DOE-2.1C Model Calibration With Short-Term Tests versus Calibration With Long-Term Monitored Data

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Two methodologies for calibrating a building energy simulation were applied to the simulation of a small credit union building. Starting from the same as-built model, the monthly end-use energy consumption tuning (MCT) methodology and the short term energy monitoring (STEM) tuning methodology were applied to obtain two "tuned" simulations of the building.

Both calibrations incorporated hourly monitored site weather data and information from building audits. The hourly monitored data set included end-use energy consumption, zone temperatures, and fan duty cycles. Specific HVAC parameters, such as resistance heat energy and system air temperatures, were also monitored. The STEM tests and analyses characterized the thermal performance of the building as a black box: the building's overall conductance, glazing shading coefficient, thermal capacitance, and heating system efficiency were determined.

Monitored monthly end-use energy consumption was used as the basis for comparison of the tuned models. The two calibrated models estimated annual HVAC energy use within 11% of the monitored consumption. However, the two calibration techniques produced significantly different inputs for building conductance, infiltration, and supply air heat loss. As a result, the two estimates of ECM savings differed significantly.

This paper describes each DOE-2 calibration, discusses the ECM savings estimates of each methodology, and addresses the issues brought out by the variance in the results.

Introduction

The Bonneville Power Administration is sponsoring the Energy Edge project to investigate the potential for energy conservation in new commercial buildings. The program determines the cost-effectiveness of individual energy conservation measures (ECMs) by analyzing four types of data: building audits, hourly monitored data, simulation results from DOE-2.1C (DOE-2), and incremental costs of ECMs. Some buildings are the subjects of additional research. A small credit union building underwent Short-Term Energy Monitoring (STEM), a three-day series of tests developed by the National Renewable Energy Laboratory (NREL).

Energy Edge has presented a unique opportunity to combine extensive monitoring data with sophisticated modeling techniques to create powerful new evaluation tools. By providing extensive data to properly calibrate the model, actual building performance can be compared to simulated baseline performance. Also, once calibrated, or tuned, the model can be used with more confidence to determine the effects of individual ECMs as they actually operate in the building.

This report describes the results of applying two different building energy simulation tuning methodologies to a small credit union in Idaho Falls, Idaho. Starting from the same as-built model, the monthly end-use energy consumption tuning (MCT) methodology and the short-term energy monitoring (STEM) tuning methodology were applied to obtain two "tuned" simulations of the building. The energy savings attributable to each ECM was estimated twice, once by each calibrated model.

This paper briefly summarizes these tuning methodologies. They are described in detail in *Energy Edge Simulation Tuning Methodologies*.

The MCT methodology establishes a framework for using monitored building data and computer modeling cooperatively to develop a quickly tuned building model.

Bonneville Power Administration (Bonneville) has standardized on the MCT methodology for the analysis of all Energy Edge buildings for which end-use data is available. The STEM tuning methodology provides information about the building shell that is not available from the typical Energy Edge building monitoring.

Simulation tuning is just one part of the analysis process. Prior to the tuning is the development of the "as-built model". This is done before any significant monitored data is available. The Energy Edge building, as-built, is modeled using hourly building energy use software (usually DOE-2). The as-built model generally incorporates information from the as-built drawings, construction inspection notes, and operations and maintenance (O&M) audits. The rest of the methodology depends on the monitored data:

- Input the site-monitored weather data. The total horizontal solar radiation is decomposed into direct normal and diffuse radiation using the clearness index and the atmospheric path length. These parameters and the directly monitored weather variables are processed into a TMY format for use by DOE-2. When using data from two calendar years, an adjusted calendar is prepared that preserves the day of the week rather than the calendar date. The weather data processing is detailed in *Energy Edge Simulation Tuning Methodologies* and the *Energy Edge Pilot Study*.
- "Tune" the model to the monitored end-use data.
- Replace the site-specific weather data with statistically valid average weather (TMY--Typical Meteorological Year) for the site.
- Derive the "tuned baseline" model by subtracting all ECMs from the tuned TMY model.
- Individually model each ECM against the tuned baseline to determine the energy savings attributable to that ECM.

The credit union discussed in this paper is one of 28 commercial buildings selected to participate in the Energy Edge project, a large-scale research and demonstration project developed by Bonneville. Energy Edge was initiated to determine whether commercial buildings can be designed and constructed to use at least 30% less energy than if they were designed and built to meet the current regional model energy code, the Model Conservation Standards (MCS) developed by the Pacific Northwest Electric Power and Conservation Planning Council.

Model Tuning

In any given Energy Edge building, monitoring can measure whole-building performance and energy consumption by end-use. However, monitoring cannot compare the performance of a unique commercial building to "what might have been" if it had not been designed to meet Energy Edge standards. Monitoring cannot establish the energy performance of the "baseline" comparison building since the baseline building was not constructed. And, used alone, hourly end-use monitoring generally cannot yield information on individual ECMs.

The model must provide simulated data on the baseline building, the Energy Edge building operating in an "ideal" mode, and individual ECM energy performance. The key word is "simulated." While modeling has demonstrated credibility in estimating energy performance, it is only as accurate as its input. The major purpose of tuning the computer model is to increase our confidence in its ability to (1) reasonably estimate the energy savings due to individual energy conservation measures (ECMs), and (2) estimate the total energy savings in the building. Model tuning is the process of finding inconsistencies between the simulation results and the monitored data, determining what model inputs are causing the inconsistencies, adjusting the input, and rerunning the model to obtain revised results. This process is repeated until the simulation results match the monitored data within specified tolerances or according to certain criteria.

It is important to note that buildings evolve due to changes in occupancy, equipment, lighting, and operating schedules. The simulation tuning is performed for a snapshot period in the life of the building. Long-term energy savings are extrapolated from the savings simulated during the snapshot period.

Monthly Consumption Tuning

Monthly consumption tuning (MCT) is the process of adjusting a simulation to match monitored data for each end-use, on both a monthly and a seasonal basis, with seasonal tuning tolerances tighter than monthly tolerances.

Monitored data are used to prepare hourly schedules for all end-uses except HVAC. Ideally, schedules are developed to describe each end-use for each zone and daytype. However, the DOE-2 limits on the number of schedules often necessitates combining schedules with similar profiles.

The monitored data are also used for comparison with simulation estimates of the monthly energy consumption for each end-use. Simulation estimates for end-uses other than HVAC closely match the monitored monthly totals after the incorporation of the end-use load schedules. To the extent that a schedule represents a particular end-use in a particular zone, the simulation estimates also closely match hourly data, since we are, in effect, "inputting the answer".

After the non-HVAC end-use schedules are incorporated, HVAC energy remains to be tuned. Monitored data are used to determine the fan operating schedules. The analyst must then determine what inputs are responsible for the remaining discrepancies between the simulated and monitored HVAC energy consumption. Inputs are adjusted, within reasonable bounds, until the simulated and monitored HVAC energy use are within the following limits:

each month	± 30%
seasonally	± 20%

Selection of calibration tolerances is a complex issue. MCT seeks a compromise between the time required for tuning and the accuracy achieved. Typically, most months will be tuned much closer than the listed tolerances, with the tuning discrepancy for one or two months approaching the tolerance. Analysts calibrating models should ask themselves: "How close a tolerance is required to fulfill the project objectives?" However, it may not be possible to quantify an answer to this question.

No evaluation is made of short-term HVAC energy use profiles. Matching hourly profiles is useful for calibration (Kaplan et al. 1990, Bronson et al. 1992), and we implicitly attempted to match hourly profiles for non-weather-dependent loads by using data-generated schedules. However, it is more difficult to match hourly profiles for weather-dependent loads, even with computerized calibration procedures. The time required for tuning HVAC energy may be minimized by not making comparisons between simulated and monitored hourly data. A case study comparing an MCT calibration with a calibration to short-term profiles is presented in *Energy Edge Revised Analysis Methodology As Applied to the Dubal Beck Office Building*. For that building, the study confirmed that the two calibrations estimated very similar ECM performance.

MCT has proven successful at reconciling the estimated and monitored consumption of a variety of buildings. All energy end-uses are tuned. Therefore, when compared to the estimates of an untuned model, we believe that this methodology can improve the accuracy of ECM savings estimates for most ECMs that can be simulated.

One of the largest drawbacks to the MCT methodology is that it relies on extensive, long-term monitored data. However, the monitoring does have significant benefits in addition to the metering of end-use energy consumption. Perhaps most significant is the disclosure of building operation and HVAC control deviations from the audit descriptions and design intent.

Short-Term Energy Monitoring Tuning

Short-Term Energy Monitoring (STEM) tuning adds information about the building shell that is not available from hourly end-use monitoring. The simulated building shell is adjusted to match the monitored data for a three-day period of special tests. These tests are designed to characterize the thermal performance of the building shell as a black box. With the "tuned" building shell as an input, the simulated HVAC efficiency is adjusted so that the estimated HVAC energy consumption matches the consumption monitored during one of the STEM tests.

The model tuning with STEM follows a very prescribed procedure. Each of the five STEM tests provides data that results in a change to the corresponding model parameter. Each of the five model parameters is adjusted to match the corresponding test results as nearly as possible. "Nearly as possible" is defined as the minimum error in a series of trial-by-error simulations. The five parameters that are tested and adjusted in the model are: (1) net building thermal conductance (UA), (2) net building thermal capacitance, (3) net building solar gains, (4) infiltration, and (5) HVAC efficiency. These parameters are tested and adjusted in the simulation on a whole-building basis.

The building load coefficient test is designed to make the building load coefficient (building UA plus infiltration $Q/\Delta T$) the primary unknown in an energy balance equation of the test time span. After a period of building equilibration, the HVAC systems are turned off and all heating is done with electric heaters (coheaters). Power consumption of the heaters is monitored and building zone temperatures are held constant. (All other sources of internal gains are turned off or monitored so they can be accurately simulated.) The building load coefficient test is run overnight with a constant indoor temperature. The model's UA inputs are all adjusted, by the same percentage, to make the model's estimate of heating energy supplied to the building match the test coheat energy as closely as possible.

Infiltration is measured during one or more of the STEM tests. The measured infiltration is entered in model. This separate measurement of infiltration allows the building UA component of the building load coefficient to be determined.

Solar gains are estimated by continuing the coheat through a period with high insolation. The solar gain is the difference in required coheat each hour from what the simulation estimates would have been required in the absence of insolation. A percentage adjustment is made to all of the model's shading coefficients and absorptances to make the model match the test results.

The thermal capacitance of the building mass is determined by a cooldown test. With the HVAC systems off, the rate of cooldown is a function of both the building load coefficient and the building capacitance. Since the building load coefficient is established by a separate test, the thermal capacitance can be determined. A percentage change is made to the specific heats of the envelope materials to make the model match the test results.

The last test measures the overall heating efficiency of the building HVAC system. The coheaters are turned off and the various zones are maintained at constant temperature by the HVAC system. The electric energy consumed by the HVAC system is monitored. Since the building shell and other parameters have been calibrated by the first four tests, the energy required to maintain the space temperatures can be calculated. This required energy is compared to the actual energy input to determine the overall HVAC system efficiency. The modeled COPs are adjusted to match the results of this test. We note that deviation from the expected overall HVAC efficiency could also be due to factors other than COP, such as duct leakage or supply duct heat transfer. These considerations must be taken into account in the model.

After the STEM tuning process is complete, end-use schedules based on the O&M audits are input and an annual simulation is run using site weather data. This simulation represents the tuned annual model. It can be compared with monthly and monitored data as a tuning check, but no further tuning is performed as part of the STEM process.

STEM tuning, if confirmed accurate, has the potential for building shell characterizations that are better than those possible with other tuning methodologies. To the extent that HVAC loads are due to shell heat gains and losses, this methodology can also improve estimates of HVAC energy use. Reducing the monitoring time to a three-day period is another obvious benefit of the STEM process.

One of the weaknesses of STEM is that it does not tune end-uses other than HVAC. Hence, estimates of energy savings for ECMs associated with other end-uses are dependent on audit descriptions and schedules, unless these end-uses are monitored before or after the STEM tests. The calculation of HVAC energy use is also dependent on the accuracy of the audit data for other end-uses.

Tuning the Credit Union Simulation

The MCT and STEM tuning processes were separately pursued so that the two methodologies could be compared. We avoided cross-fertilization of the assumptions used in each methodology. *Energy Edge East Idaho Credit Union Simulation Tuning* presents additional details pertaining to the credit union building, the simulation tuning, and the analysis of the ECMs.

Infiltration is a key issue. Infiltration was measured during the STEM tests using a tracer gas. Infiltration was measured with the HVAC fans off under two conditions: at an average temperature difference of 44°F with an ambient windspeed of 0 mph, and at an average temperature of 48°F with an average windspeed of 14 mph. A combined measurement of infiltration and ventilation was made at a temperature difference of 48°F with an average windspeed of 18 mph.

Tuning Results

Both tuned models match monitored data for monthly HVAC energy use much more closely than the untuned model. This is shown in Figure 1.

The total monthly energy for non-HVAC end-uses is shown in Figure 2. Most of the difference in the tuned models' estimates of HVAC energy results from the differences in simulation of non-HVAC end-uses. Indeed, when we input the end-use load schedules generated from the monitored data into the STEM simulation, its HVAC energy use estimates are very close to the estimates from the MCT model (Figure 3).

Key Findings

Despite the similarity of energy use estimates, the two methodologies clearly result in different tuned models. Of greatest note, the STEM-tuned building conductance is only 43% of the conductance estimated by the MCT simulation. In other words, the STEM tests and analyses indicate that, for conductance, the building performs over

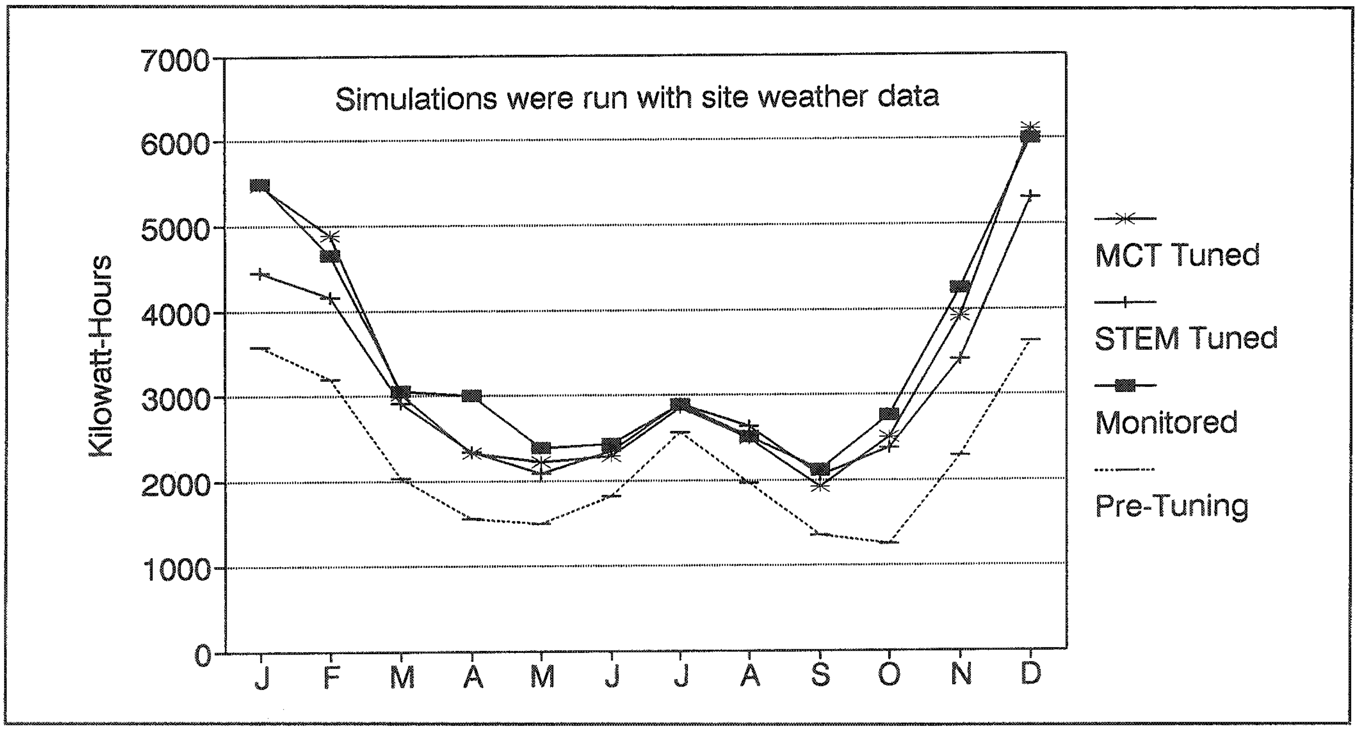

Figure 1. Comparison of Simulated and Monitored Monthly HVAC Energy Use

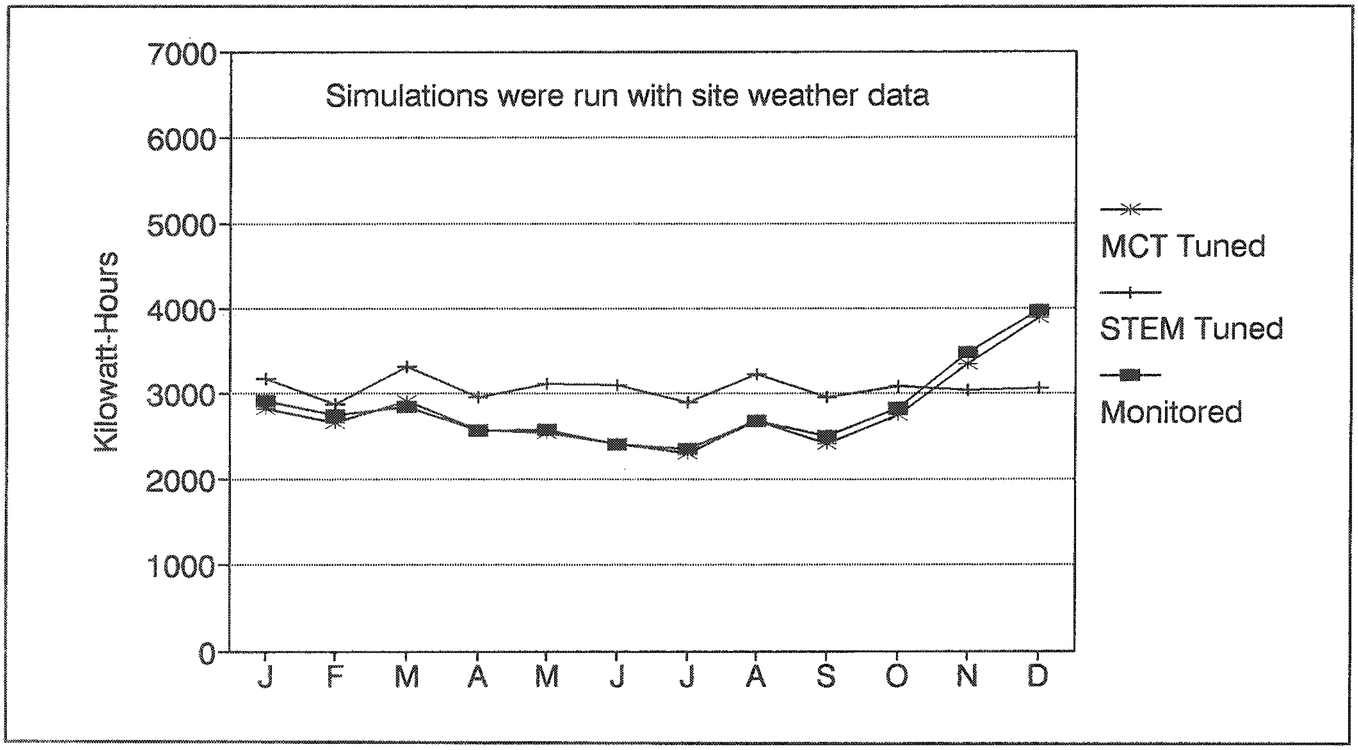

Figure 2. Comparison of Simulated and Monitored Monthly non-HVAC Energy Use

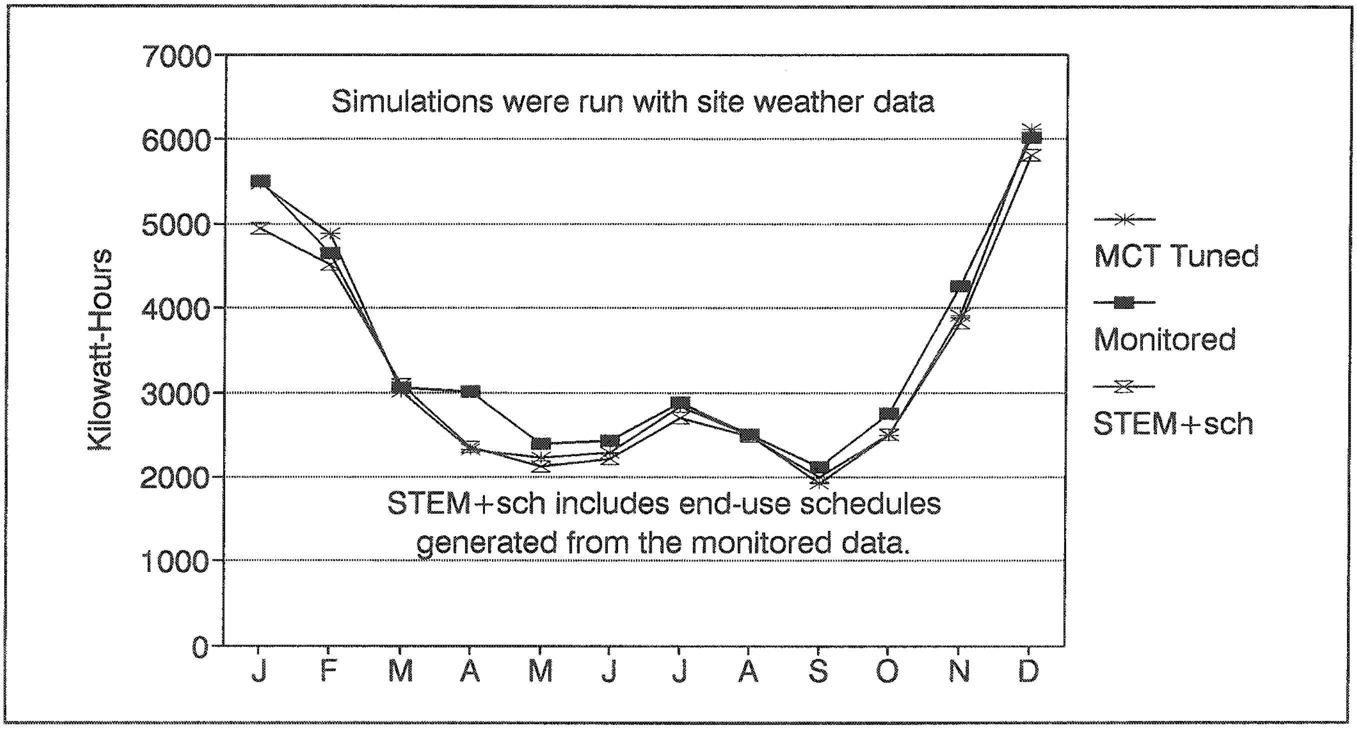

Figure 3. Monthly HVAC Energy Use for a STEM Model Using Monitored End-Use Schedules

twice as well as theory would predict! This difference between the tuned models is largely compensated by an inverse difference in the simulation of infiltration: The infiltration was adjusted to help tune the MCT model, and the wind-independent infiltration modeled for MCT was only 42% of the infiltration measured for STEM.

Table 1 summarizes the key differences between the MCT and STEM simulations. Note that the STEM model used a maximum of 100% outside air, whereas the MCT model used a maximum of 50%. The monitored data for MCT allowed us to determine that one of the heat pumps never exceeded 50% outside air. This information would not have been available from STEM tests alone, so the STEM model did not incorporate this refinement. Similarly, infiltration was measured specifically for STEM, not MCT; likewise, the duct heat loss estimated for STEM was not part of the normal MCT process. For a fair comparison of the methodologies, we tried to keep the two processes distinctly separate.

Simulation of Energy Savings

The Energy Edge methodology defines the building baseline as the building which would have been built if the Model Conservation Standards Equivalent Code (February, 1985) had been observed and no funded or non-funded ECMs that exceed code had been installed. The baseline model has the same footprint, architectural features, occupancy and operating schedules as the tuned model, unless any of these aspects is modified by an ECM.

Simulation of the baseline building permits calculation of the energy savings. The estimated energy consumed by the baseline building minus the estimated energy consumed by the Energy Edge building is the total energy savings. This is also called the interactive savings, since it includes all ECMs simultaneously.

Derivation of the baseline model was a relatively straightforward process. Many of the ECMs were well-defined, and could easily be deleted from the tuned model. These ECMs include economizers, low-E windows with wood or thermal break frames, upgraded first floor wall insulation (R-14.5), upgraded ceiling insulation (R-55), and high efficiency heat pumps. Table 2 shows the assumptions used for the ECMs and the baseline model. Note that we assumed the same ratio of simulated to theoretical conductance for the baseline STEM simulation as for the STEM-tuned model.

Table 1. Simulation Input Assumptions Differences

Parameter	MCT Simulation	STEM Simulation
Ceiling net thermal resistance	R-55	R-129
First floor wall net thermal resistance	R-17	R-40
Second floor wall net thermal resistance	R-13	R-31
Glazing conductance and shading coefficient	With internal mini-blinds U=0.38, SC=0.35 Storefront U=0.38, SC=0.66	With internal mini-blinds U=0.16, SC=0.11 Storefront U=0.16, SC=0.20
Infiltration	0.2 ACH without wind, 0.4 ACH at 10 mph	0.48 ACH without wind, 0.58 ACH at 10 mph
Damper and economizer operation	10% minimum outside air all hours, maximum of 50% outside air with economizer	7.3% minimum outside air all hours, maximum of 100% outside air with economizer
Duct-Delta-T, by zone	0.5 F degrees, all zones	0.0, 3.4, 4.3, 3.4
End-use schedules	Derived from monitored data	Per O&M Audit #3, assume max of 30% of nameplate rated power

Table 2. ECM and Baseline Simulation Assumptions

Parameter	Theoretical* Value With ECM	Theoretical* Baseline Value
economizers	economizers	no economizers
window units	Low-E	double glazed with non-thermal break frames
windows with internal blinds	U=0.38, SC=0.35	U=0.92, SC=0.81
storefront and vestibule windows	U=0.38, SC=0.66	U=0.66, SC=0.81
skylights	U=0.38, SC=0.81	U=0.77, SC=0.81
wall insulation, first floor	R-17	R-11
wall insulation, second floor	R-12	R-11
roof insulation	R-55	R-19
heat pump COP (2 types of unit)	heating: 3.00, 2.96 cooling: 2.47, 2.58	heating, 2.7; cooling, 2.28

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* Theoretical values apply to the MCT simulation. STEM simulation conductances are 43% of the theoretical values, so U-values are 57% lower and R-values are 133% higher, for both the simulation with ECMs and the baseline building.

Net HVAC Energy Savings

The two estimates of total HVAC energy savings differ by only 10%. The MCT simulations estimate an average annual HVAC energy savings of 9,942 kWh; the STEM simulations estimate an average annual savings of 9,841 kWh. However, we believe that the similarity of net savings estimates is a coincidence, and that it is due to compensating differences in savings estimates for individual ECMs, as discussed in the following sections.

Evaluation of ECM Energy Savings

An additional series of simulations must be performed in order to determine the energy savings attributable to each ECM. The simulations in this series are called the "parametric models". Each ECM is added separately to the baseline for each parametric simulation. This avoids interactive effects that occur when ECMs are combined. The parametric energy savings of an ECM is calculated as the difference between the energy consumption estimated by the baseline model and the energy consumption estimated by the parametric simulation. (We included the interactive effects in our analysis of ECM savings, but the effects were minor, and a discussion of interactive savings is beyond the scope of this paper.)

The analysis of the ECMs is dependent to varying degrees on the modeling assumptions and engineering judgment. Furthermore, without detailed investigation, one cannot know that ECMs such as improved insulation or glazing perform in exact accordance with theory. Our focus here is the difference in ECM savings estimated by models tuned using different methods.

We noted our assumption that the ratio of simulated to theoretical conductance would be the same for the baseline as for the tuned Energy Edge building simulation. When the simulation was STEM-tuned, the simulated conductance was 43% of the theoretical conductance, for all conductances. For consistency with the baseline model, we also applied this ratio to the ECMs in the parametric simulations. For example, the ECM for an increase in first floor wall insulation was simulated by the MCT parametric as a change from R-11 to R-17, an R-6 increase. The same ECM was simulated as a change from R-26 to R-40, an R-14 increase, by the STEM parametric. We examine this further in the Discussion section.

Key Findings

The two sets of simulations resulted in very different estimates for individual ECM savings. The MCT simulations estimated 50% greater savings attributable to the building envelope measures than was estimated by the STEM simulations. This is because the MCT simulations had greater building envelope conductance and lower infiltration. Since a greater percentage of heat loss was through conduction, the increased resistance provided by the envelope ECMs had a greater impact.

Note that the assumed R-value of the shell ECMs in the MCT simulations was 57% lower than the R-value of the same ECMs in the STEM simulations, yet the MCT simulations estimated 50% greater energy savings! If we had not applied the STEM adjustment factors to the ECMs, the STEM-estimated savings would have been even lower. Figure 4 presents the ECM savings estimates.

The addition of economizers is also responsible for a large difference in savings estimates between STEM and MCT. Much of this difference results from the different assumptions for maximum outside air. However, some of the difference in savings estimates may be attributable to the different simulated conductances.

Discussion

Our analysis brought to light several questions and concerns regarding the use of simulations to estimate energy savings. We were particularly curious about the result that the net conductance of the STEM-tuned simulation was only 43% of the theoretical value. Other questions dovetail to this key issue.

Evaluation of the Building Conductance Estimated by the Tuned Models

Further research disclosed a potential reason for the deviation of the STEM-tuned conductance from the theoretical value. The STEM model used the measured infiltration as an input. DOE-2 calculates the infiltration (sensible) heat load based on the input infiltration CFM and the inside-to-outside temperature difference. We learned that this traditional method can over-estimate the heat load due to infiltration. (Kris Subbarao 1991, personal communication.) The exterior structure of the building acts like a heat exchanger: the cold infiltration air is warmed as it enters the building, so the infiltration heat loss is significantly less than would be calculated using the infiltration CFM and the inside-to-outside temperature difference (Claridge and Bhattacharyya 1990, Liu and Claridge 1992a, Liu and Claridge 1992b).

We analyzed the results of the building load coefficient test to determine the sum of the infiltration and conductance heat loads. We estimated the building load coefficient to be 479 Btu/hr-deg-F based on the

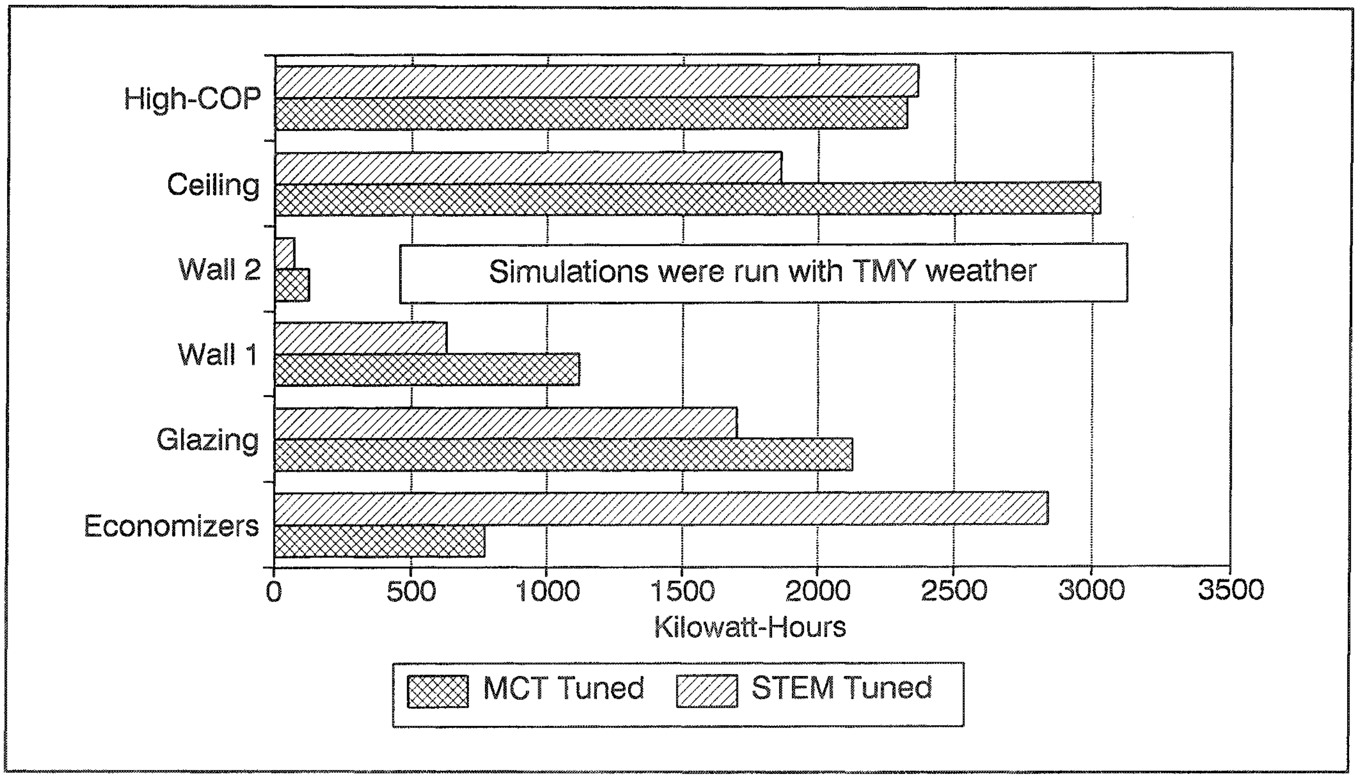

Figure 4. ECM Annual Savings Estimates by Tuning Methodology

STEM-tuned DOE-2 simulation. We had confidence in our analysis, since it resulted in a match with monitored data that was much improved over the untuned model. Furthermore, our estimate of the building load coefficient was within 8% of the value previously calculated by NREL of 519 Btu/hr-deg-F. Since our estimate of the building load coefficient seemed reasonable, if our estimate of the infiltration heat load was high, our estimate of the conductance would be correspondingly low.

We ran an additional simulation to check the potential impact of the infiltration heat exchange effect on the STEM tuning. We re-tuned the simulation assuming that infiltration did not contribute to the load. The resulting conductance was 117% of the theoretical value. Clearly, a reasonable answer is somewhere between the extremes: there is a load due to infiltration, greater than zero but less than the load calculated by DOE-2 using the measured infiltration, that will bring the tuned net conductance closer to the theoretical value.

As a further evaluation, we STEM-tuned the simulation using the theoretical conductances. This simulation best matched the building load coefficient test with the infiltration heat load at 10% of the traditionally calculated value. If our STEM methodology was correct, this suggests that the infiltration heat load in this building may, indeed, be overestimated by the conventional calculation. Table 3 summarizes the combinations of conductance and infiltration that resulted in well-tuned STEM models.

Table 3. Combinations of Infiltration and Conductance in STEM-Tuned Models

Infiltration Heat Load, % conventional*	Conductance Heat Load, % theoretical
0	117
10	100
100	43

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* conventional calculation of infiltration heat load:

$Q_{infil.} = 1.08 * CFM_{infil.} * (T_{inside}-T_{outside})$

Tuning the simulation without infiltration resulted in a thermal capacitance that was only 37% of the capacitance for the simulation tuned with infiltration. This is due to the DOE-2 assumption that there is no thermal lag associated with infiltration. This may be another weakness in simulations. However, we expect it is a minor consideration except for relatively massive buildings with unusually high infiltration.

Like the original STEM-tuned model, the annual simulation which was based on tuning without infiltration matched well with monitored data. The estimate of HVAC energy consumption is compared with monitored data in Figure 5.

Application of Tuning Modifications to the Baseline Simulation

Another important question is, how should the tuning adjustments which were applied to the as-built building shell simulation be applied to the baseline building simulation? For example, if the STEM tuning indicates that the as-built building shell has 30% lower conductance than theory would indicate, should it be assumed that the baseline building would also have a conductance 30% lower than theory? The adjustments which are applied to the theoretical conductance, shading coefficient, absorptance, thermal mass, and HVAC COP may not be directly applicable to a baseline building simulation. Our approach was to assume that the adjustment factors applied both to ECMs and the baseline building. But this assumption is untested.

Application of Tuning Modifications to ECM Evaluation

A third question is, what parts of the building shell and/or ECMs perform differently than theory? There are uncertainties associated with the treatment of ECMs for the building shell and HVAC. Since STEM relies on a whole-building approach to tuning the building shell, an improved simulation of the whole shell does not necessarily mean an improvement in the specific simulation of windows, walls, or roofs.

For example, the theoretical conductances were multiplied by 0.43 in the STEM-tuned model. This multiplier was applied to all conductances: windows, walls, ceilings, doors, etc. This is unlikely to be accurate; it is more likely that the performance of some components closely match theory, and other components are responsible for the bulk of the discrepancy between theoretical and actual performance. Therefore, although the estimate of total ECM savings should be improved by a STEM-tuned simulation relative to an untuned model, the estimates of savings for individual ECMs may not be.

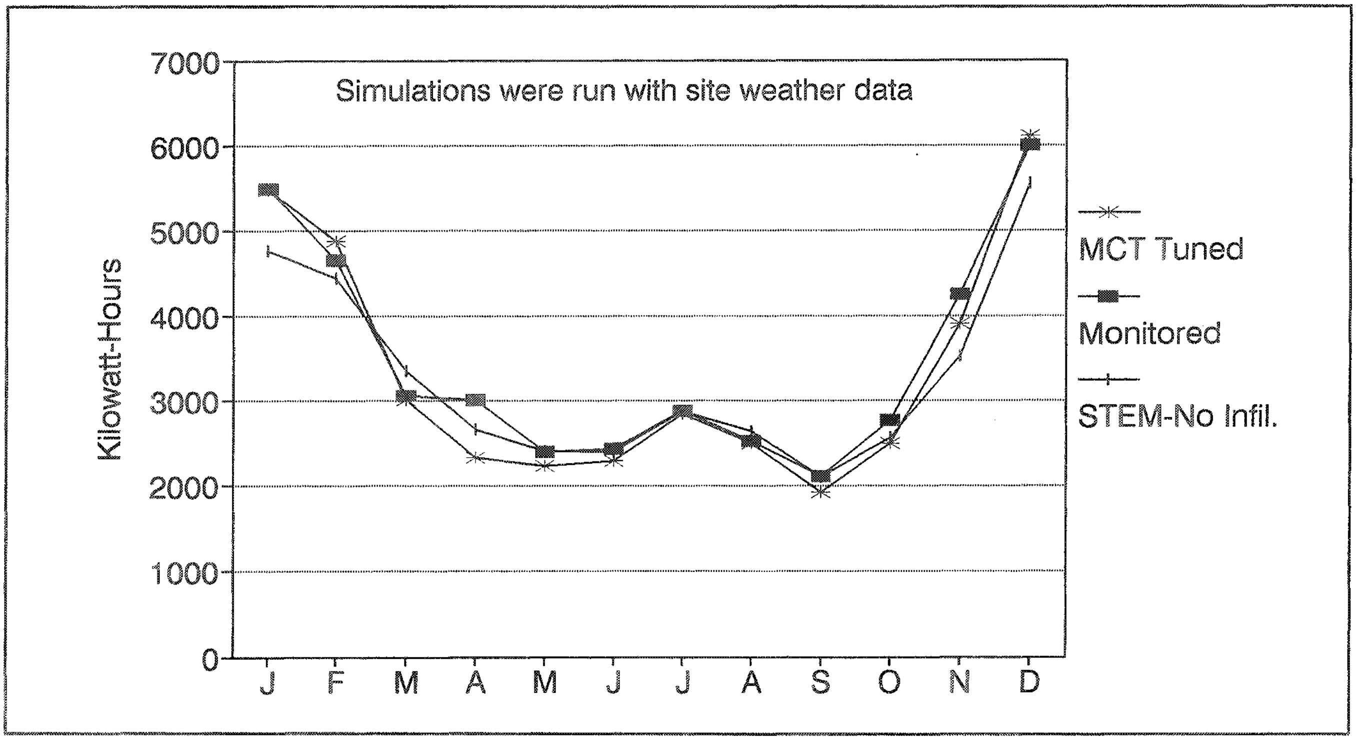

Figure 5. Monthly HVAC Energy Use for a STEM Model Tuned Without Infiltration

We also note that MCT assumes theoretical performance of the building shell and ECMs. Therefore, any deviation from theoretical performance means the simulation contains inaccuracies.

Even if a heat exchange effect of the building shell on infiltration load is fully responsible for differences in theoretical and tuned building conductances, there is still uncertainty in the evaluation of ECMs. The impacts of changes to the building shell on this heat exchange effect are unknown. These considerations can make it difficult to accurately assess the effectiveness of many building shell measures such as infiltration barriers or increased insulation.

Conclusions and Recommendations

We were able to successfully tune the DOE-2 model to monitored data using two different tuning methodologies. Surprisingly, the two methodologies resulted in assumptions that differed markedly between the tuned models. Most notable, when incorporating the measured infiltration, the STEM-tuned model had a building conductance that was only 43% of the theoretical conductance used in the MCT model. Inputs for infiltration, ventilation, and supply air heat loss compensated for the conductance difference, so both tuned models estimated annual HVAC energy use within 11% of the monitored consumption.

We derived two baseline models from the two tuned models. The two different methodologies estimated very similar total savings for the as-built building relative to the baseline. This similarity seems to be a coincidence, resulting from compensating differences in the simulations, that may not occur with other buildings. If the credit union building did not have an ECM for economizers, the two methodologies would likely have estimated much different total savings.

We found that the STEM-estimated energy savings of the shell ECMs was significantly different from that estimated by the MCT analysis. The MCT simulations estimated 50% greater savings attributable to the building envelope measures than was estimated by the STEM simulations. This is not surprising, given the differences in the tuned simulations, but it does raise questions about the relative benefits of various envelope ECMs.

The most significant concern raised by our analysis is how well conventional calculations represent the way buildings actually perform. Is our STEM analysis valid? If a building performs much differently than assumed by conventional calculations, then even a model tuned to match monitored data could calculate inaccurate estimates of energy savings. An envelope heat exchange effect on infiltration heat loss is probably a major reason for the difference between the STEM-tuned and theoretical conductance. With 10% of the measured infiltration, a retuned STEM model had a building conductance that matched the theoretical conductance. Since the infiltration heat loss may not be easily characterized as a function of infiltration CFM and inside-to-outside temperature difference, modelers should exercise caution regarding their use of measured infiltration.

We have demonstrated how a simulation can be successfully tuned several ways, with widely varying sets of assumptions. Obviously, some sets of assumptions are worse than others. The difficulty is in distinguishing the best assumptions, especially when conventional calculations may be suspect. Of course, this was a case study of one building. Errors happen, happen (Kaplan and Caner 1992). Despite our care, it is possible that the simulations could have serious errors or that we misapplied STEM, etc.

It would be beneficial to further investigate these questions. Our purpose in this study was to compare two tuning methodologies. Therefore, we did not incorporate the knowledge obtained from hourly end-use monitoring into the STEM estimates of ECM savings. To investigate some of the questions we have posed, the simulations should assimilate all of the available information about the building.

One approach to comparing the accuracy of various assumptions is to look at smaller time periods in greater detail. Rather than look at monthly total energy consumption, the hourly energy consumption could be evaluated for certain days or groups of days. This is the approach used for STEM tuning. By analyzing various days with a wide range of infiltration rates and ambient temperatures, it is likely that the more accurate sets of assumptions could be determined.

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Pacific Northwest Laboratory, Portland, Oregon, synthesized the weather variables not monitored but required by DOE-2, and formatted the weather data for use by the DOE-2 simulations.

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