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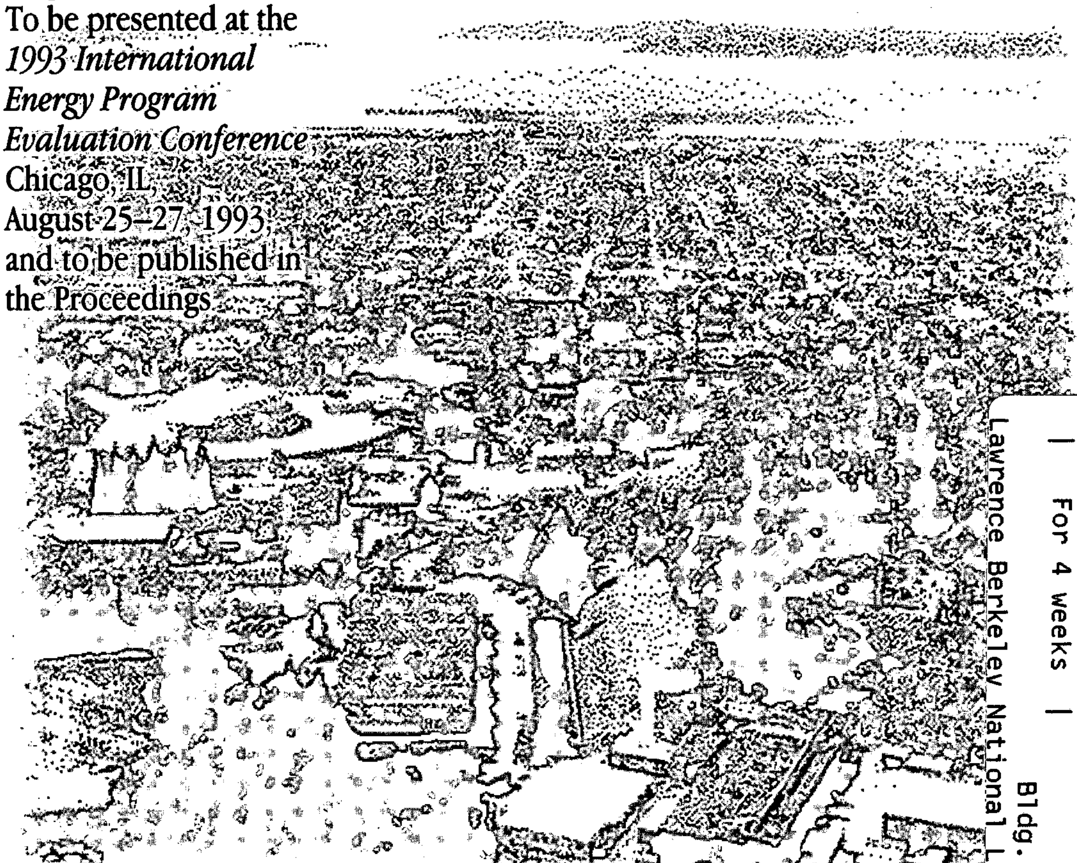

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PREDICTED VERSUS MONITORED PERFORMANCE OF ENERGY-EFFICIENCY MEASURES IN NEW COMMERCIAL BUILDINGS FROM ENERGY EDGE

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ABSTRACT

Energy Edge is a research-oriented demonstration program involving 28 new commercial buildings in the Pacific Northwest. This paper discusses the energy savings and cost-effectiveness of energy-efficiency measures for the first 12 buildings evaluated using simulation models calibrated with measured end-use data. Average energy savings per building from the simulated code baseline building was 19%, less than the 30% target. The most important factor for the lower savings is that many of the installed measures differ from the measures specified in the design predictions. Only one of the first 12 buildings met the project objective of reducing energy use by more than 30% at a cost below the target of 56 mills/kWh (in 1991 dollars). Based on results from the first 12 calibrated simulation models, 29 of the 66 energy-efficiency measures, or 44%, met the levelized cost criterion. Despite the lower energy savings from individual measures, the energy-use intensities of the buildings are lower than other regional comparison data for new buildings. We review factors that contribute to the uncertainty regarding measure savings and suggest methods to improve future evaluations.

INTRODUCTION AND PROJECT STATUS

Energy Edge is a research-oriented demonstration of energy-efficiency in 28 new commercial buildings in the Pacific Northwest sponsored by the Bonneville Power Administration (BPA). The project, which began in 1986, was developed to evaluate the potential for electricity conservation in new commercial buildings. One key objective is to determine if the buildings saved 30% of energy use beyond the regional building code, the Model Conservation Standards (MCS). Additional objectives include determining each measure's individual contribution to energy savings, incremental design and construction costs, cost-effectiveness, and potential applicability to other new buildings.

A prominent feature in the evaluation is the use of DOE-2.1 (versions C,D, and E) computer simulations, calibrated with a year of submetered data, to determine the energy savings for each measure. We compare design-stage predictions of end-use energy intensities and measure energy savings with the calibrated, post-occupancy models. This paper focuses on the performance of the energy-efficiency improvements. Additional evaluation results are discussed in a series of reports to BPA, which include multi-year utility bill tracking, methodological issues, measure cost data, and analysis of selected measures (Ref. 1).

The Energy Edge evaluation will be completed in 1993. About 18 of the program's 28 buildings will be evaluated with calibrated simulation models. Results for 12 of the 18 buildings are discussed below, which include results for about one-third of the 170 different measures included in all 28 buildings. Selected data and trends from the other buildings are also presented. Results presented in this paper are subject to minor changes as we refine the analysis. We believe, however, that the data below illustrate key findings from the program. In addition to summarizing specific results we review difficulties with the evaluation methodology and provide suggestions for future evaluations.

RESEARCH METHODOLOGY AND EVALUATION TECHNIQUES

The $16 million Energy Edge program began with a design competition to identify potential participants. After selecting the buildings, BPA paid for the incremental cost of the energy-saving features. The cost for the total package of measures had to be below 45 mills/kWh saved (4.5 cents/kWh in 1986 dollars). We assess both individual measures and the package of measures for each building. Many building owners installed additional measures identified in the design studies. Several of the buildings were too far along in the design process to be strongly influenced by the Energy Edge design assistance.

After the buildings were constructed and occupied, detailed monitoring plans were developed and data acquisition systems installed. The primary evaluation methodology is an engineering approach based on parametric analysis of a computer simulation model known as a "Tuned Model." Because of uncertainties in this approach, such as the difficulties in defining a single set of baseline assumptions, a second evaluation approach is used to compare Energy Edge buildings with regional new commercial construction buildings data, also described below.

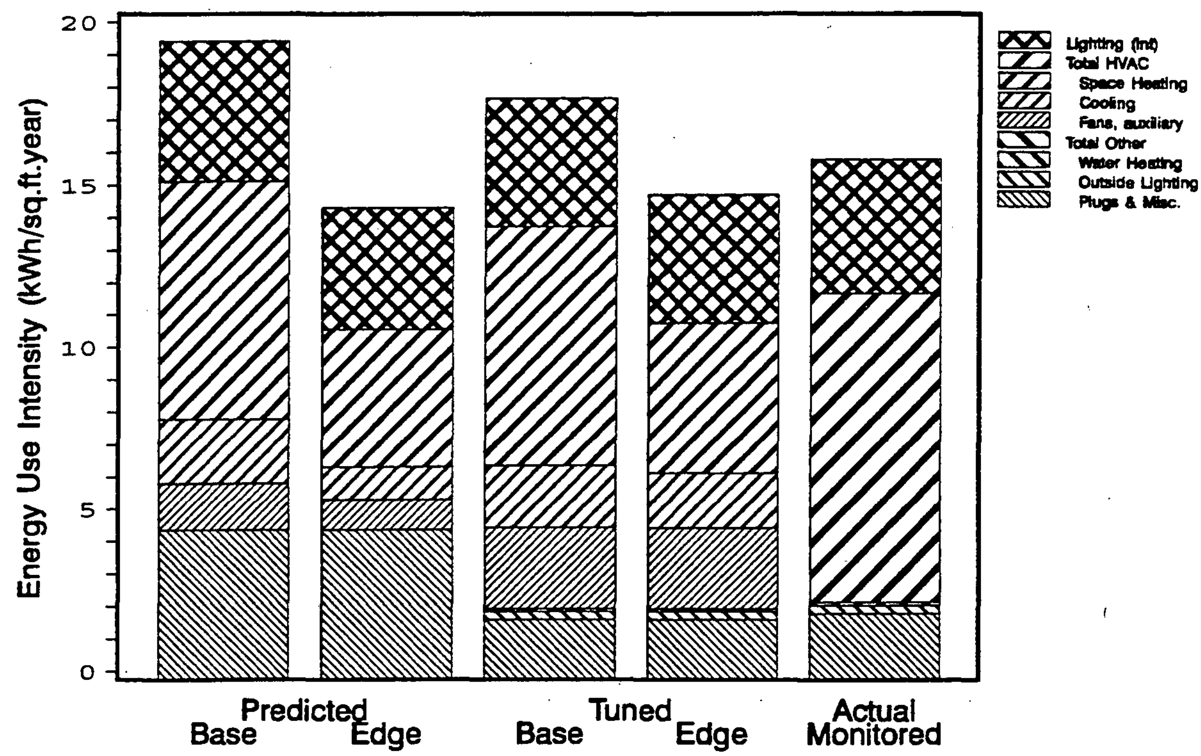
Tuned Model Approach

The tuned model evaluation methodology was developed to provide a detailed analysis of each efficiency measure based on actual building operating conditions. The model calibration procedure, known as "Monthly Consumption Tuning," begins with an as-built model developed from a documentation package and periodic, on-site operations and maintenance (O&M) audits (Ref. 2). Building schedules derived from monitored data are incorporated into the as-built model, which is run with weather data collected at each site. The model is "tuned" by adjusting assumptions to match 12 months of monitored end-use data. Examples of the tuning iterations include refining input schedules and system descriptions or changing system efficiencies to match monitored loads and energy use. Next, the site-specific weather data are replaced with long-term average weather data, Typical Meteorological Year (TMY), for the locale. A tuned baseline model is derived by defining MCS baseline conditions for each BPA funded and owner-funded measure in the tuned TMY model. Each measure is individually modeled against the tuned baseline, and the levelized cost is calculated. The measures are also modeled as a complete, interactive package.

Results for a Small Office. Figures 1 and 2 show results for the Yakima Landmark building, a two-story, 13,400 ft^2 office in Yakima, WA. Energy-use intensities (EUI) from the early predictions and tuned models are shown in Figure 1 for the Energy Edge and the hypothetical MCS baseline buildings. Actual monitored end uses, with heating, ventilation, and air-conditioning (HVAC) as a single end-use, are also shown. Some of the differences between the

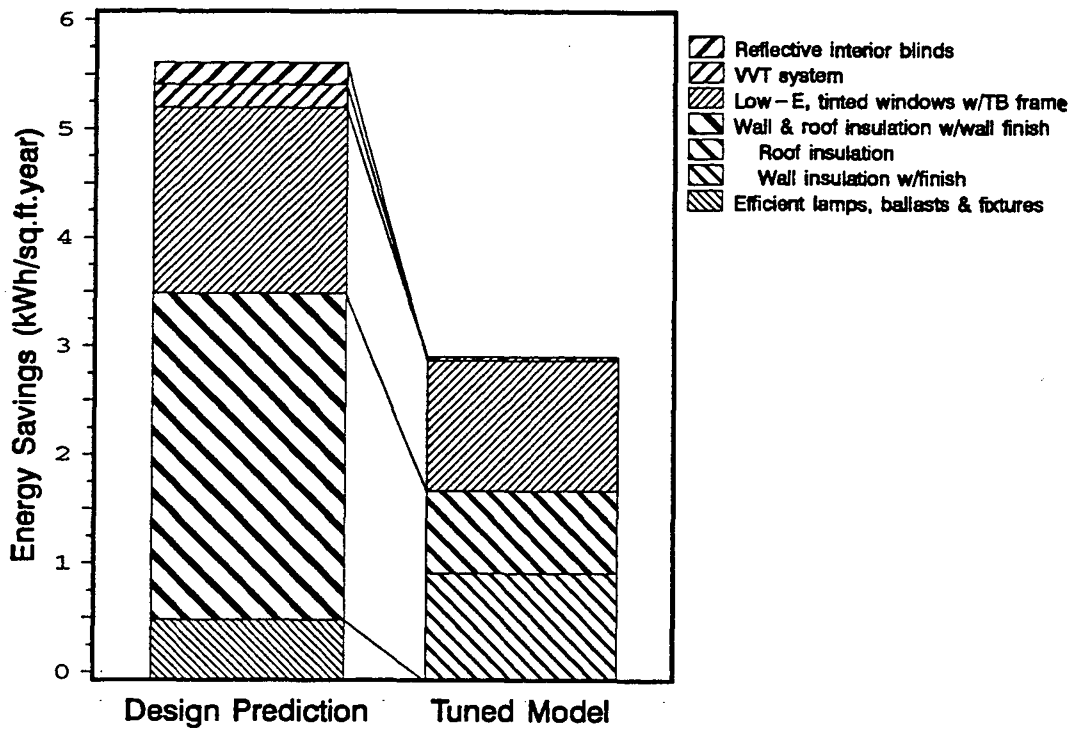
"Tuned Edge" and "Actual Monitored" end-uses is because of differences in site versus long-term average weather.

Figure 1. Design Predicted, Tuned & Monitored End-Use Energy for Landmark. The tuned Energy Edge building consumed slightly more than the design predicted Energy edge building, but the tuned baseline building consumed less than the design predicted baseline. Actual monitored end uses, with heating, ventilation, and air-conditioning (HVAC) as a single end-use, are shown.



Whole-building energy use comparisons of the predicted and tuned scenarios show a trend for this building that is consistent with the average for all 12 tuned buildings and for the subset of seven small offices. The tuned Energy Edge building consumed slightly more than the design-predicted Energy Edge building (14.3 versus 13.9 kWh/ft^2/yr), but the tuned baseline building consumed less than the design-predicted baseline (17.1 versus 18.8 kWh/ft^2/yr). End-uses that differed most significantly from predicted are ventilation (260% greater) and plug loads (about half of predicted). Total "tuned" energy savings for all measures modeled as an interactive package is 2.8 kWh/ft^2/yr; about half as much as predicted (5.5 kWh/ft^2/yr) (Figure 2). The total parametric savings (2.75 kWh/ft^2/yr), which is the sum of the savings for each measure modeled separately against the baseline, are slightly less than the interactive total. Among the first 12 buildings, parametric total savings average 10% greater than interactive, with a range from 4% less to 66% greater.

Figure 2. Energy-Efficiency Measure Savings for Landmark. Total tuned energy savings are about half as much as predicted. the early design included lighting, envelope, and HVAC measures. Only the envelope measures were evaluated in the tuned model. Efficient lighting was not installed and the VVT was dropped as a measure.



The efficiency measures installed in most of the buildings differ from the early design assumptions. At Landmark, the early design included lighting, envelope (BPA and owner-funded), and HVAC measures (Figure 2). Only the envelope measures were evaluated in the tuned model. Efficient lighting was not installed, and the power density (1.8 W/ft^2) actually exceeded both the 1985 MCS (1.5 W/ft^2) and the 1986 Washington (1.7 W/ft^2) code. The Variable-Air-Volume, Variable-Temperature (VVT) HVAC system was installed, but later reconsidered as an efficiency improvement because the VVT was not significantly better than a typical constant-volume rooftop unit. (Most VVT systems are central VVT, not rooftop VVT, and the installed system is not a good example of high efficiency VVT technology, but is a fairly common system type.) In general, tuned measure savings were less than predicted for most of the measures, as discussed below. One factor that contributes to reduced savings from the insulation is that the design prediction assumed R-6 insulation for the baseline wall, but the tuned model baseline wall is R-11.

Comparison Buildings Approach

The tuned model methodology was designed to be as objective as possible in defining a hypothetical MCS baseline building for comparison with the actual Energy Edge building.

Unfortunately, defining baseline conditions is difficult, especially for end-uses not regulated by code, such as refrigeration, cooking, or kitchen lighting. Defining baseline characteristics is also complicated by compliance options within codes. Moreover, codes contain minimal coverage of control systems, with few, if any, requirements on how to actually operate controls.

The challenge to define the appropriate baseline moves beyond code compliance toward addressing: "What would have been built without Energy Edge?" and "What is common practice?" To address these questions we compare energy use and characteristics data of both the Energy Edge and the hypothetical baseline buildings against other regional new commercial construction. Figure 3 shows energy end-uses for new small offices in the Pacific Northwest from several studies (Refs. 4, 6, and 7) and from Energy Edge. These comparison data are further discussed below. Average EUIs from seven Energy Edge small offices are shown. (Table 1 includes 6 small offices because only energy savings and no cost-effectiveness data are available for West Yakima the seventh tuned office.) On average, the actual Energy Edge buildings consume slightly more than predicted, while the tuned-baselines use less than the design-predicted baselines. Total energy savings per building are therefore less than predicted. On the other hand, the Energy Edge small offices use up to 50% less than the comparison buildings.

Table 1. Evaluation Results for 12 Tuned Energy Edge Buildings.

Building Name	City/ State	Type	Area (kft^2)	Level. cost (mills/kWh)[a]	Predicted (% Savings)[b]	Tuned	Tuned EUI ($kWh/ft^2/yr$)[c]
Thriftway*	Beaverton OR	Grocery	41.6	15	36%	27%	62
McDonald's*	North Bend WA	Fast food	4.1	24	15%	19%	132
Tieton*	Yakima WA	Grocery	3.3	29	34%	16%	55
Marsing	Marsing ID	High school	31.4	55	30%	37%	10
Dubal Beck*	Portland OR	Office	8.5	91	28%	23%	13
Evergreen	Tacoma WA	Strip retail	21.1	114	20%	5%	23
Landmark	Yakima WA	Office	13.4	140	34%	18%	15
East Idaho	Idaho Falls ID	Office/bank	5.3	174	35%	15%	14
Hollywood	Portland OR	Office/clinic	3.1	235	42%	8%	11
Edgerton	Kalispell MT	High school	55.7	311	31%	10%	13
Siskiyou*	Ashland OR	Office/clinic	3.0	344	42%	29%	9
STS	Ellensburg WA	Office/clinic	4.3	809	39%	15%	11

*Tuned % savings includes at least one additional owner-funded measures.

(a) Average levelized cost for all of the BPA funded measures.

(b) % savings estimate for restaurants and grocery stores includes all energy end-uses; for other building types the miscellaneous plug loads are not included.

(c) 11 buildings are all-electric; Thriftway includes another 25 $kBtu/ft^2$-year of gas cooking.

Predicted, Reported, and Standard Measure Cost Data

The effort with Energy Edge to develop reliable incremental measure cost data has been significant, though not as intensive as the efforts to estimate energy savings. The original plan for the analysis of measure costs was to compare the "predicted" design and construction costs with the "reported" costs from construction invoices. Inconsistencies in cost accounting and changes in measure characteristics complicated the comparisons. Problems include lack of consistency in defining costs for engineering design, amenities such as daylighting or the fire and security aspects of an energy management and control system, and indirect effects such as HVAC down-sizing. Consequently, "standard" measure costs were developed for 15 buildings using 1991 dollars for the Seattle region.

The target levelized cost of 45 mills/kWh in 1986 dollar is equivalent to 56 mills/kWh in 1991 based on the consumer price index (Ref. 8). Measure cost-effectiveness from the tuned models are primarily based on "standard" costs, though in a few cases we adjusted reported costs to 1991 dollars. Levelized costs (and measure lives) are calculated according to BPA guidelines, which are approximately equivalent to a 3% discount rate (Ref. 2).

RESULTS FROM 12 TUNED MODELS

Whole-Building Results from Tuned Models

Average predicted energy savings for the 12 tuned buildings was 35% of the baseline energy use. Tuned savings were less, at an average of 19%. Several reasons for the reduction from predicted to tuned savings are discussed below. 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 miscellaneous plug loads. However, we include two non-MCS end-uses, cooking and refrigeration, in the savings fraction for restaurants and groceries because the energy-efficiency measures interact with these end-uses. The percentage savings include both BPA and owner-funded measures. Total levelized costs for the interactive package of measures funded by BPA range from 15 to 674 mills/kWh. Four buildings met the cost-effectiveness criterion of 56 mills/kWh for the total package of measures, and only one of these four saved more than 30% of baseline energy use (Marsing High School). The most cost-effective measure packages were in the two groceries and the fast-food restaurant, which involve non-MCS end uses.

Measure Performance Results from Tuned Models

Sixty-six individual measures have been evaluated in the 12 tuned buildings (Tables 2 and 3). Both BPA-funded and owner-funded measures are included. Below we discuss results for all 66 measures, followed by a review of the data for each general category of measures, with several caveats and cautions concerning interpretation of the results.

Table 2. Energy Savings and Levelized Cost for Shell Measures.

Building	Measure Description	Predicted (kWh/ft^2-year)	Tuned (T/P)	Ratio mills/kWh	Levelized $
Dubal	Low-E windows	0.24	0.14	0.60	125
Tieton*	Thermal-break double paned	—	0.22	—	89
STS	Low-E windows	1.97	0.45	0.23	88
Siskiyou*	Thermal-break double paned	0.60	0.48	0.79	222
East Idaho	Low-E windows	0.63	0.54	0.86	226
Marsing	Low-E windows	0.51	0.65	1.26	47
Edgerton	Low-E windows	1.83	0.80	0.44	37
Landmark	Low-E windows	1.80	1.18	0.66	82
Hollywood	Wall insulation	—	0.04	—	55
McDonalds*	Perimeter insulation	—	0.06	—	20
Edgerton	Wall insulation	—	0.08	—	79
Evergreen	Wall insulation	—	0.09	—	55
McDonalds*	Wall insulation	—	0.15	—	251
Edgerton	Thermal-break wall	—	0.16	—	251
East Idaho	Wall insulation	—	0.25	—	82
Tieton*	Wall insulation	—	0.29	—	40
Siskiyou*	Wall insulation	—	0.41	—	28
Dubal	Wall insulation	0.90	0.54	0.60	47
STS	Wall insulation	—	0.62	—	635
Landmark	Wall insulation	—	0.95	—	137
Marsing	Wall insulation	—	1.12	—	90
Dubal	Roof insulation	0.37	0.15	0.39	110
STS	Roof insulation	—	0.15	—	305
Siskiyou*	Roof insulation	—	0.23	—	63
Hollywood	Roof insulation	—	0.31	—	182
Landmark*	Roof insulation	—	0.73	—	14
East Idaho	Roof insulation	—	0.75	—	59
Tieton*	Roof insulation	—	0.90	—	29
Edgerton	Roof insulation	1.52	0.92	0.61	72
Marsing	Roof insulation	—	1.03	—	42
Landmark*	Reflective interior blinds	0.21	-0.02	-0.13	na
Marsing	Reflective roofing	—	-0.02	—	na
Edgerton	Earth berming	—	0.01	—	4451
Marsing	Tinted windows	—	0.05	—	72
	Averages and Medians				
Average	Window (n=8)		0.56		115
Median	Window		0.51		89
Average	Wall insulation (n=13)		0.37		136
Median	Wall insulation		0.25		79
Average	Roof insulation (n=9)		0.57		97
Median	Roof insulation		0.73		63
Average	*Shell Measure (n=34)*		*0.42*		*253*
Median	*Shell Measure*		*0.30*		*81*

*Owner funded measure. Costs are in 1991 dollars.

Table 3. Energy Savings and Levelized Cost for HVAC, Lighting, and Other Measures.

Building	Measure Description	Predicted (kWh/ft^2-year)	Tuned (kWh/ft^2-year)	Ratio (T/P)	Levelized $ mills/kWh
	HVAC Measures				
Siskiyou	Economizer	—	0.02	—	3158
Hollywood	Economizer	0.77	0.04	0.05	415
Evergreen	Economizer	0.43	0.08	0.19	530
East Idaho	Economizer	0.93	0.11	0.12	1163
McDonalds*	Economizer	—	1.28	—	54
Hollywood	Ground-source heat pump	0.47	-0.22	-0.47	na
East Idaho*	High-COP air-air heat pump	0.19	0.27	1.42	149
STS	Water-source heat pump	2.23	0.58	0.26	1102
Siskiyou	High-COP air-air heat pump	—	0.91	—	158
Marsing	Water-source heat pump	1.31	1.99	1.52	32
Edgerton	VAV reheat boxes	—	-1.11	—	na
Edgerton	Optimal start/stop clock	—	0.03	—	67
McDonalds*	Exhaust fan ("Supervent")	1.24	0.16	0.13	436
McDonalds	Exhaust heat recovery	12.73	6.91	0.54	6
	Lighting Measures				
Edgerton	Efficient lamps, ballasts & fixtures	1.21	0.21	0.17	52
Siskiyou	Efficient lamps, ballasts & fixtures	—	0.25	—	665
Dubal	Efficient lamps, ballasts & fixtures	—	0.67	—	100
Marsing	Efficient lamps, ballasts & fixtures	1.13	0.94	0.83	23
Evergreen	Efficient lamps, ballasts & fixtures	1.44	1.12	0.78	50
McDonalds	Efficient lamps, ballasts & fixtures	—	9.37	—	23
Dubal	Occupancy sensors	—	0.04	—	402
Hollywood	Occupancy sensors	1.05	0.63	0.60	51
Thriftway	Effic lamp, ball., fixt. & occ. sens.	4.61	0.98	0.21	270
Tieton	Daylighting controls	20.60	1.04	0.05	24
	Other Measures				
McDonalds	Exterior lighting	0.53	1.01	1.91	41
McDonalds	Heat pump water heater	6.09	11.20	1.84	6
Tieton	Cooler & freezer insulation	—	0.79	—	33
Thriftway	Efficient compressor-motors	—	3.49	—	36
Tieton	Refrig. heat recov. & pressure controls	—	3.52	—	51
Tieton	Humidistat controls in door heaters	10.6	3.55	0.33	11
Thriftway	Floating-head pressure-controls	—	9.03	—	2
Thriftway	Refrigeration heat recovery system	4.85	9.58	1.98	3
	Averages and Medians				
Average	Economizer (n=5)		0.31		1064
Median	Economizer		0.08		415
Average	Heat pump (n=5)		0.71		360
Median	Heat pump		0.58		154
Average	*HVAC (n=14)*		*0.79*		*606*
Median	*HVAC*		*0.14*		*287*
Average	Efficient lamp, ballast, & fixtures (n=6)		2.09		152
Median	Efficient lamp, ballast, & fixtures		0.81		51
Average	*Lighting (n=10)*		*1.53*		*166*
Median	*Lighting*		*0.81*		*52*
Average	*Refrigeration (n=6)*		*4.99*		*23*
Median	*Refrigeration*		*3.54*		*22*

*Owner funded measure. Costs are in 1991 dollars.

Average energy savings for all 66 measures is 1.10 kWh/ft^2/yr, median savings is 0.51 kWh/ft^2/yr, and the range is from -0.22 kWh/ft^2/yr (ground source heat pump at Hollywood) to 9.58 kWh/ft^2/yr (refrigeration heat recovery at Thriftway). Average and median levelized costs are 277 mills/kWh and 72 mills/kWh, respectively. Since four measures had zero savings we have levelized costs for 62 measures; 29 were below the 56 mills/kWh target. The measures are grouped into four general categories: shell, HVAC, lighting, and refrigeration plus other. The refrigeration improvements had the highest area-normalized energy savings and lowest levelized cost. The lighting measures performed better than the shell measures, with the HVAC measures the least cost-effective.

Predicted energy savings are shown for 29 measures. Tuned savings average at 61% of the predicted savings, listed as a ratio (T/P) in the tables. The median ratio of T/P is 0.54, with a range from -0.49 to 1.98. roof insulation combinations.

Shell Measures. Average energy savings among the 34 shell measures was 0.42 kWh/ft^2/yr, median savings was 0.30 kWh/ft^2/yr, with average and median levelized costs of 253 and 81 mills/kWh. The window measures consist of low-emissivity glazing replacing double-paning (or single-paning at the two schools) and double-paning with thermal-break frames in place of double-paning without thermal breaks. The most common wall insulation measure consists of improving a baseline R-11 wall to R-19, and the most common roof insulation measure was the use of R-30 instead of R-11 or R-19. The window and roof measures tended to save more energy than the wall insulation, and were slightly more cost-effective. The three measures to reduce solar gains did not perform well, probably because of higher than predicted heating loads and lower cooling loads.

One reason the measures saved less than predicted is there were many changes in both the measure and the baseline shell characteristics. At East Idaho, for example, the baseline glazing in the early prediction was single-paning, but double-paning was used in the tuned model baseline. At Dubal Beck, the baseline wall insulation in the early prediction was R-7 and the baseline in the tuned model was R-11. Similar changes occurred at Hollywood and Landmark. The effective insulation values installed at STS and Evergreen were much less than the insulation in the early predictions. At Evergreen, the effective roof insulation was reduced because a roof leak caused water damage to the insulation, which was never repaired. The status of failed or partially-failed measures has been difficult to track. Consequently, the treatment of failed measures is somewhat irregular in the tuned models. There are no energy savings data for the failed roof measure at Evergreen, although the insulation cost was included in the levelized cost of the interactive package listed in Table 1.

HVAC Measures. The 14 HVAC measures include economizers, high-COP ground-, water-, and air-source heat pumps, and several miscellaneous measures. Average and median levelized costs are 606 and 287 mills/kWh, respectively. HVAC measures are difficult to evaluate since the energy savings are strongly dependent on how the actual and baseline HVAC systems are modeled within the simulations. There are many shortcomings in how well the simulations reflect actual system operation and control sequences. Modeling and commissioning problems with the economizers and heat pumps are described in References 1 and 5. For example, one problem in evaluating the heat pumps is the difficulty with modeling back-up electric resistance heat within DOE-2.1. Many buildings with air-to-air heat pumps use electric-resistance heat during morning warm-up. We suspect that the use of resistance heat is underestimated in some of the baseline simulations. This may explain the negative savings of the ground-source heat pump at Hollywood, further discussed below. A related issue is that the use of proper

HVAC controls, such as ramp-up thermostats to maximize the use of compressor heat and minimize resistance heat during morning warm-up, can save as much or more energy than the use of high-COP equipment. We have found that the methods by which economizers are specified, installed, and controlled greatly influence achievable energy savings. Many of the economizers have had operating problems, including dampers not opening completely, inoperable damper linkages, and suboptimal control settings. Results from analysis of the HVAC measures demonstrate the need for commissioning and improved O&M.

The negative savings of the variable-air-volume (VAV) system at Edgerton High School is similar to the VVT at Landmark, described above, because it is not a good example of an efficient VAV system. The baseline 2-pipe fan-coil system at Edgerton was found to use less energy than the VAV system. VAV systems tend to save energy when used with central cooling and economizers, but the school has no cooling, and the HVAC comparison is based on heating only.

Lighting Measures. Average and median energy savings among the ten lighting measures were 1.53 and 0.81 kWh/ft^2/yr, with average and median levelized costs of 166 and 52 mills/kWh. Seven of the measures consist of reducing lighting power densities (LPD) below the MCS code values; two are occupancy sensors and one measure is listed as daylighting.

One reason the energy savings from low LPDs were not as great as predicted is that in five of the seven buildings the installed LPD exceeded the prediction. The high energy savings for efficient lighting at McDonald's are anomalous because the baseline LPD for the kitchen lighting at 5.4 W/ft^2 is probably high for fast-food kitchens. Kitchen lighting is exempt from code, so an assumption must be made about common practice, which greatly influences the measure performance. Future evaluation efforts should carefully evaluate baseline assumptions, using regional building characteristics and energy-use data whenever possible.

Energy savings from occupancy sensors have been lower than predicted and difficult to model. Direct analysis of end-use metered lighting data does not typically provide feedback on occupancy sensors because only a small fraction of the lights on each circuit are controlled by the sensors. Anecdotal data and engineering estimates have been used to model the occupancy sensors. Many of the sensors were poorly calibrated and dropped from the tuned models. One success story, however, is the occupancy sensors at the Director building (not included in Table 1). Lighting load profiles on the floors at Director with occupancy sensors have shown significant savings (over 50%) compared to the upper floors where the lighting sweep controls, that turn off lights at night, were inoperable. Even after the sweeps were repaired the daily lighting loads were lower for floors with occupancy sensors. Anecdotes about occupancy sensors are amusing and plentiful. One favorite at the Montgomery building is the case of salesmen who were required to be in their sales area during a fixed work schedule. The salesmen rigged fans with paper streamers near the motion sensors to keep the lights on; the fans were controlled with a timeclock set to their work schedules.

There have been problems with the daylighting systems at six of the seven Energy Edge buildings with dimming controls. Most complaints are from dissatisfaction with stepped controls; more advanced continuous dimming designs are less noticeable. Daylighting savings at Tieton (Table 2) are unique because the designers justify lower lighting levels and LPDs because of the availability of daylight from the skylights. Plus, they claim that low nighttime light levels are appropriate for customers who have come in from outdoors. The dimming controls at Tieton are inoperable, but the LPD is below the MCS code value, from which the savings were derived. The energy savings, therefore, cannot be directly attributed to the use of daylight to replace electric light.

Refrigeration and Other Measures. Average and median energy savings among the refrigeration and other miscellaneous measures were high, at 4.99 and 3.54 kWh/ft^2/yr, respectively. Average and median levelized costs at 23 and 22 mills/kWh are well within the cost-effectiveness criterion of 56 mills/kWh. One irony is that refrigeration is not covered in the MCS code, and is somewhat outside the primary objectives of Energy Edge. Refrigeration is more similar to industrial process loads than most commercial building end uses.

REASONS FOR DIFFERENCES IN PREDICTED AND TUNED SAVINGS

Sorting through the reasons why savings estimates differ from predicted is complicated by the lack of information on the assumptions used in the early predictions. Future programs would benefit from standardized guidelines to ensure consistency in modeling approaches. Four general reasons tuned savings differ from predicted are:

- Measure and baseline characteristics change between design and installation.
- Building operating conditions change.
- Modeling techniques to represent the measure and the building change.
- Measures fail or are poorly commissioned, operated, and maintained.

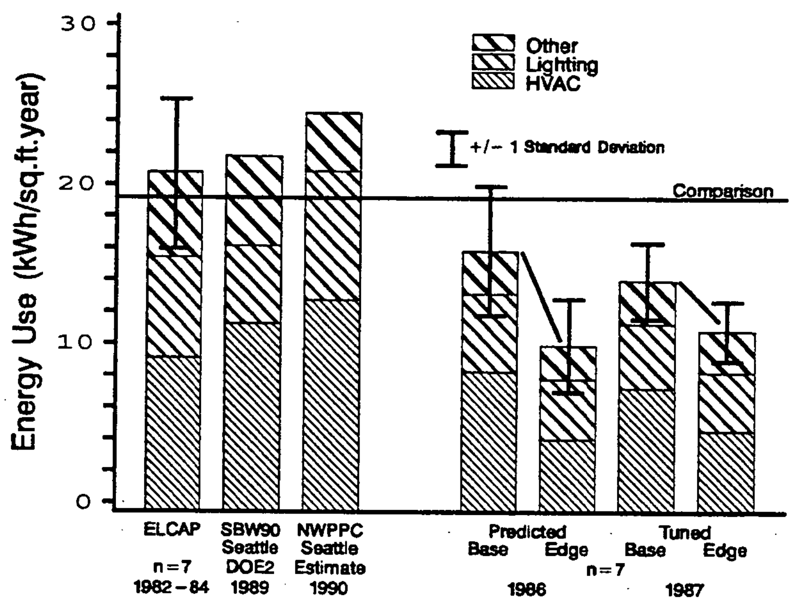
Four of the 12 buildings had fewer energy-efficiency measures in the tuned model than predicted. We mentioned examples of HVAC measures being dropped from the tuned model; vestibules were also dropped as measures because of uncertainties about modeling changes in infiltration. Perhaps the most significant factor decreasing energy savings is the change in measure characteristics. Several examples were provided above. Baseline measure characteristics have also changed. HVAC energy use was underpredicted for nine of the 12 tuned buildings, showing a general bias that influences the performance of shell and HVAC measures. Another factor for reduced savings is that the measures in the tuned models reflect actual conditions which are often not as good as ideal conditions. We see a methodological hysteresis in the modeling: starting with a hypothetical baseline model and deriving savings for each measure rarely produces the same results as starting with an actual building and re-deriving the baseline for the actual building conditions. Actual buildings are not as "well behaved" as modeled buildings.

COMPARISON OF BUILDING ENERGY AND CHARACTERISTICS DATA

Despite lower than expected energy savings from individual measures, the energy-use intensities of the buildings are lower than other regional comparison data for new buildings. We present examples of how the the end-use data (Figure 1) relate to building characteristics, illustrating that the low energy use of the Energy Edge small offices is related to the presence of the efficiency measures. We suggest it is likely that the MCS baseline buildings are more energy-efficient than 1986 common practice. Furthermore, the Energy Edge offices have low-energy characteristics compared to typical small offices built in 1990, based on comparison with a recent code compliance study for Washington and Oregon (Ref. 3). (We are examining z-statistic tests to determine if there are statistical differences in the means from various comparison group samples.)

Although higher than predicted, six of the seven Energy Edge small offices have LPDs between 1.3 and 1.7 W/ft^2, and lighting energy use is lower than in comparison buildings (Figure 3). For example, the ELCAP small offices built between 1982 and 1984 have LPDs between 2 and 3 W/ft^2 and consume correspondingly more energy for lighting. The prototype designed by SBW represents 1989 practice at 1.7 W/ft^2, with lighting energy use between the ELCAP and Energy Edge averages. The code compliance study showed a median small office LPD was 1.7 W/ft^2, meeting the Washington and Oregon codes, but not the MCS target of 1.5 W/ft^2. Based on these data, the NWPPC lighting EUI for small offices appears high for 1990 practice.

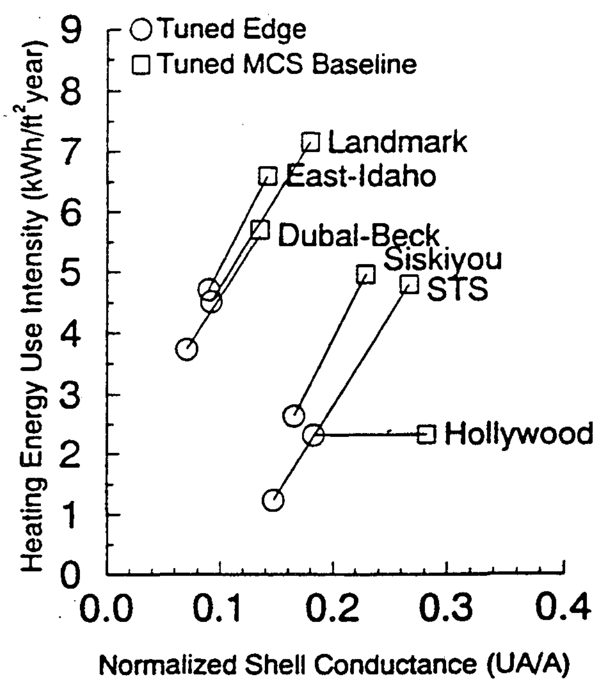
Figure 3. Energy Use of Energy Edge Small Offices and Regional Comparison Buildings. The actual Energy Edge buildings consume slightly more than predicted, while the tuned-baselines use less than the design-predicted baselines.



Comparisons of HVAC energy use are more complex than lighting because of differences in HVAC systems, weather, shell characteristics, and building loads. Surprisingly, comparing shell characteristics and heating energy use has been reasonably straightforward because a significant sample of the buildings are in the Seattle and Portland areas, which have similar climates. We have estimated an average envelope UA based on the wall, roof, and window characteristics, normalized by building floor area. The average UA/A for the Energy Edge small offices is 0.12, and heating is 3.2 kWh/ft^2/yr, with total HVAC at 5.9 kWh/ft^2/yr. By comparison, the average ELCAP UA/A is 0.19, with average heating and HVAC EUIs of 3.2 kWh/ft^2 and 8.5 kWh/ft^2/yr (all are in the Seattle area). Average heating and cooling degree days are slightly higher for the Energy Edge buildings. HVAC type is also important; as expected, heating energy use is higher in buildings with electric-resistance heat compared to those with heat pumps. The SBW UA/A is high at 0.32, with correspondingly high heating and HVAC end-uses of 7.8 and 11.3 kWh/ft^2/yr for the electric-resistance case.

As an alternative to the tuned model evaluation, we plan to derive an estimate of average energy savings for the efficiency measures in the Energy Edge small offices based on these comparisons to define an average building that might have been built in 1986. It is also useful to compare results from individual buildings to identify problems with the evaluation. Figure 4 shows the UA/A versus heating energy use for six offices; both the tuned Energy Edge and the tuned MCS baseline values are shown. All of the buildings show similar reductions in heating energy for the change in UA (i.e., similar slope), except Hollywood where results from the tuned model produced negative energy savings for the ground-source heat pump. The comparison of the heating versus UA slopes illustrates that the tuned baseline heating EUI at Hollywood is anomalous and appears to be an unreasonably low baseline. Two of the three highest curves are the buildings with electric-resistance heat (Dubal and Landmark); the third is a heat pump building in the coldest climate (7110 base 65 heating degree days in Idaho Falls).

Figure 4. Heating Energy Use versus Envelope UA/A for Small Offices. The difference in heating EUI is the heating energy saved. All show similar reductions in heating energy for the change in UA, except Hollywood with the anomalous negative energy savings for the ground-source heat pump.



At first glance, an alternative evaluation methodology based on deriving energy savings from a sample of comparison buildings looks promising. However, we have looked most closely at small offices, working with a fairly homogeneous set of buildings. Further analysis is needed to examine how this technique might apply to other building types.

CONCLUSIONS

The Energy Edge evaluation provides a wealth of information on the performance of energy-efficiency measures in new commercial buildings. Under the tuned model evaluation methodology only one of the 12 buildings met the project objective of reducing energy use by more than 30% at less than 56 mills/kWh. Average savings was 19% of baseline energy use. Twenty-nine, or 44%, of the 66 measures met the levelized cost criterion. We review factors that contribute to the uncertainty regarding measure savings and suggest methods to improve future evaluations. We have grappled with how to define the appropriate baseline. Baselines defined by code are subject to interpretation and do not cover all pertinent building energy systems, especially controls and miscellaneous end-uses. Despite the low energy savings from individual measures, the energy-use intensities of the buildings are lower than other regional comparison data for new buildings. As an alternative to tuned modeling, we are compiling regional comparison data to derive an alternative energy savings estimate for the program. Another factor in the evaluation is that end-use metering and simulation modeling is not the same as technology metering. More on-site, field analysis using flip-flop or on-off tests of measures would provide additional insights into their energy performance.

Many of the building systems would have benefited from better commissioning during start up. For example, lighting designers should have examined the problems with the daylighting and occupancy sensors during the first year of operation, and made modifications. Similarly, the economizers need to be checked periodically and their set points readjusted.

Results from Energy Edge are being used by BPA to provide guidance for commercial program design, to upgrade commercial codes, and to revise conservation supply curves. The data are also used to identify problems with individual measures to improve future applications and define commissioning, control, and O&M procedures to optimize energy savings. Questions remain regarding how these measures will perform over time.

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