-term tracking is illustrated by utility billing records for 20 of the buildings, which span periods of 18-30 months. Trends in daily average energy use, cumulated for the 12-months-to-date (to account roughly for seasonal fluctuations), show that nine of the buildings have had steadily increasing use, nine have stayed roughly constant, and 2 have declined. Figure 4 shows one example; for this Energy Edge building the rising energy consumption trend was unrelated to a change from partial to full occupancy, and needs to be investigated further. Is it due, in this case, to increased office equipment loads, longer hours of use, degrading performance of energy systems, or some other factor? More detailed analysis of monitored end-use data, focusing in particular on changes in office equipment and other receptacle loads (and corrected for occupancy and weather) will be available in the future for each Energy Edge building. These detailed, longitudinal data may help to explain multiyear trends, and perhaps to pinpoint

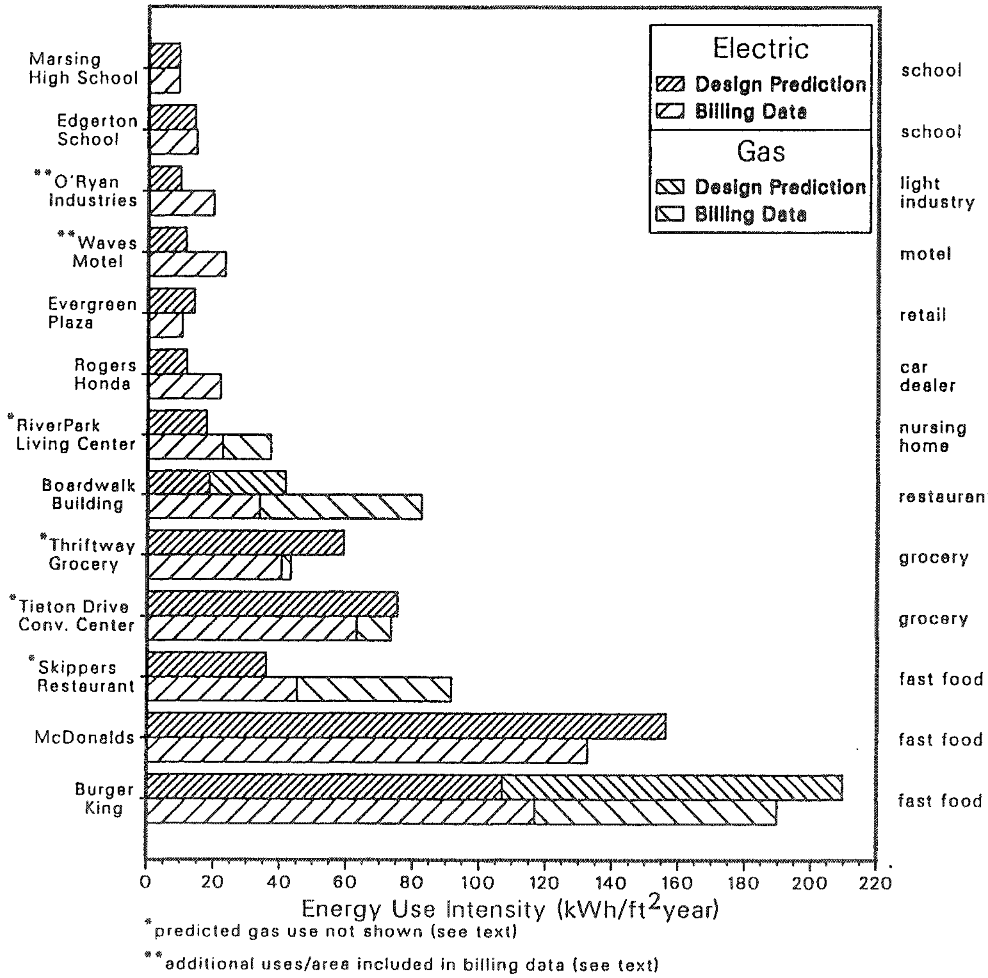

Figure 3. Predicted vs Actual Energy Use for the Energy Edge Non-Office Buildings for Which Billed and Design-Estimated Data Are Available

some of the factors affecting long-term energy performance of individual measures.

To summarize our preliminary findings based on whole-building data:

1. The predicted EUIs for the base (MCS) design of Energy Edge office buildings were slightly lower than other predictions for offices designed to meet MCS standards.
2. On average, actual use for the Energy Edge office buildings--based on unadjusted whole-building utility bill data--is lower than the EUIs for other new office buildings in the region.
3. Individually, whole-building energy use for about half of the buildings was more than 15% above predictions made at the design stage; the median ratio of billed consumption to predicted energy use was 1.11. These results, based on unadjusted billing data, would suggest savings closer to 20% than to the targeted 30% of base use. However, more detailed monitored data, plus results of the "tuned" computer models comparing the actual building with an MCS base-case design, may produce different estimates of savings attributed to the Energy Edge measures.

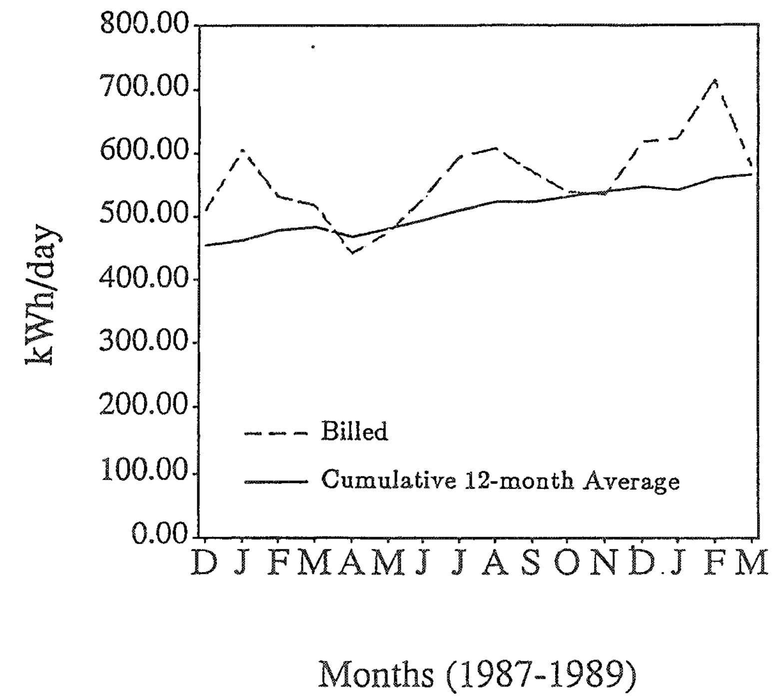

Figure 4. Daily Average Energy Use for a Medium-Sized Office Building, Showing Trends in Monthly Billing and a Moving Average for the Previous 12 Months

4. There is evidence (e.g., the Seattle study cited above) that other commercial buildings also use more energy than predicted at the design stage, often for reasons unrelated to performance of energy-saving measures.

Again, these findings reflect analysis of the partial data now available, and should not be viewed as definitive results.

ASSESSMENT OF THE PHASE ONE BUILDINGS

Four of the twenty-eight buildings were selected for more detailed early analysis, on the basis of at least one year of monitored data available as of late 1989:

- Building A (Dubal Beck) is a medium-sized office building with increased wall and roof insulation, low-emissivity (low-e) windows, an entry vestibule, and efficient lighting and controls. On an annual, whole-building basis, it used 36% more energy than originally predicted. However, results from the tuned computer simulation model, calibrated to monitored energy use showed that both the MCS base design and the Energy Edge building used about 20% more energy than originally predicted (see the pilot study discussion below, and Figures 5 and 6). While the revised estimate of aggregate energy savings for all measures in this building is close to that originally predicted, the components of these savings, by measure and by end-use, have shifted significantly.
- Building B (Caddis McFaddin) is a small office building, with increased insulation and vapor barrier, an air-to-air heat exchanger, high-efficiency heat pump, and efficient lighting. It consumed 8% less energy than predicted, during an initial occupancy period prior to a change in tenant. No end-use predictions were available for comparison with the monitored end-use data, in order to determine where the reductions occurred. Costs of the measures in

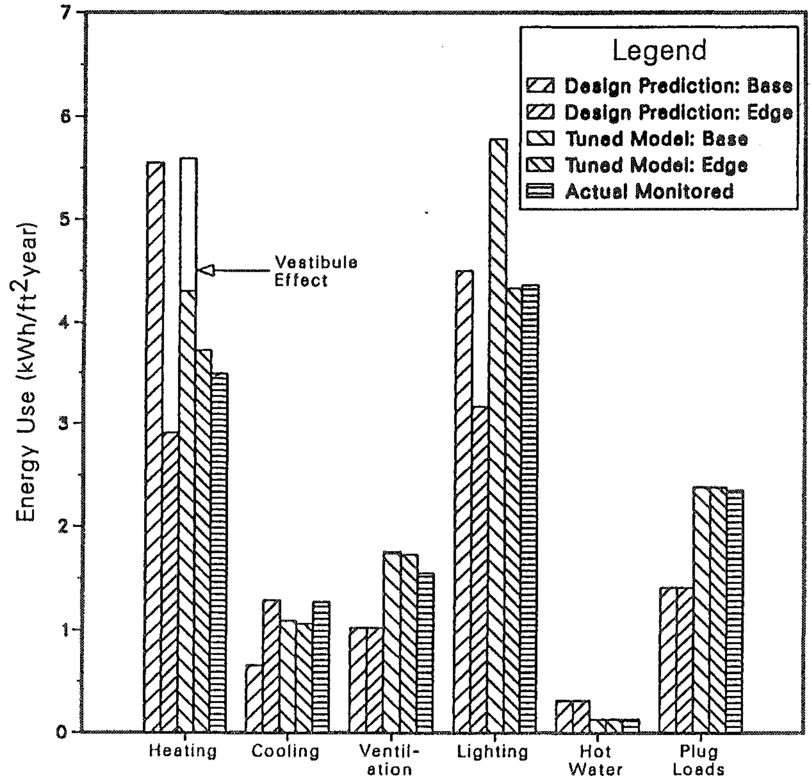

Figure 5. End-Use Comparisons of Design, Tuned, and Actual Energy Use for the Pilot Study Office Building

this building were also significantly lower than originally estimated.

- Building C (Siskiyou Clinic) is a small medical office building with high-efficiency heat pumps, economizers, efficient lighting and controls, and added insulation. It used 6% less energy than predicted. Lighting was a smaller percentage of the total than predicted, with increased HVAC energy making up most of the difference. All measures were reported as performing satisfactorily, with the exception of occupancy sensors in the examination rooms that are sometimes triggered by people in the hallway outside the rooms.

- Building D (Edgerton School) is a primary school, with efficient lighting, low-e windows, increased insulation, and earth berming. Based on the billing data, it used 3% more energy than predicted. However, monitored data from the building service-entrance circuit showed slightly less energy use than predicted (this discrepancy may be due to measurement error or/and significant losses from on-site transformers). Interviews with teachers and staff at the school indicate a great deal of satisfaction with the quality of the lighting and thermal environments, including the degree of occupant control.

ANALYSIS OF THE PILOT STUDY

The pilot study of Building A produced "tuned" model estimates of energy savings, by measure (see Kaplan 1990, for a full discussion on the use of monitored data for tuning simulation models). Total estimated savings for the building, based on the tuned model, were within 10 percent of savings predicted at the design stage--but only if one assumes that the vestibule reduced infiltration significantly. There were major differences between the results of the original, design-stage modeling and the final, tuned model in terms of both the absolute magnitude of energy use for the base-case and the Energy Edge building (Figure 5), and the

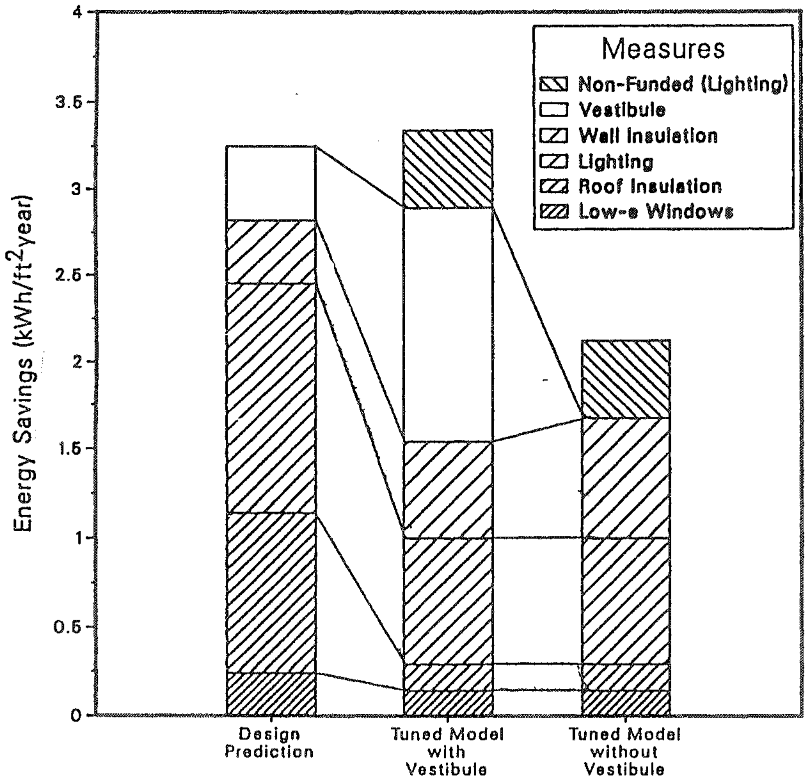

Figure 6. Comparisons of Savings by Measure for the Pilot Study Office Building

share of total savings attributed to individual measures (Figure 6).

Figure 5 shows a breakdown of annual energy use (kWh/sq.ft-yr.), by end use, for: the two design-stage predictions (base case and Energy Edge building), two revised predictions using the tuned model (base and Energy Edge), and actual site-monitored data. The close agreement between the final two bars in each group is unsurprising; that was the objective of the model-tuning process. This close agreement does confirm that a complex building simulation model can be calibrated to replicate (on an annual basis) monitored data. Figure 5 does show that, compared to the original predictions, the tuned model estimated: less savings in heating energy, no change (rather than an increase) in cooling energy, and about the same savings for lighting energy.

Based on the tuned-model calculations, the six measures in the pilot building produced combined savings of 13,100 - 25,300 kWh/year. The design-stage predicted savings were slightly higher, at 27,800 kWh/year. Savings by measure are shown in Figure 5. This wide range of savings is due to a single measure, the entry vestibule, reflecting in part different interpretations of the scope of the measure (i.e., what the base case design would have been, in the absence of a vestibule and hallway buffer zone), and in part due to the absence of measured data on the vestibule's actual effect on infiltration rates. This important parameter will soon be measured, as part of a series of one-time tests.

Due to significant changes in the estimates of savings by measure, the final cost-effectiveness of each measure in the pilot study building differed from that predicted at the design stage, Considering the Energy Edge measures as a total package, results from the tuned model show aggregate levelized costs ranging from 37 to 70 mills/kWh (excluding design costs of about 5%). Once again the vestibule, because of its large share of estimated savings and assumed long lifetime (50 years), has a major impact on overall cost-effectiveness of the package of measures. Looking individually at the measures in this building, only wall insulation and the vestibule (if it produced the assumed savings) had levelized costs below 45 mills/kWh. The low-e glass and occupancy sensors, in this application, were estimated to have levelized costs above 100 mills/kWh. Both costs and savings of individual measures may vary significantly among buildings. A future step in the analysis will be to compare these values, for similar measures installed in more than one Energy Edge buildings, and then to determine which values may be most applicable to other new commercial construction in the region.

ASSESSMENT OF THE METHODOLOGY

Use of calibrated building models is an important tool to disaggregate whole-building performance, to determine savings due to each measure or subsystem, and to extrapolate monitored results to other climate conditions, operating practices, or building configurations (including, in this case, the base case MCS design). Such modeling has its limits, however, and is most effective when used in conjunction with one-time measurements, controlled or "on/off" testing of measures, on-site occupant surveys, and careful observation and logging of operating practices. Modeling can also play an important role in helping to define which site-specific measurements are needed and which may be unnecessary. The specific approach of using a tuned model (as demonstrated in the Energy Edge pilot study) might be refined with additional steps to validate the tuned model with a separate subset of data, use actual hourly values for loads and schedules input to the model (rather than monthly daytype-averaged values), and incorporate improved measurements for critical parameters in each building. Further discussion of the Energy Edge monitoring and analysis methodology is found in Harris et al., 1990.

Once the model for a given building has been calibrated (and separately validated) using site-monitored data, model parameters can be changed in order to estimate savings for each measure and for various combinations. This should be done not only for building-specific operating conditions (i.e., schedules, setpoints, equipment and occupant loads), but for typical operating conditions for buildings of that type in the region. This standardization of operating conditions is as important for comparative analysis as is standardization of weather inputs to the model using long-term average weather files.

Continuous, multi-channel monitoring of building end-uses, equipment status, and other conditions is only one option for data that can be used to empirically calibrate ("tune") a building simulation model. Experience with the Energy Edge pilot study showed that such monitoring may not provide all the needed data; additional one-time measurements or controlled tests (e.g., measured infiltration rates) may be required. Conversely, much of the data gathered over a year or more of continuous monitoring may be of little or no help in model calibration. Some of the monitored Energy Edge data, for example, show trivial loads for the water heating end use, or essentially no variation over the year in well-scheduled loads such as outdoor lighting. Such lessons about what is important to monitor continuously, and how controlled tests or short-term measurements can complement continuous monitoring, will provide useful guidance for future projects.

KEY ISSUES AND WORKING HYPOTHESES

In previous sections we discussed initial findings on whole-building performance and on the value and limits of tuned simulation models. In addition, a number of issues have been identified that will be the subject of continuing analysis. At present, these are stated as "working hypotheses":

Quality Control and "Building Commissioning"

Buildings and measures often don't perform as well in practice as expected at the design stage. Quality-control during construction and post-construction commissioning are essential steps--beyond the design stage--to assure effective, sustained performance. We have recommended that commissioning procedures be tested at some, if not all, of the Energy Edge sites, and the resultant added costs and changes in energy performance carefully documented. Steps are now underway to develop and pilot-test commissioning procedures at several of the Energy Edge sites, with similar efforts getting underway as part of utility programs for new commercial construction in other parts of the country.

Broader View of "Energy-Saving Measures"

Building energy performance is often influenced by many factors other than the set of specific, energy-saving measures. Some of these factors are treated in current building codes; others may be incorporated in future code refinements. Still other features may be difficult to influence through design-based building standards. Several Energy Edge buildings offer examples of additional energy-saving opportunities, beyond the specific measures identified with the program. Many of these involve improved operation and maintenance practices, such as better control of miscellaneous receptacle loads during unoccupied night and weekend hours, correction of improper equipment settings (economizer setpoints too low, distribution system fans operated intermittently during the day but left "on" at night, etc.), and failure to control the simultaneous use of equipment to avoid large peak demand charges on electric bills. A point of interest: some of these additional measures may represent strategic opportunities to test both hardware measures and improved operations, on a retrofit basis, using the instrumentation already in place in the Energy Edge buildings.

Improved Cost Data and Analysis

The cost analysis for measures in the Energy Edge buildings was hampered in some cases by inadequate documentation of both the originally predicted and the actual, as-built costs. There were also institutional pressures, stemming from the design and management of the program, that may have affected cost estimates and decisions on how to allocate "overhead" costs like design, modeling, and reporting. Other issues in estimating costs included the definition of "base case" conditions, the widespread variations in measure costs at the time the buildings were built, and treatment of subsequent changes in cost for many of the measures. All of these point to the need for an added step, not anticipated in the original cost-effectiveness methodology: an analysis of "standard costs" for each major energy-saving measure. Such a standard cost would generalize from specific experience in the Energy Edge buildings, to reflect the estimated cost (or range of costs) that might be typical of new buildings constructed in the region for the next few years. This additional step is now under way, and will be incorporated in future analyses of cost-effectiveness for the Energy Edge buildings. Similarly, a standard set of assumptions concerning measure lifetimes and operation-and-maintenance (O&M) costs is important for consistent and reliable cost-effectiveness analysis, and for comparing the Energy Edge results with those from other studies. Ideally, of course, conservation measure lifetimes would be based empirically on long-term performance tracking, rather than on some average of practitioners' opinions.

Long-term Tracking

To understand conservation performance and cost-effectiveness it is essential to have more than a 1 or 2 year snapshot immediately after a building's construction (or retrofit). Longer-term tracking is needed, for both system performance and O&M costs, especially for measures whose cost-effectiveness rests on an assumed lifetime of more than a few years.

Feedback to Designers and Building Operators

In some cases, timely feedback to building designers on discrepancies between predicted and actual energy performance can influence future assumptions during the design stage, and thus improve the accuracy of design calculations and modeling. Similarly, the availability of credible, understandable data on the performance of real buildings with energy-saving features can help reduced the perceived risk of continued investments in energy conservation.

Selective Data Collection and Analysis

A conventional approach to building performance monitoring involves installation of special-purpose sensors and data loggers, to collect end-use data (along with equipment status, flows, ambient conditions, etc.) on a continuous basis for at least a year. For the Energy Edge program, this continuous on-site monitoring was supplemented by using the monitored data to calibrate a detailed building simulation model. Since both of these activities are costly and time-intensive, it will be useful to examine, in light of the final results, how much each increment of effort and detail actually contributed to improving the initial performance predictions. The Energy Edge buildings, now thoroughly instrumented, may offer special opportunities to test new approaches to simplified, short-term diagnostic measurements, to see if they produce results that can be reliably extrapolated to longer-term performance.

Opportunities for Further Cost Reductions

In the past, energy conservation programs have often focused primarily on achieving maximum energy savings, with cost-reduction viewed as a constraint or a secondary consideration. As both utilities and public agencies begin turning to "energy conservation resources" to meet growing demand, it is time to give equally serious attention to ways of achieving a given level of performance at minimum cost. Among the Energy Edge buildings, costs to achieve the same 30% savings target varied widely, from about $1-2/ft^2 as much as $10/ft^2 (as estimated at the design stage). Of course, specific features of energy-saving measures are expected to vary somewhat among buildings, and these numbers do not necessarily reflect consistent treatment of design costs and other "unallocated" expenses. Still, this wide a range of costs bears closer examination, for what it says both about optimal selection of measures and how effectively they were implemented in the different Energy Edge buildings.

Better Definition of "End-use Services"

For some end-uses and building components, reliable performance comparisons cannot be made without clearly specifying the level of services delivered. Performance of lighting systems, for example, cannot be assessed purely in terms of the installed lighting power density (watts per square foot) or the annual kWh of energy used--without also specifying what quantity and quality of lighting is delivered to serve the activities and occupants in that building. In many cases, these final services from energy are poorly defined; improved quantification will be increasingly important, as designers and code-writers seek each new increment of energy efficiency.

FUTURE WORK

Future analyses of Energy Edge building performance and program impacts will include examination of the monitored end-use data, "tuned" modeling of the remaining buildings, and use of refined cost data (including "standard" cost estimates) to evaluate the cost-effectiveness of each measure. We will compare results from the tuned models with design predictions, and attempt to account for differences on the basis of changed input assumptions, model accuracy, and other factors. We will give increased attention to assessing the net impact of the program on both savings and costs, and to translating the lessons learned from Energy Edge into implications for future programs.

Specifically, the Energy Edge analysis provides an empirical foundation for "Energy Smart," the next-generation design assistance program for new commercial construction in the region. Energy Edge results will also help to guide other long-term conservation programs currently being designed by the Bonneville Power Authority and others. The present research will help policy makers to set incentive levels for future programs, and contribute to a data base for estimating commercial supply curves and electricity load forecasts. Finally, by documenting the actual performance of the 28 Energy Edge buildings for the architectural and engineering community, the program hopes to move "common practice" in the region towards more energy-efficient design.

ACKNOWLEDGEMENTS

This work was jointly supported by the Bonneville Power Administration and by the Assistant Secretary for Conservation and Renewable Energy, Office of Building and Community Systems, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. The authors are greatly indebted to many other participants in the Energy Edge program, including

BPA staff, program sponsors, contractors, and building owners who have all contributed their effort, skills, and insights to help make the program and its associated data-gathering and analysis activities both challenging and fruitful.

REFERENCES

Baker-Reiter (BR) Associates. 1988. "Electrical Energy Consumption and Building Characteristics of Office and Dry Goods Retail Buildings in the Pacific Northwest." Prepared for the Bonneville Power Administration, End-Use Research Section. June.

Energuard Corporation. 1984. "Summary of End Use Data in Commercial Buildings." Prepared for the Bonneville Power Administration. December.

Harris, J.P., Diamond, R.C., de Buen O., Hatcher, A., Nordman, B., and Piette, M.A. 1990. "Energy Edge Impact Evaluation, Findings and Recommendations from the Phase One Evaluation." Report by Lawrence Berkeley Laboratory, to the Bonneville Power Administration. May.

Kaplan Engineering. 1989. "Energy Edge Pilot Study." prepared for Bonneville Power Administration. September.

Kaplan, M.B. et al. 1990. "Reconciliation of a DOE-2.1C Model with Monitored End-Use Data for a Small Office Building." *ASHRAE Transactions,* 96:1.

Momentum Engineering, Ecotope Inc, and Synergic Resources Corporation. 1988. "Major Projects Rule: Phase Two Evaluation, First Year Report." Prepared for Seattle City Light. December.

Northwest Power Planning Council (Council). 1988. "Conservation Resources for the 1988 Power Plan Update." Staff Issue Paper 88-13. June.

Northwest Power Planning Council (Council). 1986. "Northwest Conservation and Electric Power Plan." Vol. 2.

Piette, M.A., Flora, D., Crowder, S. 1985. "Energy-Efficient New Commercial Buildings in the Northwest Region: A Compilation of Measured Data." Lawrence Berkeley Laboratory Report, LBL-19293. May.