Optimizing the Post-Occupancy Evaluation Timeline for Commercial New Construction Simulation Modeling

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ABSTRACT

Utility energy efficiency programs have increasingly identified commercial new construction as an avenue for achieving significant energy savings. These programs usually require analysis of whole-building energy savings through simulation modeling, with baseline models based on energy codes prevailing at the time the relevant jurisdiction approved the building's construction permit. Projects using simulation modeling to estimate *ex ante* savings, however, present multiple challenges for impact evaluations. As these projects are designed prospectively, we find as-built space types, operational parameters, and occupancy patterns can vary from the original designs. Thus, each project requires unique modeling adjustments, based on site verification. A common evaluation technique involves post-occupancy calibration with utility billing data to adjust the simulation model. Utility billing data offer a means to examine a building's performance and the effectiveness of energy efficiency measures. In doing so, defining the post-occupancy time period plays a critical role in calibration. Generally, the more post-occupancy data available, the more accurately evaluators can calibrate a model to match actual building performance. Many utility programs, however, operate using stringent timelines for project implementation and for reporting final evaluation results to oversight bodies. This paper provides a sensitivity analysis of calibrated models' accuracy over a range of time periods. We first examine model performance immediately after adjusting an as-designed model to reflect the as-built physical condition. We then provide results from simulation model calibrations that span the first year of facility occupancy. The sensitivity analysis results can inform utility program design and reporting requirements.

Introduction

Energy efficiency plays an increasingly important role in commercial new building design and construction, with developers and building owners realizing that cost-effective energy efficiency improvements allow them to reduce tenant costs. Thus, developers can price leased spaces at more competitive levels. Building owners or tenants also find value in buildings certified through Leadership in Energy and Environmental Design (LEED) or other similar rating systems, which require some degree of energy efficiency.

Utilities increasingly recognize the value energy-efficient new construction can offer by producing substantial energy savings. Such savings often represent opportunities unlikely to be recovered during future retrofits, particularly those involving improvements to a building's envelope. Larger savings can be achieved through program engagement early in the design cycle, when holistic, integrated design options can be considered.

New construction energy efficiency encompasses a wide range of measures, including the following:

- Reductions in lighting power density
- High-efficiency heating and cooling systems
- Underfloor air systems and dedicated outdoor air systems

- More efficient windows or insulation
- Integrated designs for better daylighting or solar shading

Whole-building energy simulation models generally provide the most effective method for characterizing the performance and benefits of integrated design options. Most utility programs set a baseline as a state's or jurisdiction's prevailing energy code at the time they issue a construction permit. In general, the energy code is a version of the ASHRAE 90.1 standard, incorporating various jurisdiction-specific amendments. A project developer usually must create a baseline simulation model, using code minimum requirements for elements such as the building envelope, space conditioning equipment efficiencies, and lighting power density that reflect the same expected operational parameters and occupancy patterns as the building's final design. Reported energy savings represent the difference between the design model's annual energy consumption and the code baseline model's energy consumption.

New Construction Challenges

Utilities throughout North America have retained Cadmus to conduct independent impact evaluations of new commercial building construction programs or of new construction energy efficiency measures incented through custom programs. Energy efficiency programs usually provide incentives based on a building's design intent, but they sometimes lack mechanisms to verify whether proposed measures have been installed and operate per the design.

A building's form and function may change greatly during the process from design to permitting to construction and final occupancy. Building owners or developers may "value engineer" various energy efficiency measures out of final building designs, deeming them as "unnecessary expenditures," and building simulation models may not incorporate these changes. Building owners and developers generally focus on finalizing construction and attracting tenants. Rarely are they willing to pay for as-built drawings that document changes made during the construction process or for updating simulation models based on these changes. Energy efficiency program implementation staff also rarely learn the full extent of design alterations. Consequently, a building's final form and equipment details often differ from original designs upon which utilities base incentives.

After construction, buildings may experience changes in operational parameters from original designs. For example, facility management staff may not effectively commission mechanical systems, and building operators may manually override HVAC controls to address tenant complaints about comfort issues. Thus, space conditioning systems may operate at lower efficiency levels, higher flow rates, different temperatures, or vary in other operating conditions than those established in the original design.

Program implementers employ various methods to improve the accuracy of post-construction design models. Often, post-construction reviews by the implementer can help mitigate shortcomings in the new construction process. Such reviews can provide a program with a mechanism to conduct post-construction inspections. Implementers may review building submittals to confirm installation of measures such as improved insulation R-values and fenestration U-values. The review may include energy simulation models to make adjustments that more accurately reflect installed measures and expected performance. Building owners and developers understand post-construction reviews could reduce incentive payments if they reveal measures have not been installed or do not operate effectively. A program's financial incentives often prove helpful in offsetting costs and potentially reduce value engineering that removes designed measures.

Post-Occupancy Calibration Process

Program impact evaluations seek to calculate actual energy savings achieved by a sample of projects and to ensure energy efficiency programs operate cost-effectively for ratepayers. Cadmus conducts impact evaluations at varying periods following a new construction project's approval by an energy efficiency program. Generally, the length of the post-occupancy evaluation time period is determined by the regulatory body overseeing the energy efficiency program.

To verify reported program participation and to estimate gross energy savings in the impact evaluation, we estimate changes in gross energy consumption between the calibrated baseline and the as-built simulation models. Given these evaluations are for new construction programs and prior basis does not exist for estimating energy consumption and savings, we build our calibration process based on original energy models submitted to demonstrate incentive compliance. Figure 1 provides an overview of the evaluation process.

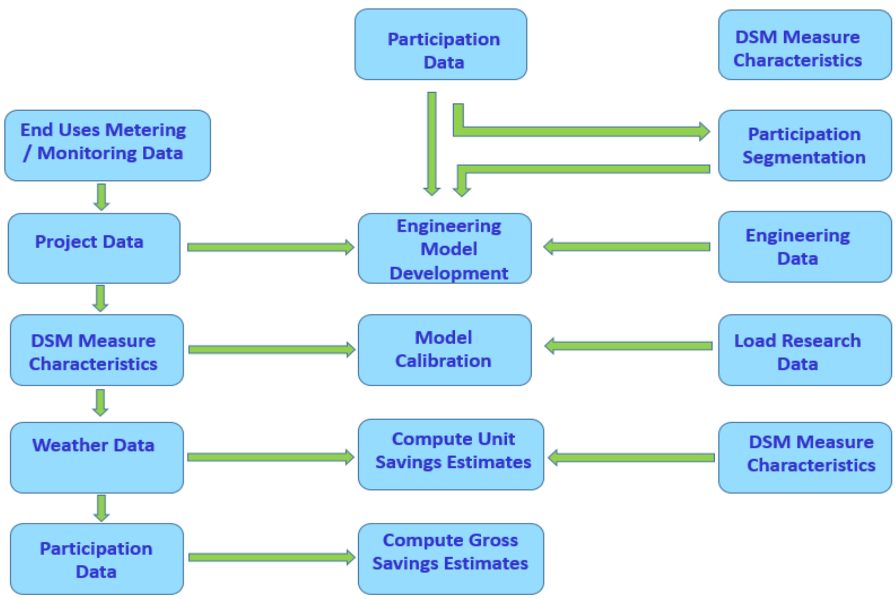

Figure 1. General Overview of Whole-Building Model Evaluation Process

Cadmus implements the following steps (in chronological order) to transform original simulation models into calibrated models:

- **Review original models and supporting incentive documentation:** We review original models received from the program to confirm whether modeled measures match incented measures (e.g., HVAC units), both qualitatively and in magnitude. Where incented measures are not collectively modeled to account for interactive effects, we aggregate efficiency measures within one model to address interactive effects. We notify program staff and request more accurate models whenever the modeled savings do not match reported savings.
- **Site visit preparation:** In preparation for site visits, we review modeled assumptions related to building occupancy and to system types and operations. We identify unusual consumption trends in the billing data (where available in advance) to aid in identifying possible reasons for discrepancies during site visits and in interviews with site contacts. Site contacts often offer valuable insights regarding unusual consumption trends resulting from operations rather

than designs (e.g., periods when gas heating equipment failed and the facility relied on electric resistance heating).

- **Site verification**: We conduct site visits to verify modeled inputs (such as envelope construction, energy system operational parameters, building operational schedules, and energy-efficient measure characteristics [e.g., quantities, capacities, and efficiencies]) and confirm whether estimated end-use consumption matched modeled end uses. We sample spaces to estimate the typical installed lighting power density, the percentage of lighting equipped with lighting controls, and equipment densities. Where accessible, we obtain energy management system (EMS) trend data to develop a more detailed understanding of equipment operation cycles and set points. Where accessible, we document installations of energy efficiency measures by photographing the physical measures and nameplates indicating the equipment's rated capacity and efficiency.
- **Model calibration:** Following site visits and post-occupancy data collection, we identify differences in modeled assumptions and site-verified operational conditions. We modify original models to mirror occupancy behaviors in the building and verified system inputs to develop the "as-built design" model.[1] In some cases, we modify original models to represent the installed system and corresponding baseline cases (when originally modeled systems differ from those installed). The calibration exercise involves modifying models' operational and load parameters to align with a facility's utility billing data and any available system-specific data. The end product of this process serves as the "whole-building reference" model.

Utility billing data is not the only input needed for solid calibration. Evaluation engineers also rely on energy management system (EMS) trend data as a source of highly granular performance data on energy efficiency systems, such as chillers and air handlers. These data (often in 15-minute increments) provide more specific detail on system operation than what can be deduced from an on-site verification or monthly utility data. Most large, newly-constructed facilities install an EMS to control building systems, so the data, and the capability to track the data, should be present. Some facilities do not set up their EMS trends, and therefore miss the opportunity to track and tune their system performance as ambient temperature and humidity conditions change.

Cadmus incrementally modifies models using site-verified data, calibrating them to simulate performance within +/-10% of the annual billing data and to exhibit no more than a +/- 20% variance in actual vs. calibrated energy on a monthly basis. Site-verified modifications most commonly include extending occupancy and system operations schedules, thermostat set points, and control set points, and adjusting lighting power densities, plug loads, and equipment efficiencies. In a few instances, calibration adds energy end uses (e.g., elevators, exterior lights, commercial kitchen appliances) if these have not been originally modeled in the building, but building utility meters include their consumption. Accounting for non-incentivized building systems helps bridge gaps between a building's calibrated and actual energy consumption and mimics interactive effects on incented measures that may be associated with those interactive effects.

The calibration effort for as-built models initially uses actual meteorological year (AMY) weather data to closely match billing data for the given year. Cadmus reviews monthly variations between modeled and actual consumption for discrepancies. Once the as-built design model has been satisfactorily calibrated (based on site-verified data) to match billing data, we revise the baseline models to match operational parameters (e.g., schedules, plug loads, set points) of the as-built design model.

[1] More detail on model naming conventions and descriptions can be found in the Uniform Methods Protocol for Commercial New Construction at http://www.nrel.gov/extranet/ump/pdfs/20130912_ump_commerical_new_construction_draft.pdf

Finally, we calculate the typical annual evaluated savings for the project by running baseline and as-built models using Typical Meteorological Year 3 (TMY3)[2] weather data.

Challenges with the Timing of Post-Occupancy Calibration

Following post-verification model adjustments, the availability of post-occupancy data (i.e., utility billing data and EMS trend data) can present a significant constraint in simulation model calibration. These data provide the most effective means to characterize a system's performance, based on temperature and occupancy patterns. Depending on utility reporting constraints, projects may be evaluated as soon as several months after construction to one or two years after occupancy. The length of the post-occupancy period presents a variety of problems. Generally, more time works better than less.

Some utilities must present annual results in the first quarter following the end of the preceding calendar year. This creates problems if construction completion and initial occupancy occurs near the end of the calendar year. As shown in Figure 2, without sufficient post-occupancy billing data, evaluators can find it nearly impossible to calibrate simulation models with reasonable accuracy over a range of ambient conditions. Here, only two months of utility billing data are available before reporting energy savings. The limited data points indicate actual consumption significantly higher than the as-designed model value. Generally, this indicates a building saved far less energy than expected or the modeling contractor underestimated base load assumptions (e.g., lighting, plug loads). We often find the latter case true. The steep, increasing slope of consumption in actual billing data indicates the building likely increased occupancy and/or continued to undergo system commissioning. In this case, the new construction model could not be calibrated due to limited, high-discrepancy data, and required the application of other, less rigorous approaches (such as verifying model inputs).

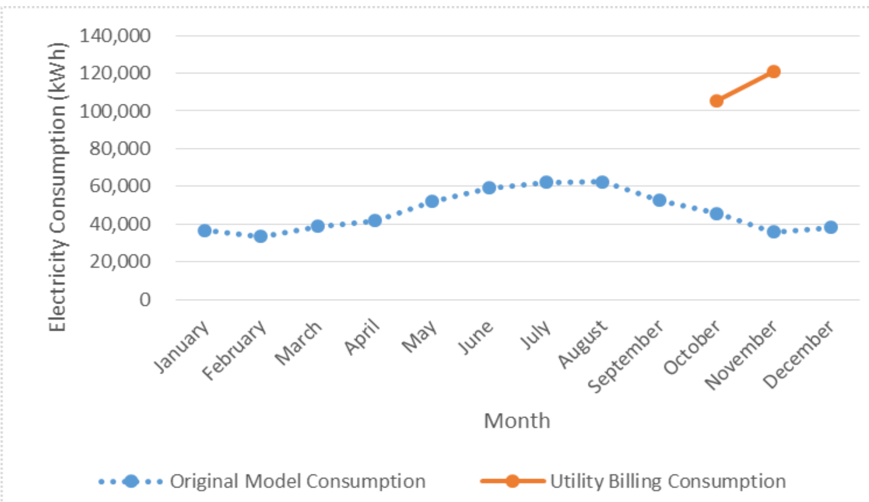

Figure 2. Comparison of Design Model and Actual Consumption for Limited Data Project

The process faces another challenge in obtaining sufficient calibration data beyond the period when building systems have been commissioned (sometimes called "shake out"). After construction, modern buildings with sufficiently-complex controls and space conditioning equipment require a period

[2] http://rredc.nrel.gov/solar/old_data/nsrdb/1991-2005/tmy3/

for installation contractors to adjust systems to more appropriately reflect design intent, while ensuring occupant comfort (which often trumps design intent or energy efficiency). In many cases, building owners also hire contractors to commission systems through rigorous functional testing. This can result in wild building consumption swings as systems are initialized, tested, and their operations further refined.

Figure 3 illustrates this process using billing data for a high school. School construction completed in January 2012, and electricity consumption then increased dramatically as contractors brought systems online and conducted functional testing. Consumption declined as contractors commissioned systems, adjusting them to expected operation levels. The school became occupied in fall 2012 (shown by the vertical line), after which billing data showed expected and reasonable variance levels for normal operations.

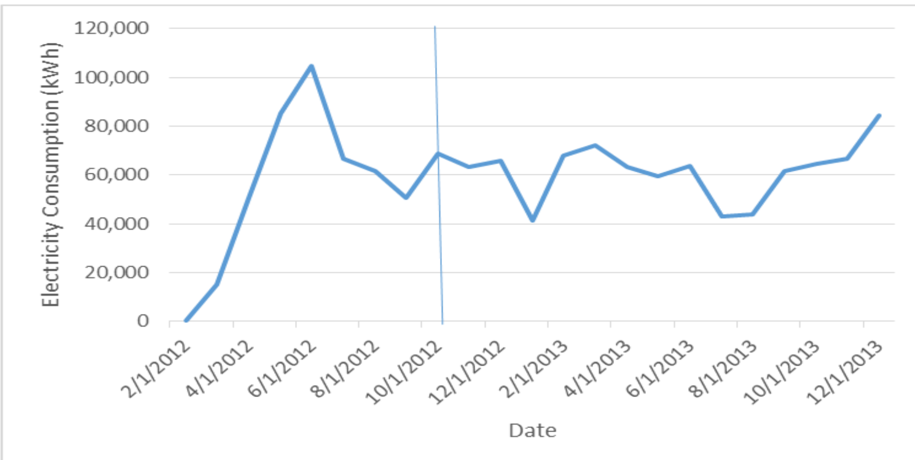

Figure 3. Initial Variance in Electricity Consumption for Newly-Constructed School

The occupancy level, relative to expected final occupancy, presents another key issue during the post-construction period. Some building types require one or more years to reach their full occupancy rates (e.g., office buildings with large numbers of leased tenant spaces; data centers, which often take several years to build their server capacity to the design load; multifamily residential, which often requires months or years to lease or sell all available units). To illustrate this, Figure 4 shows 23 months of billing data for a new construction multifamily residential building. Consumption gradually increased over the nearly two-year period as occupancy increased. In this case, an evaluation would have underestimated consumption with only the first year of utility billing data available (unless adjusting the model to account for occupancy rates).

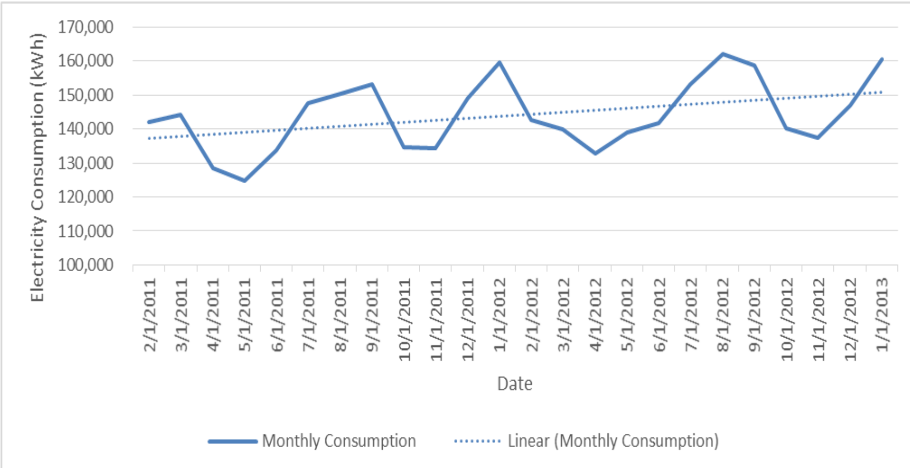

Figure 4. Utility Billing Data on Multifamily Building to Demonstrate Occupancy Growth

Analysis of Post-Occupancy Calibration

This study examined varying time frames for post-occupancy calibration with electricity and/or natural gas utility billing data for five, newly constructed, education buildings. These included primary education, secondary education, and university structures. All buildings were located within the same utility service territory, in a heating-dominant climate. Time frames covered three-month increments, from construction completion to one year, using data from the first full calendar year after initial occupancy. The buildings represented the following educational types:

- Building 1: University
- Building 2: High school
- Building 3: K-8 school
- Building 4: K-5 school
- Building 5: K-5 school (gas data only)

Each calibration employed an iterative version of the process previously described. We first compared as-built model consumption to as-designed model consumption, along with actual utility billing data for a full year. As shown in

Figure 5, on-site verification did not identify significant adjustments to the as-designed model; so un-calibrated as-built model consumption closely matched as-designed model consumption. Both indicate a sharp dip in summer to reflect the period when school was not in session. Actual utility data indicated the building operated quite differently from the model prediction, particularly during summer. The data comparison implied a lower base equipment power density than predicted and that the school provided some cooling level throughout the summer.

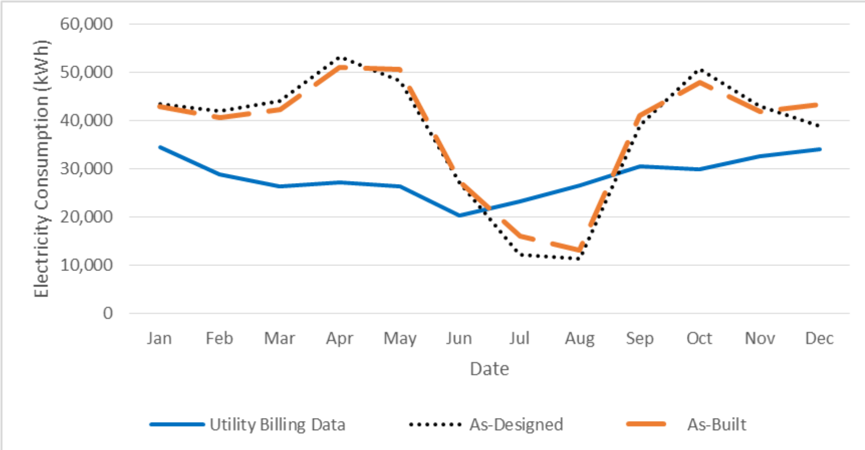

Figure 5. Energy Model and Actual Electricity Consumption for Building 4

We then calibrated the as-built model by comparing actual consumption for January through March against the first three months of predicted model consumption data. This process employed AMY data to ensure closer agreement between actual and modeled behaviors. For each set of models, we reran the calibrated as-built model using TMY3 data to obtain predicted energy consumption for a full year (but only based on the first three months of data). We then added the resulting consumption curve to the previous graph, as shown in Figure 6. This calibration brought the initial consumption data closer to metered data, though the overall consumption curve continued to vary considerably from the utility billing data due to the lack of cooling season data.

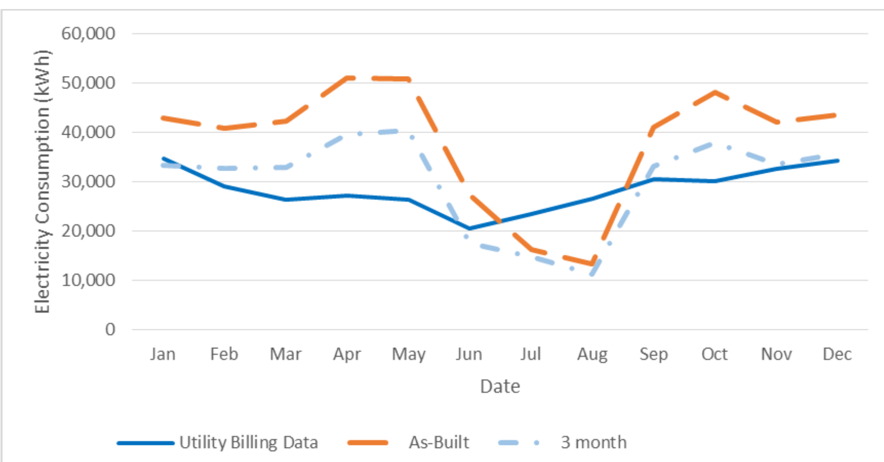

Figure 6. Calibration of Building 4 As-Built Model to January-March Utility and Weather Data

We repeated this process three more times, adding data cumulatively for the following periods:

- April through June
- July through September
- October through December

We then added the resulting iterative curves to the consumption graph, as shown in Figure 7. Each iteration resulted in slight adjustments to equipment loads, HVAC operational patterns, and other parameters listed previously. These adjustments brought the predicted results closer to actual utility billing data. This correlation became particularly evident with the nine- and 12-month calibrations.

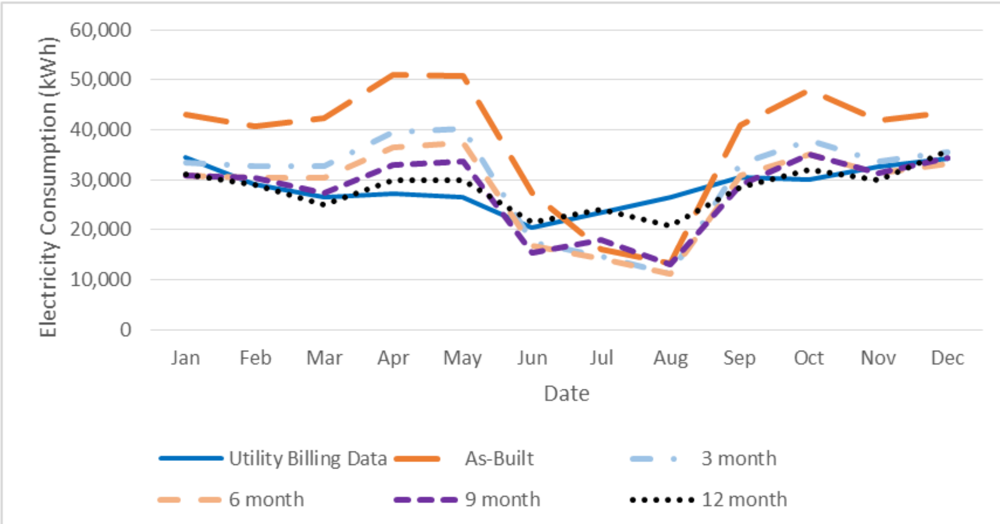

Figure 7. As-Built Consumption Curves for Iterative Calibration on Building 4

As discussed, we then adjusted the baseline model using the same modifications in base loads, equipment operations, set points, and occupancy patterns used to calibrate the as-built model. The adjusted baseline model therefore represented final expected consumption for the counterfactual, code baseline building. Figure 8 offers a comparison.

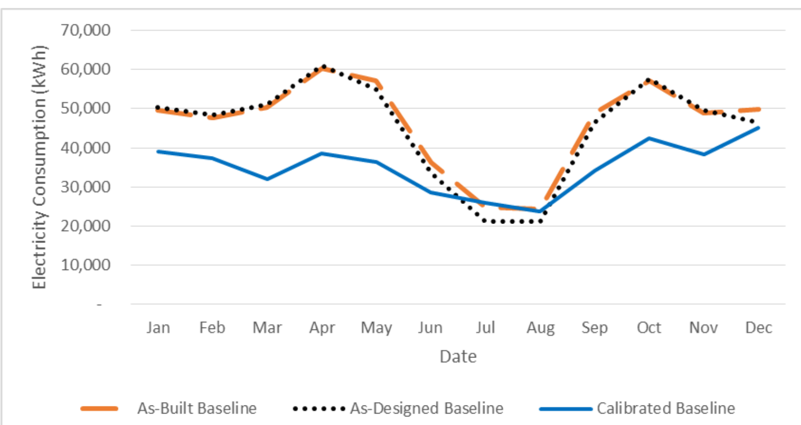

Figure 8. Baseline Consumption Curves Throughout Calibration Process for Building 4

We considered the as-built model with a full 12 months of calibration as most representative of actual building performance. Wherever possible, we examined utility billing and weather data for multiple years to ensure consistent performance before selecting the appropriate range of data to use in calibration. If data appeared consistent, we used the full year model's energy consumption as the basis for the final estimated energy savings, after rerunning the calibrated models with TMY3 weather data.

As an example, Figure 9 shows multiple years of data in a university building (Building 1). In this case, utility billing data shows larger consumption during the second summer and fall, but cooling degree day data shows a corresponding increase to account for higher consumption. Thus, we could assume a stable and consistent overall consumption pattern resulted.

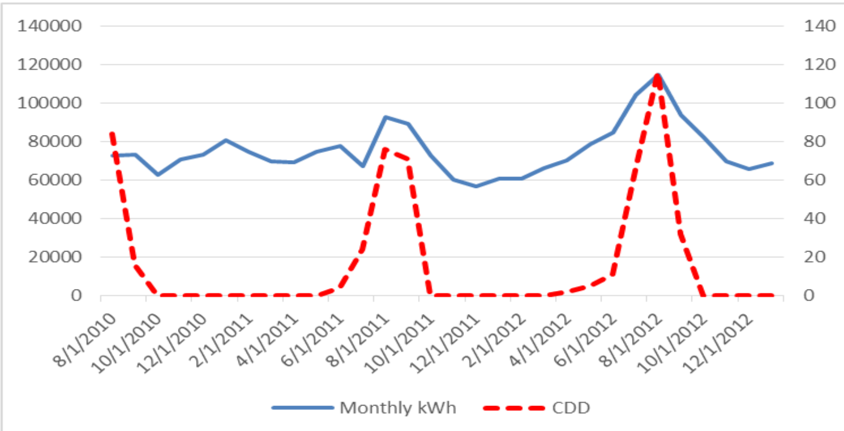

Figure 9. Two-Year Utility Billing and Cooling Degree Data for Building 1

The iterative calibration process resulted in varying differences between the predicted energy consumption and actual utility billing data over the course of the year, as shown in Table 1.

Table 1. Variance in Reported and Evaluation Model Consumption for Final Calibration Process

Building	Fuel	Baseline Building Model			Whole-Building Reference Model		
		As-Designed	As-Built	Calibrated	As-Designed	As-Built	Calibrated
1	Electricity (kWh)	699,976	865,748	967,203	612,920	760,807	892,150
2		5,314,291	4,375,022	4,404,334	2,903,131	2,896,527	2,614,962
3		546,336	667,645	585,880	444,656	490,081	500,097
4		542,343	555,461	422,018	454,082	459,174	337,550
1	Natural Gas (therms)	15,402	25,088	31,397	10,673	18,537	25,907
2		15,156	9,870	11,898	12,346	7,950	10,097
3		25,330	27,839	25,677	15,651	18,338	16,245
4		18,232	18,449	18,557	11,545	13,588	16,117
5		18,444	19,136	20,682	15,471	16,061	17,586

The variance between predicted and actual consumption also resulted in variance for the key metric: energy savings. Figure 10 and Figure

Figure 11 show the variance in realization rates throughout the iterative process for electricity and natural gas. All curves converged to 100% at 12 months as we used that data as our final evaluated consumption value. The electricity curves initially varied a great deal from the final value, but generally converged close to the final value after three to six months. The natural gas data showed as-built consumption estimates closer to the final values than in the electric data, although the iterative calibration variance indicated gas consumption followed a different curve than the as-built. Heating season data after nine months refined the final consumption curve to match the billing data.

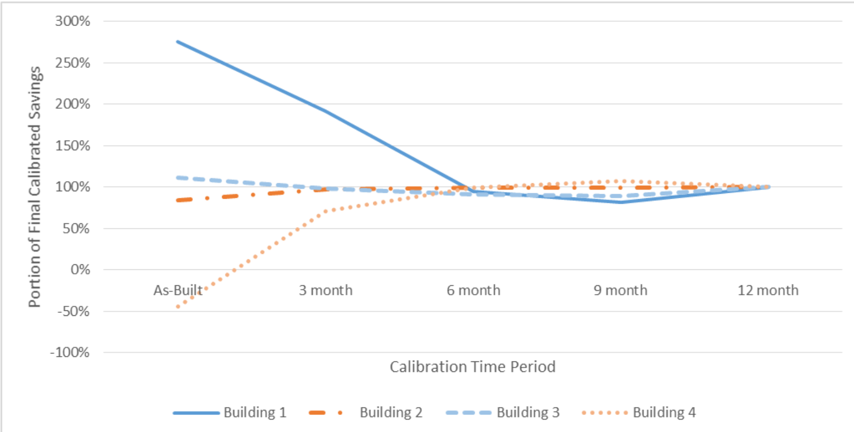

Figure 10. Iterative Electricity Savings Relative to Final Calibrated Savings

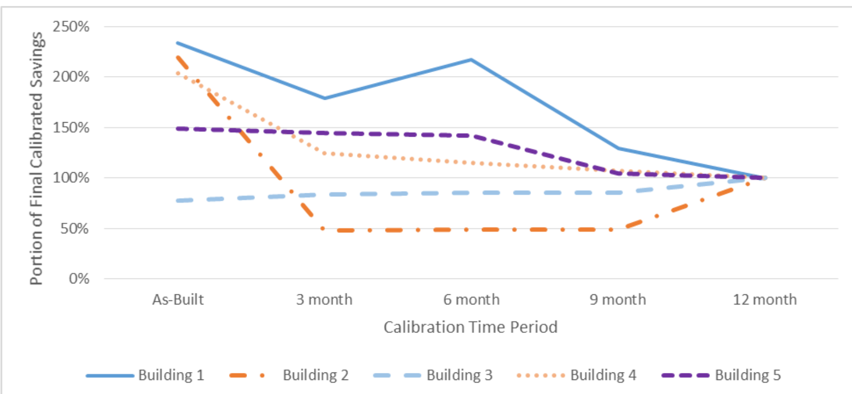

Figure 11. Iterative Gas Savings Relative to Final Calibrated Savings

Table 2 shows changes in savings throughout the calibration process and the final realization rate between reported and evaluated energy savings.

Table 2. Variance in Energy Savings Realization Rates for Different Stages of Calibration Process

Building	**Fuel**	**As-Designed Savings**	**As-Built Savings**	**Calibrated Savings**	**Realization Rate**
1	Electricity (kWh)	87,056	104,941	69,043	79%
2		2,411,160	1,478,495	1,789,372	74%
3		101,681	177,564	85,783	84%
4		88,260	96,287	84,468	96%
1	Natural Gas (therms)	4,660	6,426	5,617	121%
2		2,810	1,921	1,801	64%
3		9,680	9,500	9,432	97%

4		6,687	4,861	2,441	37%
5		2,973	3,075	3,096	104%

A variance in realization rates, typical for new construction projects, resulted (Cropp, Lee, Castor 2014). The results also illustrate the difficulty in assigning prospective correction factors to reported energy savings due to varying levels in the realization rates.

Conclusions

In the course of conducting numerous commercial new construction impact evaluations, Cadmus has identified many complexities that can increase the error potential for energy savings estimations. Variance between as-designed model consumption and actual billing data are expected, as a model developer cannot predict with 100% accuracy how facility engineers and occupants will use a building. One of the most significant challenges in evaluating such projects involves acquiring sufficient post-occupancy utility billing and/or EMS trend data to calibrate simulation models within a reasonable level of actual energy consumption. Our data and experience indicate the following issues represent the most likely error sources from insufficient post-occupancy data:

- Mismatched as-designed and actual base equipment or lighting power density
- Equipment operational variance during system initialization and commissioning
- Fluctuations in building loads as occupancy increases
- Variations between expected and actual equipment operations or occupancy patterns

While the examples in this study only represent educational facilities, we have found these types of issues are pervasive across all building types. The data indicate as-built model electricity consumption often varies significantly from actual electricity consumption in utility billing data. In a heating-dominant climate, at least six to nine months of post-occupancy billing data are required gain a sufficient understanding of how systems perform and to adjust model parameters to more effectively match actual building consumption. For natural gas, obtaining billing data for the final three months of the calendar year (i.e., the transition from shoulder season to heating season) proves critical for the model to most accurately reflect actual building performance.

The data indicate such a wide range of realization rates for these relatively similar building types within the same utility program that it would not be feasible to develop and apply a prospective realization rate adjustment to align the reported savings with anticipated evaluated savings. Each building and each model represent unique challenges to verify actual conditions and to adjust the simulation model.

Extending the time period between building construction and evaluation reporting would improve the accuracy of energy efficiency savings estimates for new construction impact evaluations. Best practices would require at least 12 months of post-commissioning utility billing data for use in calibration. In some cases, reasonably accurate results may be obtained using more limited data from a full shoulder season and the transition to the cooling or heating season, depending on which represents the dominant space conditioning load for the relevant geographic area. We acknowledge, however, that the regulatory environments within some jurisdictions may preclude this time frame. In such cases, the utility and regulators may need to accept a likely unquantifiable level of error in evaluated energy savings for commercial new construction projects.

Reference

Cropp, J., A. Lee, and S. Castor. 2014. "Evaluating Results for LEED Buildings in an Energy Efficiency Program." *In Proceedings of the ACEEE 2014 Summer Study on Energy Efficiency in Buildings*. Washington, D.C.: American Council for an Energy-Efficient Economy.