Leveraging Expensive On-Site Survey Data
A New Residential Evaluation Strategy

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One of the biggest costs in measuring residential new construction program impacts is the development of good simulation engineering data of program savings. In this study, detailed DOE-2 engineering simulations were used to develop site-specific engineering priors for the regression analysis of billing data. Normally, this approach is too expensive for residential evaluations, because of the time involved in conducting detailed on-site surveys and preparing computer simulations of the as-built homes. By leveraging a relatively small quantity of on-site data, we were able to simulate a much larger sample of buildings and so increase the precision of econometric analysis with solid engineering priors.

The strategy is based on the observation that developers build many houses using a given plan type. These houses are very similar to each other; the physical differences among them that affect energy use are primarily in solar orientation and shading. To account for this, a detailed, on-site survey was done at one of the houses in each plan type group. Then, sidewalk surveys were done for up to seven of the other houses having the same plan type, to collect data on orientation and shading. Key operational/behavioral characteristics, such as occupancy patterns and thermostat operation, were identified through a mail survey. Thus, the simulation model, developed from the on-site survey for one house in the group, was adjusted using sidewalk and mail survey data for the other houses in the group. Twenty on-site surveys were thereby leveraged into 116 simulations for individual houses.

The simulations were used in a Statistically Adjusted Engineering (SAE) regression analysis of billing data, which estimated the percent of predicted savings from the simulations that were found in the billing data. These results showed that the combination of sidewalk and on-site survey simulations produced a lower standard error and a higher statistical confidence (T-statistic) than either set of simulation results alone.

This paper discusses the advantages and the problems encountered with this approach.

INTRODUCTION

The Sacramento Utility District (SMUD) operated its Advantage Builder residential new construction program in 1993 and 1994 (and continues to operate it in 1995 and 1996). An impact evaluation study was commissioned to determine program impacts for the 1993 and 1994 years.

The program focused primarily on improving cooling system efficiency, but also included zone control, duct insulation improvements, wall and ceiling insulation improvements and fenestration shading. Efficiency improvements were described as a percentage reduction in energy use compared to the Title 24 energy code baseline. Three tiers of incentives were offered for homes that reduced energy use by 15% (using prescriptive measures), 25% (using a point system to determine measure savings) or 50% (using a customized computer simulation method).

The program was directed at residential production builders, and offered financial incentives to offset the incremental first cost of extra efficiency measures. The incentives increased with increasing efficiency of the buildings, up to the full incremental cost of efficiency measures installed. The program achieved good market penetration, estimated in excess of 80% of new houses constructed in the service territory in 1994.

The program measured its energy savings relative to the California Title 24 building energy efficiency standards (Title 24). This is, of course, a calculated difference, because new construction programs do not lend themselves to direct before/after comparisons the way retrofit programs do.

For the impact evaluation, savings were calculated both through computer simulations and through. This paper focuses on the technique for developing the simulation data.

METHODOLOGY

DOE-2 simulations were developed to calculate the energy savings of program measures for a sample of participant and of non-participant houses. Data from a variety of sources was incorporated into the simulations in order to make them reflect the realities of each house as closely as possible.

A key concept in this analysis was the ''plan number''. This refers to a particular model of house built by a particular builder, who usually assigns a unique plan number to the model. Typically, a builder will build many houses of the same model and plan number, with minor cosmetic variations. Physically, these houses are quite similar, with the same overall dimensions, construction assemblies, mechanical systems, efficiency measures, etc. In this study, houses with the same plan number were grouped together. An on-site survey was performed to obtain the physical features of each house, and a sidewalk survey was done for the other houses in the group to identify differences in orientation and shading. Other data was collected as well, as described below:

(1) **Site survey data of as-built features** (one on-site survey per plan number)
This allowed the simulations to account for the physical characteristics of the houses and the installed efficiency measures, such as glazing area and orientation, roof/wall area and insulation, air conditioner size and performance rating, etc.

(2) **Mail survey data on occupancy patterns and thermostat operation** (one survey response per household)
This allowed us to distinguish, for example, between buildings occupied all day long vs. buildings occupied only at night, or between thermostats kept at a constant setting vs. thermostats set back during the night. It also identified the number of occupants (which determines internal heat gains), and the natural ventilation practices of those occupants.

(3) **Title 24 energy code compliance documentation** (one set per plan number)
This showed the required Title 24 baseline values for insulation, glazing, equipment efficiency, etc. These values can vary, depending on the compliance approach used. The documentation also showed the as-designed levels of efficiency measures, glazing areas, overall house square footage, etc., which were cross-checked against the on-site survey data for consistency and accuracy.

(4) **Sidewalk survey data of solar orientation and shading** (one survey per simulated house)
This allowed us to distinguished solar heat gain variations, such as west-facing windows vs. north-facing windows, or houses shaded on the west by neighbor houses vs. houses fully exposed to afternoon sun; factors which are site dependent and vary house to house.

(5) **Detailed simulation results** (one set per simulated house)
Month-by-month energy use and savings data for each simulated house.

Figure 1 shows these data sources diagrammatically.

Surveys

The Advantage Builder program impact evaluation included a mail survey which was sent out to a sample of new home owners, both participants and nonparticipants. A total of 466 valid mail survey responses were received, out of 947 sent out (a 49% response rate). These represented more than 77 different plan numbers (for 46 of the non-participant responses, plan numbers could not be identified). Of those 77 different plan numbers, two-thirds of them had two or more house responses, and two of them had fourteen responses. As shown in Figure 2, the average was 4.26 responses per plan number. These mail survey responses provided the sample frame for selecting the on-site and sidewalk survey sample points.

This distribution of responses made it possible to select plan numbers for the on-site surveys which could provide an adequate number of sidewalk surveys. The strategy was to select plan numbers which had the maximum number of models built, and then to arrange for a detailed on-site survey of one of the houses in a given plan number group. Sidewalk surveys were conducted for several of the other houses in the group. Because it did not matter which of the houses

Figure 1. *Data Sources for Simulations*

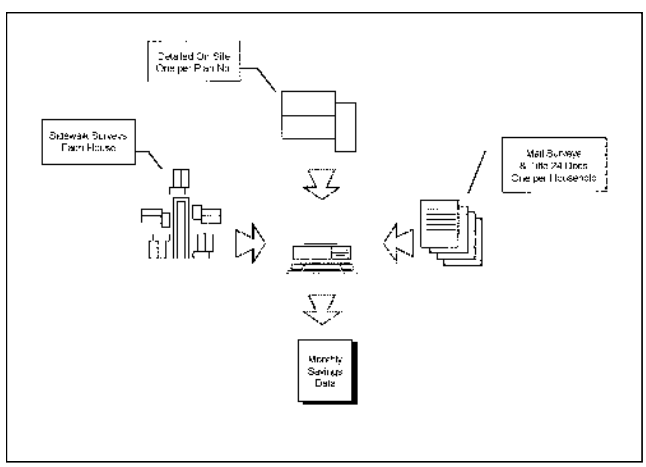
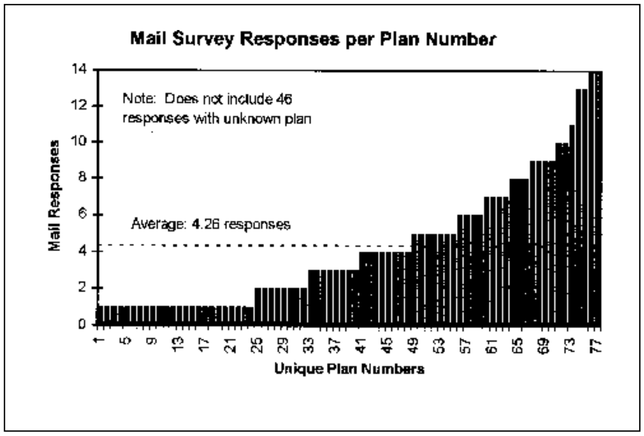


Figure 2. *Mail Survey Responses per Plan Number*



we visited for the on-site survey, it was possible in almost all cases to find one of the homeowners who was willing to grant access to an auditor.

The actual number of unique plan numbers surveyed, and the number of sidewalk surveys conducted for each, are shown in Figure 3. There were 33 unique plan numbers, with up to eight sidewalk surveys per on-site survey. Two of the on-site surveyed houses had no sidewalk surveys. A total of 133 sidewalk surveys were conducted. The average was four sidewalk surveys per on-site.

The Advantage Builder program participants fell into three tiers, differentiated by overall building energy efficiency, Tier 1 being 15% more energy efficient than Title 24 and Tier 3 being at least 50% more efficient. Figure 4 shows how the participant buildings surveyed were distributed across these three tiers, and the total numbers of on-site and sidewalk surveys conducted for both participant and non-participant houses.

This methodology requires that there be good data for each participant house including, at a minimum, the plan number,

Figure 3. *Sidewalk Surveys per On-Site Survey*

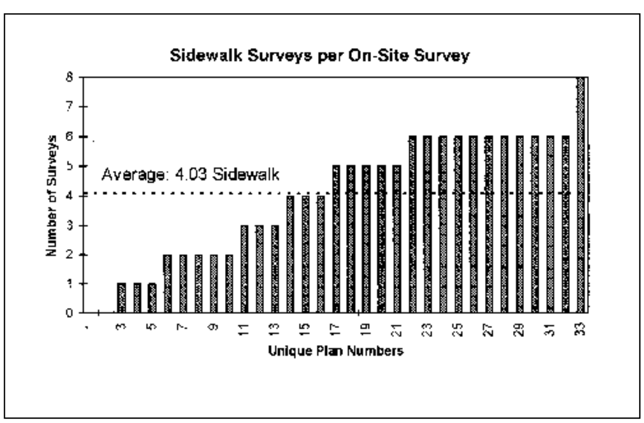
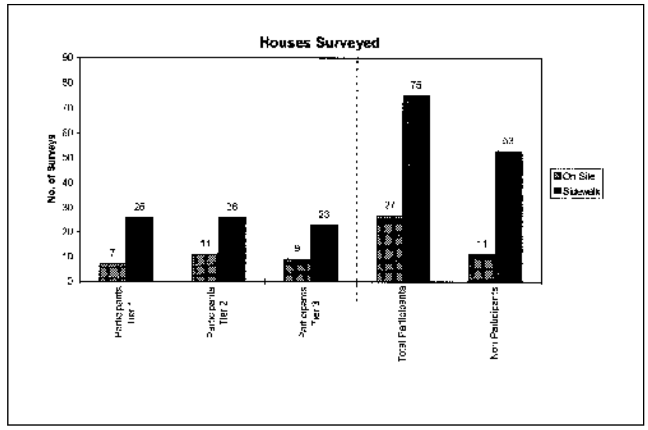


Figure 4. *Number of Surveyed Houses*



address and occupant name. The phone number is useful for making contact to schedule on-sites. Title 24 energy code compliance calculations are useful for determining measure baselines and other energy information about the houses. Finally, the billing data associated with each house is needed.

Normally, this information is readily available for the participant from the program tracking system and files. It must also be obtained for the non-participant sample, which can be more difficult. In this project, we were able to identify a number of home builders who were willing to cooperate with plan number, address data and Title 24 calculations.

Data Analysis

The DOE-2 simulations prepared using this strategy provided a basic engineering estimate of savings for the energy efficiency measures in each house. However, this data was not taken as the final savings result. Instead, it was used as an intermediate result in a Statistically Adjusted Engineering (SAE) analysis.

The SAE analysis used a time-series (monthly), cross-section regression technique that used the simulated energy use as the program effect variable. One of the advantages of using a monthly model was that it allowed consideration of results from portions of the year. The final model used only the summer months, as the SMUD program was focused on cooling energy savings. The model controlled for all of the following independent variables:

- Square footage of house
- Cooling degree days
- Days in the billing period

- Number of people in household
- Education
- Income
- Manual thermostat (presence of, as opposed to clock thermostat)
- Presence of second refrigerator
- Presence of electric range
- Presence of electric clothes dryer
- Presence of electric hot tub

RESULTS

In order to test the effectiveness of the on-site/sidewalk survey strategy, three SAE analyses were run. These runs were limited to the houses for which DOE-2 simulations were developed, and for which there was adequate billing data. The three runs were:

(1) On-site survey houses. There were 13 participants and 7 nonparticipants, for a total of 20 houses.

(2) Sidewalk survey houses. There were 57 participants and 39 nonparticipants, for a total of 96 houses.

(3) Combined. All of the above houses, with 70 participants and 46 nonparticipants, for a total of 116 houses.

The results of these three runs are summarized in Table1.

Note that the total number of houses in this analysis was 116, which is less than the number of houses in the survey/simulation phase. Unfortunately, an adequate number of months of billing data were available only for 116 of the simulated houses.

In this model, ''Predicted Savings Fraction'' indicates the percent of predicted savings from the simulation that were found in the billing data. The highest value, very close to 1.0, was found for the on-site surveys. The T-statistic was good, although the standard error is large at 0.41. This is attributable to the wide variation in house energy use patterns and the small sample size. The sidewalk survey houses have a substantially lower Predicted Savings Fraction and T-statistic, although it is still quite significant. The standard error is also substantially lower. The combination of on-site and surveyed houses, however, gives the most reliable estimates.

Table 1. *Comparison of On-Site and Sidewalk Survey Results*

Variables	Sidewalk	On-Site	Combined
Predicted Savings Fraction	0.5879	1.0130	0.6432
T-Statistic	2.14	2.50	2.75
Probability	0.0329	0.0140	0.0062
Standard error	0.2750	0.4056	0.2340
Sample (partic./ nonpart.)	57/39	13/7	70/46
kWh/month	47.26	81.44	51.70
90% Confidence Interval	25.9 to 68.6	27.1 to 135.8	31.8 to 71.6

It has the largest sample size, which naturally improves the overall analysis. Compared to the sidewalk surveyed houses, the combination group has a higher Predicted Savings Fraction (nearly 0.65), the lowest standard error and the highest T-statistic.

We conclude from this analysis that the overall strategy worked quite well. Because of the time-consuming nature of the on-site surveys, the budget could not support a large number of such houses in the sample. We could, however, perform a large number of sidewalk surveys and prepare DOE-2 simulations for all of the sites. Using both sets of simulation results in the regression analysis improved the overall accuracy compared to what would have been attainable with only one or the other survey technique.

The potential existed for even greater leveraging of the data, but a number of difficulties limited the leveraging for this particular project. These difficulties were mostly related to the completeness and consistency of the program records. Some of the records in the tracking system database had been inadvertently scrambled, resulting in mismatches between addresses and plan numbers. This was discovered during the sidewalk survey phase, when it became obvious that different types of houses were being shown with the same plan number. This resulted in some 50 ''orphaned'' sidewalk surveys which were not associated with one of the houses for which we had on-site data. If this problem had not occurred, there would have been an average of six sidewalk surveys per on-site house.

CONCLUSIONS AND RECOMMENDATIONS

This approach for leveraging residential survey data is useful for impact evaluations which seek to use detailed simulation data in calculating savings. The major cost in developing the simulations lies in the on-site survey and the modeling of the physical parameters of each house. It is a small incremental cost to perform the sidewalk survey and to add a few questions to the mail survey instrument.

This technique adds some complexity to the sampling and data availability tasks, due to the need to coordinate the various data sources. Indeed, these problems limited the usability of some of the data that were collected. These problems are minor compared to the value of the detailed simulation data that results.

The biggest limitation of this technique is that it depends on having identical floor plans for each group of plan numbers. It would not work nearly as well for dissimilar houses, even if they had similar square footage, window areas or construction assemblies, because residential building loads are quite sensitive to these parameters. The goal of the technique was to control for as many building parameters as possible in the simulations, and so as to leave the SAE analysis a much smaller number parameters to control.

Another advantage of this technique is extra information the simulations can provide. For this study, the simulations produced estimated monthly energy use and savings, customized to each house in the simulation group. The potential exists for readily obtaining even more detailed data, such as hourly load profiles, and estimates of coincident peak load. It would also be possible to evaluate savings for individual measures, such as air conditioner efficiency or high performance glazing. This additional data can all be obtained from the DOE-2 simulation models, and the incremental cost for the additional data is low because the major expense of building the models has been taken care of.

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