LBL-35644
UC-1600

Over the Energy Edge: Results from a Seven Year New Commercial Buildings Research and Demonstration Project*

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August 1994

* This work was jointly supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings Technologies, Building Systems Division of the U.S. Department of Energy under Contract #DE-AC03-76SF00098 and the Bonneville Power Administration.

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Energy Edge was a research oriented demonstration project that began in 1985. Twenty-eight commercial buildings were designed and constructed to use 30% less electricity than a hypothetical simulated baseline building. Average savings from the 18 buildings evaluated with post-occupancy, "tuned" simulation models were less, at 17%. The cost-effectiveness of the energy-efficiency measures at six of the 18 projects met the target cost-of-conserved (CCE) energy of 5.6¢/kWh for the total package of measures. The most important reason energy savings were not as great as predicted is that the actual, installed energy-efficiency measures and building characteristics changed from the design assumptions. The cost effectiveness of the measures would have been greater if the baseline was common practice rather than assumptions based on the regional building code. For example, the Energy Edge small offices use about 30% to 50% less energy than comparable new buildings. Savings also would have been greater if commissioning had been included within the program. Future projects should consider lower-cost "hands-on" evaluation techniques that provide direct feedback on measure performance based on functional and diagnostic testing, with annual check-ups to ensure persistence of savings.

Introduction

Energy Edge was a research-oriented demonstration of energy efficiency in 28 new commercial buildings that provided Northwest conservation planners with information about how energy-efficiency measures perform in actual, occupied commercial buildings. This paper presents a summary of key findings from the multi-year project evaluation (Piette et al. 1994). Beginning in 1985, the project, sponsored by the Bonneville Power Administration (BPA), was developed to evaluate the potential for electricity conservation in new commercial buildings. Energy Edge involved designing new commercial buildings to reduce electricity consumption by 30% from a hypothetical baseline. Baseline energy was estimated using the 1985 Model Conservation Standards (MCS, NWPPC 1985). The MCS are similar to ASHRAE Standard 90A-1980, with more stringent lighting requirements.

The primary objectives of the impact evaluation were to assess the overall performance of the Energy Edge buildings and examine the energy savings and cost-effectiveness of individual energy-efficiency measures. Over 200 individual energy-efficiency measures were tracked. This paper summarizes performance data for all 28 buildings and results from 18 buildings that were evaluated using post-occupancy, calibrated, (or "tuned") simulation models.

This paper begins with a description of the project and the evaluation methodology. We then present results from the tuned models and whole-building energy use. The small office buildings are compared to other small regional office buildings to illustrate their relatively low energy use. Next, we discuss the cost-effectiveness of individual classes of measures and total savings for the program as a whole. Finally, we describe methodological issues that complicated the evaluation, with suggestions for future programs.

Project Description

The $15 million Energy Edge program began with a design competition to identify buildings undergoing initial construction or extensive remodeling. Designs had to use electric heat to be eligible. Computer simulations were developed for each building that entered the competition to evaluate the cost effectiveness of energy saving features.

Measures were chosen to reduce energy use by 30% from what might have been built without the project's design assistance or incentive payments. BPA paid for the incremental cost of the energy-saving features. The estimated cost effectiveness for the package of measures was to be below 45 mills/kWh saved (4.5¢/kWh in 1986 dollars, 5.6¢/kWh in 1991 dollars). Most building owners also installed additional measures identified in the design studies; these are "owner-funded" measures.

After the buildings were selected, detailed monitoring plans were developed and data acquisition systems installed to collect information about how energy was used in each building (Gardner and Lambert 1987). Monitoring typically exceeded a full year, with an average of about 100 channels of data, including on-site weather.

Evaluation Methodology

The tuned model evaluation methodology was developed to provide a detailed analysis of each efficiency measure based on actual building operating conditions (Kaplan Engineering 1992). The evaluation was based on a "hands off" approach, using monitoring and periodic operations and maintenance (O&M) audits to observe how each building and energy-efficiency measure performed over time. There was limited interaction between the project sponsors, monitoring contractors, modelers, and the building owners and operators. We comment below on some of the shortcomings of this approach.

After the buildings were occupied (though not always 100%), information from O&M audits plus end-use and weather data were used to develop DOE-2.1 simulations to represent the actual building. This process has been described in several previous reports (Kaplan Engineering 1992, Kaplan Engineering and PECI 1993, and Kaplan et al. 1992). A tuned baseline model was derived by defining code baseline conditions for each measure. Each measure was individually modeled against the tuned baseline, and a levelized cost calculated. BPA-funded measures were also modeled as a complete, interactive package. The levelized cost used is equivalent to a cost of conserved energy (CCE) at a 3% discount rate with measure lifetimes based on BPA technical requirements for the Energy Smart Design program. All costs were inflated to 1991 dollars by Lawrence Berkeley Laboratory.

Several factors complicated our ability to compare design-phase and tuned model energy savings estimates. The primary constraint is a lack of information regarding the assumptions in the design predictions. Also, many of the energy-efficiency measures that were installed differed markedly from those considered in the design, and actual building conditions also differ from design assumptions. Another factor was that while the tuned model methodology was designed to be as objective as possible in defining a hypothetical MCS baseline building, defining the baseline is complicated by compliance options within codes, which contain minimal coverage of systems such as controls and their operation.

The challenge in defining an appropriate baseline moves beyond code compliance to ask: "What would have been built without Energy Edge?" and "What is common practice?" To address these general questions we compared energy use data from utility bills with regional new buildings stock data to derive a net savings estimate for the program based on a "comparison buildings" approach. Ideally this approach would have included developing a statistically valid sample of non-participants to serve as a baseline for the Energy Edge buildings. Without such a sample, we drew upon existing buildings data to make the comparisons. We compared energy use and characteristics of both the Energy Edge and the hypothetical base buildings with other new commercial construction in the Pacific Northwest using a variety of published data to estimate a typical energy use intensity for each building type. The major drawback of this simple approach of comparing whole-building energy use is that it does not consider conditions in the building that create more intensive loads than typical, such as longer hours of operation, high process loads (e.g., a computer center), or severe climatic conditions. The utility billing data were also used in evaluating how energy use changed over time.

Results

Energy Savings Estimated from Tuned Models

Compared to the total energy use estimated in the design phase, energy use in the actual buildings is, on average, about 40% greater than predicted, as listed in Table 1. Energy use ranges from 32% less than design-phase predicted to 148% greater, with a median increase of 27%. Seven, or one-fourth of buildings used less energy than predicted. The greatest increase in energy use is from heating, ventilation, and air-conditioning (HVAC) equipment (which was greater than predicted for 14 of the 18 tuned buildings). More hours of operation and less use of night set-back contributed to the increase. Energy savings from the tuned models were less than design-phase predictions for most of the measures. The lack of savings was not only related to the poor performance of some of the efficiency measures, but was also a result of differences in the actual buildings from the predictions.

Average predicted energy savings for the 18 tuned buildings were 32% of the design-phase baseline energy use. Post-occupancy tuned savings estimates were less, with

Table 1. Energy Use, Measure Savings and Cost-Effectiveness of the 28 Energy Edge Buildings

Building	Location	Floor Area (kft²)	CCE ($91)[a] Tuned (¢/kWh)	CCE ($91)[a] LBL (¢/kWh)	% Savings[b] Pred.	% Savings[b] Tuned	EUI (kWh/ft² year)[c]	% Change in EUI from Pred.
Small Office								
Caddis McFaddin	Spokane, WA	2.1	--	--	39	--	10	9
Siskiyou	Ashland, OR	3.0	28.7	31.0	42	29	8	-7
Hollywood	Portland, OR	3.1	23.5	30.7	42	8	11	33
STS	Ellensburg, WA	4.3	67.4	67.8	39	15	10	-32
East Idaho	Idaho Falls, ID	5.3	17.4	23.6	35	15	13	52
Dubal Beck	Portland, OR	8.5	7.3	11.2	28	23	13	32
Landmark	Yakima, WA	13.4	14.0	10.4	34	18	14	5
West Yakima	Yakima, WA	16.2	--	--	33	11	11	48
Large Office								
Emerald PUD	Eugene, OR	24.8	15.5	9.9	37	29	10	36
Eastgate	Bellevue, WA	25.1	4.3	5.3	24	26	21	148
Director[d]	Portland, OR	79.7	8.0	12.0	37	25	12	16
Eugene W&P	Eugene, OR	91.3	--	--	28	--	20	-22
Bellevue	Bellevue, WA	389.0	na	na	31	-6	22	5
Montgomery Park[d]	Portland, OR	782.9	--	--	22	--	16	104
Gateway	Seattle, WA	1,087.0	--	--	46	--	25	25
Retail								
Evergreen	Tacoma, WA	21.1	11.4	2.9	20	5	22	43
Fast Food								
Skipper's[d]	Bellevue, WA	2.5	--	--	50	--	61	71
Burger King[d]	Vancouver, WA	2.7	1.2	2.4	20	7	130	22
McDonald's	North Bend, WA	4.1	2.4	3.1	15	19	134	-13
Grocery								
Tieton[d]	Yakima, WA	3.3	2.9	3.7	34	16	54	-25
Thriftway[d]	Beaverton, OR	41.6	1.5	2.5	36	27	46	5
School								
Marsing	Marsing, ID	31.4	5.5	5.8	30	37	10	-3
Edgerton	Kalispell, MT	55.7	31.1	53.7	31	10	13	-6
Miscellaneous								
Waves Motel	Cannon Beach, OR	3.3	--	--	26	--	24	110
O'Ryan	Vancouver, WA	6.0	--	--	49	--	19	124
Boardwalk[d]	Olympia, WA	12.6	--	--	38	--	45	142
Rogers Honda	Albany, OR	13.3	--	--	31	--	24	106
Riverpark[d]	Eugene, OR	47.0	--	--	33	--	20	13
Average					32	17		40

"--" not available. "na" not applicable (because of negative energy savings).

(a) CCE estimates for BPA-funded measures only. (Emerald PUD measures owner funded, but considered BPA-funded because owner is a utility.) LBL CCE was adjusted for consistency.

(b) % savings estimates for restaurants and grocery stores include all electricity end uses; for other building types plug loads excluded.

(c) EUI: Energy-Use Intensity from tuned models or utility bills.

(d) Building uses additional natural gas not included in EUI.

average savings of 17%. Results for each building are shown in Table 1. For most buildings, the savings fractions are based on the MCS end use totals only, which do not include plug loads, refrigeration, or cooking end uses.

Results from the tuned models show that the CCEs for the interactive package of measures funded by BPA range from 1.5¢/kWh to one case where there were no net savings. Six, or one-third of the 18 projects evaluated with Tuned models met the cost-effectiveness criterion of 5.6¢/kWh for the total package of measures, and a seventh was within 5% of the target. Only one met the 30% savings target. The most cost-effective measure packages were in the two groceries and the fast-food restaurants, and involved non-MCS end uses.

Many of the measures in the buildings with the lowest energy-use intensity (EUI) were found to be the least cost-effective. Conversely, many of the measures in the buildings with the highest intensities were the most cost-effective (e.g., McDonald's, Tieton, Thriftway). This suggests that the evaluation may be biased toward buildings with higher energy use. The building that illustrates this problem most clearly is Eastgate, which used more energy (per unit of floor area) than the other offices, yet the measures were found to be the most cost-effective. One reason energy use was high in this building is that they had minimal use of night setback. It may be simply easier to identify savings in high energy buildings. The comparison building evaluation approach concludes, for example, that buildings with high EUIs saved less energy than those with low EUIs.

Inconsistencies and gaps in documentation hampered our ability to definitively explain why the design-phase predictions of energy savings differ from tuned model results. There are several reasons for differences. For example, not all of the measures in the design-phase predictions were installed in each building (and in a few cases measures were added). However, the tuned and design-phase predicted CCEs for the set of measures common to both were not necessarily closer because of other factors that changed from the design model to the tune model.

Many measures included in the actual buildings were not included in the tuned model because of partial measure failure, ambiguity, and limitations of the simulation model. For example, since it was difficult to model infiltration changes from vestibules, they were dropped as a tuned measure. Modeling techniques also differed between the design-phase and tuned models. Some measures simply failed because of poor equipment performance (e.g. bad damper linkages in economizers) and installation (e.g. poor daylighting or occupancy sensor calibration).

The tuned model methodology was developed to account for changes in building conditions that influence energy use, such as equipment loads and schedules. For example, the prediction for the Tieton Convenience Store was based on 24-hour operation and the actual building operated 16 hours per day. We did not, however, anticipate that measure characteristics for both the baseline and the Energy Edge systems would change from the design-phase prediction to the actual building. For example, the design-phase baseline window system used to assess the Low-E windows was a single-paned window at the East Idaho Credit Union. In the tuned model the baseline was a double-paned window. Therefore, the energy savings from the tuned model was necessarily less than from the design-phase model because the tuned baseline is a more energy-efficient technology. Similarly, we also found differences in both the baseline and the Energy Edge insulation values in most of the buildings.

Building Energy Performance Trends

From one to six years of monthly utility bills were compiled for all 28 buildings. On average, energy use increased during the first four years of operation, climbing to 36% more than the design-phase predictions. Fourth year energy use was six percent greater than third year energy use, with no average increase in the fifth year.

Compared to the total sample of 28 buildings, energy use for the 15 office buildings was closer to design-predicted consumption. Figure 1 shows how energy use for the 15 office buildings changed over time. The data are 12-month rolling average energy-use intensities (EUIs); each point is the sum of the previous 12-month's energy use, normalized by floor area. Average consumption for the 15 office buildings (continuous thick line) is well below that of the comparison buildings, although EUIs for two office buildings (Gateway and Bellevue) have reached or surpassed all three comparisons. The highest of the three comparison EUIs (24 kWh/ft^{2}year) is from the Northwest Power Planning Council forecast for offices built in 1990 (NWPPC 1991). The SBW EUI (22 kWh/ft^{2}year) is an estimate of energy use for 1989 common practice (SBW 1990). The third sample of comparison EUIs is based on measured data for seven small office buildings built between 1982 and 1984 (from the End-Use Load Conservation and Assessment Program, ELCAP, Taylor and Pratt 1989).

Small Office Building Energy Performance Trends

We examined the building characteristics and energy use data for seven small office buildings because they are the largest and most homogeneous sample of buildings by type

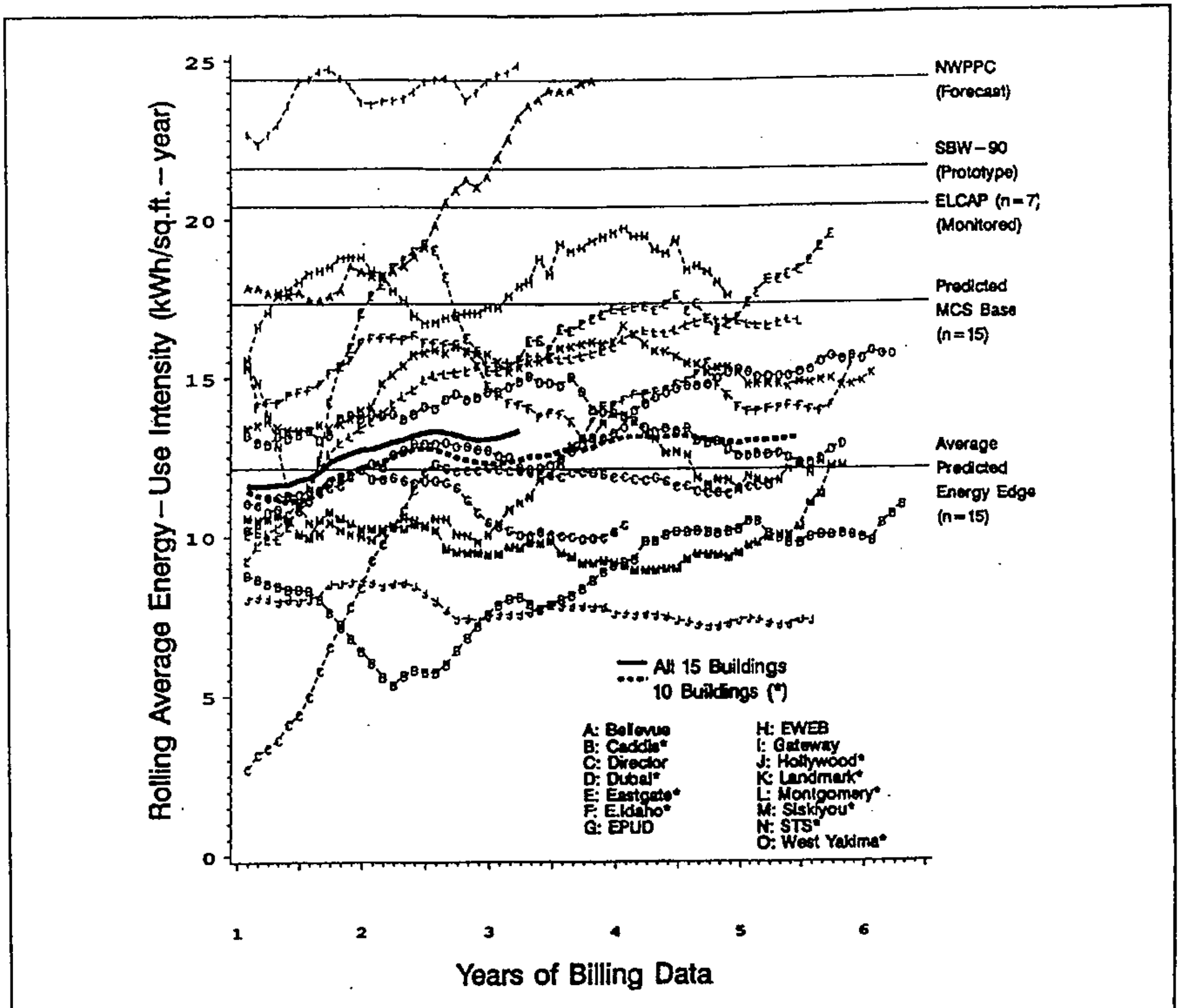

Figure 1. Energy Consumption Over Time for 15 Energy Edge Office Buildings and New Regional Comparison Buildings

within Energy Edge. Figure 2 shows average end use energy for the seven small offices compared to the regional comparisons described above. The design-phase predicted EUI is shown, along with the original baseline. Two average EUIs from the tuned models are also shown, representing the "tuned Energy Edge" EUI and the new baseline created from the tuned model (tuned baseline). On average, the actual Energy Edge buildings consume slightly more than design-phase predicted, while the tuned baseline is less than the predicted baseline. Total energy savings per building are therefore less than design-phase predicted. On the other hand, the Energy Edge small offices use up to 50% less than the comparison buildings. Standard deviations are shown on the figure for the ELCAP and Energy Edge results.

We also compared Energy Edge building characteristics with results from a study of commercial sector code compliance in the Northwest. The comparison showed that many of the lighting and shell characteristics in the Energy Edge offices are as good as, or better, than typical small offices built several years later (Kennedy and Baylon 1992). For example, lighting power densities (LPDs) in the Energy Edge small offices were lower than typical buildings built in the mid-1980s. The baseline LPD used in Energy Edge was the MCS 1.5 W/ft^2. Typical practice in 1986 was about 1.8 W/ft^2. Energy savings from the lighting measures would be greater than the tuned models indicate if the baseline were common practice rather than MCS compliance. Similar comparisons of shell and other equipment characteristics were explored in the evaluation.

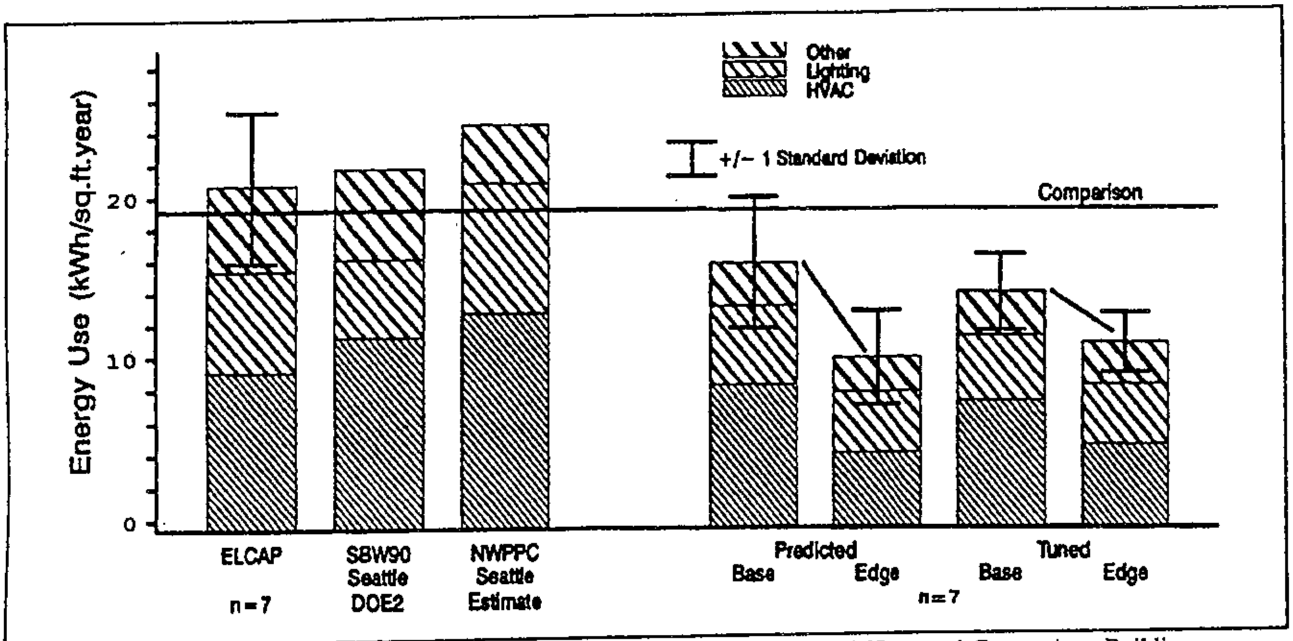

Figure 2. End-use Energy Consumption for Seven Energy Edge Small Offices and Comparison Buildings

Measure Performance

On average, tuned energy savings for individual measures were 20% less than design-phase predicted energy savings. Among the 78 measures evaluated in the 18 tuned building models, 41% met the cost-effectiveness criterion. Predicted CCEs are available for 39 of the 78 measures; only 18 (46%) of these measures met the CCE target (Figure 3). One reason many of the design predictions did not meet the CCE target is that the cost-effectiveness screening was only for the package of measures, not individual measures. So, the most cost-effective measures carried the least cost-effective measures through the screening.

Among the general classes of measures, the refrigeration and miscellaneous measures were the most cost-effective with median CCEs of 5.4 and 1.6¢/kWh, respectively. Lighting measures were the next most cost-effective at 7.5¢/kWh (median), followed by shell measures at 7.8¢/kWh. The HVAC measures were the least cost-effective, with median savings of 12.7¢/kWh.

The most important reason energy savings were not as great as predicted is that measures changed. For example, the installed insulation levels were often less than the design values, and lighting power densities were higher than initially specified. A second important reason for lower savings was the problems associated with dynamic measures, such as control measures. These measures were often poorly commissioned: that is, they were not correctly calibrated and set-up for proper control, and operation. Analysis of specific measures, such as energy-efficient heat pumps and economizers, revealed that ensuring proper operation and control of building equipment can save as much, or more energy than installing more efficient equipment.

Net Program Savings

Total energy savings were predicted to be about 17 GWh/year for all 28 buildings. Estimates of the achieved savings range from 13% to 71% of predicted savings, depending on the extrapolation from limited results to total savings for all 28 buildings. The lower savings estimates are dominated by the poor performance of the largest buildings. Several of the smaller buildings saved more than predicted and consumed less energy than predicted. The highest savings estimate is based on the comparison buildings approach described in the final report (Piette et al.1994).

BPA spent about $4.1 million on the incentive payments to the building owners to install the energy-efficiency measures and about $1.6 million to deliver the program, excluding evaluation costs. Based on this, the project was originally estimated to cost about 3¢/kWh saved. Estimates of the achieved CCE range from 4 to 22¢/kWh based on the range in energy savings described above.

Methodological Issues and Recommendations

The Energy Edge evaluation was expensive because of the time required to collect and process the continuous

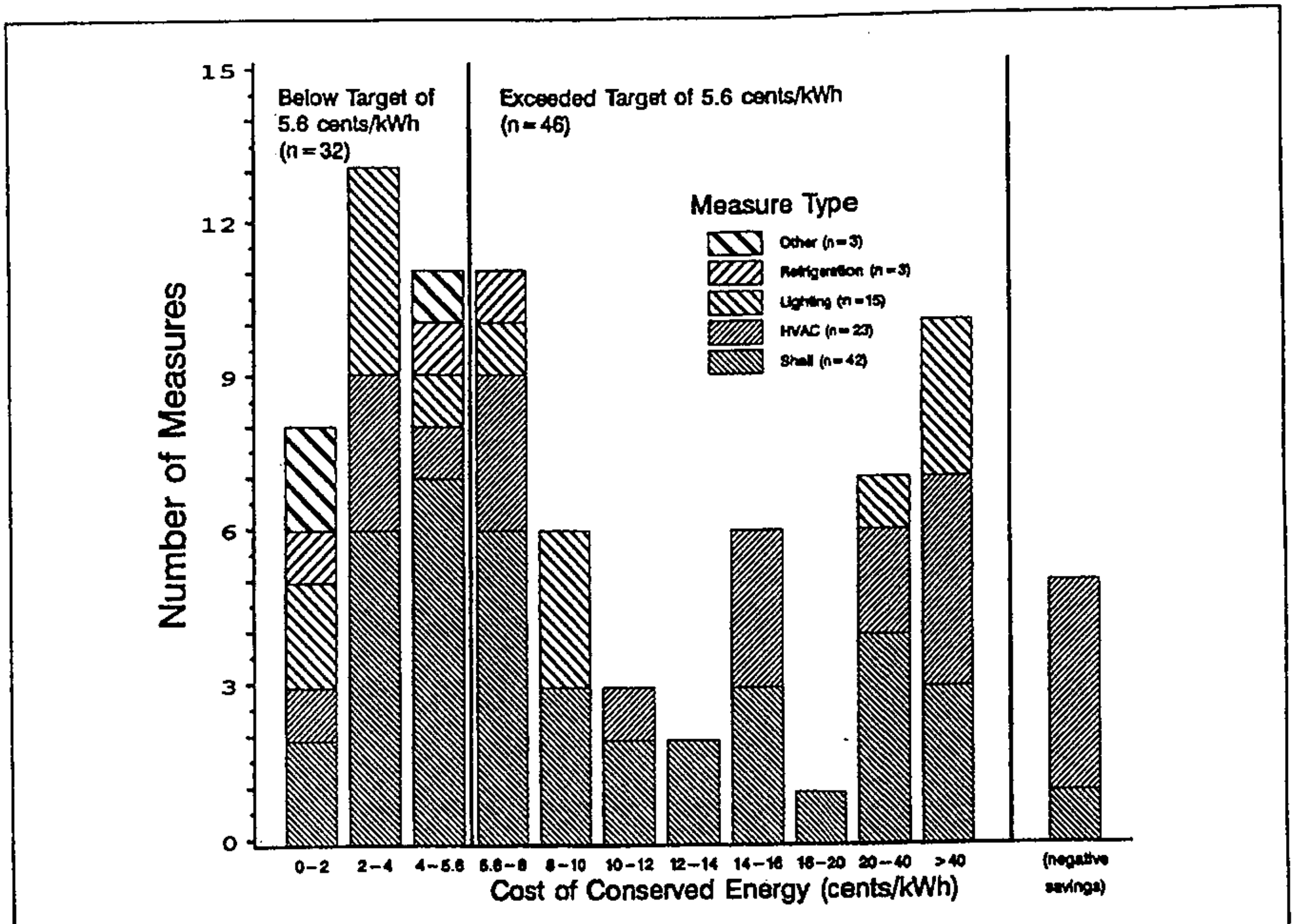

Figure 3. Distribution of CCEs for 78 Measures with Tuned Energy Savings from 18 Buildings. Forty-one percent of the measures met the CCE target

end-use monitoring (which often did not provide suitable information for the analysis of measure performance). In addition, it took about 400 hours to develop each of the 18 tuned models, including the measure savings analysis (Kaplan Engineering and PECI 1993). As discussed, the results are uncertain for some energy-efficiency measures because of difficulties in defining baseline assumptions. Measures that were most difficult to model are HVAC and lighting controls, and infiltration measures.

Energy Edge was a "hands-off" evaluation. Only on rare occasions were the data used to identify and correct operating problems. More recent monitoring and demonstration programs, such as ACT^2 (Krieg and Baker 1992) or the Texas Loanstar Program (Belur, Kissock, and Haberl 1992), have shown that "hands-on" evaluations provide valuable knowledge about operating problems and optimal control strategies, increasing the likelihood that actual savings will meet or exceed design targets.

As part of the hands-on approach, commissioning is needed to ensure optimal performance of energy-efficiency measures and whole-building systems. These procedures include verifying proper equipment installation and calibration, functional and diagnostic testing, and preparation of O&M guidelines supported by O&M training. Careful tracking of deficiencies corrected by commissioning is needed to identify the benefits from this extra step during building or retrofit start-up and urge common practice to make this "business as usual". Annual check-ups revisiting the status of energy-efficiency measures, building conditions, and control sequences should help maintain energy savings over time and provide feedback on persistence of savings.

Summary

Although many of the measures did not perform as well as predicted, there are several successful, low-energy buildings among the 28 case studies. Energy use ranged from 32% less than design-phase predicted to 148% greater, with a median increase of 27%. The most important reason energy savings were not as great as predicted is that the actual measures and building conditions changed from the design assumptions. Forty percent of the measures met the target CCE (of 5.6¢/kWh). The cost effectiveness of the measures would have been greater if the baseline was based on common practice rather than the code.

In this paper we have only skimmed the surface of the lessons from Energy Edge. The project's success will be based on whether the issues identified in the project have some bearing on what to do (or not do) in related future projects. The Energy Edge evaluation was expensive, and future projects will benefit from lower-cost "hands-on" evaluation techniques to verify proper equipment installation and calibration. Annual check-ups revisiting the energy-efficiency measures, building conditions, and control sequences should help maintain energy savings and provide feedback on persistence of savings.

Acknowledgments

We are grateful to the dozens of participants who have assisted in conducting the Energy Edge evaluation, with special thanks to Mike Kaplan from Kaplan Engineering and Grant Vincent from BPA. Thanks also to Jeff Harris, Kristin Heinemeier, and Katy Janda from LBL who assisted in the evaluation research. This work was jointly supported by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Technologies, Building Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098 and the Bonneville Power Administration.

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