The Performance of the Energy Edge Buildings: Energy Use and Savings

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The twenty-eight buildings in the Energy Edge Program provide unique opportunities for studying the energy performance of new commercial buildings. In this paper we focus primarily on the results of the data analysis, and, to a lesser degree, on the analysis methodology. The questions we investigate include: How does the actual energy use compare to the predicted values (both for the building total and by end use)? How do these buildings compare to other new buildings in the region? How do these buildings change over time? We address these questions by examining billing data for 27 buildings (in some cases up to four years of records), hourly sub-metered end-use data for ten buildings, and results from simulation models from five of the buildings. We analyze the energy savings attributable to the conservation measures through direct analysis of the monitored data and from simulation models that have been "tuned" with the monitored data to reflect the actual operation of the building. Among the key findings has been the observation that while the buildings are using roughly 10% more energy than predicted, on average, they are consuming 30% less energy than typical new construction in the region. In reviewing the results for 20 categories of energy conservation measures, we discuss such issues as the difficulties in defining baseline conditions, and the problems in simulating certain strategies, e.g., daylighting and space-conditioning controls. We suggest simplified approaches that could be of use for the next generation of new commercial building research, demonstration, and design-assistance programs.

Introduction

The Energy Edge Project was initiated in 1986 to demonstrate cost-effective energy savings in new commercial buildings in the Pacific Northwest (Miller et al. 1990). The 28 Energy Edge buildings are typical of new commercial construction in the region: offices, schools, fast-food restaurants, clinics, supermarkets and convenience stores, and range in floor area from 2000 to over 1,000,000 ft^2 (200-100,000 m^2).

By January 1992, monitored end-use data have been collected--in some cases for over three years--at eighteen of the buildings. Utility billing data have been analyzed for 27 buildings (the 28th building, Gateway Tower in Seattle, is only recently occupied), and as many as four energy audits per building have been completed. The calibration of the computer simulation models has been completed for ten buildings, although we discuss only the first five buildings in this paper. Cost data for the individual conservation measures are being compiled that will allow for analysis of predicted, actual, and standardized costs. Finally, a post-occupancy evaluation of occupant satisfaction was completed at seven of the office buildings (Heerwagen et al. 1991).

Previous reports (Miller et al. 1990, Harris et al. 1990, Diamond et al. 1990a) review the lessons learned in the design and implementation of the program, and give preliminary findings on the performance of the buildings and energy-saving measures. This paper brings together the individual data streams and presents a summary of our current understanding of the impact of the Energy Edge project (Diamond et al. 1992).

Building Performance

Our analysis of the energy performance of the Energy Edge buildings is based on three types of comparisons: (1) Comparisons of actual energy use to predicted energy use, (2) Comparisons of actual energy use with energy use of similar new buildings in the region, based on end-use metering and prototype simulation, and (3) Comparisons of actual energy use with hypothetical baseline buildings that meet the Model Conservation Standards (MCS) code requirements.

While the third comparison was originally thought by the program designers to be the most important, we find the first two comparisons to be more informative in providing a benchmark for overall building performance. The third comparison strategy is hampered by the difficulty in interpreting the code to define the baseline building. In addition to presenting our findings from these comparisons we include in this section a discussion on code compliance and results from the surveys of occupant satisfaction.

Comparing Actual to Predicted Energy Consumption

We begin the comparative analysis by analyzing the energy consumption based on the utility bills, comparing the design-stage simulation estimates with actual consumption. These comparisons provide an initial indication of the overall performance of the buildings, while also revealing the inherent limitations of these types of comparisons. Differences in operating conditions, building characteristics, and levels of service provided cannot be taken into account when comparing the design predictions with the actual consumption based solely on the utility bills.

We have up to four years of utility billing data for the Energy Edge buildings, which allows us to examine the changes in consumption over time. In order to compare buildings that vary widely in size, we use the annual Energy Use Intensity (EUI), which is the building's energy consumption normalized by its conditioned floor area (kWh/ft^2-yr).

Table 1 shows the multiyear electricity consumption data for the 27 occupied buildings. The data are presented in two ways: as consumption compared to previous year and as consumption compared to predicted use. Figure 1 summarizes this table by presenting the mean and median consumption for both the entire sample and for the nine buildings for which we have four years of data.

The energy consumption of the 27 buildings in their first year of operation was 10% higher on average than their predicted values. Eleven buildings used less than predicted, 16 used more than predicted. Nine buildings were within 10% of their predicted values.

By the second year, energy bills were 23% higher, on average, than their predicted values. We saw no readily apparent factor, e.g., type or size of building, to explain which buildings used more energy and which used less energy than predicted, although buildings which had predicted very low energy use tended to be the farthest from actual consumption. Of the 16 buildings that used more energy than predicted in their second year, 14 used more energy than predicted in their first year of operation.

The energy consumption of the 27 buildings increased 20%, on average, in their second year of operation. The high rate of increase in year 2 at the Director Building and at Eastgate are probably due to increased occupancy. While the Director building had the highest percentage increase in consumption from the starting year, total energy use was still less than predicted. At Eastgate, the increase in consumption led to a level of energy use nearly twice the predicted value.

We have three years of utility bills for 21 of the buildings. The mean value for the group rose from 23% above predicted energy use in year 2 to 31% above predicted in year 3. We have four years of utility bills for 10 of the buildings. By year 4, the mean energy consumption is 52% greater than predicted.

From the utility billing data we can only speculate why the energy use increased in nearly every building. To determine if the increases are due to changing occupancy patterns, increased equipment densities, or failures of the measures, we plan to look at how specific end uses change over time. In the next section we look at the primary end uses, but we do not yet have enough information to track these end uses over time.

To better understand the differences between predicted and actual EUIs, we investigate the end use data. We have monitored, sub-metered data for end-use comparisons from ten buildings: eight offices, a school and a fast-food restaurant. To simplify the comparisons, we have divided the electricity consumption into primary end uses: (1) Lighting (interior only), (2) Total HVAC (heating, cooling, fans, etc.), and (3) Other (hot water, plugs, exterior lighting, miscellaneous). Eight of the ten buildings are all-electric; two of the offices have back-up gas-fired boilers, but as their use is small, we consider total electricity use to be the total building energy use.

Lighting. The energy used for interior lighting represents 32% of the total electricity consumption for the eight office buildings for which we currently have data. Of the three end uses, lighting had the best record of predicting actual consumption, on average. For the ten buildings, the measured mean lighting consumption (4.15 kWh/ft^2-yr) was 8% higher than the predicted value (3.84 kWh/ft^2-yr). For the eight office buildings, the actual consumption was within 2% of predicted. The individual buildings ranged from a 59% underprediction (Edgerton School) to 31% overprediction (Siskiyou Clinic).

Table 1. Energy Use for the Energy Edge Buildings, Comparisons of Actual with Predicted and Previous Year. Data are 12-Month Moving Averages

		Energy Edge EUI (kWh/ft^2-yr)		Annual Comparisons						
				1st to	2nd to		3rd to		4th to	
Building Name	Billing Started	Pred.	1st Mov. Avg.	Pred.	1st	Pred.	2nd	Pred.	3rd	Pred.
Bellevue	05 89	20.90	13.90	0.67	1.04	0.69				
Boardwalk	07 88	18.50	33.00	1.78	1.11	1.98				
B.King	09 88	107.00	112.10	1.05	1.04	1.09				
Caddis	11 86	9.00	8.80	0.97	0.69	0.67	1.30	0.87	1.17	1.02
Director	03 88	10.00	2.70	0.27	3.37	0.92	1.31	1.21		
Dubal	06 87	10.10	13.20	1.31	1.05	1.37	1.05	1.44	0.95	1.37
Eastgate	06 87	8.40	9.70	1.15	1.77	2.03	0.89	1.81	1.13	2.04
E.Idaho	04 87	9.10	15.40	1.69	1.05	1.78	0.89	1.59	0.99	1.57
Edgerton	08 87	14.10	14.80	1.05	0.97	1.02	0.95	0.97		
EPUD	02 89	7.60	9.80	1.29	1.03	1.33				
Evergreen	09 87	14.00	10.10	0.72						
EWEB	07 88	25.40	16.60	0.65	1.10	0.72	0.96	0.69		
Hollywood	09 87	8.30	8.00	0.97	1.06	1.03	0.88	0.91		
Landmark	02 87	13.90	13.40	0.96	1.05	1.02	1.10	1.12	1.07	1.20
McDonalds	11 87	156.30	125.30	0.80	1.10	0.88	1.06	0.94		
Marsing	10 87	9.30	8.90	0.96	1.02	0.98	1.24	1.22		
Montgomery	10 87	8.20	9.20	1.13	1.48	1.67	1.13	1.89		
ORyan	08 86	9.70	13.10	1.35	1.23	1.68	1.72	2.87	0.82	2.34
Riverpark	10 87	17.60	18.80	1.07	0.98	1.05	1.02	1.06		
Roger	12 87	11.70	20.50	1.75	1.08	1.89	1.03	1.96		
Siskiyou	04 87	10.80	9.80	0.90	1.09	0.98	0.90	0.88	0.96	0.85
Skippers	01 87	35.80	43.70	1.22						
STS	04 87	13.20	14.20	1.08	0.71	0.76	0.98	0.75	1.38	1.03
Thriftway	10 87	59.30	40.20	0.68	0.99	0.67	0.98	0.66		
Tieton	04 88	75.40	85.90	1.14	0.95	1.08	0.93	1.01		
Waves	03 87	11.40	21.10	1.85	1.03	1.91	1.05	2.01	1.05	2.11
W.Yakima	12 86	7.80	10.20	1.31	1.21	1.58	1.02	1.61	1.07	1.72
N		27	27	27	25	25	21	21	10	10
AVG				1.103	1.2	1.231	1.1	1.308	1.1	1.525
Std. Dev.				0.366	0.5	0.443	0.2	0.545	0.1	0.490

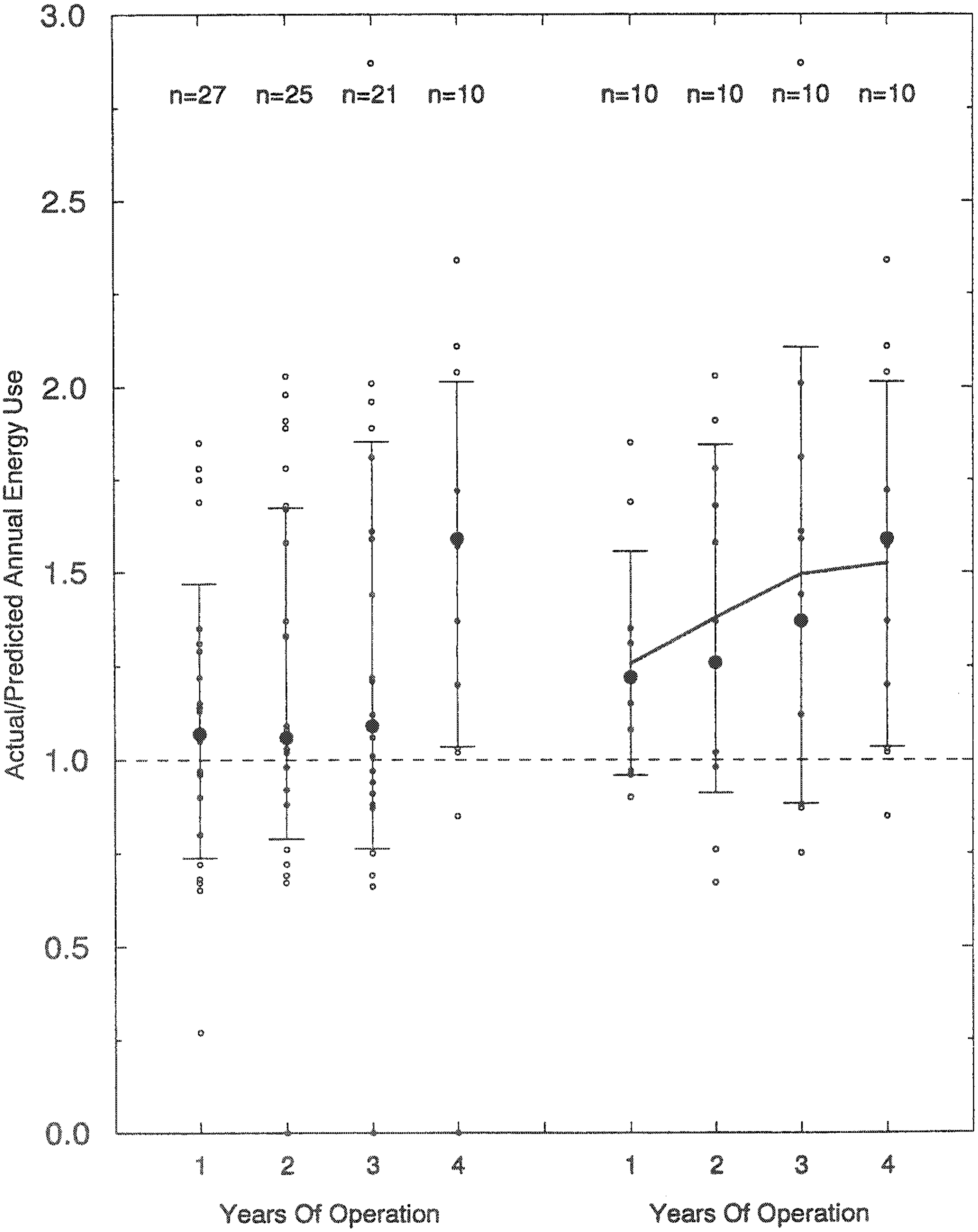

Figure 1. Energy Consumption (from utility billing data) Over Time. Figure shows individual buildings (small circles), medians (solid dots), one standard deviation above and below the mean (dashes), and a solid line connecting the means for the buildings for which we have four years of data.

HVAC. The energy used for heating, cooling, fans and pumps represents 45% of the total electricity consumption for the office buildings. The actual and predicted HVAC electricity EUIs were within 11%, on average, with a mean HVAC consumption of 7.57 kWh/ft^2-yr compared to the predicted mean of 6.79 kWh/ft^2-yr. For the eight office buildings, the actual mean was also within 11% of predicted. The individual buildings ranged from a 134% underprediction (East Idaho Credit Union) to 30% overprediction (STS office building).

Other. The "other" category includes hot water, exterior lighting, plug loads and miscellaneous end uses, representing 22% of the total electricity consumption for the office buildings. For the eight office buildings, actual consumption was 22% more than predicted. Individual buildings showed a spread ranging from a 46% underprediction (Dubal Beck) to 40% overprediction (STS).

Comparing the Energy Edge Buildings to Other Buildings in the Region

Comparing the actual energy consumption of the buildings with the predicted energy consumption is limited by our ability to correct for the differences between the design predicted and actual building for such factors as design, weather, construction, and use. Because of these limitations we find it useful to look at building end-use data from other sources within the Pacific Northwest. These comparisons provide benchmarks for both the actual building and for the design predictions.

The most useful data available for comparison buildings includes the monitored data collected under the ELCAP program (Taylor 1989) and the 1989 building stock end-use characterization developed for Bonneville (SBW Consulting, Inc. 1990). These two data sets (based on actual new construction), together with the forecasts for new construction prepared for the Northwest Power Planning Council (NWPPC 1991), provide the benchmark for our comparisons with the Energy Edge buildings.

Figure 2 shows total energy consumption for the twelve office buildings over a three year period, with their average predicted consumption, the predicted mean consumption for the MCS baseline buildings, and the three indices representing regional new construction. From Figure 2 we can see that energy use in the Energy Edge offices is generally increasing over time, but is still much lower than other new buildings in the region. We also see that predicted MCS baseline buildings are also low-energy buildings compared to regional stock.

Figure 3 shows the mean end-use energy consumption for the eight Energy Edge office buildings for which we have end-use data, together with the end-use data from ELCAP, NWPPC and SBW. The figure shows that the Energy Edge office buildings are low-energy buildings for all end uses, as compared to the actual and forecasted consumption for new offices in the region.

Total heating and cooling energy use is nearly half the use of the comparison buildings and a third of the Council's forecast. Lighting energy use is half the Council forecast and significantly less than the comparison buildings. Overall, the Energy Edge office buildings are using nearly 50% less energy than their measured and forecasted counterparts.

Comparisons of Actual Energy Consumption with the MCS Code Baseline

The original plan for the Energy Edge buildings was to demonstrate that the buildings could consume 30% less energy than an equivalent building built to the MCS code, at a cost of conserved energy less than 45 mills per Kilowatt-hour. A "baseline building" was defined for each building to provide a basis for comparison.

A difficulty in comparing the Energy Edge buildings to the MCS code is the lack of standard definitions for a baseline, forcing the modeler to make several assumptions in order to create a baseline building. There are also ambiguities because the MCS do not apply to all end uses.

For the five buildings for which new MCS baselines were created, consumption averaged 24% less than baseline for the primary MCS end-uses (HVAC and lighting), approaching, but not achieving, the original goal of 30% less energy use. The savings are linked to the definition of the new baseline, and for this reason we prefer to look at actual comparison buildings in demonstrating that the Energy Edge buildings are, in fact, low-energy use buildings (Figure 2).

Code Compliance Issues

One of the surprising findings in looking at the data from the operations and maintenance audits was the number of instances where the buildings did not meet the requirements for the MCS baseline building. For example, when the Energy Edge buildings were designed, the MCS specification for office building lighting power density (LPD) was 1.5 W/ft^2. The predicted values ranged from 1.1 to 1.5 W/ft^2, with a mean value of 1.3. The actual installed

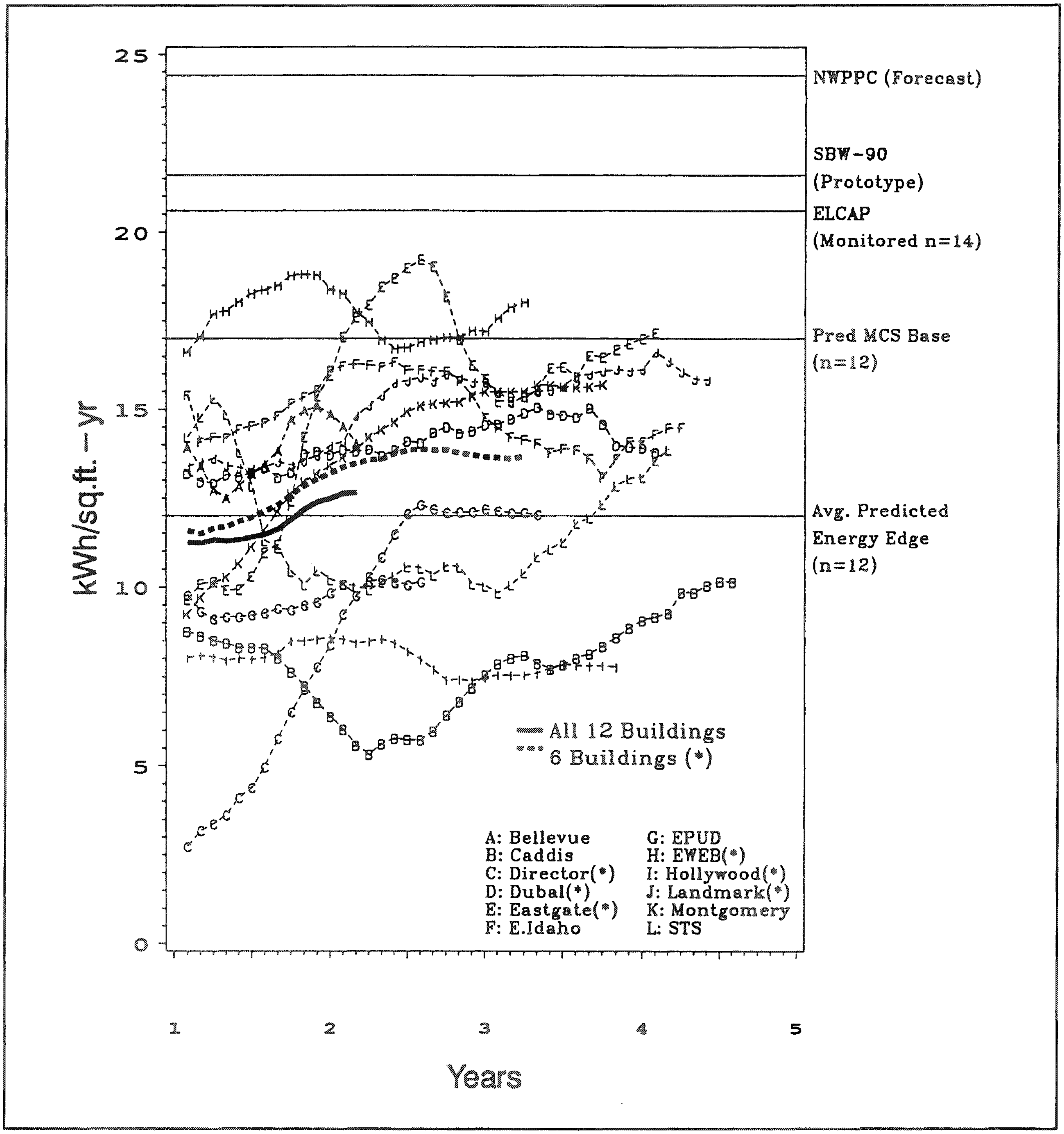

Figure 2. Energy Consumption Over Time for Twelve Energy Edge Office Buildings With Comparison Buildings. ELCAP data are from 14 post-1980 all electric buildings. NWPPC are the 1989 forecast numbers for new construction. SBW-90 are prototypes based on 1989 current practice, with Seattle weather.

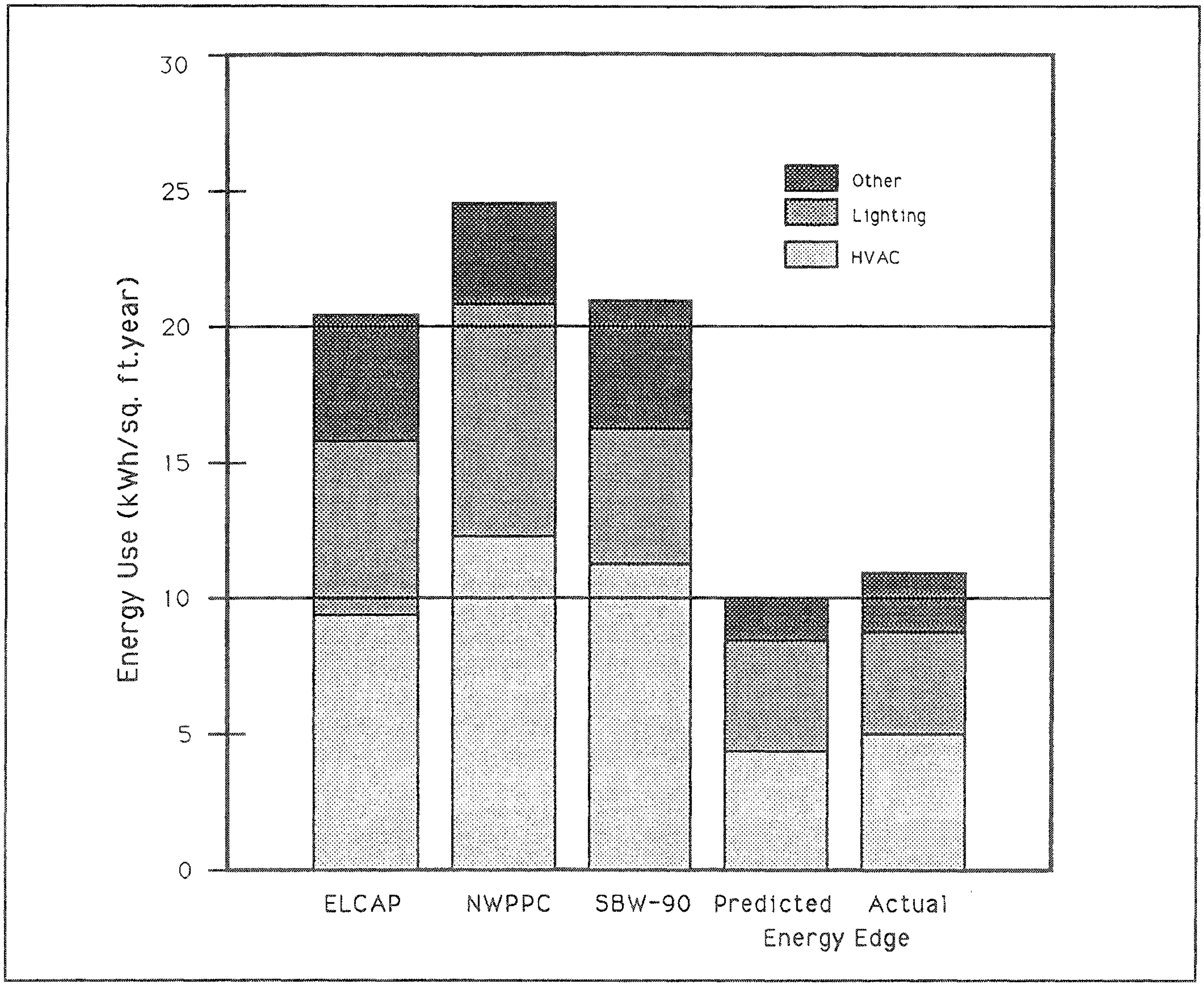

Figure 3. End Use Energy Consumption for Eight Energy Edge Office Buildings With Comparison Buildings. ELCAP data are from 14 post-1980 all electric buildings. NWPPC are the 1989 forecast numbers for new construction. SBW-90 are prototypes based on 1989 current practice, with Seattle weather.

LPDs, based on building audits, ranged from 1.1 to 3.0, with a mean of 1.8, which is greater than the code value of 1.5! In fact, six of the eight offices had LPDs greater than the code allowance, and these buildings were part of a demonstration project, that, in theory, would have been scrutinized more carefully during code compliance checks.

We have found similar instances with mechanical systems in the Energy Edge buildings as well. For example, the HVAC system at Edgerton School is less efficient than the MCS baseline. The finding that code violations occurred in the construction of the Energy Edge buildings--and by extension, in other new construction--has important implications for utility forecasting and planning for future conservation acquisition programs.

Occupant Satisfaction with the Building Performance

The ultimate goal of the Energy Edge program is to accelerate the design and construction of new energy-efficient buildings throughout the region. The buildings must also meet the expectations of the users and owners for their functional and aesthetic features. A post-occupancy examination (Heerwagen et al. 1991) documented high occupant satisfaction with the Energy Edge buildings. Their survey of 264 occupants in seven of the Energy Edge office buildings (66% response rate overall) found a very high level of user satisfaction with the workspaces and with the aesthetic and functional aspects of the buildings. In specific cases, the occupants were disturbed by high and low temperatures, glare, noise, and lighting controls, but for the most part, their responses to the survey were positive. This finding, the report notes, underscores the idea that buildings can be energy efficient without a loss of user amenity.

Performance of the Energy Conservation Measures

Our analysis of the individual measures is based on results from the computer simulations that were "tuned" with monitored data, and from direct analysis of the measured data. The goal of the model tuning was to have the simulation be within 15% of the whole building monthly consumption, 10% of the whole building seasonal consumption, 30% of the monthly end uses and 25% of the seasonal end use consumption (Kaplan 1992).

The analysis of the performance of measures is not as straightforward as the analysis of the performance of the buildings. Because of the limitations in the methodology to analyze the individual measures, we caution that these results are preliminary, and are not to be taken as generalizations. We include the findings to illustrate the strengths and weaknesses of various approaches to analyzing the conservation measures.

Performance of Measures

Before presenting the energy savings data we review four reasons why efficiency measures may save a different amount of energy than predicted, illustrating these categories with specific examples from the Energy Edge buildings.

First, there may have been changes in the measures themselves, such as the use of fewer efficient T8 lamps in the overall lighting system or a different heat pump coefficient of performance (COP). The rated heat pump COPs were higher at Siskiyou and West Yakima, and energy savings from the heat pumps were greater than predicted.

Second, building operating conditions or characteristics, such as hours of use or type of occupancy, may differ from predicted. At McDonald's the hot water consumption was far greater than predicted, and the savings from the heat-pump water heater was nearly twice as great as predicted (6.09 kWh/ft^2-yr versus 11.2 kWh/ft^2-yr).

Third, the modeling technique may differ, which is particularly important when a simulation model does not adequately characterize a certain measure. Turning again to McDonald's, DOE-2.1C cannot adequately characterize the exhaust ventilator because it uses average room temperatures instead of temperature distributions within the kitchen space. The energy savings estimates range from 3.10 kWh/ft^2-yr based on theoretical calculations, to 1.24 and 0.16 kWh/ft^2-yr from two different modeling methods using DOE-2.1C.

A fourth reason for a change between predicted and actual performance is measure failure or poor installation. At Siskiyou, for example, neither the daylighting controls nor the occupancy sensors were modeled as operational because of poor calibration and sensor placement.

We cannot always determine which of the four reasons explain why a measure's performance differed from the prediction; often there are a combination of reasons. An additional complication is we cannot always compare predicted and measured savings directly because the data from the predictions did not include disaggregated savings for individual measures. The HVAC savings estimate at Siskiyou, for example, included both the economizer and the high-efficiency heat pump.

Most of the measures are saving less than predicted. In Figure 4 we plot the tuned savings versus the predicted savings for the measures in four office buildings (Dubal Beck, East Idaho, Siskiyou, and West Yakima), plus the McDonald's restaurant. In addition to the individual measures we show averages with the darker, bold symbol for the four groups of measures (HVAC, Lighting, Shell, Other). Although the sample size is small, we review the measure specific data to provide some indication of trends and issues that have implications for evaluation methodologies and technology performance analysis.

HVAC Measures. HVAC measures were included in four of the five buildings, consisting of four types of measures: high-efficiency heat pumps (in 3 buildings), economizers (in 3 buildings), and exhaust ventilation and heat recovery at McDonald's. The average predicted savings for these seven HVAC measures was 2.74 kWh/ft^2-yr. Average savings from the tuned models was 1.44 kWh/ft^2-yr, 47% less than predicted.

The efficient heat pumps saved more than predicted. One reason for this is among the two buildings with disaggregated heat pump savings, the predicted savings (0.19 kWh/ft^2-yr at East Idaho and 0.13 kWh/ft^2-yr at West Yakima) were low compared to predictions at other buildings. (Predicted savings at Caddis McFaddin were

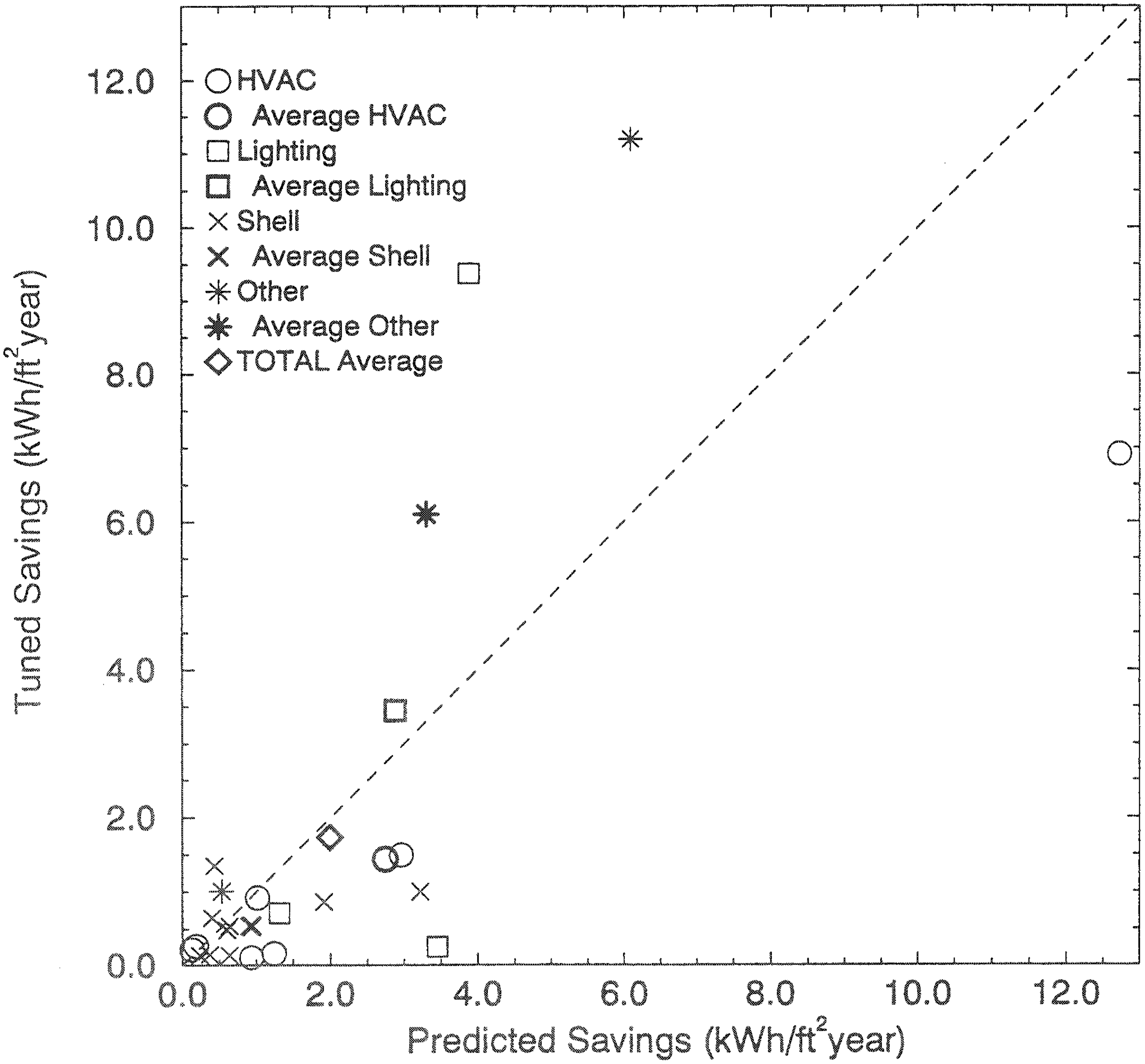

Figure 4. Tuned Savings Versus the Predicted Savings for the Measures in the Four Office Buildings. If all the measures saved as predicted the points would fall along the dashed line shown in the figure.

0.87 kWh/ft^2-yr.) As mentioned, one reason for the increase in tuned savings is the increase in the installed heat pump COPs. In our investigations into the heat pumps, we found that proper heat pump controls to minimize the use of back-up resistance heat can be as important as the use of high-COP equipment (Piette et al. 1992).

The tuned savings for the economizers tended to be less than predicted, ranging from 0.02 kWh/ft^2-yr at Siskiyou to 1.28 kWh/ft^2-yr at McDonalds. Several problems have been noted with the economizers, such as improper control settings and frozen or poor damper systems. Poor damper systems also appear to have created high outside airflow rates in several of the buildings (e.g., Siskiyou and Hollywood), thereby increasing heating loads.

Lighting Measures. Four of the five buildings with tuned models had lighting measures. We cannot compare the savings for individual measures because they are grouped together with various combinations of efficient-lamps, ballasts, fixtures, occupancy sensors, and daylighting controls. The predicted savings for the lighting measures averaged 2.37 kWh/ft^2-yr. The savings calculated by the tuned models averaged 2.58 kWh/ft^2-yr, 9% more than predicted. Lighting savings were less than predicted at three of the four buildings. The average savings are greater than predicted because of the large (area normalized) savings at the fast-food restaurant. The savings increased because of a change in the assumed baseline lighting power density, which increased to 5.4 W/ft^2 in the kitchen area. Ironically, the kitchen area is exempt from the code, so the baseline lighting power density is not well defined.

As mentioned earlier, many of the buildings had higher lighting power densities than predicted. Surprisingly, we did not find that this increase was correlated with greater energy use. The range in predicted versus actual hours of use and lighting control schedules help explain the difference between predicted and actual energy use. A second factor that caused actual energy use to decrease below the prediction is that the measured maximum peak demand for lighting is typically less than 80% of the installed, audited lighting power. Three factors that contribute to differences between audited and measured peak demand are improper accounting of ballast factors within audits, thermal effects (lamps typically operate hotter than standard test data), and diversity (not all of the lamps are on at one time).

Shell Measures. All five of the buildings had shell measures that include low-emissivity windows, wall and roof insulation, infiltration barriers, and vestibules. Ten of the predicted measures were disaggregated to allow for comparison with the tuned savings. The predicted savings for the ten shell measures averaged 0.93 kWh/ft^2-yr. The savings calculated by the tuned models averaged 0.58 kWh/ft^2-yr, 38% less than predicted. The only shell measures that showed greater savings than predicted were the roof and wall insulation at Siskiyou, and the vestibule at the Dubal Beck. The increased savings were probably due to different assumptions about the measure between the predicted and tuned models (Kaplan 1989). The evaluation of infiltration measures is further complicated by the difficulty in defining baseline infiltration rates.

Among these five buildings, the predicted savings for the shell measures was about one third the savings for either the lighting or the HVAC measures. For comparison, among all 28 Energy Edge buildings the average predicted savings for the three classes of measures were: 1.82 kWh/ft^2-yr (average of 26 HVAC measures), 1.83 kWh/ft^2-yr (23 lighting measures), and 1.29 kWh/ft^2-yr (33 shell measures).

Other Measures. One building had measures in the "other" category, which consisted of exterior lighting controls and a heat-pump water heater. Both measures saved more than predicted. As mentioned, the heat-pump water heater savings increased because of the increased demand for hot water. None of these first five buildings had HVAC control measures, which were used in nine of the other Energy Edge buildings.

Lighting Data and Commissioning the Director Building

In addition to analyzing the performance of measures based on the computer models we can also evaluate the performance of the individual measures based on the sub-metered monitored data. The lighting specifications for the Director Building included several types of efficient lighting systems: 32 W T8 lamps (with efficient core-coil ballasts) in offices and corridors, occupancy sensors, daylight dimming, PL-13 compact fluorescents in accent fixtures and restrooms, and high-pressure sodium lamps in the parking garage. Two findings from the audits suggested lower energy savings than predicted: 34 W and 40 W lamps are used in many areas instead of the 32 W T8s, and the daylight controls have been disabled in most areas because the office workers were dissatisfied with their performance, possibly because of the stepped dimming. On the bright side, most of the occupancy sensors are operating as intended.

Based on the audit data we determined that about half of the power on the fifth floor--or 5584 W of the total 11,803 W--was controlled by occupancy sensors. These 5584 W also represent about half of the total power in the building controlled by occupancy sensors (12,745 W). To evaluate the savings from occupancy sensors we compare the average hourly load shape for the fifth floor with other floors. Most of the lights are controlled by tenants, and, during weekends, the lights on floors 7, 8, and 9 tend to be left on, as were half the lights on floor 6. The Energy Management Control System, an Energy Edge funded measure, was originally intended to control the lights throughout the building, but is currently only used to control some corridor and lobby lights on floors 1, 2, 4, and 5. (The building management was apparently so pleased with the low-energy consumption post-retrofit that they didn't see the need to add the additional lights to the EMCS.)

Three average load shapes are shown in Figure 5, representing floors 1 and 2 combined, 5, and 6. This plot shows the average hourly lighting load normalized to the maximum peak hourly demand for the channel. We see the average demand as a fraction of the maximum to be much less for floor 5 (about 65% at noon) than the average for the channels without occupancy sensors (86% for floors 1 and 2, and 88% for floor 6).

Based on this average load shape, the lighting energy use of floor 5 is only 49% of the energy use of floor 6. Notice also that the savings from occupancy sensors are more significant in the morning and afternoon, when occupancy is more sparse than mid-day, a characteristic of these systems that is not captured with the simple lighting power density adjustment method used in the tuned models.

Ensuring the Performance of Measures

While the majority of the energy-conserving measures installed in the Energy Edge buildings are performing well, several measures have not done as well as expected. In particular, control measures, both for lighting and for HVAC, have been the weak link in energy performance. There are several reasons for their failure, including poor design, poor equipment, improper installation and calibration, and lack of maintenance. Our previous report (Diamond et al. 1990b) discusses each of these in more detail. While there is no single procedure for ensuring measure performance, we briefly review three activities that could lead to better performance of these measures.

Improved Operations and Maintenance Procedures. The failure of the economizers in the Energy Edge buildings illustrates the need for easy-to-diagnose systems that would alert the operator that the economizers are not working, and for guidelines to improve operations and maintenance (O&M) procedures for these and other measures. The O&M audits have been useful in identifying problems in measure performance, but fall short in providing explicit diagnosis and follow-up steps to remedy the problems.

Performance Criteria and Commissioning. Documentation of performance criteria is essential in determining whether measures are performing as intended. As an example, the Energy Management Control System (EMCS) at the Director building was designed to control the lights throughout the building. When the EMCS was initially installed, the lights were not added to its control function. The EMCS system now controls some of the lighting, and the commissioning activity currently underway is determining whether the energy-efficiency measures are performing as intended.

Understanding Occupant Interactions. The failure of the daylighting controls is an example of where not enough attention was paid to the needs and behavior of the building occupants. When the measure interfered with the needs of the occupants, they disabled the measure.

Conclusions and Key Findings

Our work in analyzing the Energy Edge buildings has raised new questions about the use and value of predicted energy consumption, baseline definitions, tuned models, monitored data, the role of code compliance and commissioning to ensure the validation and durability of energy savings, and other issues of importance to utilities in the design and management of new commercial acquisition programs. We summarize below some of our key findings from the evaluation of the Energy Edge program.

Building Performance

The 28 Energy Edge buildings, as a group, are using more energy than predicted, but are, on average, low-energy buildings when compared to new construction in the area. The eight Energy Edge office buildings for which we have end-use data consume an average of 11 kWh/ft^2-yr, about 50% less energy than other new construction (predicted and actual) in the region.

Energy consumption, based on the third year of utility bills, is increasing in 60% of the buildings. The next phase of the analysis will look at the individual end uses in groups of buildings to examine where the energy use is increasing the most.

Lighting energy use is nearly as low as predicted, averaging 3.6 kWh/ft^2-yr, which is surprising, given that the installed lighting power densities are often higher than predicted--and, in some cases, higher than their MCS code (1985) baseline of 1.5 W/ft^2. The finding that lighting power densities are higher than code (but lighting energy use is lower than these levels would suggest) has implications for code compliance and energy forecasting in the region.

Finally, the analysis of the occupancy surveys has shown high overall levels of tenant satisfaction in the seven Energy Edge office buildings that were surveyed. This finding underscores the idea that new commercial buildings can be energy efficient without any loss of user amenity.

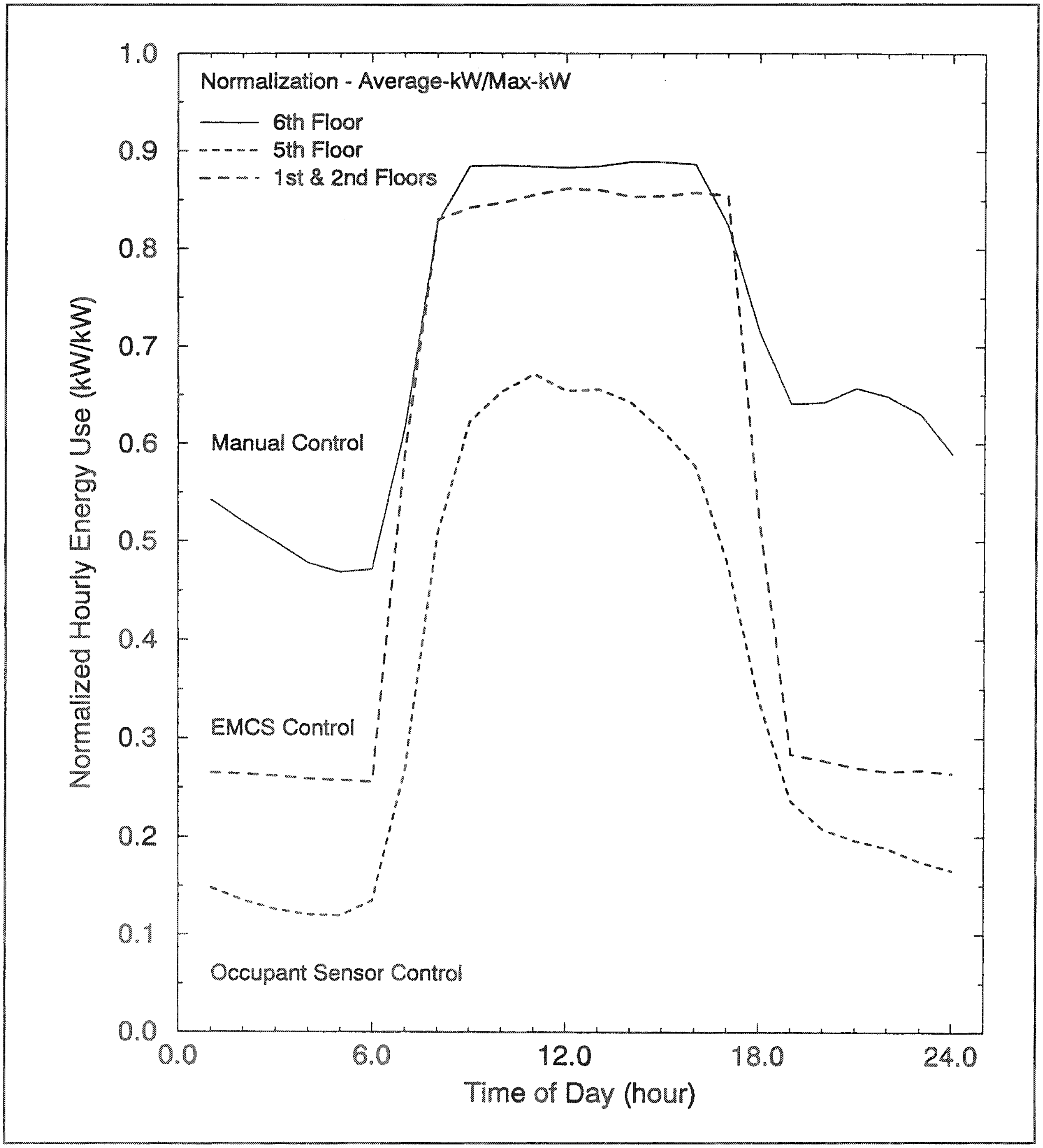

Figure 5. The Average Weekday Hourly Lighting Load at the Director Building Normalized to the Maximum Peak Hourly Demand for the Channel. We see the average demand as a fraction of the maximum to be much less for Floor 5 (about 65% at noon) than the average for the channels without occupancy sensors (86% for Floors 1 and 2, and 88% for Floor 6). Also, night savings are much larger than day savings for the floors with occupancy sensors.

Measure Performance

Based on the results from the first five tuned models, the measures are saving 13% less energy than predicted. Lighting measures, as a group, are saving more than predicted, but HVAC and shell measures are saving less. Heat pumps are performing better than predicted, and an analysis of their monitored data shows that better controls could improve performance even further.

Economizers in the smaller buildings have not been performing well, saving only a small amount of their predicted values. Control measures, both for lighting and HVAC, continue to be a problem. Performance criteria, commissioning, operation and maintenance procedures, and better understanding of occupant interactions, are all needed to ensure measure performance and the durability of energy savings.

Methodology Assessment

The results of the analysis suggest that within Energy Edge we have been more successful at predicting energy use than energy savings. While the tuned-model approach has revealed several limitations in its ability to calculate energy savings for all measures, the strength of the Energy Edge methodology is that multiple sources of information are available to supplement the tuned model.

A major lesson learned has been that the MCS code does not provide a consistent baseline from which to calculate the savings of individual measures. A secondary finding has been the difficulty in comparing predicted and actual savings due to the lack of detail in the documentation of the predicted models. Better comparative analysis of the end-use EUI in the early phase of the program would have spotted unusual end-use EUIs and improved the design-predictive models.

Looking Ahead

Like similar large-scale monitoring programs, e.g., the Texas Loanstar program (Turner 1990) and ELCAP (Taylor 1989), the Energy Edge buildings will continue to provide a testing ground for new methodologies proposed for commercial acquisition programs. In particular, we see the need for continued analysis of the Energy Edge measures and buildings, with an emphasis on understanding the factors and forces that affect their energy performance and measure savings over time. At the same time, we see the need to look at new construction trends and the performance of other new buildings in the region to establish baselines for comparisons. Bonneville, and others, will benefit from greater insight into these processes in order to validate their investment in energy efficiency.

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