Guidelines for Energy Simulation of Commercial Buildings

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Energy Edge is a large-scale research and demonstration project funded by the Bonneville Power Administration to test energy conservation in commercial buildings. The project involves intensive building computer simulation work using an hourly analysis program, DOE2.1C. We have written a set of guidelines that distills the experience we have gained from the building simulation work. The two primary purposes of the guidelines are to advise conservation program managers on the use of modeling, and to improve the accuracy of design-phase computer models.

This paper provides an overview of the guidelines. We address at some length a few of the more important issues raised in the guidelines. These include: (1) what program managers can reasonably expect from computer simulation, (2) what program managers can do to improve the reliability of simulation in their programs, (3) what are some of the main sources of discrepancies between the savings predictions of design-phase models and those of as-built or calibrated models, (4) which simulation inputs have the greatest impact on the results, and (5) what modelers can do to minimize error in their work.

Introduction

The Guidelines for Energy Simulation of Commercial Buildings (Kaplan Engineering 1992), hereafter called the Guidelines, distills the experience gained from intensive computer building simulation work for the Energy Edge project. The purpose of the Guidelines is twofold: to advise conservation program managers on the use of modeling, and to improve the accuracy of design-phase computer models. To achieve these purposes, the Guidelines:

- discusses the value of modeling for energy conservation programs
- discusses strengths and weaknesses of computer models
- provides specific guidelines for model input
- discusses input topics that are unusually large drivers of energy use and model inaccuracy
- provides guidelines for developing baseline models
- provides basic requirements for model documentation.

Though most of our Energy Edge experience is associated with the DOE2 software, we have attempted to make the Guidelines more broadly applicable.

Energy Edge is a large-scale research and demonstration project funded by the Bonneville Power Administration (Bonneville). This project 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 regional model energy code, the Model Conservation Standards (MCS) developed by the Pacific Northwest Electric Power and Conservation Planning Council. Secondary objectives of the project are to determine the incremental costs and energy savings of a wide variety of energy conservation measures (ECMs) and to compare the predictive accuracy of design-phase models with models that are calibrated with monitored building data. Twenty-eight commercial buildings were selected to participate in Energy Edge. All but two were new construction.

In the area of research, Bonneville decided to pay special attention to the methods for determining actual energy savings. Typically, design-phase computer analysis must deal with relatively little information about the reality of a specific building and its operation. Energy Edge attempted to expand the present limits of energy modeling by monitoring the selected buildings in great detail and then using the monitored data to ground the models in reality. This resulted in at least three distinct models for each monitored building--the design-phase model, the as-built model, and the calibrated (or tuned) model.

In this research, Kaplan Engineering was responsible for the coordination of the as-built modelers and the review of the as-built building models as well as the calibration of the models to monitored data. It is this experience that has led to the Guidelines for Energy Simulation of Commercial Buildings.

Bonneville is now incorporating the Guidelines into the design and operation of its Energy Smart Design (ESD) program. The ESD program is Bonneville's primary vehicle for acquiring energy savings from commercial buildings in the Pacific Northwest.

Organization of the Guidelines

The Guidelines has two main parts. The first part presents modeling from the perspective of the conservation program manager. Topics include:

- The strengths and weaknesses of modeling. This section seeks to help the program manager better decide when and when not to use modeling.
- Alternatives and complements to modeling.
- Basic quality control procedures.
- Areas for further research.
- The inevitability and implications of assumptions and errors. This section has the objective of giving program managers a more realistic understanding of what they can expect from modeling.
- Modeling in the context of the Energy Edge experience.

The second part presents detailed technical guidelines for modelers. Topics include:

- A plea for an expanded role for the modeler--that modelers take more responsibility in ensuring that recommended ECMs are successfully implemented. The Guidelines recommends that modelers write detailed performance specifications and check design documents and submittals.
- Suggestions aimed at decreasing model complexity where possible.
- Discussion of how modelers can interact actively with their simulations.
- Common sources of simulation error.
- Simulation input. This section covers the most critical aspects of loads, systems, and central plant input, including: zoning, infiltration, window and wall U-values, shading and solar gain, daylighting, thermal mass, unconditioned spaces, interior walls, above-ceiling spaces, heat loss to ground, weather, general receptacle loads, computer rooms, lighting, commercial refrigeration, cooking equipment, HVAC equipment capacity and part-load efficiency, HVAC controls, multiple zone systems, ventilation, fans schedules and supply air volume, fan heat, and hidden energy users.
- Development of the baseline model (the building as modeled without ECMs). This section presents guidelines for developing consistent and reasonable baselines.
- Three steps for model error checking: input check, output check, and check against energy use indices (EUIs) compiled by others.
- Recommendations for specific contents for model documentation.

The appendices of the Guidelines provides several technical aids for the modeler. These include a table of U-values for walls and roofs (corrected for framing), tables of EUI values by end-use for various building types, recommended default occupancy schedules for various building types, and sample controls sequences and performance specifications for our Renaissance modeler.

Modeling From the Program Manager's Perspective

In this section we discuss a few of the major modeling topics of interest to conservation program managers. The Guidelines expands upon these and other related topics.

Appropriate Application of Simulation

Computer simulation of building energy performance can be an expensive endeavor. For this reason, program managers want to know when this expense is warranted. Whole-building modeling is not necessarily the optimal tool for all energy analysis. It should not be used when a more simple or less costly method of analysis can yield adequate results. Similarly, a complex software program should not be used when a simple one can adequately address a specific building or ECM. Complex programs do not necessarily yield more accurate results.

(Conversely, a simple program should not be used when a more complex one is needed to adequately address specific ECMs or buildings.)

On the other hand, program managers may see some value in a standardized approach to energy analysis. This permits easier review of modelers' work and eliminates discrepancies due to different software. It does not however eliminate discrepancies due to different modelers or techniques. It also tends to force selection of software suited to the highest common denominator (i.e. the most demanding building type or ECM). This can be expensive.

In general, modeling is best suited for the analysis of ECMs that either interact with or directly affect HVAC performance. An important exception to this generality is light-dimming controls in day-lit buildings. Modeling is overkill for analysis of ECMs that yield to simple manual calculations. We also suggest that energy analysis computer programs are relatively poor tools for estimating electrical demand or for sizing HVAC equipment.

As a general rule, the energy analyst should not resort to computer modeling when a simpler method can do the job as well. If modeling is indicated, the program selected should fit the task; it should not be selected simply for the convenience or comfort of the modeler. Sometimes modeling can be profitably integrated with another form of analysis--for example, engineering spreadsheet calculations. Whenever possible, the analyst should check the results of one form of analysis against another method.

Modeling can be no more accurate than the assumptions that lie behind both the proposed building and the baseline building models. Even though the model performs complex calculations accurately on these assumptions, the result will be misleading if the assumptions are faulty. The Guidelines provides guidance for development of some of the more critical assumptions.

ECM savings are estimated as the difference between two models--the as-designed model and the baseline model. Modelers typically turn most of their attention towards the as-designed model. But we have found the baseline model to be one of the most significant sources of discrepancies between the savings estimates of different modeling phases (or modelers). We provide guidelines for baseline model development in this paper and in part 2 of the Guidelines.

An accurate model can be useful on several levels. Most commonly, it is used to estimate the energy savings of specific ECMs. Financial decisions are based on these estimates. Building design decisions can also benefit from modeling. The model can often illuminate obscure aspects of the designed building performance. Sometimes the model can uncover design weaknesses or error.

Can modeling be used for program evaluation? More research is needed on the statistical reliability of model predictions. The Energy Edge project case studies indicate a strong variability in the results from different models, modelers, and model-phases. This variability may tend to disappear and the estimates become more reliable when applied to a very large number of buildings. However, it has yet to be determined if modeling (with its high costs) is more accurate than other lower cost evaluation techniques when averaged over a large number of buildings.

Modeling is only one aspect of the technical tasks in a successful conservation program. Model estimates cannot be reliable for many ECMs if the ECMs are not installed, commissioned, and maintained properly. Energy Edge provides many examples of the failure of non-commissioned ECMs.

Quality Control by Program Managers

Models are complex and vulnerable to error. Models are to error as sponges are to water. Computer simulation is often the best available method for estimating ECM savings. But it is a method that needs rigorous quality control. We make several recommendations concerning quality control:

(1) We recommend that utilities develop minimum qualifications for their modelers and that they enforce them. Qualifications should include experience in modeling a wide range of buildings and building types, preferably with several different software programs. If it is likely that complex hourly analysis programs will be required, then extensive experience in such programs should be required of the modelers. We also believe that HVAC design experience is extremely valuable to a modeler. It engenders a real-world perspective that people who solely model do not have.

If the infrastructure cannot supply enough modelers who have those qualifications, then supplemental required training should be considered.

(2) We strongly recommend that every model on which important decisions are to be based should be reviewed by a competent modeler. Review should include the baseline model as well as the as-designed model.

(3) Utilities should consider providing training to modelers. This training should address both technical modeling guidelines and program-related expectations.

(4) The modeler should compare the end-use energy use indices (EUIs) of every baseline model to statistical data for similar building types. Significant discrepancies should be investigated. The Guidelines provides the statistical data as well as direction for this comparison.

(5) For retrofit projects, modelers should compare the baseline (the building before retrofit) to historical billing data. Significant discrepancies should be investigated.

(6) The modeler should comprehensively document the model.

Though error (or its little brother, uncertainty) is rarely completely eliminated, diligence in following the above steps will eliminate the grossest and most damaging errors. Then program managers can have some confidence in the reliability of modeled energy savings predictions.

Technical Guidelines

In this section we discuss a few general modeling issues and strategies. The Guidelines covers each of these topics in greater detail, as well as including the other topics mentioned previously.

An Expanded Role for the Modeler

Analysis is only a small link in the chain of activities that produce actual energy savings. Once savings estimates have been used to select an ECM, it is the quality of the manufacturing, design, installation, operation, and maintenance of the ECM that determine how much energy is actually saved. We recommend that the modeler's role be expanded to help assure that savings are actually delivered.

Critical parameters, assumed in the analysis, need to be written down by the modeler to serve as performance specifications, along with assumed operating setpoints, schedules, and maintenance requirements. The modeler should then check design documents, bids and equipment submittals to assure that the performance specifications are being met. The design documents, whether they are written by a manufacturer or a consultant, should indicate that adequate attention has been assigned to fitting the general technology to the specific building.

Modeler-Simulation Interaction

We recommend that modelers start any simulation with an opinion about what the results should be. The modeler should consider information about typical:

(1) Btu per square foot per year total consumption by building type,

(2) end-use breakdown fractions, and

(3) shapes of annual consumptions.

The modeler should also have some sense of what the energy savings for each ECM will be, either from back-of-the-envelope calculations or previous modeling experience.

If the simulation produces results that fall dramatically outside the range of anticipated results, the modeler's most reasonable first reaction should be to try to bring the simulation into line--always remaining open to the possibility that the simulation is correct. The order of attack for bringing the simulation into line is important, and should be roughly as follows:

(1) Careless Errors. Look for careless errors in the inputs.

(2) Simulation Output. Examine parts of the simulation output that might lead to some clarification of the difference between simulation results and the expected values.

(3) Understanding of the Simulation Algorithms. Reread the appropriate sections of the simulation users' manual to check whether the simulation has been properly understood, and correct any errors resulting from such misunderstandings.

(4) Increased Attention to Input Detail. Consider redoing more carefully any inputs that were developed in a rush if it seems the difference might create a more reasonable outcome.

(5) Fiddling with Inputs with a High Degree of Uncertainty. Tweak uncertain inputs within a reasonable range of values to move the simulation results toward the expected answers. (This is complex and dangerous. "Responsible tweaking" requires modeler experience, judgement, and integrity.)

The overall strategy is thus first to increase accuracy, then tweak, and finally to consider that either there is a bug in the simulation or an error in the preformulated answers. For unexpected ECM savings, try hand calculations to see whether the same results can be approached manually.

If modelers don't start each simulation with an idea of the reasonable range of outcomes, they will be at a disadvantage in routing out careless errors and misunderstandings about how the simulation works. On the other hand, a modeler who resorts to unrealistic inputs to generate what appear to be the "right" outputs may be working from erroneous preconceptions. It is important to know when to stop arguing with the model and to start listening.

Significant Sources of Model Error

Most modelers exhibit some biases in their selection of modeling assumptions. In this section we discuss some of the biases that have become apparent from our Energy Edge work.

Equipment Power Density. We identify two significant modeler biases that relate to equipment power density:

(1) Underestimates from using rules of thumb. Equipment loads for offices (plug-loads and receptacles) tend to be vastly underestimated. The time-worn rule-of-thumb has been 0.5 W/ft^2. Recent studies indicate that a power density of 1.0 to 1.5 W/ft^2 is more appropriate (Pratt et al. 1990).

(2) Overestimates from using nameplate data. When modelers have access to audit data, the opposite tendency occurs. Use of nameplate capacity as the connected load in a computer model overestimates consumption. As a general rule of thumb, we advise that nameplate ratings be multiplied by 1/3 to get the appropriate power density input for typical office equipment (personal communication with M.A. Piette, March 1992).

Unoccupied Equipment and Lighting Schedules. Modelers often assume that the lighting and equipment loads go to zero during unoccupied periods. Monitoring data has shown that in fact 10% to 30% of the lighting and at least 30% of equipment loads are on during unoccupied hours in typical office buildings (Taylor and Pratt 1989). Similar values apply to other commercial building types. The appendices of the Guidelines includes recommended default schedules for various building types.

Modelers should be cautious when departing from the typical schedules in the appendix. Though building developers and owners will often predict operating schedules, our experience is that they are, at best, only temporarily correct.

Window Shading. In the course of reviewing design-phase simulations of Energy Edge buildings, we found that interior and exterior shading are among the most commonly overlooked model inputs. We recommend that the modeler assume, unless there is firm evidence to the contrary, that the building has interior, occupant-operated shading. Extensive shading by adjacent buildings or trees, as well as shading of the building by itself all need to be taken into account by the modeler.

Window and Wall U-Values. Modelers commonly ignore the effects of window frames and metal wall studs on U-values. For multiple paned windows with metal frames that have no thermal breaks, an overall window U-value more than the U-value of the double glazing should be used. Metal wall studs should also be taken into account when calculating the average wall U-value. Heat loss through walls and windows is otherwise significantly underestimated. The Guidelines includes an appendix with adjusted U-values.

Operation Assumptions. Modelers typically assume that both the baseline and the as-designed building operate according to design intent. Commissioning and auditing experience tells us that this is just not the case. Though we are not suggesting that the design-phase modeler simulate broken buildings, we are suggesting that modelers be aware of this issue and be humble about their simulation estimates. Much anecdotal evidence suggests that computer simulation based solely on design intent is quite misleading as to the true cost and energy savings of these ECMs. It is critical that the building owner (and, for that matter, the energy provider) understand that it is not sufficient to just analyze and fund such ECMs. Ongoing attention to operation and maintenance is required.

Focusing on Significant Inputs

It is important in computer modeling of buildings to focus on the inputs that are most critical to making an accurate estimate of energy savings from the ECMs under consideration. Any input directly affected by the ECMs should be given careful scrutiny in both the baseline and the post-ECM runs. In addition, glazing U-values, infiltration, ventilation, fan schedules, lighting and equipment watts per square foot, and thermostat settings are almost always important. The risk of significant error from other inputs depends to some degree on the size of the building and whether or not it is new construction.

In small buildings, critical inputs include roof U-values, heat loss to ground, and heat transfer through unconditioned spaces such as attics, storage areas, and garages. In large buildings, zoning, economizer controls, air distribution system type, and multiple-zone HVAC system controls become more critical than in small buildings, because many of the HVAC zones have no exterior walls and therefore are cooled even in the winter.

For retrofit projects, the greatest difficulty is determining how the existing equipment is controlled. Manual adjustments to mixed air setpoints and unoccupied period equipment operation can have a critical impact on building consumption, but are not easy to ascertain. When applying ECMs to the simulation of an existing building, it is critical to input actual (non-default) values for important HVAC parameters.

Simulation Input

In this section we discuss a few of the major topics of simulation input covered in the Guidelines. However, these are condensations. The Guidelines covers each of these topics in much greater detail, as well as including the other topics mentioned previously.

Loads

Zoning. A major goal of any simulation is to take something that is extremely complex (a building) and to model it as simply as possible yet as accurately as necessary. One of the most critical steps is the zoning of the building. The more complex the building, the more important this step becomes. Buildings with a small number of zones are much easier to manage than buildings with an abundance of zones. Also, all software programs have some limit as to the maximum number of zones that can be modeled.

Aggregation of loads into zones, systems, and plants can have a significant impact on predicted energy consumption, particularly for large buildings and buildings served by multiple-zone heating and cooling systems.

Zoning in simulation models is based on, but is not identical to, HVAC zoning. Modelers routinely combine HVAC zones to make their models manageable. There can be one or many HVAC zones in a model zone. There will rarely be more than one model zone per actual HVAC zone.

When describing a building in a model, the first step is to zone the building. When placing zone boundaries, it is very important to remember that: (1) a zone represents a mass of air on which a heat balance is performed, and (2) surfaces, scheduled loads, and controls provide mechanisms for energy flow into and out of a zone.

One approach to zoning a building is to start with the entire building as one zone and then subdivide that zone as needed. If a single-zone model is sufficient for the needs of a project, then there is no need to go any further in zoning the building.

There are many different criteria which may be used to determine additional zone boundaries. Five basic criteria are usage, type of controls, solar gains, perimeter or interior location, and fan system type. These five characteristics are sufficient to define almost all of the necessary zone boundaries, yet there may often be special conditions which require additional zones to be created. The Guidelines provides specific examples and criteria for optimum zoning.

Infiltration. Infiltration can be one of the most significant energy drivers in a building simulation. This is also the simulation parameter about which the modeler is likely to have the least information.

Modelers often assume that infiltration air falls to zero during periods of HVAC operation. This assumption rests on the assumption that system operation will result in building pressurization. However, this presumes a well-designed, well-balanced, and properly operated air distribution system. It also presumes the absence of other infiltration-related effects such as tall building stack-effect, a high frequency of occupant or customer entry and egress, normally-open loading docks, and so forth. The presence of any of these effects should prompt the modeler to reconsider infiltration input.

We recommend that the ASHRAE Standard 90.1 mandated value for infiltration during hours of no HVAC operation, 0.038 CFM/ft^2 is a reasonable beginning assumption (ASHRAE 1989). However, modelers should consider the characteristics of the building being modeled to determine its ultimate suitability. We further recommend, if the software package being used has the capability, that the modeler split the volume between wind-dependent and wind-independent infiltration. We should note, however, that DOE2 does a relatively poor job of simulating wind-dependent infiltration. DOE2 modelers often rightly choose to model infiltration as wholly wind-independent. Turning our attention to baseline building input, we recommend that this model use the same infiltration input as the design model unless a specified ECM directly affects infiltration.

Window Unit U-Values. In most commercial buildings, the window units have a much greater effect on building heating and cooling loads than do the exterior walls. However, modelers often are comparatively careless with their input of window unit characteristics. Window units have U-value and shading coefficient characteristics that can differ significantly from those of the glazing only. Glazing characteristics must be adjusted to account for the opaque frame area.

Typically, the design-phase modeler will not have accurate information about the window units to be installed. If modelers have knowledge of the specific window types to be installed, then we recommend that they use the manufacturer's rated window unit U-values (and shading coefficients) as a first preference. If these are not available, or are suspect, then the modeler should either refer to the ASHRAE Fundamentals Handbook (1989), Chapter 27, Table 13, or use the Lawrence Berkeley Laboratory computer program WINDOW 3.1.

Thermal Mass. The Guidelines discuss at some length the implication of building mass on energy behavior. Thermal mass affects the timing of cooling loads as well as energy storage behavior. Thus inputs describing mass can be important in estimating cooling load shapes and coincident peak demand in buildings of heavy construction. Accurate building weight simulation improves the accuracy of night setback and night flushing savings estimates, as well as the effects of solar gain on HVAC loads.

DOE2 provides two methods for dealing with transient heat gains in a space--precalculated weighting factors and custom weighting factors. The program uses the precalculated factors as a default. So, if modelers decline to select a method, they have, by default selected one. The DOE2 Reference Manual (Lawrence Berkeley Laboratory 1980) suggests using custom weighting factors in: (1) buildings with thermostat set-back and/or set-up, (2) all passive solar buildings, (3) masonry buildings, (4) heavy construction buildings, (5) any building in which it is necessary to define the distribution of the solar radiation within the building, and (6) buildings located in sunny locations with large amounts of solar energy entering the spaces.

We have found that the use of custom weighting factors instead of precalculated weighting factors has made a significant difference in heating and cooling end-uses in buildings that meet some of the above descriptions. We suggest that the modeler follow the DOE2 reference manual recommendations concerning when to use custom weighting factors.

Interior Walls. Modelers can often avoid significant extra modeling effort by ignoring interior walls. As a first rule, the modeler can often not model an interior wall if the thermostat schedules for the zones on either side of the wall are the same in setpoints and hourly profiles. However, the modeler must take care that an interior zone with high internal heat gains (lighting, equipment, etc.) has some means of transferring this heat to adjoining perimeter zones. Otherwise, these interior zones may see unoccupied period temperatures float absurdly high. In addition, sometimes input of interior walls is needed to properly simulate thermal mass or light-dimming controls in day-lit buildings.

Weather Files. It is our experience from Energy Edge and other modeling projects that minor variations in weather input data usually have a relatively minor effect on simulation results. Typically we find about a 5% or less annual difference between simulations using TMY and site-gathered weather files. Monthly differences are, of course, more noticeable. But for design-phase modeling, monthly energy consumption is usually not of prime importance.

However, we have found an exception to the statement that minor local variations in weather usually has a minor effect on simulation results. In one Energy Edge simulation we found that an average local 5 F degree increase in dry bulb temperature from the TMY data resulted in a 70% to 80% increase in HVAC energy consumption (Kaplan Engineering and Portland Energy Conservation, Inc. 1992). We believe that this degree of effect can occur when the thermal balance temperature of a building is close to the average annual dry bulb temperature. The effect may also be tied to the volume of outdoor air introduced through infiltration and ventilation.

We recommend that the design-phase modeler use the best readily available weather data for the location closest to the project site. But we don't generally recommend that the modeler (or the utility) spend additional time to gather and process extensive site-specific weather data. A compromise position that may have merit is to monitor or otherwise acquire local outdoor dry bulb temperature only, and to integrate this series of values into the TMY weather file.

Internal Loads. The objects located in a building affect the energy consumption of the building in two ways: (1) they may consume energy directly, and (2) they may affect the amount of energy consumed for HVAC. People and hot food are examples of objects which affect HVAC consumption without consuming energy directly; equipment and lighting generally affect consumption both ways.

Simulation programs draw on several different modeler inputs to compute both the direct energy consumption of internal loads and the effect of these loads on HVAC operation. We have already discussed the importance of distinguishing between equipment nameplate power rating and average operating energy consumption. It is critical that the modeler carefully select input values for maximum hourly energy consumption and daily consumption profiles (i.e. hourly schedules). The Guidelines recommends values for both types of input for several different building types.

The modeler must also carefully consider what portion of the internal loads become sensible or latent cooling loads to the HVAC equipment. Program defaults are often inappropriate--especially for cooking equipment, certain process equipment, and lighting.

HVAC Systems

System Selection. All energy simulation programs offer the modeler some latitude in HVAC system selection. Our work and the work of others has shown that selection of the HVAC system type is one of the strongest drivers of simulated energy consumption in a building (Gale C. Corson Engineering 1990).

The familiar names of system types offered by the programs can lull the modeler into thinking that there is a good match between the actual or designed system and the simulated system. From a system simulation perspective, an HVAC system is a combination of equipment type (along with their operating characteristics, part load performance, etc.) and system control. Most programs will default to specific equipment types and control sequences once a system type has been selected. Sometimes these defaults are representative of the actual design, but often they are not. And in some programs, these defaults cannot be overridden.

The actual operating differences between one air distribution system type and another often depend more on differences between the user-specified control options than characteristics intrinsic to the distribution system types. Such control options include economizer cooling, central supply air temperature reset, fan duty cycling, and variable air volume. User-specified control options are restricted for some air distribution system types, so the user should take this into account when selecting a system.

Therefore, the modeler must ensure that the important characteristics of the design or actual building are being captured mathematically by the program. If they are not, the modeler should consider using a system type that may not be the same as the actual designed system, but that more closely represents its operation than the program default for that system. If the program does not offer good options, the modeler should consider use of a different program.

The modeler should carefully question the default simulation of system type. Questions the modeler should consider might include: (1) What control options are available for each system type? (2) Does the system type allow outside air ventilation? (3) Does the program default for part-load efficiency represent the actual equipment performance? (4) Is reheat being assigned automatically if multiple zones are assigned to a "single" zone system? (5) Are the supply fans on continuously, on only during occupied hours, or cycling on and off at all times? (6) Is the reheat source electric or gas? A competent modeler will think of many other questions that must be asked when selecting system type and developing system inputs.

Controls. Controls are one of the most important factors in the simulation of energy consumption. Theoretical savings for control ECMs are easily overestimated. Accurate predictions of energy savings can only be achieved if control ECMs are defined by a sequence of operations common to the model, the installed system, and the use of the system once it has been installed.

Although general terms like optimum start, intelligent recovery, and cold deck reset are often thrown about as though their definitions were clear-cut, that is not the case. The energy savings from any one of these strategies depends on the details of how it is achieved. A modeler cannot accurately model any of these functions unless a sequence of operations has been established.

Information about specific control components (e.g. thermostats, sensors, actuators) is best obtained by talking with the manufacturer's design engineers at their central office. Information about the sequence of operations, though, is best obtained, often with difficulty, from either the bid documents or from the controls contractor.

Communication between the analyst and the other parties in any project involving controls is important to achieving consistency between estimated and actual energy savings.

In any communications between the analyst and the designers, manufacturers, owners or building operators, it is important to seek a common understanding and documentation of the sequence of operations underlying the estimated savings. Clarity can sometimes be achieved during the design and bidding phase through use of performance specifications, written either by the designer or, if necessary, the modeler. These specifications should include sequences of operations to be performed by the new controls.

It is also important that modelers do what they can to promote documentation and building operator training. Even a simple night setback thermostat can be difficult to use properly without adequate documentation. Control documentation should include a description of the intent of the controls under all modes of operation, the control algorithms being used, and a clear explanation of how to change the control settings and schedules. The performance and full specifications should require adequate documentation, and training of the occupant or building operator.

The Guidelines discusses in detail a number of specific common controls situations. These include warm-up controls, heat pump setback, perimeter heat (e.g., baseboard), economizers, and energy management and controls systems.

Simulation of Multiple Zone Systems. Simulation of single zone systems is usually relatively straightforward. Assuming that the modeler did a competent job of zoning the building, the simulation is more or less forced to account for heating and cooling load appropriately. However, when a single system serves multiple zones, there is ample opportunity for errors in heating and cooling load accounting. Simulation of simultaneous heating and cooling where none actually occurs (and vice-versa) is a common problem. Other common problems are inappropriate reset control, inaccurate part-load simulation, and erroneous system linkage with central plant equipment. The Guidelines discusses in detail the inputs for multizone, dual duct, variable air volume, and water-loop heat pump systems.

Fan Schedules. Fan schedules and supply CFM are important in determining heating and cooling consumption because they are closely linked to (1) outside air ventilation HVAC loads (in the northwest, one of the strongest drivers of HVAC energy consumption), (2) the amount of reheat or mixing of hot and cold air that takes place in multiple-zone systems, (3) central plant equipment operation, and, of course, (4) fan motor energy consumption.

In computer simulations, the fan operation during unoccupied periods is typically designated as either off, cycling on only as necessary to maintain heating and cooling setpoints, or on continuously. Even during occupied periods, many building operators allow their fans to cycle to meet load. The amount of time the fan is off has a dramatic effect on energy consumption. Modelers should take care in their assumptions about fan schedule and fan mode of operation during both occupied and unoccupied periods.

If the minimum ventilation air is input as a percent of the total supply CFM, the supply CFM becomes important in determining the outside air loads on the HVAC system. In new construction, the supply CFM is generally determined by the design cooling loads. However, designers will usually specify a certain minimum supply CFM to ensure adequate air distribution and ventilation.

For retrofit projects, the existing supply CFM may be more or less than what is required to satisfy current loads. If that is the case, allowing the simulation to assign supply CFMs may wrongly estimate heating, and to a lesser extent, cooling loads. Modelers should read the original design CFM off the mechanical drawings or, preferably, the latest air balance report, unless the building operator or owner indicates that there has been a significant undocumented change in the air flow rates.

For both new and existing buildings, the modeler should check that the input for design supply CFM/ft^2 looks reasonable. If audit or design information is available, these should be used. If not, rules of thumb in the Guidelines can be used.

Exterior and "Hidden" Energy Users

Modelers often overlook energy-using equipment exterior to the building and equipment within the building that does not contribute to HVAC heating or cooling loads. External loads might include such things as car washes, laundries, swimming pools, exterior lighting, gas pumps, water pumps, and sidewalk heating systems. Non-HVAC driving interior loads might include elevators, process equipment, and so forth. If the modeling intent is to estimate the actual utility bills that the owner will be paying, then it is imperative that the modeler try to calculate or simulate these loads. However, if the modeling intent is to estimate either HVAC system performance or the incremental savings of ECMs that influence the HVAC systems, then it is less important to simulate the hidden energy users.

Another "hidden" internal load that is easily missed but that can strongly drive building energy use and HVAC performance is a large mainframe computer system. Such systems can have an annual energy use index (EUI) on the order of 2.0 kWh/ft^2-yr for large office buildings (Pratt et al. 1990). The modeler should specifically ask the owner and design team whether they plan such a computer system for the building in question. Since these systems are typically served by a stand-alone air conditioning system, the modeler may decide that the purpose of the design-phase modeling can be met without considering the computer center and its supporting equipment.

The Baseline Building

We cannot over-stress the importance of the baseline building model. The energy savings calculation always has two parts--the building to be evaluated (with one or more ECMs) and the baseline building. Error in the calculated savings can arise equally from error in the as-designed building or from error in the baseline. But we have found that modelers most often are sloppiest in their creation of the baseline model.

The Energy Edge project attempted to comprehensively define baseline for the range of building types encountered in the project. However, one of the lessons learned from the project was that it is impossible to cover all of the building aspects in a baseline definition. Nevertheless, it is possible to state a hierarchy of sources for definition. These might include local building or energy codes, national standards (e.g., ASHRAE 90.1), an independently compiled definition of common construction practice, and existing conditions (retrofit projects).

In addition to these sources, Energy Edge provided modelers with a list of parameters to be held constant between the baseline and energy efficient design unless an ECM directly addresses one of the parameters. These parameters include (1) weather, (2) occupancy and function, (3) lighting usage schedules, (4) zoning, (5) internal equipment schedules and loads, (6) ventilation air schedules and amounts, (7) heating and cooling system schedules, (8) thermostat setpoints and schedules, (9) floor and wall area, (10) energy source (no fuel switching), (11) external shading, and (12) infiltration.

Error Checking

At the same time that modelers keep track of how the software works and assess its accuracy, they also need to keep a vigilant eye on their own contributions to the simulations.

Computer building energy simulations require a large number of inputs, some of which are less than exciting. An accurate simulation requires that the modeler provide an accurate detailed description of the building to be simulated, and enter that information into the computer without careless errors. Patience with detail is an important part of good simulation work.

We recommend the following protocol for error checking:

(1) Check the calculation of inputs for errors prior to keyboard input.

(2) Check to make sure the units of measure (e.g. kW, hp, feet, Btu) agree with instructions in the simulation manual.

(3) Check inputs for typographical errors before running the model.

(4) Check output to see whether end use consumption and hourly and monthly profiles are reasonable. (Compare actual and simulated consumption where possible.)

(5) Do not "tweak" uncertain inputs before the previous steps have been taken.

(6) Compare output of the baseline building simulation to statistical end-use data for a similar building type. Though modelers should not expect identical end-use percentages, gross disparities suggest that the output be questioned.

The Guidelines recommends specific types of input and output reports to investigate. An appendix gives a table of statistically derived energy use indices for various end-uses and building types in the northwest.

Model Documentation

The as-designed model (and the corresponding baseline) may be used in several different ways. Its primary use of course is to estimate ECM savings. Beyond this, the model may be used as the basis for a future as-built model, or even a tuned and calibrated model. It also may be subjected to expert review. Finally, it may serve the modelers themselves as a basis for other building simulation projects.

<u>In all cases, proper technical use can be made of the models only if modelers have thoroughly documented the assumptions, calculations, sources, and so forth that they used when developing the models.</u> Without this documentation, future users can never know whether a given input was based on calculation, informed assumption, guess, desire, or error. As a corollary, lack of documentation promotes distrust of the simulation results.

Excerpting from the Guidelines, we recommend that modeling documentation include (1) a list of project contacts, (2) software used and the reasons for selection, (3) a list of all information sources used, (4) a building description including envelope, HVAC, lighting, and miscellaneous equipment, (5) operating schedule assumptions, (6) a description of building zoning as modeled, (7) code compliance check calculations, (8) a detailed description of each ECM modeled, (9) a table showing modeling results, (10) a table showing annual end-use EUIs, (11) a table summary of all recommended ECMs, (12) a description of any software package limitations that affect the simulation, (13) a description of any known bugs, errors, and so forth in the software or the model, (14) all backup calculations and assumptions, and (15) hard copies of specified input and output reports.

Conclusions

The Energy Edge project provides one of the most comprehensive "real world" experiences to date with respect to modeling commercial buildings. We have learned much about the sources of model errors and their impacts on model accuracy. Although this project has been a fertile ground for modeling lessons, much research work remains. There is much we don't know about the reliability of computer simulation for ECM savings estimates.

In the meantime, we believe the Guidelines will serve as a valuable tool for conservation program managers and commercial building modelers. The Guidelines will help (1) assure the appropriate use of building simulation models, and (2) improve the accuracy of model outputs--especially with respect to energy savings estimates for ECMs. We also believe that modelers have an important role to play in helping assure that the ECMs they recommend actually deliver the energy savings that were estimated.

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