Using Calibrated Energy Models to Help Understand, Manage and Improve Existing Building Energy Performance

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Abstract

Energy modelling has a long and well-demonstrated track record of adding value to the design process for new buildings, by helping inform and evaluate design decisions that impact energy use. Its use in existing buildings is much less widespread however, in part because decisions about managing and improving energy performance can be informed by other well-established methods such as energy audits, retro-commissioning and sub-metering. However, just as energy modelling enables a comprehensive, collaborative and contextualized way to design low energy buildings, so too can it provide an effective method for achieving low-energy existing buildings. This paper presents several case studies where calibrated energy models were used during a comprehensive energy investigation to identify and analyze opportunities to improve energy performance, and discusses lessons learned, including the benefits of calibrated energy models, and ways in which the conventional energy modelling process used in new buildings must be adapted for the unique challenges of existing buildings.

1 Introduction

Buildings account for roughly 30% of total Canadian energy use and about 25% of associated greenhouse gas (GHG) emissions (NRCan, 2011). At the same time, reducing how much energy buildings use represents one of the most cost-effective ways to reduce global GHG emissions (McKinsey & Company, 2009)[1]. While significant effort has been expended on improving the energy performance of new buildings through better technologies and tougher regulations[2], new buildings replace only about 1% of the current building stock (NRCan, 2012)[3]. Significant effort must therefore also be invested in improving existing buildings.

The good news is that in the Commercial and Institutional building sector in Ontario (the focus of this paper), a combination of factors have in fact led to a renewed focus on and investment in improving existing buildings. Competitive pressures from new high-performance buildings, reputational risks for real estate firms of not improving energy performance, regulatory requirements for public agencies to disclose energy use and develop energy management and reduction plans, escalating energy costs and corporate sustainability mandates are among the top reasons.

Historically, efforts to reduce existing building energy use focused on performing energy investigations to uncover opportunities. In most cases, these investigations, referred to as energy audits, focused largely on capital equipment upgrades such as installing variable speed

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[1] In this context, we define cost-effectiveness as the financial cost (or net benefit) of abating future GHG emissions by replacing business-as-usual technologies with low-carbon alternatives. Strategies that improve building energy efficiency have a negative abatement cost, in other words, a net cost benefit over the lifecycle of the technology, when savings from reduced energy consumption are taken into account.

[2] Examples include the 2011 National Energy Code of Canada for Buildings (NECB 2011), the 2012 Ontario Building Code (OBC 2012) and Version 2 of the Toronto Green Standard (TGS v2.0)

[3] There were an estimated 482,266 building in Canada in 2009. Of those, an estimated 30,102 were constructed in 2005 or later. Assuming that the same number of buildings were constructed in each of the years 2005-2009, approximately 6,020 buildings were constructed in 2005, an increase of about 1% over the estimated number of 452,164 buildings built prior to 2005.

drives on fans and pumps and replacing inefficient equipment with more efficient models. The total investment required to improve overall building energy performance using this approach tends to be back-end heavy; that is, the energy audit is a relatively low investment investigation which more often than not identifies opportunities with relatively high costs and long paybacks.

More recently, retro-commissioning is being used as an alternative approach to improving the energy performance of commercial buildings. By asking questions like "Is this the most efficient/effective way to operate this system?" rather than "Is this the most efficient piece of equipment available?" retro-commissioning aims to uncover low and no-cost opportunities but typically requires a higher level of up-front investigation investment.

Our approach is to combine both methods, focusing on operational opportunities while also considering more capital-intensive projects. The step-by-step process, similar in fact for both audits and retro-commissioning, is to:

- Collect utility information;
- Benchmark current performance;
- Collect and review facility documentation;
- Interview the Building Operations Team[4];
- Perform initial walk-through;
- Develop initial list of findings;
- Perform additional site visit(s) including diagnostic monitoring and functional testing;
- Perform calculations to estimate savings and costs of selected energy conversation measures (ECM);
- Summarize all findings and recommendations in final report; and
- Present and discuss findings with Owners/Managers/Operators.

On five recent projects, whose ultimate objective was to identify opportunities to reduce energy use by undertaking a comprehensive energy investigation and analysis, we used a calibrated energy model to assist with the ECM calculations. This paper outlines the methodology used to develop these models, presents the results of the calibration and the overall energy investigation, discusses lessons learned and provides suggestions for future work.

2 Background

Of the five buildings discussed here, three are large commercial office towers, one is a mixed-use complex with office, retail and residential spaces and one is a large hospital. A general description of each building is presented in Table 1 below.

Table 1: Project Descriptions

Project	A	B	C	D	E
Type	Office	Office	Office	Mixed (Office, Retail, Residential)	Hospital
GFA (ft^2)	3,300,000	602,000	1,165,000	919,000	703,000
Heating	Hot Water (HR Chillers)	District Steam	Hot Water (HR Chillers +	Hot Water Boilers	Hot Water Boilers

[4] In our experience, interviewing Building Operators prior to conducting a facility walk-through can help focus investigation efforts and ensure that any specific areas of concern are reviewed on site. In a lot of cases, the two tasks are actually performed concurrently.

			Boilers)		
Cooling	Chilled Water (DX)	Chilled Water (District)	Chilled Water (DX)	Chilled Water (DX)	Chilled Water (DX)
HVAC Systems	Perimeter Induction Units Interior CV CUs	Perimeter Induction Units Interior CVs/VAVs	Perimeter Induction Units Interior VAVs	Induction Units (office) Fan coils (retail and MURB)	Constant Volume AHUs
Current Energy Intensity (ekWh/ft^2)	39.4	43.5 89.2 (incl. data centres)	20.6 (current) 25.4*	59.4 (incl. data centres)	99.7
Software used for Analysis	eQuest	eQuest	EE4	EE4 + SIMEB	DOE2.1E

1: Extrapolated for full occupancy

3 Methodology

Considerable work has been done previously in areas of energy model calibration, the use of energy models to identify retrofits, and methodologies for accomplishing both. Some of the work has focused on addressing current gaps, for example the need to adequately incorporate uncertainty (Franconi & Nelson, 2012), and the need to improve development time and cost-effectiveness (Pappas & Reilly, 2011), while a lot of effort has gone into identifying and addressing the perceived lack of specific, generally-accepted or standardized methods of calibration and into suggesting new methods: specifically (Coakley, Raftery, Molloy, & White, 2011), (Heo, Choudhary, & Augenbroe, 2012), (Raftery, Keane, & Costa, 2009), (Reddy, 2006) and (Westphal & Lamberts, 2005) to cite but a few.

Streamlining and standardising modelling and calibration practices is certainly necessary in order to improve quality, provide a common and fair playing field for service providers and increase the use on modelling as a trusted, verifiable decision-making tool. In the absence of clear and common guidelines, service providers must still rely on experience, expertise and sound professional judgement. The purpose of this paper is not to evaluate various approaches but to share some key insights from our experience with identifying conservation opportunities with calibrated models, which were developed through a combination of experience, expertise, sound professional judgement and current industry guidelines such ASHRAE Guideline 14 (ASHRAE, 2002) and the IPMVP M&V protocol (IPMVP, 2012).

The specific approach used to develop and calibrate the energy models presented in this paper generally followed the one outlined by (Hubler, Tupper, & Greensfelder, 2010):

- Utility Bills Analysis: Calendar normalizing the utility data to match standard monthly energy model outputs from the meter reading dates, identifying anomalies and understanding the utility rate structure;
- Building Drawings: Reviewing architectural, mechanical and electrical drawings and performing building area takeoffs;
- Weather Analysis: Obtaining Actual Meteorological Year (AMY) hourly weather data for the analysis period being considered;
- Develop an Audit Checklist: Identifying the most important inputs to be requested during the energy audit;

- Identify Known/Unknown Model Parameters: Classifying parameters according to those that were firmly established in the audit, those that might be partially understood, and those that were completely unknown;
- Estimate Values for Unknown Parameters: Determining appropriate values for parameters that could not be identified during the audit;
- Create and Analyze Initial Model: Creating a baseline model with all known parameters and the expected values for the unknowns;
- Calibrate Model to Address Individual Loads: Calibrating parameters against known energy consumption using available sub-metering data;
- Calibrate Remaining Parameters: Comparing the predicted with the measured energy performance to adjust remaining uncertain parameters (often this can be items such as lighting, plug and occupancy daily profiles); and
- Comparing the Model Output and Measured Data: Quantifying the difference between energy simulation outputs and measured data.

In our opinion, the above approach can be considered a best practice guideline, which must often be modified and adapted to suit the unique aspects of each project, such as schedule and budget constraints, and gaps in information. It is worth discussing some of these general issues in more detail as well as providing some specific comments on the calibration process for each project. It is also worth commenting on where the above process is similar and where it is different to the approach used on new construction (NC) energy modelling.

3.1 Utility Bill Analysis

Since ultimately the energy model outputs will be compared to observed data, notably utility bills, the same time period must be used for both. Monthly billing periods often do not start on the 1st day of each month and do not always have the same number of days as the calendar month.

The easier way of aligning energy model monthly outputs to utility bills is to time-shift or calendar-normalize the utility bills. This is done by summing the average use of each month times the corresponding number of days in the month. For example, if the January gas bill includes use from December 21 to January 22, then

$$\begin{aligned} Normalized\ Janary\ Use &= 22\ days\ \times Average\ Janaury\ Daily\ Use \\ &\quad + 9\ days \times Average\ December\ Daily\ Use \end{aligned}$$

Since this approach approximates daily billed use from the monthly data, it is less accurate and therefore may be inappropriate if additional analysis must be performed based on the actual billing period. For example, for Project E, utility payment adjustments will be calculated based on the difference between the predicted and the billed energy use. Since daily billed energy use is not readily available, the energy model output must be time-shifted to allow for direct comparisons. In this case, this was accomplished by extracting hourly energy consumption data from the model, and summing the hourly values into a monthly usage that aligned with each monthly billing period. For Project E, both approaches were used. As shown in the Table 2 below, the annual difference in billing data between the two approaches is less than 1% and the two approaches yield similar differences when compared to simulated energy use (the statistical degree of alignment is discussed in more detail in Section 3.5). Note that time-shifting model output data has a small impact on total simulated energy use since aligning the data to match the utility billing periods required adding two extra days. Given the similar outputs generated by the two approaches and recognizing the additional effort required to analyze hourly model data, calendar-normalizing utility bills appears to be an acceptable approach when considering annual analysis, but may not be appropriate if subsequent monthly comparisons are required since the monthly differences between the bills and the model are greater.

Table 2: Comparison of Utility Bill Normalization Approaches

Month	Time-shifting Utility Bills		Time-shifting Simulation Outputs	
	Normalized Billed Gas Use (m^3)	Simulated Gas Use (m^3)	Billed Gas Use (m^3)	Normalized Simulated Gas Use (m^3)
January	596,670	609,865	598,446	608,927
February	554,673	548,808	593,047	657,905
March	436,512	520,059	419,252	494,616
April	383,297	421,493	434,350	466,772
May	322,397	275,611	325,798	315,334
June	232,438	212,434	240,022	215,930
July	219,854	207,656	239,795	230,499
August	232,415	212,175	233,478	208,986
September	281,457	234,118	247,925	208,986
October	372,411	309,349	344,750	282,344
November	425,657	437,997	386,448	364,540
December	501,116	541,118	452,736	482,719
Total	**4,558,897**	**4,530,685**	**4,516,047**	**4,537,558***
Annual Difference between Actual and Calendar-Normalized Bills				**0.9%**
Annual Difference between Calendar-Normalized and Un-Normalized Simulation				**0.2%**
Annual Difference between Billed and Calendar-Normalized Simulated Energy Use				**0.5%**
Annual Difference between Calendar-Normalized Billed and Simulated Energy Use				**-0.6%**

* Normalized simulated annual energy use includes two additional days to align with billing periods.

Another important aspect of utility analysis is to understand anomalies. Industry best practices recommend collecting 2-3 years of utility data. If energy use is relatively stable during this period, average utility profiles can be used. If however there is significant year-to-year variation, averages should not be used. That being said, marked differences in yearly energy use, if caused by a change in building systems or how they are operated, might aid in calibration efforts. Although not explored in depth on these five projects, it is possible to achieve alignment between predicted and actual usage despite off-setting errors in the model. In other words, the energy model may be able to reproduce the observed energy use profile, but it may not actually represent the way the building operates and therefore may not accurately predict the performance of contemplated energy conservations measures. If however, a major capital upgrade or operational change was undertaken recently and utility data is available before and after the upgrade, it may be possible to achieve stronger validation that the model accurately captures the building's characteristics and behaviour by having two sets of calibration data to match to (one model with the recent change implemented and one without). One foreseen challenge is that some capital upgrades may be implemented over many months so that it would be difficult to establish exact before and after timeframes. Nonetheless, we believe the issue of how to identify and minimize the risk of offsetting errors is an interesting area for additional research.

Another potential issue is missing utility data. This was problem we faced on Project D – electric demand information was not available for the month of November (electricity consumption was tracked by Management in a spreadsheet, while electric demand data needed to be obtained directly from monthly utility bills and the November bill was missing). We interpolated November demand based on the average demand in October and December. Here too however, caution should be used. In the case of Project D, the averaging approach was justified since electric demand was relatively constant during spring, fall and winter months and since the majority of the demand was due to seasonally-independent loads like lighting and receptacles. Averaging utility data for weather-dependant loads during change-over periods like spring and summer, however, may not be appropriate (if 1,000 lbs of steam is used in April and none in June, assuming 500 lbs of steam use in May could be a poor assumption without knowing more about how and when the steam-consuming equipment operates).

3.2 Weather Analysis

We obtained Actual Meteorological Year (AMY) weather files for four of the five projects discussed (using actual weather data was not considered necessary for Project A). For projects B, C and D, the AMY was chosen to correspond to the most recent calendar year for which the most complete set of energy consumption was available. The client for project E required the analysis to be based on a 12-month period spanning two calendar years (April 2012 – Match 2013). In this case, two AMY weather files were obtained and a custom file was created to run from January to March 2013 then from April to December 2012 since the simulation software requires the weather file to start in January.

Although AMY files are recommended by industry guidelines such as ASHRAE Guideline 14 (ASHRAE, 2002) and the IPMVP M&V protocol (IPMVP, 2012), (Pappas & Reilly, 2011) suggest that using a Typical Meteorological Year (TMY) weather file is likely a reasonable approach. We discuss this idea further in Section 5.

3.3 General Model Development

One of the first steps to developing a model is performing take-offs on the architectural (physical) attributes of the buildings. While readily available for NC modelling (either from drawings or early-stage design briefs), information about existing buildings may often be missing. In some cases, full drawings are not available and site measurements, approximations from photographs or digital maps, or other methods must be used to create the architectural elements of the energy model. For all five projects, detailed architectural drawings were available. In the case of one project a Construction-stage energy model was also available, which greatly decreased the amount of time required to develop the final as-built model of the building. However, since that model was developed for LEED (Canada Green Building Council, 2003) purposes, additional equipment and areas of the building not considered during LEED modelling needed to be added.

Zoning can also present an interesting challenge to model development. Similar to NC modelling, zoning should be based on HVAC systems, similar operation and similar loads. In the case of the three office towers, this resulted in relatively simple arrangements of one large core zone and one perimeter zone per elevation. Although combining zones across multiple floors can considerably reduce development and simulation run-time, this was not done for the office tower projects. Firstly, there was considerable variation in lighting and plug loads and occupancy profiles between different floors that we wanted to capture. Secondly, separate systems served the low and high rise portions of the buildings. That being said, in general, zoning of EB models tended to be less detailed that NC zoning.

3.4 Model Inputs

Some of the biggest challenges to existing building (EB) energy modelling are knowing what input data is required and the availability and reliability of that data. Industry guidelines such as ASHRAE's Procedures for Commercial Building Energy Audits and Guideline 14 offer some suggestions on determining important information to collect. Additional guidance is provided by (Hubler, Tupper, & Greensfelder, 2010). While information about the "physical" aspects of the building – equipment size and capacity, envelope dimensions and characteristics, etc. – is important and necessary, in our experience (of which the majority is on medium/large commercial office buildings) operational information is more critical to EB modelling and ultimately to improving the performance of existing buildings. Some of the big ticket operational items that have a greater impact on energy use and calibration efforts than physical attributes are:

- *Schedules of operation for the HVAC and lighting systems*. These can vary greatly from the idealized schedules most modellers are accustomed to using in NC models and are often the single-most influential parameter to obtaining calibration.
- *Outdoor air volumes*. It is best to obtain direct airflow measurements. Calculating OA based on supply air, mixed air and return air temperature and airflow is possible, but requires more effort and should be based on relatively cold weather to exaggerate the differences in temperatures. Inference from damper position (% open) is the least accurate estimate due to the non-linear relationship between flow and damper position.
- *Sequences of operation* such as supply air and supply water temperature reset schedules and economizer cycles. These can be difficult to obtain due to lack of documentation, lack of knowledge from the Operations Team, lack of Building Automation System data or combination of all three.
- *Exceptional loads* such as data centres. On some commercial buildings we investigated data centres accounting for less than 5% of total floor area can represent more than 50% of total energy consumption. Quantifying these loads and how they impact base-building systems is critical to calibration and subsequent analysis.

The second challenge is that the necessary data is often unavailable. In that case, values from previous projects or industry benchmarks may need to be used. Sensitivity analysis can be used to narrow down the range of possible inputs values to the most probable ones. Alternatively, complimentary data can be used to inform inputs. In the case of Project E, no information was available about plug load densities and schedules, while lighting systems were controlled manually. Using initial construction-phase lighting power and equipment power densities (based on LEED modelling defaults) as a starting point, the available hourly electrical interval data was compared with the hourly electric data from the model to derive model schedules based on the facility usage. Examining the data from a number of typical weekdays, weekend days and holidays we were able to program model schedules to match. A noticeable drop in facility energy consumption on weekends and holidays compared with typical weekdays was observed and the initial model schedules were adjusted accordingly.

Lastly, the available data may not be reliable. This tends not to be an issue with NC modelling – poor assumptions notwithstanding, if design information is available, it is typically reliable and accurate to the extent possible given the stage of the design. Existing building data on the other hand may simply be inaccurate. One example of this is sub-metering data from un-calibrated meters. Usually, it is obvious if a meter reading is an order of magnitude off (perhaps due to an incorrect unit conversion which was the case for Project E's chilled water sub-meter). Similarly, knowing enough about typical energy end-use patterns will usually flag big calibration errors (if for example sub-metering shows that pump energy in an office building with variable-speed drives represents 50% of total electricity consumption). But it is next to impossible to spot small-to-medium meter calibration errors. This is not an insurmountable challenge – bad sub-meter data can eventually be addressed during calibration efforts (the model may simply not behave as expected unless only the sub-metered data is eliminated or adjusted), but it certainly requires more effort and time (both of which are often in short supply). Whenever possible, obtain calibration report for all meters (and submeters) used in the analysis.

3.5 Comparing the Model Output and Measured Data

Another challenge of EB energy modelling is knowing when the job is done. The development of an NC model consists of simulating the performance of the building based on the design information available at the time and the job is done once the information is captured in the model. While the extent of available information varies at different milestones along the design process, at any given time when the model is being developed a fixed amount of information is available to be used for the model (assumptions must often be made to account for unknown design parameters and as the design nears completion the number of unknowns theoretically drops off to zero).

With calibrated EB modelling, the task is to recreate observed performance – EB models are "done" when simulated performance aligns with observed data. The degree of alignment (or strength of calibration) can be quantified simply by comparing the difference in annual energy use, or through more rigorous statistical methods such as those outlined in ASHRAE Guideline 14, namely the Normalized Mean Bias Error (NMBE), which measures the variation between predicted and observed values and the Coefficient of Variation of the Root Mean Square Error (CVRMSE) which measures the scatter of the data. When using monthly data, Guideline 14 recommends achieving a NMBE of +/- 5% and a CVRMSE of +/- 15%. Ultimately, however, the degree of alignment is a project-specific objective, often chosen by the modeller or specified by the client.

Table 3 summarises the calibration strength of the five models considered in this paper ("N/A" indicates that the particular energy source is either not used in the building or observed data was not available, while a dash "-" indicates that calibration to that energy source was not attempted).

Table 3: Calibration Summary

	Metric	A	B	C	D	E
Calibration Target		10% Annual	10% Annual	10% Annual	ASHRAE Guideline 14	ASHRAE Guideline 14
Electricity	Annual	-2.9%	-10.8%	1.6%	-1.8%	3.5%
	NMBE	3.1%	11.8%	-1.8%	1.9%	-3.8%
	CVRMSE	3.4%	14.2%	12.5%	3.0%	5.0%
Electric Demand	Annual	-	-	-	8.1%	1.1%
	NMBE	-	-	-	-2.2%	-4.0%
	CVRMSE	-	-	-	5.8%	4.9%
Natural Gas / Steam	Annual	-6.2%	-6.0%	-2.2%	-13.4%	-0.6%
	NMBE	6.8%	6.6%	2.4%	14.6%	0.7%
	CVRMSE	34.3%	23.5%	77.6%	24.3%	11.2%
Chilled Water	Annual	N/A	-11.6%	N/A	N/A	-
	NMBE	N/A	12.6%	N/A	N/A	-
	CVRMSE	N/A	41.4%	N/A	N/A	-

These calibration results prompt some key observations and warrant additional commentary. Most of the projects exhibit a higher CVRMSE value for gas (or steam) and chilled water usage. This is mostly due to the relative lack of alignment in shoulder seasons which is likely caused by variations in the amount of outdoor air and related parameters such as economizer cycle operation – two examples of higher variations in shoulder seasons can be seen in

Figures 1 and 2 below (for both Projects D and E the highest monthly variations occur in March, April, May, September and October). Additional investigation and model calibration would have been necessary to reduce the variation during these periods of the year. Since overall alignment targets were largely met, this was not done. It also would have been interesting to investigate what impact, if any, this higher variation during the shoulder seasons would have on energy conservation measures which derive the majority of their savings from changes to equipment operation during these times (for example, implementing an automated wet-bulb temperature-based switchover from mechanical to free cooling). For Project B, the main focus of the existing building investigation was to reduce purchased steam which accounts for about 60% of total energy. Purchased chilled water accounts for only 2% and thus was not a focus of the calibration efforts.

Figure 1: Project D Calibration Results

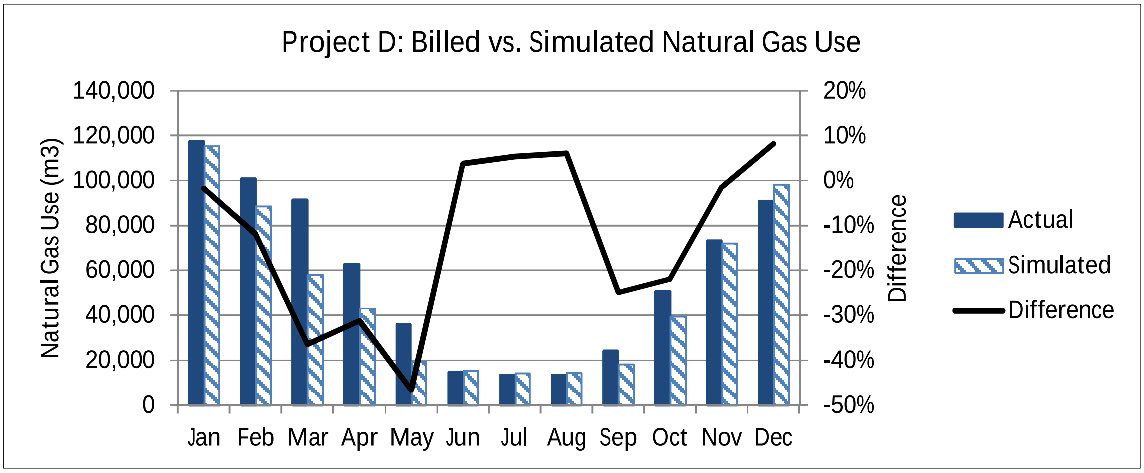
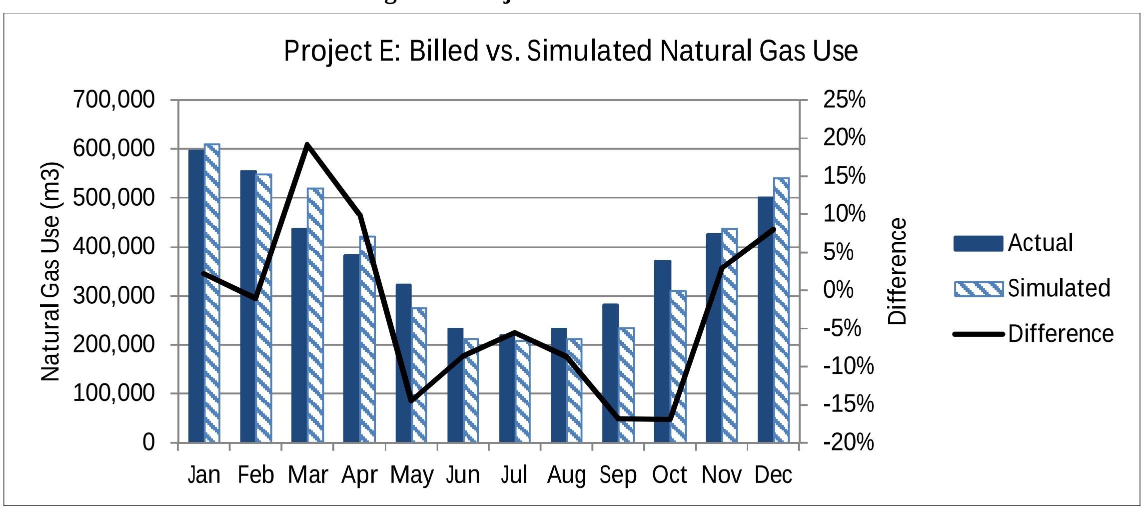


Figure 2: Project E Calibration Results



As outlined in Section 3.1, the two calendar-normalization approaches used on Project E yielded similar annual differences between billed and simulated data (0.5% and -0.6%). As shown in Table 4 below, the two other calibration metrics, NMBE and CVRMSE are also comparable between the different normalization approaches. When taken as a whole, based on this limited analysis, no conclusions can be drawn about the accuracy of one approach over the other (additional analysis in this area may be required, but in our opinion, it would appear that, for most consulting work, either approach would pass the "reasonable-person" standard).

Table 4: Calibration Strength of Utility Bill Normalization Approaches

Comparison	Actual Utility Bills vs. Calendar-Normalized Simulation Results	Actual Utility Bills vs. Un-normalized Simulation Results	Calendar-Normalized Utility Bills vs. Un-normalized Simulation Results	Calendar-Normalized Utility Bills vs. Normalized Simulation Results*
Annual Difference	0.5%	0.3%	-0.6%	-0.5%
NMBE	-0.5%	-0.4%	0.7%	0.5%
CVRMSE	11.1%	13.7%	11.2%	15.8%

* This approach consists of time-shifting the actual bills to start on the first of the month, and time-shifting the raw simulation outputs (which start on the first of the month) to match actual bills, which is not a valuable or recommended approach – the resulting calibration metrics are shown just for informative purposes.

It is interesting to note that in terms of absolute difference, the two approaches yield nearly identical results; however in this example one approach over-states whereas the other under-predicts (the results could easily have been reversed, or both approaches could have yielded under or over-predictions). In some cases, such as performance contracting, energy guarantee pain-share/gain-share adjustments or measurement and verification for incentive programs, this difference between a negative and a positive value could represent tens of thousands of dollars in payments and create some concerns about the motives behind using one approach versus another (unfounded since predicting this outcome before starting the process is likely impossible).

4 Results

The results of the five energy investigation projects are summarized in Table 5. The overall savings and paybacks are consistent with other similar investigation of commercial and institutional buildings for which calibrated models were not developed (savings were calculated using spreadsheet tools). The three most significant findings (and those consistently observed across all projects) are that:

- *Buildings are not shutting down*. Fans and lighting schedules are not consistent with actual occupancy patterns and equipment tends to run when it is not needed.
- *Outdoor air is poorly controlled* and in many cases buildings are providing too much based on actual occupancy patterns.
- *Sequences of operation are not optimal*. Examples of this include not re-setting chilled and how water supply temperatures, improper operation of economizer cycles (in some cases not used altogether), manual overrides on variable speed systems and not implementing pressure reset strategies for variable speed pumps and fans.

Table 5: Investigation Results

Project	ECMs	Energy Savings	Cost Savings	Simple Payback
A	14	29,853,000 ekWh (26.5%)	$2,029,000 (21%)	6.5 years
B	20	15,000,000 ekWh (30%)	$880,000 (19.5%)	3 years

C	12	7,700,000 ekWh (26%)	$900,000 (23%)	4 years
D	12	5,700,000 ekWh (10%)	$550,000 (12%)	4 years
E	10	10,560,000 ekWh (15%)	$678,000 (19%)	7.7 years

5 Discussion and Lessons Learned

5.1 Choice of Software

In commercial energy investigations, schedules and budgets are over-arching constraints. All five projects were developed in DOE2.1 (EE4) and DOE2.2 (eQuest) software (Hirsch & LBNL), which is freely-available, well-documented and has a strong track-record of use in the Canadian consulting industry. Difficulties with capturing some aspects of building operation (which more complex tools might be capable of simulating directly) can be overcome with simplifications and well-established workarounds without sacrificing accuracy (relative to the accuracy required and the accuracy of other aspects of the overall investigation such as costing of ECMs) and/or working directly with the source DOE code (which was done for Project E). In addition, some of the main improvements that newer or more complex tools provide over older software – namely the ability to model new and innovative HVAC equipment, systems and controls – are not necessarily a benefit to EB modelling which is often done on older buildings which may have simpler and older equipment.

It should be noted that SIMEB (https://www.simeb.ca) was used on Project D to aid in calibration efforts. While it is nearly impossible to attempt to compare the amount of calibration effort required on this project relative to the others, we suspect that SIMEB offers some advantages and may reduce simulation development time. That being said, simulation development time is only one component of the overall energy investigation and efficiency gains in this phase of the project may not significantly impact the overall effort.

Other simulation platforms (such as EnergyPlus and Virtual Environment to name but two) can successfully be used for calibrated models and can offer some advantages such as greater flexibility to define HVAC systems, equipment and associated controls. In the end, the choice of software for consultancies will mostly likely depend on the experience and expertise of individual modellers; however a high degree of professional care should always be applied by modellers in recognizing, acknowledging and accounting for software limitations and individual competencies.

5.2 Weather Effects

(Pappas & Reilly, 2011) suggest that using a TMY weather file is likely a reasonable approach when calibrating energy models to identify retrofits since the savings are estimated from a baseline and the ECM using the same weather (in their analysis, running the analysis with a weather file with 36% fewer heating degree-days and 36% more cooling degree-days changed the payback period for the ECM bundle by less than one year). Presumably, using TMY files, which are part of most commercially-available software packages or otherwise readily available, has the potential to save model development time compared with constructing AMY files from raw weather data. However, AMY weather files for common locations can now be quickly obtained at very low cost[7], so there ought to be very little difference in model development time or cost between the two approaches.

That being said, this suggestion differs from the calibration approach recommended by Guideline 14 and warranted some further exploration. Although Project B, C, D and E were calibrated using AMY data, the final models were also run using TMY files in order to compare the alignment to utility data from the two different approaches (Project A was initially calibrated to TMY data and obtaining AMY data retro-actively was not justified at this point). Table 6 below shows the annual difference between predicted and observed energy use for different fuel consumed as well as the value of the two statistical measures of calibration reference by ASHRAE Guideline 14.

Table 6: Running AMY-calibrated models with TMY data

Project	Fuel	AMY			TMY		
		Difference	NMBE	CVRMSE	Difference	NMBE	CVRMSE
B	Electricity	-10.8%	11.8%	14.2%	-9.5%	10.4%	13.5%
	Steam	-6.0%	6.6%	23.5%	24.9%	-27.1%	35.8%
	Chilled Water	-11.6%	12.6%	41.4%	-42.2	46.0%	48.2%
C	Electricity	1.6%	-1.8%	12.5%	2.0%	-2.2%	12.7%
	Natural Gas	-2.2%	2.4%	77.6%	-4.8%	5.2%	74.1%
D	Electricity	-1.8%	1.9%	3.0%	Pending	Pending	Pending
	Electric Demand	8.1%	-2.2%	5.8%	Pending	Pending	Pending
	Natural Gas	-13.4%	14.6%	24.3%	Pending	Pending	Pending
E	Electricity	3.5%	-3.8%	5.0%	3.0%	-3.3%	5.8%
	Electric Demand	1.1%	-4.0%	4.9%	1.2%	-4.6%	5.3%
	Natural Gas	-0.6%	0.7%	11.2%	4.1%	-4.4%	14.2%

The above analysis by no means represents a rigorous attempt at evaluating the claim that TMY calibration is appropriate. However, the data suggests that TMY data may be appropriate for loads less strongly dependant on weather (which is logical) – for example, a significant portion of electricity use in these models is due to lighting and plug loads. Project C and E also suggest that TMY files may even be appropriate for natural gas (a weather-dependant variable); however there is a large difference in the strength of the calibration for the weather-dependant fuel sources in Project B. To explore this issue further, additional analysis is warranted for each project in order to determine if these results can be explained due to differences between weather files (for example, does the difference in predicted gas usage correspond to the difference in heating degree days between the AMY and TMY files) or if this suggests there may be issues in the way the models are calibrated (if TMY and AMY data is comparable, one might expect closer agreement between the two sets of calibration metrics). Ultimately, a side-by-side calibration attempt using AMY and TMY weather files for the same project may be required to offer more conclusive results.

5.3 Calibration vs. Investigation

It was interesting to note that the factors which in our experience have the biggest impact on calibration efforts and which require considerable effort to obtain, namely information about schedules and sequences of operation are also the most common findings in our investigations and ones which often have the biggest contribution to overall energy reduction potential. It may be possible that there is some unintentional bias in the identified ECMs that magnifies

[7] For example: www.weatheranalytics.com

this observation. In some cases, these buildings have already undertaken some capital upgrades so the pool of potential ECMs is more heavily skewed towards operational improvements.

That being said, this nonetheless highlights the interesting observation that the process of understanding how the building operates in order to develop a calibrated model actually also identifies the biggest energy-saving opportunities. This in turn suggests an interesting area for further research. Instead of developing a calibrated energy model and then using it to calculate the savings from identified ECMs, it may be possible to develop a theoretical "Best Case" model from mostly "physical" building parameters and assume ideal operation (not unlike NC models). In that case comparing these "Best Case" models against observed utility and sub-metering data would highlight the "opportunity gap". The total energy saving potential of the building would simply be the difference between the predicted energy consumption of the idealized model and the actual bills and more detailed comparisons of end-uses might highlight areas to focus investigation efforts on. While the idea is interesting, further investigation of this approach may find that the results are too optimistic and the comparisons not granular enough.

5.4 Capturing synergistic effects

One obvious benefit to using an energy model is the ability to more easily account for synergistic effects and the interaction of ECMs. The most readily cited example of the latter is accounting for the impact of lighting change on heating and cooling loads. While it is certainly possible to do so with spreadsheet tools by applying correction factors, energy models can allow increased accuracy relative to required effort.

Secondly, energy models allow for more realistic and easier estimation of the impacts of stacking ECMs. In nearly all energy investigations, the savings of individual ECMs must be calculated so that implementation decisions can be made about each one. At the same time, bundling ECMs, a common strategy for reducing overall payback thresholds, is also necessary. With spreadsheet tools, considerable effort is required to adjust ECMs so that interactions are properly accounted for. For example, for project C, implementing water-side free cooling in winter will result in reduced chiller operation. However, the chiller plant optimization savings assume current system operation, with the chillers running in the winter months. When both measures are considered together, the winter chiller savings cannot be claimed from chiller plant optimization if the chillers have been turned off for free cooling; otherwise we would be 'double-counting' savings. Again, while it is possible to address these issues with other tools, energy models are more effective at doing so.

5.5 Benefits over spreadsheet tools

All models, be they simple spreadsheet tools or sophisticated hourly simulations, are ultimately simplified representations of how a building actually behaves and precision should not be mistaken for accuracy. A well-developed spreadsheet tool can be just as good (or bad) at predicting performance compared to a poorly-developed energy model – although the focus in on houses rather than larger, more complex commercial/institutional/MURB buildings, a summary report published by the Oregon Energy Trust shows comparable performance between simple and more complex tools (MetaResource Group, 2012). Ultimately, it is a question of the required level of accuracy and precision. In our experience, well-developed spreadsheet tools which use hourly weather data and attempt to account for the interaction of loads and parameters can provide adequate fidelity as might be required for say, ASHRAE Level 1 and even Level 2 Energy Audits (but not Level 3). However, energy models can offer greater flexibility than spreadsheet tools both in terms of the extent of the kinds of "What if?" questions that can be asked, and in terms of being "future-proof" (because they are more dynamic rather than purpose-built to look at a particular EEM like some spreadsheet tools). Models can also more easily and accurately capture some complex building systems and strategies such as cogeneration and chilled water plant optimization. Finally, in rare situations when there are many stakeholders and differing opinions about energy performance improvements and the "math" behind proposed ECMs, a model (developed with industry-standard software) can provide potentially greater transparency when analyzing performance and discussing the impacts of individual ECMs (provided all stakeholders can agree on the inputs to the model).

One potential drawback is that energy models can require more effort. It is difficult to compare the level of effort required to develop a calibrated energy model and use it to perform ECM calculations relative to more traditional approaches like spreadsheet tools. Based on anecdotal evidence from these five project compared to other energy investigations completed by our firm on similar buildings, using calibrated models does require some additional effort and time. The choice of whether to use a model in lieu of other tools will likely depend on the availability of qualified resources (rather than differences in required effort) and some of the "value-add" considerations discussed below.

5.6 Long-term value

Finally, one of the most interesting benefits of calibrated energy models is the long-term value they can provide. Models can also more easily be used in subsequent years to help understand, manage, track and improve performance since a calibrated model is capable of predicting the building's response under varying conditions. Some specific examples include:

- Asking "What if?" questions about contemplated changes to building operations (this could include estimating the impact of tenant changes, new technologies, capital upgrades, etc.).
- Evaluating the predicted performance of long-term capital upgrade projects on annual operating budgets and cash-flows (for example, knowing the yearly impact from a phased upgrade of induction units on each floor – a common upgrade in many older commercial buildings).
- Tracking ECM implementation (a model can easily be updated with "after" data to help track performance, and perform Measurement and Verification)
- Forecasting operational budgets under varying climate and utility scenarios (such as climate change and fuel cost escalation).

6 Conclusion

In the short term, energy modelling is unlikely to be deployed to manage and improve existing building energy performance as extensively as it has been used to aid the design of new buildings. Some of the barriers to more widespread use include resource capacity issues and potentially higher levels of required effort (these are easier to perceive than actually observe). And as much as energy modelling is not the only way to improve the energy performance of new buildings, it is not the only way to go about improving the performance of existing buildings. Energy modelling will likely never replace the need for sound energy management and approaches like retro-commissioning (although advances in Cloud Computing and computer-based Automated Continuous Commissioning tools which rely on a form of predictive simulation are blurring the lines between energy tracking, investigation and improvement), but it is a more-than-capable, useful and flexible tool to add to the existing building energy toolbox and one which can readily support current methods and provide long-term value to building owners, managers, tenants and energy professionals.

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