Two DOE-2.1C Model Calibration Methods

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ABSTRACT

This paper discusses two techniques used for calibrating hourly building energy use simulations to monitored data. One method is based on short-term test results, and the other relies on a year of hourly monitored data. Both calibration methods use site weather data and information from the building audits. Monitored monthly total end-use energy consumption is used as the basis of comparison.

This paper describes each method and discusses the differences. A case study compares the results of two separate calibrations of a DOE-2 model of a small commercial building.

INTRODUCTION

This report describes two methodologies that use monitored building data and computer modeling data cooperatively to calibrate a building model. The monthly end-use energy consumption tuning (MCT) methodology relies on a year of hourly monitored data. The short-term energy monitoring (STEM) tuning methodology uses measured data obtained over a short (typically three-day) series of tests. It provides information about the building shell and HVAC system that is not available from the long-term hourly monitoring used for MCT.

These calibration techniques rely on the prior development of an "as-built model." The subject building, as built, is modeled using hourly building energy use software (usually DOE-2). The as-built model incorporates information from the as-built drawings, construction inspection notes, and operations and maintenance (O&M) audits. The tuning process calibrates the as-built model to measured data. Further information on these methodologies is provided in Kaplan and Portland (1992a).

This paper also presents a case study of the application of the two tuning procedures. Starting from the same model of a small commercial building in the Pacific Northwest, the MCT methodology and the STEM tuning methodology were applied to obtain two "tuned" simulations of the building. We present an overview of the two calibrations and discuss differences between them.

THE PURPOSE OF MODEL TUNING

In any given 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 with special energy conservation features. 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 energy conservation measures (ECMs).

The major purpose of tuning the computer model is to increase confidence in its ability to reasonably estimate the building's energy use and also the energy savings benefits of efficiency improvements. Model tuning matches simulated data to monitored data, within specified tolerances or according to certain criteria.

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 can be extrapolated from the savings simulated during the snapshot period, with the understanding that future changes could have an impact on expected savings.

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. The data set monitored for MCT includes end-use energy consumption, zone temperatures, and fan duty cycles. Specific heating, ventilating, and air-conditioning (HVAC) parameters, such as resistance heat energy and system air temperatures, are also monitored.

Monitored end-use energy consumption data are used to prepare hourly schedules for all end uses except HVAC. 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, "inputing 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 remain-

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ing discrepancies between the simulated and monitored HVAC energy consumption must be analyzed and model inputs adjusted, within reasonable bounds, until the simulated and monitored HVAC energy use are within the following limits: each month, $\pm 30\%$; seasonally, $\pm 20\%$.

The tolerances are considered flexible goals. Good engineering judgment is needed when tuning the model. For example, if the simulated HVAC energy consumption is in tune for 11 months of the year, but the twelfth month is 5% out of tune and it only accounts for 3% of the annual HVAC energy, it is not critical to tune that twelfth month.

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 MCT implicitly attempts 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 comparing simulated and monitored data on a monthly rather than an hourly basis. An MCT calibration of the simulation of a small commercial building was compared with a calibration to short-term profiles (Kaplan 1989; Kaplan and Portland 1991). The case study confirmed that, for the subject building, the two calibrations estimated very similar energy savings and ECM performance.

MCT has proved successful at reconciling the estimated and monitored energy consumption of a variety of buildings. One drawback to the MCT methodology is that the extensive, long-term monitored data are costly to obtain. 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.

MCT Monitored Data Analysis

Calibrations with MCT benefit from extensive hourly monitored data. For example, 50 separate channels were monitored for a 3,310-ft^2 convenience store and 121 channels were monitored for a 21,110-ft^2 retail and medical plaza. For the case study building, a 5,313-ft^2 credit union, 60 channels were monitored. Several tools were developed for manipulating the monitored data to facilitate the model tuning. These tools can be classified into three areas (see Kaplan and Portland [1992a] for further details):

- adjusted calendar,
- weather file generation, and
- load and operation schedules generation.

Adjusted Calendar The DOE-2 model operates on the basis of a standard calendar year. However, the monitored data used to inform and compare with the model predictions usually include data from two calendar years. When monitored data from two calendar years (for example, 12 months beginning in October) are re-ordered so that the sequence of data starts with January 1, it is possible to create the sequence so that either the calendar date or the day of the week is preserved but not both. Because the DOE-2 model results are compared with the metered data on the basis of daytyped hourly load profiles, it was decided to use the approach that preserves the day of week. Thus all metered data are adjusted based on an alternative calendar that is developed for each building.

Weather File Generation Specific weather variables, not directly monitored but required by the model, are synthesized. These include the direct normal solar radiation and the amount of sky covered by clouds. The synthesized and monitored weather data are processed into a TMY (NOAA typical meteorological year) format.

Load and Operation Schedules Generation The MCT methodology requires that lighting and equipment loads, thermostat settings, and fan operating modes be entered in the DOE-2 simulation so that these can be taken into account when calculating HVAC loads. Ideally, schedules would be developed that describe each end use for each zone in the building that is separately monitored. However, DOE-2 limits the number of schedules allowed. Thus the number of schedules must be reduced by combining those with similar hourly profiles.

Daytyping is the process of identifying groups of days in which a building's operation is reasonably uniform. Uniformity can be defined in several ways but generally means similarity of daily energy consumption and/or hourly load profiles. Only two daytypes were necessary for analysis of the credit union: (1) normal weekdays and (2) weekend days. Schedules were developed for these two daytypes. A slight dissimilarity of load profiles for different days within a daytype was not a major concern since the challenge was to match total energy consumption on a monthly and seasonal basis without regard to load profiles. Other typical office buildings would also be satisfactorily simulated with two daytypes. Buildings with more complex occupancy or operational schedules might require the simulation of more daytypes.

MCT Procedure

The MCT process, shown in Figure 1, follows these steps:

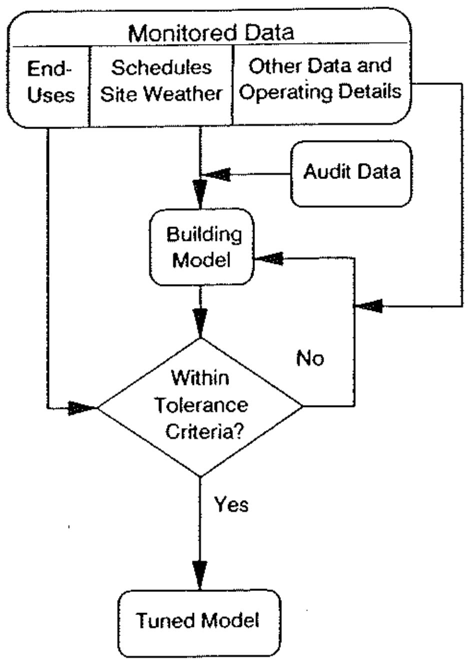

Figure 1 Monthly consumption tuning.

- Select an annual tuning period. This 12-month period should make maximum use of the best available monitored data while avoiding months of atypical building operation.
- Run the DOE-2 model using monitored weather data to get a preliminary comparison between the modeled energy consumption and the monitored data.
- Input the end-use load schedules derived from the monitored data. Run the simulation and again compare the DOE-2 simulated end-use energy consumption against the monitored data for the selected tuning year. If the two are in agreement within the tolerances allowed, the model is considered tuned.
- If the modeled energy use is still not within tolerance of the monitored data, the monitored data are used to determine which model inputs should be changed to better simulate the actual building.

In general, each tuning step consists of using the monitored data to try to determine what model inputs are causing inconsistencies, adjusting the inputs, rerunning the model, comparing the new simulation output to the monitored data, and documenting the iteration. Generally, only a fraction of the available data is used in tuning a building simulation with MCT. The first adjustments to the model are to correct obvious errors. Common areas of discrepancy include the input assumptions for fan power and operating schedules, thermostat setpoints, and economizer operation. Then, the less well defined energy drivers, such as infiltration, can be adjusted. The bounds for the input adjustments are set by the question, "Is the adjusted magnitude reasonable?" Then, if the model is still not tuned, an increasing portion of the monitored data is explored to determine additional discrepancies between the simulation and the actual building. The iterations continue until the results are within the tolerances. In rare circumstances it may be concluded that the model cannot be tuned within the specified tolerances.

SHORT-TERM ENERGY MONITORING TUNING

The short-term energy monitoring (STEM) process (Subbarao et al. 1990) provides specific information about the building shell or HVAC system under a controlled situation. These tests are designed to characterize the thermal performance of the building shell as a gray box (Subbarao 1988).

STEM tuning is a profile-tuning methodology for HVAC energy consumption. Other end uses are not tuned. The simulation of the building shell is adjusted so that the model output matches the data monitored during the test period. 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.

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

STEM tuning has the potential for better building shell characterizations than tuning methodologies that rely solely on long-term hourly monitored data. 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 heating. 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.

STEM-Monitored Data Analysis

Like MCT, the STEM methodology uses hourly monitored data. However, these data are taken over a three-day period only, rather than for a year or more as is the case with MCT. STEM uses a limited monitored data set. For example, during tests on the 5,313-ft^2 credit union, only 14 parameters were monitored.

Since monitored site weather data are required, STEM uses the same weather file generation procedure that is used in the MCT methodology.

Heat Flow Terms

There are typically five primary terms affecting the air temperature within a building space. Two of the five primary terms are either directly measured or calculated from a direct measurement. There is a one-to-one correspondence between the other three primary terms and the three building shell tests. Therefore, through sensitivity study of these three unknown primary terms, the simulation can be adjusted to match the results of the three building shell tests. These parameters are tested and adjusted in the simulation on a whole-building basis.

The primary heat flow terms measured or calculated directly are (1) the heat flow to the room air due to the internal gains and (2) the heat loss from the room air due to infiltration.

The primary heat flow terms to be adjusted are (1) the building's conductive heat loss, (2) the heat flow to the room air from the building mass due to changes in inside air temperature, and (3) the heat flow to the room air due to solar gain.

STEM tuning uses DOE-2 to account for all of these terms, as well as terms of secondary importance. The primary terms are adjusted to match the results of the tests. The STEM methodology uses the assumption that the secondary terms do not need to be adjusted to satisfactorily match the test data.

Tuning Criteria

During most of the STEM tests, the building is heated with electric heaters, called coheaters. The test coheat energy and space temperatures are entered in the model, so any model inaccuracies result in simulated HVAC operation to maintain the temperatures. Since the HVAC was off during the building shell tests, any simulated heat extraction or addition represents the energy imbalance, or difference, between the test and the simulation.

Sensitivity study of the parameters driving the primary heat flow terms is the foundation of the tuning process. The goal is to minimize the energy imbalances by changing the building shell parameters. Each of the model parameters is adjusted, in turn, to cause the simulation output to match the corresponding test results as nearly as possible. "Nearly as possible" is defined as the minimum energy imbalance in a series of trial-by-error simulations. The imbalance is not the same for all hours of the simulation. Therefore, a statistically valid combination of the imbalance for all hours must be employed. The root-mean-square (RMS) energy imbalance is used to compare results from different inputs.

Some minor residual RMS error is to be expected. NREL provided some reference values normalized for building floor area. For periods without solar gains, it is reasonable to expect a residual RMS error less than 0.5 Btu/h·ft^2. For periods with solar gains, the residual error is likely to be closer to 1.0 Btu/h·ft^2. Our case study tuning of the credit union resulted in residual errors of 0.32, 0.66, and 0.93 Btu/h·ft^2, respectively, for the building load coefficient, thermal capacitance, and solar gains test periods.

STEM Tests and Tuning Procedures

The STEM tuning follows a very prescribed procedure. The building shell parameters for conduction, effective mass, and solar gains are adjusted first. After the building shell is tuned, the HVAC efficiency is adjusted. These tests have been described in other papers (Burch et al. 1990; Subbarao et al. 1990; Subbarao 1988; Koran et al. 1992; Kaplan and Portland 1992a); our emphasis is on the tuning of a DOE-2 simulation.

- *Building Load Coefficient Test*. In tuning the simulation for this time period, a multiplier is applied to all of the model's conductance (UA) inputs to make the model match the test results as closely as possible. The conductance inputs to be so adjusted include those for insulation, structure materials, and windows. Resistances, such as for air films, are adjusted inversely to conductances.
- *Infiltration Test*. The measured infiltration is entered into the model prior to the sensitivity study of the building conductance. (Direct use of the measured infiltration may, however, be a source of error. See Claridge and Bhattacharyya [1990], Liu and Claridge [1992a, 1992b], and Koran et al. [1992].)
- *Thermal Capacitance Test*. A multiplier is applied to the inputs for the specific heats of the envelope materials to make the model match the test results for this time period.
- *Solar Gains Test*. A multiplier is applied to the input absorptances and glazing shading coefficients to cause the model to match the test results for the daytime test period.
- *Analytical Iterations*. Although each STEM test is designed to make one of the unknowns in the energy balance equation the dominant term, the parameter adjustments have interactive effects. Therefore, some iteration is necessary to further tune the parameters and minimize the residual error. Three iterations were required to satisfactorily tune the simulation of the 5,313-ft^2 credit union. Note that the lighter the weight of the building, the quicker the impact of solar gains and the less critical the heat storage terms become. Therefore, with a very lightweight building, little analytical iteration will be required. With heavier buildings, more analytical iteration is involved to appropriately account for these terms.
- *HVAC Efficiency Test*. Since the building has been calibrated for use as a calorimeter by the first four tests, the energy required to maintain the space temperatures can be calculated. The simulated energy

required is compared to the actual energy input to determine the overall HVAC system efficiency. The heat pump heating electric input ratio (EIR = 1/COP) is adjusted to minimize the RMS error in electricity consumed. To the extent that they are unknown, it is also appropriate to adjust different HVAC parameters, such as duct leakage, duct heat loss, part-load efficiency, and so forth. Note that the HVAC efficiency determination is dependent on the accuracy of the building shell calibration.

Figure 2 is a flow chart of the STEM tuning process.

Important STEM Tuning Details

Two groups of details must be taken care of to execute the STEM tuning. The first group involves specific DOE-2 simulation techniques. The second group emphasizes the importance of accurately simulating the STEM test conditions. The short time duration of the tests makes attention to the test particulars imperative for successful STEM tuning. These details are covered more extensively by Kaplan and Portland (1992a, 1992b) than they are here.

DOE-2 Simulation Techniques The sensitivity study of the energy drivers requires that the conductivity, specific heat, shading coefficient, and absorptance of the building be adjusted. This is easy to do with the DOE-2 PARAMETER command. For example, we gave the multiplier for conductivity the PARAMETER name P-COND. All conductivities in the input file were multiplied by P-COND. P-COND was varied to minimize the energy imbalance for the building load coefficient test.

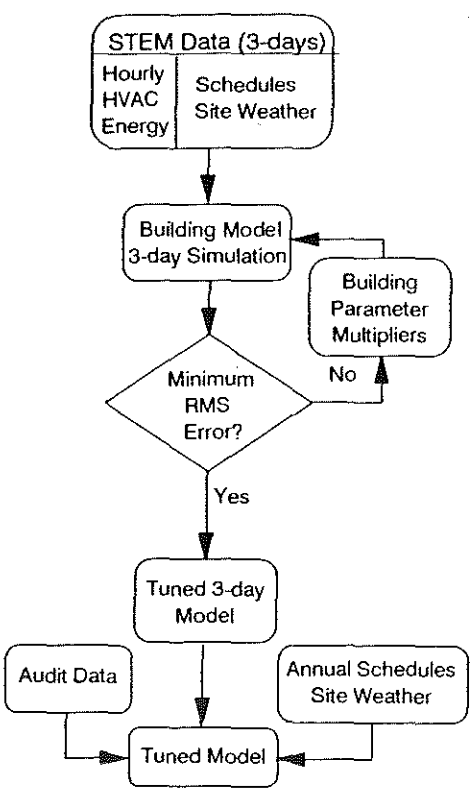

Figure 2 STEM tuning.

The sensitivity study cannot be performed if DOE-2 library materials are used. All materials must be explicitly defined because it is not possible to modify the thermal characteristics of DOE-2 library materials. Each material must be given a user name and defined in a MATERIALS command. For example:

Typical input code:

```
WALL2-CON=LAYERS      MATERIAL=(BK05,...) ..
```

Code for parameter adjustment:

```
WM-BK05=MATERIAL      THICKNESS=.3333
                      CONDUCTIVITY=P-
                      COND TIMES 0.2083
                      DENSITY=80.0
                      SPECIFIC-HEAT=P-MASS
                      TIMES 0.2 ..
WALL2-CON=LAYERS      MATERIAL=(WM-
                      BK05,...) ..
```

(P-COND is the multiplier on the audit conductivities and P-MASS is the multiplier on the audit thermal capacitance.)

The custom weighting factors feature of DOE-2 should be used. If custom weighting factors are not used, it may be difficult to adjust the building effective mass for tuning to cool down test results.

Key Elements of Simulation Accuracy Prior to the sensitivity study of the primary terms affecting the space temperature, the known energy drivers and other simulation inputs must be modified to match the test results:

1. The measured infiltration should be input, with specific inputs for wind-dependent and temperature-dependent terms as appropriate.
2. Schedule inputs for equipment, lighting, and occupancy must be modified to reflect the special circumstances present during the test period. For example, the equipment schedule must be changed to match the power measured each hour during that time. The thermostat schedules should be adjusted to eliminate setback/setup for the pre-test control period and to match the measured space temperatures during the test. This scheduling is critical to the success of the tuning.

The simulation of the HVAC test can be a metaphorical thorn in the analyst's side. *The details of the system operation during the HVAC test must be known if the STEM-tuned model will be used for an annual simulation.* These details include the fan duty cycle and air temperature drop in the supply ducts. For annual simulations, the DOE-2 input for supply air temperature drop, DUCT-DELTA-T, should generally be set to a value less than 1°F (LBL 1984). However, *for simulating the HVAC test, the correct temperature drop during the test must be measured or calculated* and entered in the model. In our case study, the use of an annual average for DUCT-DELTA-T resulted in an incorrectly "tuned" HVAC COP that was only 53% of the manufacturer's rated value. However, when the duct air temperature drop calculated at the STEM test conditions was input, the tuned HVAC COP was within 15% of the manufacturer's value!

If the indoor fans were in auto mode during the HVAC test, the simulation must be carefully tailored to match the test. This is because DOE-2 does not simulate part-hour operation of the fans. Since the HVAC test time period is only a few hours in duration, simulation estimates of fan energy and ventilation (outside) air may be too inaccurate for satisfactory tuning of HVAC efficiency unless the modeler accounts for deficiencies in the simulation with compensating adjustments in the inputs for fan energy and outside air.

Since it is difficult to simulate tests of short duration, it should be clear that only hourly simulation programs are appropriate for tuning to short-term test results. Note, however, that if the time period of concern is very brief, even an hourly simulation program may be inadequate.

Annual Simulation

Once the model has been tuned for the three-day STEM test period, an annual simulation is developed. The accuracy with which the STEM-tuned model simulates annual energy consumption is largely dependent on how well the building operation is known. Information on controls, setpoints, and occupant behavior must be obtained through audits and/or additional monitoring because STEM testing does not address normal building operation.

It is sometimes difficult or impossible to simulate actual HVAC system operation with DOE-2. The complexities of analyzing building energy use necessitate assumptions within the program that may not reflect actual system operation. Without monitored data, it can be impossible to determine if the DOE-2 assumptions are representative of the actual building.

Because of these concerns, the annual simulation may need to be developed in several steps, rather than just running the STEM-tuned model for a whole year. Simulation errors may become apparent when the annual simulation is compared with monitored or billing data. As with any tuning procedure, it is important to correct errors as soon as they become apparent.

RESULTS OF MODEL TUNING METHODOLOGIES CASE STUDY

In our case study of the 5,313-ft^2 credit union, the MCT and STEM tuning processes were pursued separately so that the two methodologies could be compared. We avoided cross-fertilization of the assumptions used in each methodology. For additional information, see Koran et al. (1992) and Kaplan and Portland (1992b).

In the case study building, HVAC accounts for 55% of the total electrical energy consumed annually. Heating energy is 44%, cooling energy is 17%, and fan energy is 39% of total HVAC energy. Both tuned models match monitored data for monthly HVAC energy use much more closely than the untuned model, as shown in Figure 3.

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 match much better with monitored data than the simulation with audit schedules. This is shown in Figure 4.

Despite the similarity of energy-use estimates, the two methodologies clearly result in different tuned models. Of greatest note, the STEM-tuned building load coefficient is only 65% of the building load coefficient for the MCT simulation. In other words, the STEM tests and analyses indicate that the building shell performs 50% better than a typical audit-based DOE-2 simulation would predict.

Another notable finding is that the HVAC overall efficiency (energy to the space divided by the energy input) during the STEM HVAC test was STEM-tuned at 82%. Using the same data but different analytical tools, NREL estimated the overall efficiency to be 86% (Subbarao et al. 1990). The MCT simulation estimated the overall efficiency at the STEM test conditions to be 155%. Figure 5 shows the roots of the seemingly poor HVAC performance estimated by the STEM simulation.

CONCLUSIONS AND RECOMMENDATIONS

Two methodologies for calibrating DOE-2 building energy simulations to monitored data have been described. Compared to STEM, MCT does a more accurate job of estimating non-HVAC energy consumption because it benefits from the use of monitored end-use data. If HVAC energy use is relatively independent of building shell heat gains and losses, MCT should also do a more accurate job of estimating HVAC energy consumption. A drawback to MCT is the need for long-term hourly monitored data on end uses, temperatures, and HVAC operation.

Despite our confidence in monthly consumption tuning, we recommend caution in its application for calibrating a simulation. A given HVAC energy consumption can result from an efficient HVAC system with a relatively poor building shell, an inefficient HVAC system with a relatively good building shell, or any combination thereof. MCT depends totally on building audits and drawings, the modeler's understanding of the HVAC system, and the simulation tool's calculations to estimate the performance of the building shell.

In contrast, STEM benefits from direct tests of the building's thermal performance. Our case study of the

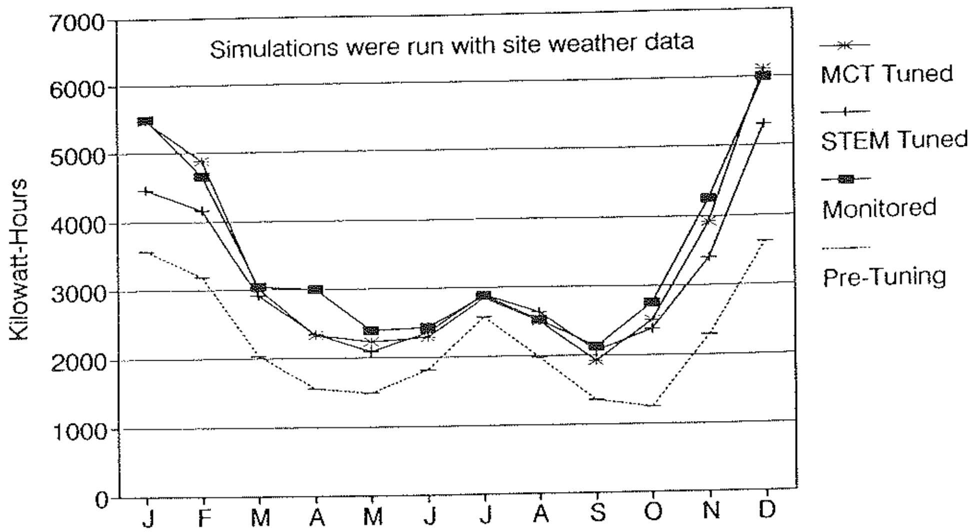

Figure 3 Comparison of simulated and monitored monthly HVAC energy use.

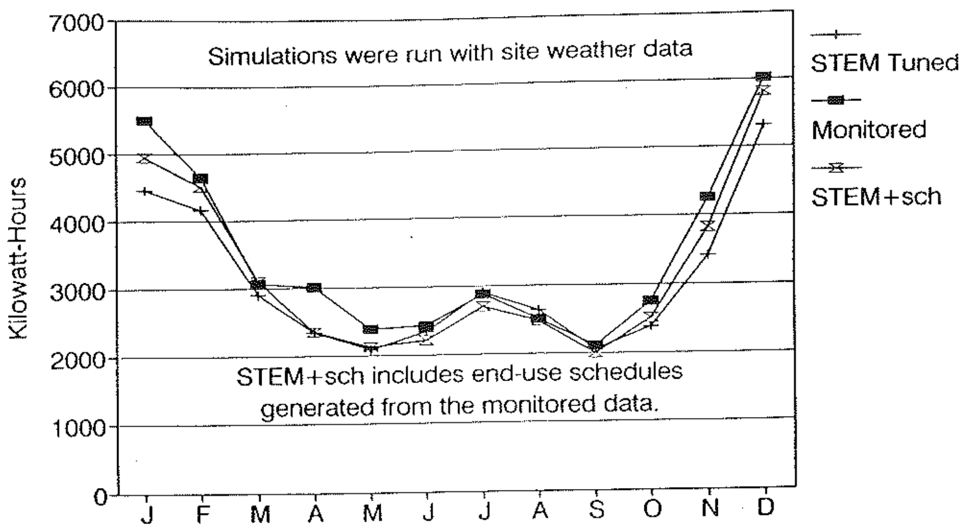

Figure 4 Monthly HVAC energy use for a STEM model using monitored end-use schedules.

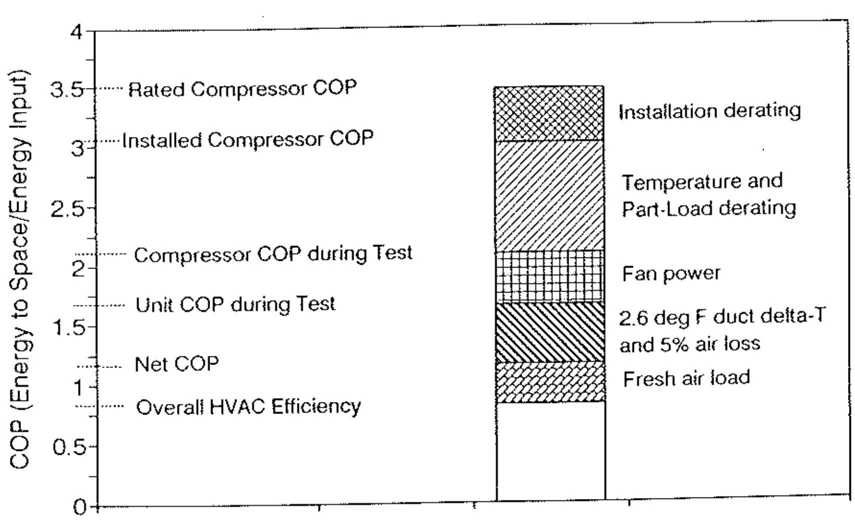

Figure 5 Modeled heat pump performance 5,313 ft² credit union.

STEM process was very successful at tuning HVAC energy use. Because of its emphasis on the building shell, thermal mass, and HVAC efficiency, STEM should be most reliable for buildings whose energy consumption is dominated by HVAC heating. With appropriate tests, STEM should also reliably estimate the cooling energy use for buildings with a cooling load dominated by shell heat gains. The greatest weakness of STEM is that it reveals little about the internal loads or occupant behavior.

Combining STEM and MCT should result in a more accurate simulation than applying either methodology alone. A STEM-tuned model's estimates of long-term energy use could benefit from the extensive MCT monitored data, and an MCT-tuned model could benefit from the STEM tests of the building shell and HVAC performance. The disadvantage of combining the two methodologies is that the necessary data collection and model tuning are more complex than for either methodology alone.

A major purpose of model tuning is to improve the model's estimates of energy savings. However, a well-tuned model is not yet a guarantee of reasonable energy savings estimates, since a model can be tuned several ways, with widely varying sets of assumptions (Koran et al. 1992). Research should be done to compare simulation estimates with direct measurements of savings for specific ECMs. Savings estimates should be made with models calibrated to various levels of detail. Calibration criteria levels could include whole-building annual energy consumption, monthly end-use consumption, and hourly end-use consumption. Such research could help determine the monitoring and modeling detail necessary to reliably estimate energy savings.

ACKNOWLEDGMENTS

Lambert Engineering, Bend, Oregon, performed the monitoring for the buildings we have tuned using the methodologies described in this paper.

Lawrence Berkeley Laboratory, Berkeley, California, provided the statistical data analyses used to derive end-use load schedules from the monitored data.

National Renewable Energy Laboratory, Golden, Colorado, performed the STEM tests with the assistance of Lambert Engineering. It also provided background information on the STEM tests and analyses.

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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