Impact Evaluation of Commercial Construction Using Alternative Engineering Simulation Tools

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ABSTRACT

Evaluation of new construction programs often relies on engineering simulation models of the "as-built" facility, calibration or "tuning" to match consumption and then changing the model to represent the baseline facility without the energy conservation measure (ECM). Savings are estimated as the difference between the "tuned" as-built and baseline modeled consumption. Unfortunately, computer models are complex, time consuming and difficult to calibrate to actual weather and other operating conditions. We compared traditionally modeled results against a statistical adjustment and a simplified simulation spreadsheet tool (EZ Sim). The comparison showed that both alternatives provided results comparable to DOE2 models but the spreadsheet tool was much easier to use, especially with limited data for inputs. Results from the sample buildings were analyzed for an average realization rate by ECM and by facility type. These realization rates were then applied to adjust initial impact estimates for the remaining participants. Programmatic impact results for three years are presented. In addition to a less costly method for impact evaluation, the spreadsheet method also has application for performance-based contracting since it can set performance targets. These can easily be compared to the utility bills as an initial commissioning check.

Introduction and Background

The PacifiCorp Energy FinAnswer program provides design assistance and financing for commercial-sector energy conservation. The program emphasizes new construction and major remodels. Between 1992 and 1997, 894 commercial customers participated. Program projects produced expected energy savings of 148,503 MWh and verified savings of 130,177 MWh, for an overall realization rate of 88%.

Regression methods applied to commercial sector programs have serious limitations. In the case of new construction, there is no baseline for billing comparison. The range of energy conservation measures is broad, including both small lighting changes as well as major HVAC modifications. Prior engineering estimates of savings are subject to uncertainty due to design assumptions that may vary from as-built conditions. As a result, Statistically Adjusted Engineering (SAE) estimates are subject to measurement bias.[1] Furthermore, such a study may require non-participant data that are difficult or costly to obtain.

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[1] Regression models assume that the independent variables are non-stochastic (i.e., their values are fixed numbers). When this assumption is violated, measurement bias occurs. Engineering estimates of savings used in SAE model are highly suspect of being non-stochastic. While instrumental variable techniques present a possible remedy, more often than not,

Instead, the methodology for evaluation of the impact of new commercial construction programs has relied on engineering simulation models. Since no pre-treatment data exist for new construction, performance is estimated based on a comparison to a hypothetical baseline. In general, the approach is to develop a model of the "as-built" facility, calibrate or "tune" that model to match the utility bills and other site data, then use the model to estimate what a comparable facility would have used without the conservation measures installed. It should be noted that models used in the project design cannot be applied without adjustment for "as-built" conditions that depart from initial assumptions. Developing a calibrated model requires an on-site visit or commissioning report to document what has changed from design assumptions. Even for retrofit cases that have pre-treatment data, the changes may be so extensive that the old baseline no longer applies. Thus, a "hypothetical" baseline is often needed in many retrofit cases as well.

In evaluation, the expense and resource requirements of computer modeling limit the number of cases that can be examined in detail. Typically, the budget permits detailed modeling of only a representative sample. Results from this sample must then be extrapolated to other participants in order to develop the impact estimate for the entire program.

Methodology

In this paper, we discuss a comparison between three alternative impact calculation methods -- DOE2 modeling, statistical modeling and a simplified engineering model. We confirmed that simplified method provided reliable results at reduced cost. Although the other methods provided similar results, their cost and resource requirements were much greater. The simplified method was then used to develop programmatic results for over three years of program activity.

DOE-2 Modeling

We applied traditional engineering simulation modeling using the DOE-2 program to a sample of 24 facilities. This process included on-site visits to identify where "as-built" conditions departed from the initial design models. Billing data included hourly load profiles. We found that DOE-2 modelers did not always utilize all the available information, particularly the hourly load profiles. Hourly profiles were useful in two ways:

- First, they confirmed the estimated operating schedule. In cases where the load profile showed a change in scheduling, the modeled schedule was adjusted.

- Second and more importantly, the load profiles revealed cases where the building had a significant non-weather dependent load. This load might be due to outdoor lighting or indoor equipment. In several cases, the load was not apparent during the site visit.

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such corrective actions are not taken. (For a complete discussion of the topic consult any Econometrics text such as Gujarati, D, Essential of Econometrics, 2nd Edition, Irwin-McGraw-Hill, 1999.)

Consequently, the load profile information proved very important at some sites in assigning energy consumption to end uses. Without the load data, none of the modeling procedures would have provided an accurate picture of consumption. Furthermore, the error would not have been apparent without supplemental information from the load profiles.

Statistical Adjustment

We developed a regression technique to adjust the results of the initial DOE-2 design models to the observed hourly loads. The regression model had the following form:

$$kW_t = \sum_{t=1}^{24} \beta_i [FDOE2_{it} + \Delta X_{it}] + \beta_{25} * \Delta CDH_t + \beta_{26} * \Delta HDH_t + \varepsilon$$

where

kW_t = Actual hourly load data for hour t.

$FDOE2_{it}$ = Estimated kW demand for hour t from the Final Uncalibrated DOE-2 Model for end use i (for a total of eight possible end uses) at hour t. (t=1 to 24 per day).

ΔX_{it} = End-use specific correction factors that account for differences in building systems, equipment, and occupancy between the Final Uncalibrated DOE-2 Model and the as-built conditions for hour t and end use i. (We call these the X-factors.)

ΔCDH_t = Deviations of actual cooling degree hours from long-run weather conditions represented by TMY (i.e., "normal") values used in FDOE-2 for hour t.

ΔHDH_t = Deviations of actual heating degree hours from long-run weather conditions represented by TMY (i.e., "normal") values used in FDOE-2 for hour t.

ε = Error in the prediction not accounted for in the regression model.

The model assumes that metered load (kW demand) for each hour of the building is a function of the consumption predicted from the Final Uncalibrated DOE-2 Model, adjusted for the "X-factors" and weather deviations. X-factors are the end-use specific differences observed during site visits between the as-built conditions and the DOE-2 modeling conditions. The X-factors include differences between actual and assumed occupancy, hours of operation, installed measures and equipment, ratings and sizes of equipment, and square footage. The total consumption estimated by the Final Uncalibrated DOE-2 Model is the sum of as many as eight end uses. Different X-factors apply to each end use and are incorporated into the regression model.

The other two variables used in the regression model are the differences between long-term heating- and cooling-degree hours and the actual weather. The weather files used in the DOE-2 modeling represent the "typical" (TMY) weather for the area where the building was located. This "typical" weather may differ significantly from the actual weather conditions in a specific year. The changes in weather are calculated as the difference in the TMY weather sets used in the original DOE-2 models and the actual weather for the year. The model yields 24 correction factors for the DOE-2 consumption (one for each hour of the day) for weekday and weekend daytypes. As shown in the general regression equation, an intercept term (α) is not included. The adjustment method assumes that any change in heating and cooling is proportional to the change in degree-hours. The goal of the regression modeling is to produce multiplicative coefficients that can be directly applied to the uncalibrated Baseline DOE-2 results.

We found that the regression method could provide similar results as the DOE-2 modeling without extensive engineering resources. However, the regression approach still required large amount of data to operate. The data sets include hourly DOE-2 outputs from the initial design model, hourly metered consumption and actual weather data, as well as site visits to verify any deviations from the initial design (the X-factors). In a few cases, where there were extreme differences between the baseline and as-built cases, the regression technique was unable to accurately derive a suitable baseline.

Billing Simulation Tool (EZ Sim)

The simplified simulation tool is based on performance curves that duplicate DOE2 results. The methodology, however, is very different from DOE2's. While DOE2 produces a detailed hourly simulation, the simulation tool computes monthly energy consumption primarily based on average daily temperatures. Hourly data are not required.

The tuning process is similar with any of the modeling techniques. First, the modeler includes all the available updated site information. Based on the site visit, this might include lighting densities, operating schedules, descriptions of equipment, and building characteristics. The FinAnswer program included sufficient documentation as inspection reports and commissioning reports that it was not necessary to conduct additional on-site visits when using the simplified simulation tool. Tuning was accomplished by comparing billing to predicted consumption, as demonstrated in Figure 1. Although this example shows only electricity consumption, the tool analyzes both electric and gas bills, normalizing consumption to consistent units (watts/square foot).

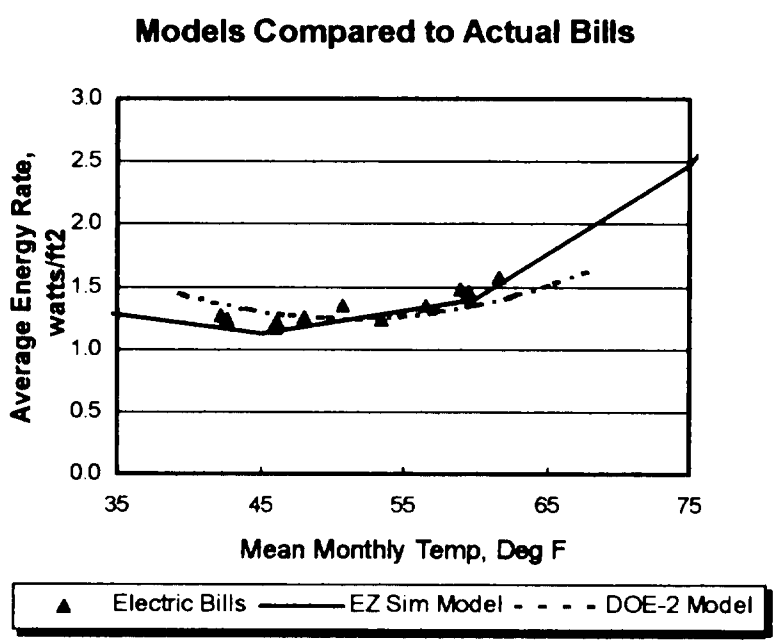

Figure 1. Comparison of Modeled Example

Figure 1 shows an example of actual billing data (months) as observation points. These are compared to lines that represent consumption as predicted by the engineering models. (Note that the lines do not represent a statistical curve fit to the data points.) If necessary, algorithm parameters can quickly be adjusted so the predicted consumption matches actual billing. Figure 1 also demonstrates that, in this case, the EZ Sim tool is better able to match the actual performance of the building than the "tuned" DOE-2 model. That is because the DOE-2 modeler is working with average weather data at a different site, rather than the actual weather data appropriate for this facility.

Since the DOE-2 modelers did not always capture all the site information, direct comparison of results was difficult. To facilitate comparison, we performed a benchmark comparison in which modeling parameters were set to match those used in the DOE-2 modeling. Results from this comparison are shown in Figure 2. Since there was a wide range in the size of projects, results are presented as the realization rate or the ratio of the "tuned" estimate of savings to the initial design savings estimate. Perfect agreement between the models would result in points lined up on the 45-degree line. Based on the comparisons, we determined that the simplified methodology provided results that were similar to the regression model and were consistent with DOE-2 when the same modeling parameters were applied.

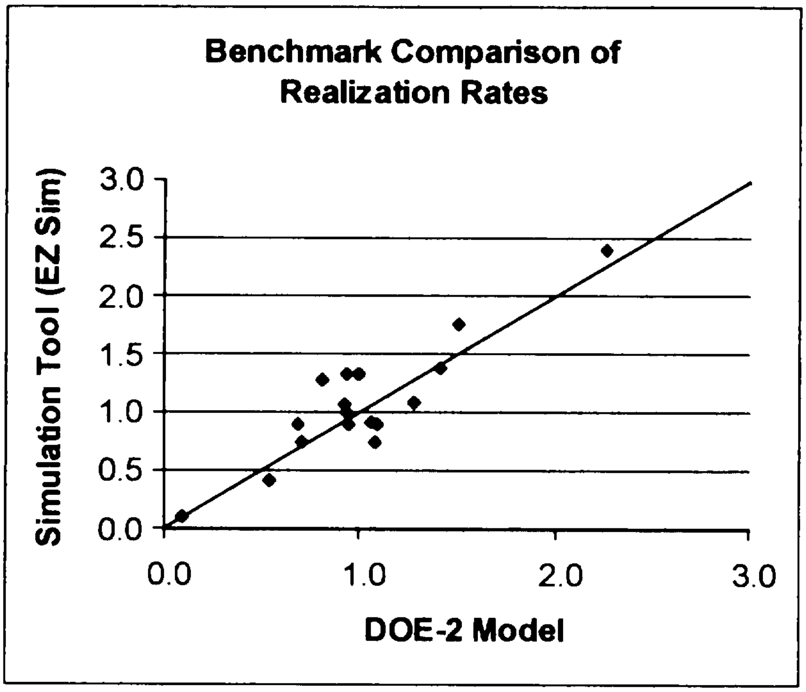

Figure 2. Benchmark Comparison

Results of Alternative Methods

Comparisons between the different methods are shown as Table 1. The statistical regression method provides similar estimates of savings as the calibrated DOE2 method at somewhat reduced cost. Both these methods require engineering review of project files, but can rely on properly documented inspection reports to replace site visits. In this study, the cost of the statistical regression for 24 sites was approximately $20,000, while for the DOE-2 modeling, the cost was about $37,500 because of the time involved in conducting additional site visits. In contrast, use of the simplified simulation method required only about $700, primarily in engineering review of project files. (Note: Only the first two modeling methods are graphed together as Figure 2.)

Table 1 Comparison of Models as Shown in Figure 2

Sample Site No.	Expected Savings kWh	Simplified Simulation Model (EZ Sim) Realization Rate	DOE2 Simulation Model Realization Rate	Statistical Regression Model Realization Rate
117	1,129,964	1.00	0.93	0.74
144	86,041	1.07	0.93	0.99
151	222,623	0.74	1.08	1.10
159	76,610	1.27	0.81	1.14
162	173,874	0.91	1.06	1.41
166	48,600	0.11	0.09	0.10
170	2,941,948	1.08	1.28	1.39
174	291,127	0.90	0.68	0.72
182	260,902	0.42	0.54	0.18
198	367,054	2.40	2.27	3.60
199	695,617	1.76	1.51	1.60
200	143,865	1.32	1.00	1.53
209	45,978	0.90	1.09	0.68
233	546,133	0.90	0.94	1.02
249	178,983	0.75	0.70	0.90
253	84,351	1.38	1.41	1.53
264	193,295	1.33	0.93	1.02
Sample	7,486,965	1.14	1.17	1.28

Realization Rate Methdodology

Actual savings differ from those predicted during the initial design study for a variety of reasons. If operating hours are longer or more fixtures are installed, the realization rate will be higher. This explains those cases where the realization rate exceeded 100%. If some of the measures are not installed or if operations are less than anticipated, realization rates will be reduced. We computed the realization rate for each energy conservation measure and averaged by measure type and facility type. The result provides a representative realization rate that can be applied to similar facilities where modeling was not applied.

For example, in one year, the modeled estimates included 17 large office buildings where T8 lights were installed. These 17 projects provided an average realization rate of 170%. The high savings were a result of extended operating hours and increased floor area beyond that assumed during the design stage. We assumed that other facilities in the same building category would also exhibit the same realization rate. Thus, we extrapolated savings to sites that were not directly modeled using the average realization rate.

This average realization rate differs from that derived using SAE in that there was no attempt to regress observed savings against prior estimates. It should also be pointed out that averages were not weighted by size, since that would have resulted in a few large projects dominating the realization rate. For the same reason, sites that were extreme outliers were removed from the averaging process.

In order to operate within a reasonable budget, the evaluation sought to directly model the largest projects and a reasonable sample of remaining projects. These results were then used to extrapolate savings to those projects not directly modeled. Savings of directly modeled sites totaled 63,306 MWh or 48% of the total programmatic savings. Thus, almost half the savings were directly modeled with the remainder of the savings extrapolated from those results.

Programmatic Impact Results

Realization rates for energy savings as shown in Table 2 have been high but declined over time. There were several reasons. (1) The early years marked a period of high construction and high participation. Some of these projects expanded in scope and created more savings than anticipated. (2) Due to enactment of more efficient energy building codes, the lighting efficiency baseline increased. Some of the savings predictions had assumed 40W fluorescent lights fixtures for the baseline. This assumption was corrected in the impact analysis, which reduced savings from many lighting projects. (3) Commissioning was less emphasized in later years.

Table 2. Programmatic Impacts 1992-1997

Study Period	Predicted MWh	Adjusted MWh	Realization Rate
1992-1995	79,591	78,673	0.99
1996 (preliminary)	31,844	24,150	0.76
1997 (preliminary)	37,068	27,354	0.74
All Years	148,503	130,177	0.88

Conclusions

(1) Documentation of project files is critical to evaluation. Project files were frequently incomplete. Electronic files for the DOE2 models were often missing or were not operational.

(2) This evaluation demonstrated that the hourly load data are useful for verifying the building operations. However, the utility is no longer collecting hourly data except for very large customers.

(3) Statistical adjustment provides similar estimates of savings as the calibrated DOE2 method at somewhat reduced cost. The simulation tool was the lowest in cost to implement. All methods require engineering review of project files but could rely on properly documented inspection or commissioning reports to replace site visits.

(4) All the modeling methods provided evidence that program savings are high for the Energy FinAnswer program.

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