Billing Simulation Tool for Commercial Buildings

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ABSTRACT

A spreadsheet tool has been developed that allows quick adjustment of a simplified engineering model to match actual utility bills. The tool utilizes billing analysis of commercial facilities to: (1) diagnose energy patterns and end-use consumption; (2) calibrate savings estimates to agree with actual usage; (3) verify vendor claims for energy products and services, (4) generate performance targets and compare against actual energy bills. This application represents a low-cost, simplified commissioning check or verification for performance-based contracts.

The tool is designed to operate with only simple information about the facility and to focus on the HVAC system. It represents one quick approach to treating the facility as an integrated whole. Case examples illustrate how the tool is useful in diagnosing energy problems, guiding on-site audits, establishing predicted targets for O&M tracking and performance verification.

Overall precision of the results was quite good. In one study, savings estimates were provided with a SE value less than 5% of annual consumption. This value defines the level of resolution that can be expected from monthly whole-building analysis. The project demonstrates that sufficiently precise simulations can be developed from whole-facility billing data at a greatly reduced cost compared to traditional engineering models.

The Energy Services profession faces a challenge in the new deregulated business environment. Facility managers are being asked to make new and important business decisions regarding energy purchases. Obviously, they would like to utilize as much information as possible. Yet few managers are allowed additional budget for energy analysis. Utility programs to subsidize efficiency improvements are disappearing, leaving the burden on facility staff and service providers. In this article, we discuss one solution to minimize any additional cost by extracting the information hidden in data that are already available—namely, **the utility bills**.

These bills are a resource of highly accurate, site specific measurements. The problem is that, at the whole-building level, details of specific energy end uses are hidden. However, billing data can be combined with an engineering model to provide a useful deductive tool analyzing how energy is being used and what alternatives exist. For smaller customers and smaller facilities, this approach may be the only one that is affordable.

How would such analysis be useful? Here are a variety of applications:

- Benchmark the facility against what is "typical."
- Understand facility operations, identify operational errors, track on-going performance, identify and diagnose major problems, run "what if" scenarios to test explanations for observed performance.
- Reveal end uses, verify vendor claims.
- Calibrated savings estimates that are matched to actual consumption, find targets of opportunity for efficiency improvements.
- Simple level commissioning check, generate performance targets and compare to future billings.
- Validate performance contracts.

These applications fit into a project timeline:

(1) at the front end—for initial scoping of a project, prioritizing between multiple projects, identifying opportunities and estimating savings

(2) during the execution—for tracking ongoing operations and commissioning checks

(3) and at the back end—for verifying performance savings.

Performance Verification deserves additional discussion because it is different from mere commissioning. Both have the goal of ensuring that the expected energy savings actually occur. However, commissioning is focused on checking that the installation and operation match the design intent. Typically, commissioning relies on inspections, one-time tests and short-term monitoring during installation. Depending on the time of year, some equipment may not be operating when checked. Commissioning agents are cautious about claiming long-term savings because they understand that conditions may vary over time.

Yet demonstration of consistent savings in an annual basis is what's important to the customer. The customer needs to be assured of the bottom line—that the savings actually show up as bill reductions.

Why aren't utility bills used more often? For one thing, post-retrofit bills are not available until some time after the installation. Thus, they are generally not available during commissioning.

Furthermore, there is legitimate skepticism about simply comparing bills. Every manager knows that there were certain periods of unusual weather or other factors that affected the bills. An engineering model provides a way to adjust or normalize for those unlikely events.

Nevertheless, utility bills are the bottom line for the customer. At some point, the fiscal manager wants to see the savings quantified. How much would the bills have been without the efficiency measures? The answer needs to be communicated in a format that a lay person can understand. Having the results buried in a dense engineering report does not provide a sufficient answer.

So to summarize the needs, the Billing Simulation approach was designed to include:

- **Simulation tool** that ties together whole-building bills and a simplified engineering simulation—user can quickly ''tune'' the engineering model to match the bills.

- **No complicated software—**use standard spreadsheet as basis.

- **Minimal set of inputs**—model will run using standard assumptions, but can be updated to include site-specific details when they are available.
- **Use of real-time**, local weather (not average weather data) that can be readily obtained.
- **Option to change physical parameters** using typical engineering values, such as standard equipment ratings, allowing modeling of conservation measures.
- **Savings estimates** that are calibrated to match the actual usage.
- **Results communicated** in simple-to-understand graphics.

METHODOLOGY

The simulation model uses a monthly methodology (White and Reichmuth, 1996). That is, instead of going through all the computations of computing thermal loads by hour, the model computes the thermal loads on a monthly basis, Since the utility bills provide only monthly data for comparison, there is no point in more laborious computations. This fact allows the model to be implemented in a standard spreadsheet.

Modeled results are compared to billing data in an Operations Profile chart as shown in Figure 1. This chart shows average monthly energy use, normalized for building size, plotted against average monthly temperature. The advantage of this type of chart is that performance follows a similar profile over a range of climates—hence, one building's performance can be compared to other facilities or under different climatic conditions.

To illustrate, Figure 1 shows an example of an all-electric building. One observes that the performance profile is a U-shaped curve. The left side informs about the heating requirement; the right side informs the cooling requirement. The bottom of the U informs about the non-seasonal loads for lights and plugs. Hence, the shape of the U-curve informs us about the end uses within the facility.

"Tuning" or calibrating the model is the process of adjusting those end uses until the modeled performance matches the billing data. Even if billing data are not provided for a full year, a few data points are

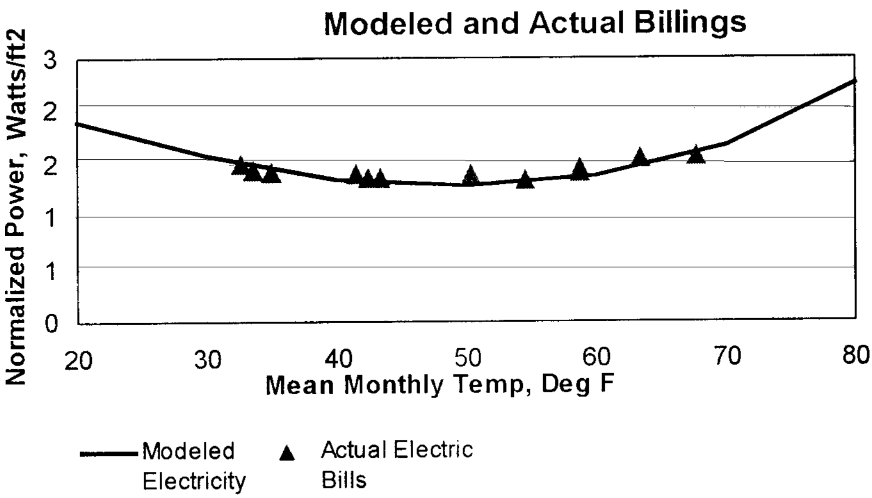

Figure 1. Operations Profile Example

sufficient to distinguish if the facility has moved to a new operations profile.

The process of calibration is also transparent. A lay person can understand the principle of the Operations Profile plot. This means that the analysis process can be explained to the owner or fiscal manager. These persons are stakeholders that need to feel comfortable with the explanation for how savings are computed.

To accurately determine a shift in end uses requires that perturbations due to weather can be isolated. This means that it is important to review the utility bills against weather variables for the same time period. Figure 2 shows an example of weather during a study we made for the World Bank in Jamaica. One might think that weather is relatively uniform in a tropical climate. Indeed, for the pre-retrofit year 1996, weather was similar to the long-term average.

But for the post-retrofit year in 1997-8, there was an atypical weather event. Temperatures and humidity were each about 5% higher than usual, causing increased cooling loads. For some facilities, the increase was about 10% of electrical consumption. Since we were looking for savings of about 15%, the weather effect would interfere with simply comparing pre/post bills. However, the simulation model computes normalized performance during "typical" weather.

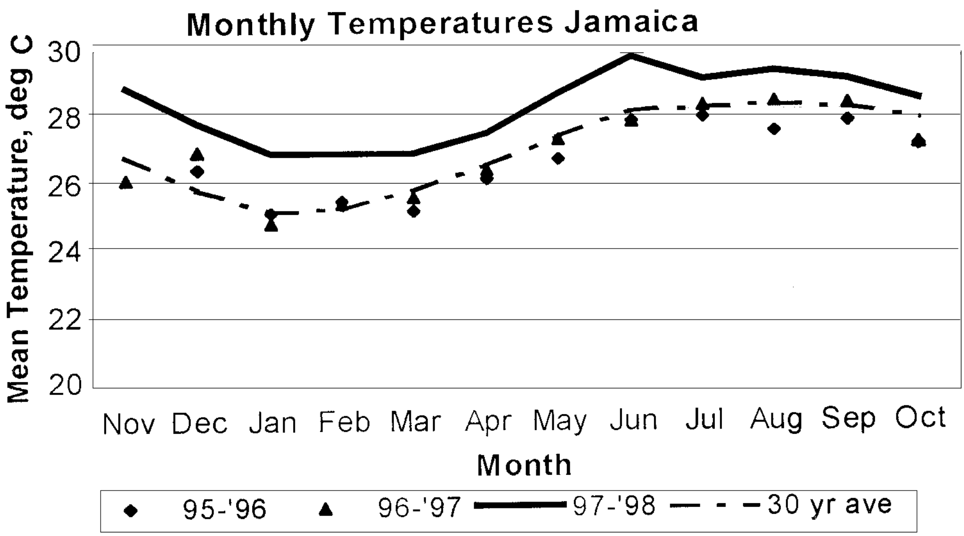

Figure 2. Weather Variation Example

Detailed weather data, including solar irradiation and latent humidity, are not easily obtained. Instead, the model uses the local average temperature as a proxy and estimates the other weather variables. Average daily temperature is easy to obtain on a local basis.

APPLICATIONS

Review Operations

The process of matching bills often reveals information that was not apparent. For example, Figure 3 shows electricity use for a community college campus. An energy audit was conducted and the resulting site description (insulation values, lighting density, etc.) has been included in the model. Yet actual energy use is much higher than expected. How do we explain this?

Answer: Excess Outside Air! To get a model that matches the bills, one must assume a high ventilation rate as shown in Figure 4. This would be equivalent to the facility being ventilated at full design rate for 24 hours per day, seven days a week. Is this even possible? When the facil-

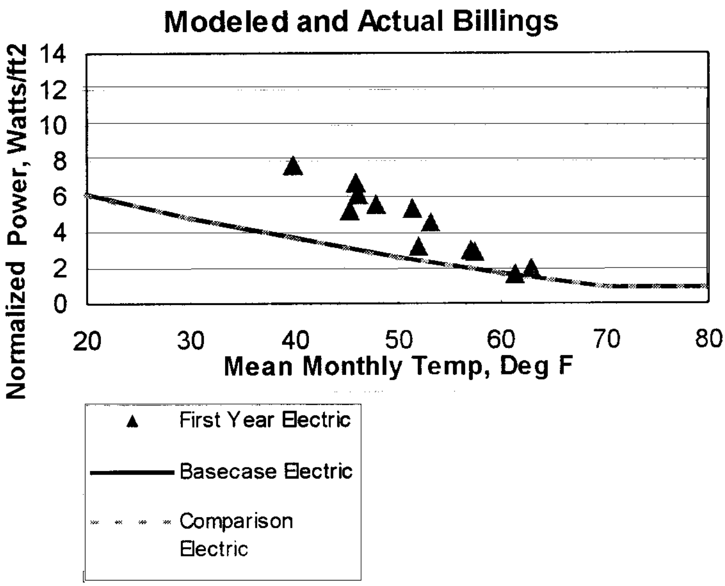

Figure 3. College Example

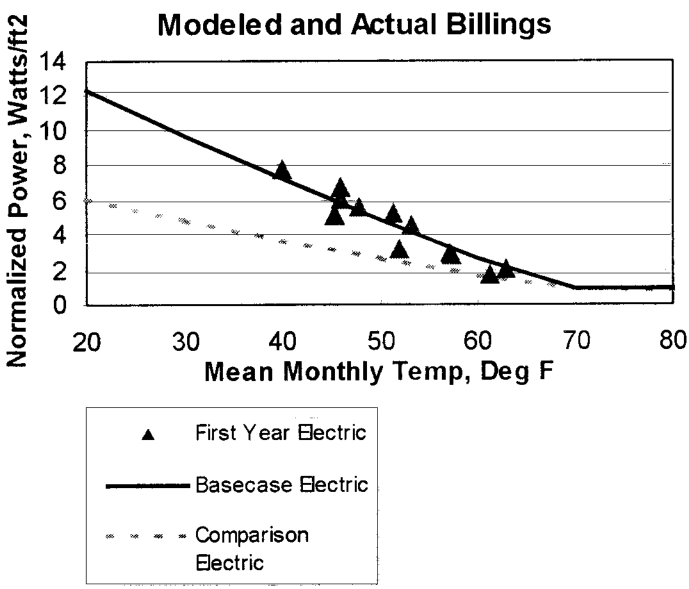

Figure 4. College Modeled With OSA

ity manger was queried, he acknowledged this fact: the building's fans were running full-time without any controls. Simple time clock controls could provide savings of about 1 million kWh per year.

Review End-use Breakdown

The endues breakdown falls out of the operations profile above. These components are tabulated on an annual basis and provide a useful check as shown in Figure 5. For example, suppose a vendor estimates savings for efficient fans. How does that estimate compare to the modeled estimate of total fan energy? Are the savings realistic? The simulation tool provides a way for a manager to quickly check on specific end uses.

Inform the Energy Audit

It should be apparent that no modeling tool is able to specify all the facility details without additional information. For example, the process of tuning the model may indicate that internal energy use is high. But is that due to high lighting, high plug loads, extended operat-

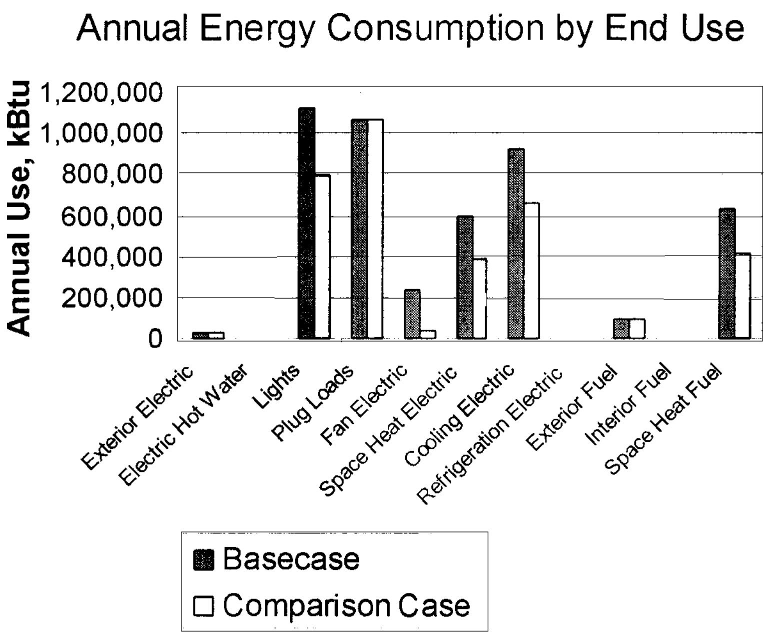

Figure 5. Annual End-use Breakdown

ing hours or some combination of all three? The model is not able to distinguish.

However, the model can be used to develop testable hypotheses and to indicate which information is lacking. For example, the model could be used to compute the lighting level that was required to account for the observed bills. Now the energy auditor has a clear idea of what to investigate while on-site. Reviewing the bills before the site visit assures the site visit is used efficiently to resolve the most important questions.

Screen Conservation Opportunities

Reviewing a number of candidate facilities allows them to be ranked according to their potential. This permits a manager to focus of the most productive opportunities. For example, Figure 6 shows the operations profile for a small-town hospital. One observes that electricity usage is not high—the only explanation is that occupancy is low. Gas is used throughout the year, perhaps because a boiler is used to supply domestic hot water.

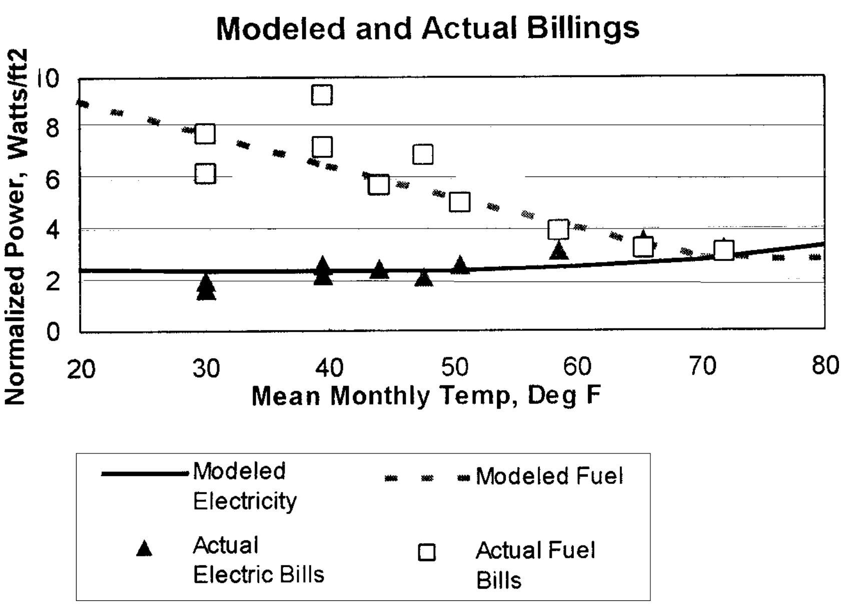

Figure 6. Screening Small Hospital

Is this a good candidate for savings? Probably not. Since occupancy is already low, the potential for electric savings is low. There is potential for gas savings but the dollar value may not be large.

In contrast, Figure 7 shows an older office building. Electric consumption is high, more than can be explained from lighting. This facility probably has an inefficient HVAC system and would be a good candidate for savings.

Set Performance Targets

Verification is a unique application for this tool. One can forecast what future consumption is supposed to be. Then, as the future bills come in, they can be checked against the predictions. This answers the question: "is this building on track for savings?" In this sense, it provides a simplified commissioning check. For facilities without a large budget, this may be the only affordable type of commissioning.

Figure 8 shows an example of a Commissioning Chart. This chart shows monthly consumption computed for the weather conditions occurring during the second, or post-retrofit, year. The baseline is shown as a black line; the actual consumption is shown as white bars-, and the predicted consumption is shown as gray bars. If the two sets of bars are in reasonable agreement, the measures are performing as expected. The difference from the base (black line) shows the actual savings.

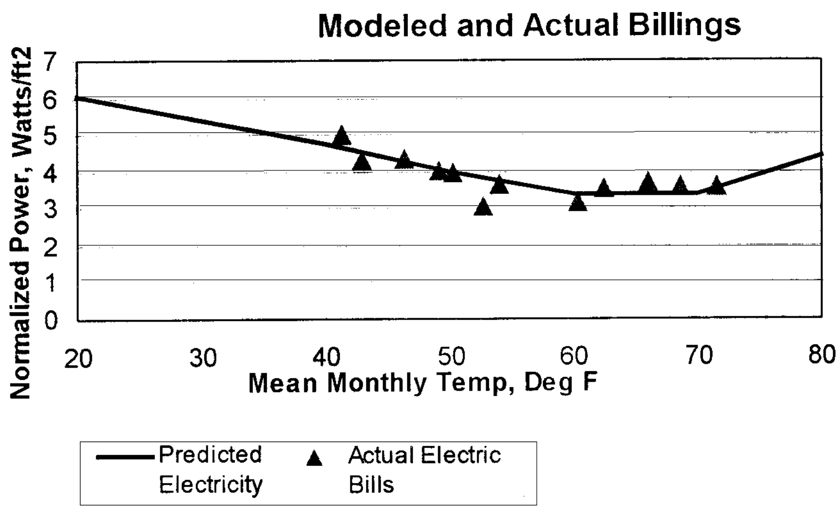

Figure 7. Screening Large Office

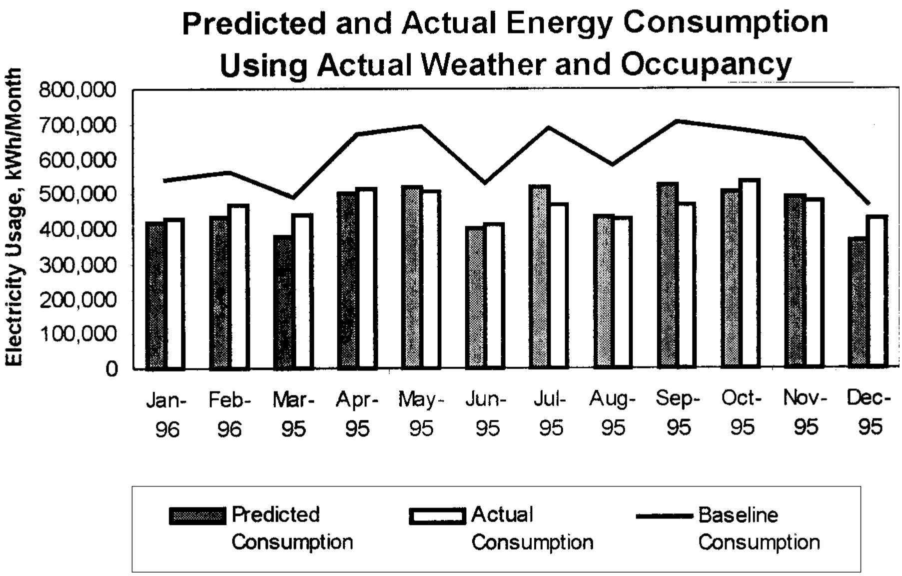

Figure 8. Commissioning Plot Example

Figure 8 provided a useful story to an Energy Service Company (ESCO). In this case, the ESCO had completed Phase One of a project and was ready to start Phase Two. But the owner wanted proof of savings before he would start a new phase. The ESCO had copious data in the form of trend log reports but no good way to communicate the information so that the owner could understand.

However, when the monthly bills were presented as shown, the owner was pleased to see savings in a form that he could understand. The owner was then willing to start negotiations on Phase Two.

The same approach can also be used to review on-going operations. In this case, the model is set up and, as new utility bills come in, they can be checked against the expected consumption to identify any discrepancy.

Adjust Baseline for Changed Conditions

Figure 9 shows another example of a commissioning plot. In this case, a school installed efficient lighting. Yet Figure 9 shows that the predicted and actual bills (gray and white bars) are not in agreement. The bills did not decrease as expected. **What happened?**

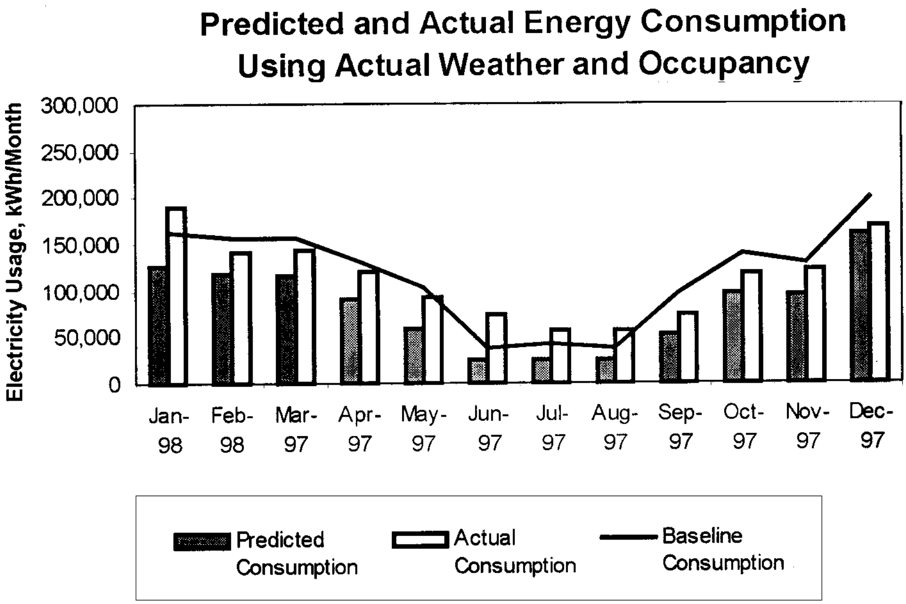

Figure 9. School Retrofit

The school staff explained the change. Due to a community concern to keep kids off the street, the school instituted a midnight basketball program. Now the gym is open 24 hours. When the model is revised to include the new operating hours, we see a better picture of the operation in Figure 10. Now it is clear that the consumption is close to that expected and there are large savings compared to what the old facility would have used with longer operating hours.

This is an example of using the model to create a "hypothetical" baseline. Often the retrofit opportunity is used to remodel or change other operations. The old baseline is no longer relevant to the changed facility. Yet, because the model is based on engineering parameters, it is not difficult to adjust for the changed conditions. Other examples of adjustment to a hypothetical baseline include:

(1) Supermarket retrofit where new refrigeration cases were added at the same time as efficient lighting.

(2) Retail retrofit where air conditioning was added at the same time as the efficient lighting.

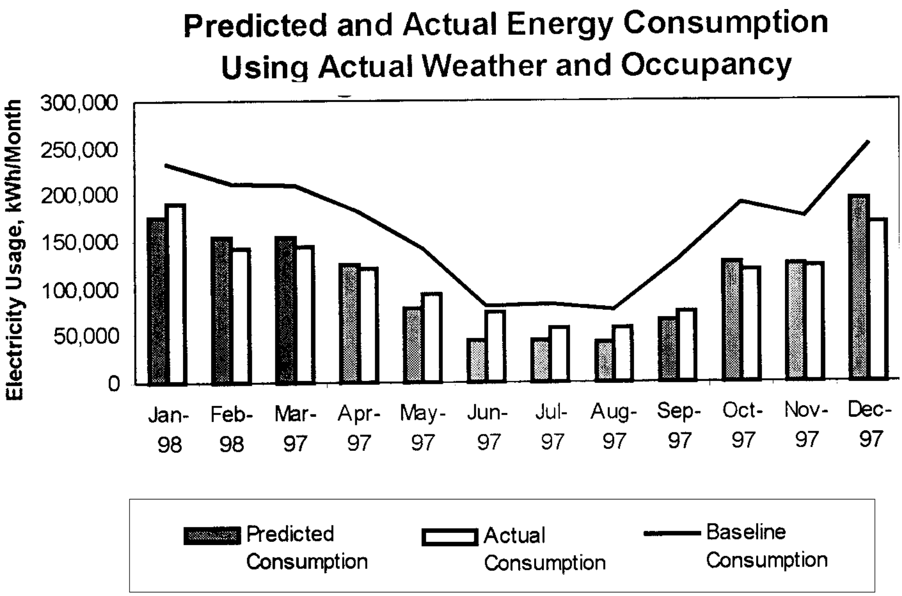

Figure 10. Revised School

Performance Verification

Measurement and Verification (M&V) is an important part of any installation project. This task provides proof that installed measures are really working (commissioning), may be necessary for performance-based contracts or shared savings arrangements and reassures fiscal managers that the investment was well spent. Verification is distinguished from commissioning as follows

- **Commissioning uses short-term tests or inspections during installation.**
- **Commissioning assures that measures are installed and operating as designed.**
- **Commissioning can't tell if the savings are there on a year-round basis or if design assumptions are off.**

Verification over the long-term is an expectation for performance-based contracting. Typically, such contracting requires that all parties agree on:

- **Baseline for estimating savings**
- **How to estimate partial savings during installation**
- **Interactive effects between measures**
- **Adjustments for weather, occupancy changes, or other changes that interfere with simply comparing the pre- and post-retrofit utility bills**

Specifics of baseline conditions and adjustments away from baseline can be easily accomplished within the engineering model in a form that can be referenced as part of the agreement.

The standard reference for many Federal and international agencies is the USDOE sponsored International Performance Measurement and Verification Protocol (IPMVP). This protocol may seem intimidating but is a series of commons-sense guidelines. The IPMVP protocol presents several Measurement and Verification (M&V) options; in this case, we focus on Option D, specified as the use of calibrated engineering simulation models.

There is one important new requirement—the IPMVP asks for precision estimates (error bands) on savings. For example, if one computes savings of 100,000 kWh, one should also be able to state that the 90% Confidence Limit of this estimate is +/- 20,000 kWh. Such a precision estimate is not a result that engineers typically provide. This brings up the question—how accurate are modeled estimates?

Precision Study

We recently participated in a World Bank-funded study to verify savings for several projects in Jamaica following IPMVP guidelines including reporting precision. Results are interesting for several reasons.

Figure 2 presented earlier showed the weather influences that affected the Caribbean during this study. The climate effect was about the same magnitude as the expected impact. A direct comparison of pre/post bills would not be able to distinguish savings. Thus, some method of normalizing for weather must be applied to accurately measure savings. This demonstrates the importance of having a modeling tool that is able to incorporate actual local weather instead of using average weather.

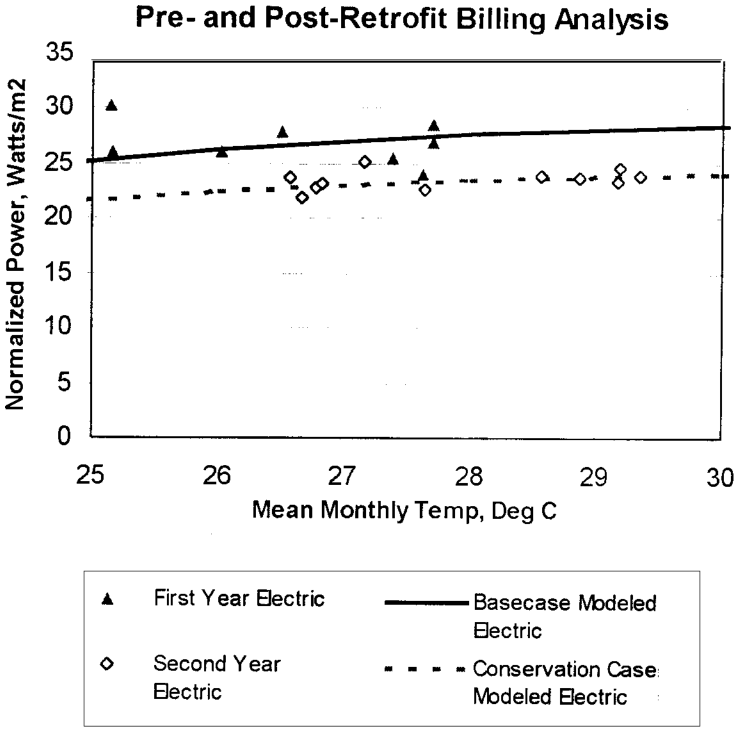

Figure 11. Pre/Post Model Example

Figure 11 shows the pre/post models for one participant. Pre-retrofit conditions were rather noisy. The Standard Errors of the annual consumption estimate are 121,975 kWh or 2.1% pre-and 52,648 kWh or 1.1% post-retrofit. The Standard Error of the savings is based on the difference of the two annual estimates.

In this case, the SE of the difference is 133,676 kWh or 2.4% of the annual pre-retrofit whole-building consumption. The annual savings are estimated at 15%, with 90% confidence limits of 260,399 kWh or 4.6% of total consumption. Thus, the precision of this method is clearly quite sufficient to provide a reliable savings estimate.

For the other Jamaican projects, we observed that the models also matched monthly consumption well. That is, the SE error was relatively small compared to the total amount of monthly consumption. In general, the standard error estimate of annual consumption was about 2% of total annual consumption. Comparing two years to estimate savings produces an error of the savings estimate at about 5%. Thus, we can expect to distinguish savings that are larger than 5% of total annual consumption.

For those participants with both pre- and post-retrofit billing data, reliable estimates of savings are obtained as shown in Figure 12. For the first participant, savings were slightly negative and not statistically significant. Investigation determined that the conservation measures were not appropriately installed in this case. For the other participants, the savings estimates were strongly positive and significantly different from zero.

The relative precision of the savings estimate depends on the magnitude of the savings. In this study, confidence limits of about +5% of annual consumption are about 30% of the savings estimate. However, this level of accuracy is quite sufficient to eliminate the null hypothesis and provide creditability to the estimates. This level of resolution is about as good as could be expected for any sort of whole-building model.

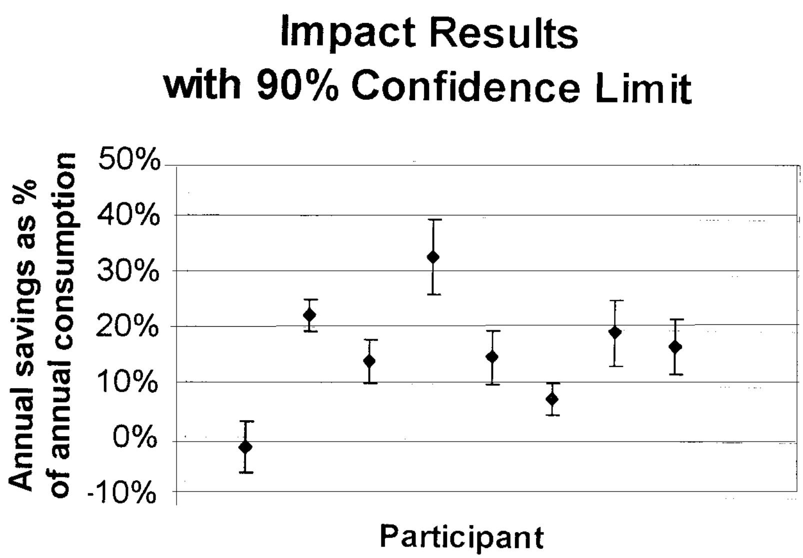

Figure 12. Precision of Results

COST OF VERIFICATION

The IPMVP indicated the anticipated cost and level of accuracy for verification options.

Option C: Statistical Analysis

- Monthly data, accuracy 20% of savings, cost 1-3% of retrofit project cost

- Hourly data, accuracy 5-10% of savings, cost 3-10% of retrofit project cost

Option D: Calibrated Simulation

- Monthly data, accuracy 20% of monthly consumption, cost 5-10% of retrofit project

- Hourly data, accuracy 1-5% of monthly consumption, cost 100% of annual bill

In this study, we were able to model with the accuracy expected for hourly modeling but at a cost similar to that of statistical analysis, about 1% of project costs.

CONCLUSIONS FROM THE JAMAICAN STUDY

1. Weather normalization is required. Climatic changes prevent simply comparing pre-post bills.

2. Monthly simulation method is sufficiently precise. Standard error of the savings estimate was 2-3% of annual consumption for savings that were 15-20% of annual consumption.

3. Relative accuracy of the savings estimate depends on the size of the savings, relative error of savings corresponded to about 90/30 precision in this study.

4. Option D of IPMVP was accomplished without additional monitoring expense, using whole-building utility bills supplemented with audits and available site information.

SUMMARY

- Simplified modeling tool links utility bills and engineering simulation offers a breakdown of energy end uses.
- Provides similar results to complicated engineering models, but with greatly reduced data requirements.
- Produces graphic outputs that are readily understood.
- Quickly matches to actual bills and weather, providing a tuned, as-built model.
- The tuning process often reveals operations problems and is a mechanism for on-going quality assurance.
- The tuned model provides calibrated savings estimates, generates performance targets that are a simple-level form of commissioning or performance verification at low cost.

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Stellar Processes, EZ Sim Manual, http://www.ezsim.com, 1999. Further information, including case examples and technical papers, is available on this website.

ABOUT THE AUTHOR

David Robison, P.E., M.S., is the owner of Stellar Processes, Inc. His firm manages projects that involve research and evaluation. Expertise includes technical support and financial analysis for demand-side bidding, energy end use metering and analysis, modeling methods for commercial building energy consumption and commissioning.

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Recent projects include the development of a simplified simulation tool to verify energy performance of commercial buildings. This tool has proved very useful for performance verification and evaluation. Funding from the Northwest Energy Efficiency Alliance has supported training seminars for energy professionals in use of the new tool. Mr. Robison has participated in several projects involving verification for DSM bidding, as well as the large-scale monitoring of residential and commercial systems.

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