Guidelines for Energy Simulation of Commercial Buildings

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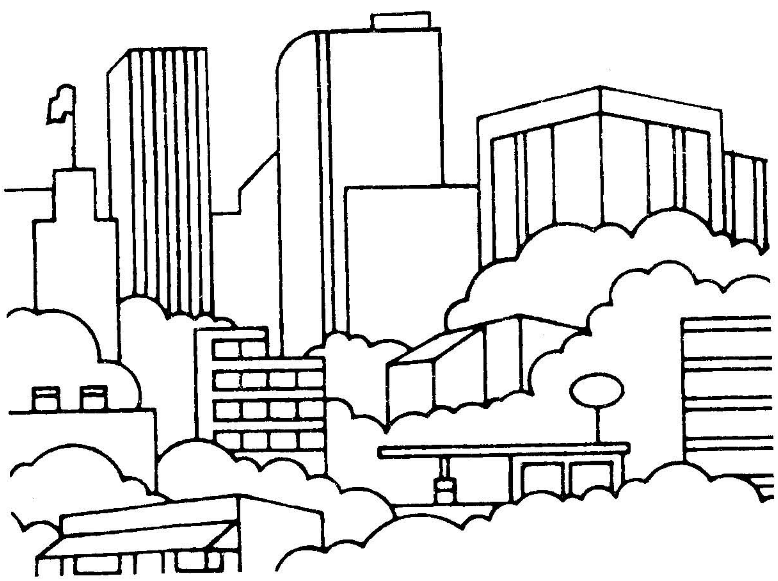

Bonneville
POWER ADMINISTRATION

GUIDELINES FOR ENERGY SIMULATION

OF

COMMERCIAL BUILDINGS

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INTRODUCTION

This report distills the experience gained from intensive computer building simulation work for the Energy Edge project. The purpose of this report is twofold: to use that experience to guide conservation program managers in their use of modeling, and to improve the accuracy of design-phase computer models. Though the main emphasis of the report is on new commercial construction, it also addresses modeling as it pertains to retrofit construction. To achieve these purposes, this report will:

- discuss the value of modeling for energy conservation programs
- discuss strengths and weaknesses of computer models
- provide specific guidelines for model input
- discuss input topics that are unusually large drivers of energy use and model inaccuracy
- provide guidelines for developing baseline models
- discuss types of energy conservation measures (ECMs) and building operation that are not suitable to modeling and present possible alternatives to modeling for analysis
- provide basic requirements for model documentation.

Energy Edge is a large-scale research and demonstration project developed by the Bonneville Power Administration. 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 current 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 energy savings of a wide variety of ECMs and to compare the predictive accuracy of design-phase models with models that are carefully tuned to monitored building data.

Twenty eight commercial buildings were selected to participate in Energy Edge. All but two were new construction. Building types include large, medium, and small offices, a grocery, a warehouse, a convenience store, restaurants, a nursing home, retail stores, medical offices, schools, a motel, and a strip mall. Funded ECMs include a wide range of envelope, lighting, HVAC, and controls measures.

In its demonstration aspects, Energy Edge is intended to encourage owners and developers to exceed MCS requirements with energy-efficient technologies. Four "Sponsors" -- the Oregon Department of Energy, the Washington State Energy Office, Portland Energy Conservation Inc., and Pacific Power -- assist in administering the Energy Edge project.

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 attempts 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 model in reality.

Though we doubt the reader will find better entertainment elsewhere, we acknowledge that not all readers will want to read all of this report. For the benefit of those semi-readers, we provide this guide to the report:

- Conservation program managers and others with a program perspective will find the Modeling for Conservation Programs chapter of most interest.

- Beginning and intermediate modelers should read the Philosophy of Modeling chapter. We hope this will help deepen their understanding of modeling assumptions and error.

- All modelers should read all of Part 2, Technical Guidelines. This section proposes default assumptions and modeling requirements for Bonneville's Energy Smart project. It also proposes new requirements for model documentation.

- The last chapter of Part 1, Technical Overview of Energy Edge Modeling, provides both program managers and modelers with interesting, and perhaps, useful information about the role of modeling in the Energy Edge project. The last part of this chapter summarizes lessons we learned from the modeling. We hope that this section will save interested parties the discomfort of first-hand experience.

In proof-reading our work, we have found that our tone often sounds excessively negative when we discuss modeling error, accuracy, and reliability. Yet we are avid modelers, and we firmly believe in the value of computer simulation for energy conservation programs. This contradiction is due to the fact that we intend this report, and especially part 2, to be an in depth discussion of the more troublesome aspects of modeling. The less troublesome aspects do not require extensive treatment.

We wish to acknowledge the invaluable assistance of Phoebe Caner of Seattle City Light, who updated her work from an 1985 unpublished manual for modelers. Much of that work has been incorporated in part 2 of this report.

Note on gender usage: Whether to use "his", "her", "his/her", or "their" is a common problem in report-writing. We are uncomfortable with the grammatical error in using "their" to modify a singular subject; we are weary of the historically-correct reversion to "his" to salve this discomfort; and we would feel silly to litter this report with "his/her". Therefore, we have elected to use "her".

EXECUTIVE SUMMARY

Computer simulation of building energy performance can be an expensive endeavor. For this reason, program managers wish to know when this expense is warranted. In this report we address this and other questions related to modeling. When can modeling provide useful information? Who can make best use of that information? When are methods other than modeling better suited to the task at hand? What can modelers do to maximize the accuracy and reliability of their models? What can program managers do to ensure quality in the modeling phase of their programs? What other program activities are needed to increase the benefit of the modeling?

Modeling is not necessarily the optimal tool for all energy analysis. It should not be over-used. 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.)

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 daylighting lighting controls. Modeling is overkill for analysis of ECMs that yield to simple manual calculations.

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. This report provides guidance for development of some of the more critical assumptions. However, we cannot address all possible assumptions for all possible buildings. Therefore much of the success of modeling necessarily rests on the experience, skill, and integrity of the modeler.

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 that the baseline model is 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 part 2 of this report.

Models are complex, and are very subject to error. Models are to error as sponges are to water. We intend with this statement to inject realism, not pessimism, into the modeling activity. Computer simulation is often the best available method for estimating ECM savings. But it is a method that must be subjected to rigorous quality control. We make several recommendations concerning quality control:

- We recommend that the Energy Smart modelers' qualifications be enforced. If the infrastructure cannot supply enough modelers who have those qualifications, then supplemental required training should be considered.

- 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.

- The more complex the software program, the more likely input error is to occur. Modeler experience and budget must increase as the complexity of building and software increases. A carelessly or inexpertly-used complex program may yield less accurate estimates than an equally carelessly used less complex program.

- 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. This report provides the statistical data as well as guidelines for this comparison.

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

- The modeler should comprehensively document the model.

Much work remains on evaluating the reliability of model estimates. There have been a number of studies comparing modeled end-use energy predictions to monitored end-use data. But there have been few that attempt the comparison of modeled ECM energy savings with monitored data. But the latter comparison is the crux of evaluating modeling as a program tool. Program managers also wish to know what level of monitoring is necessary. We know that models informed by monitored data yield different results than uninformed models, but we cannot prove that the former results are better.

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. Slightly less obviously, design decisions can benefit from these estimates. 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? Perhaps. 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. But this variability may tend to disappear and the estimates become more reliable when applied to a very 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 commissioned and maintained properly. ("Commissioning" can include many different tasks, but for our purposes here we define it simply as ECM performance verification.) Energy Edge provides many examples of the failure of non-commissioned ECMs.

PART 1 THE CONSERVATION PROGRAM PERSPECTIVE

1. MODELING FOR CONSERVATION PROGRAMS

A primary purpose of this report is to give energy conservation program managers information that will better enable them to wisely use computer simulation of buildings in the programs they create. To achieve this purpose we will discuss the strengths and weaknesses of computer simulation, how to maintain quality control over the modeling process, and what other work should be done to increase our understanding of the value of modeling for conservation programs.

1.1 THE STRENGTHS AND WEAKNESSES OF COMPUTER SIMULATION

Computer simulation of building energy behavior is primarily useful for understanding the operation of the building heating and cooling systems. Energy end-uses that do not impact HVAC can be analyzed with a spreadsheet, other software, or with a pencil and envelope as effectively as with a building energy simulation software package. Outdoor lighting, elevators, and domestic hot water are examples of such end-uses.

In evaluating ECMs, the modeler must judge whether the candidate ECMs are likely to have significant interactive effects on HVAC performance. If so, computer simulation can analyze these effects more efficiently, comprehensively, and accurately than any other available method. Simulation packages excel at handling complex and exhaustively repetitive arithmetic calculations. Depending on the simulation package used, simulation can also be an effective tool for dealing with multiple end-use schedules--whether or not these can be expected to affect HVAC performance.

Computer simulation also offers the advantage of standardizing the energy calculations. Most simulation packages are based on well-researched ASHRAE algorithms. (However, it is interesting, given the common basis of most programs, that different programs can give such wildly different estimates.)

When is it inappropriate to utilize computer simulation for energy analysis? Certainly it is inappropriate when the only ECMs of concern are those that have no effect on the HVAC systems. We suggest that there is another type of ECM for which simulation analysis is inappropriate. This category includes those ECMs about which the modeler can only guess baseline and design behavior. We would include ECMs that affect infiltration and occupancy sensor lighting controls in this category.

In the case of infiltration-related ECMs (e.g. vestibules, caulking, and vapor barriers), HVAC theory is inadequate to give the modeler a firm basis for input assumptions. In the Energy Edge program, we have taken the tack of not modeling such ECMs, and noting that the fact that they haven't been modeled adds a measure of reliability to the energy savings estimates for the remaining ECMs.

In the case of occupancy sensor lighting controls, the problem lies in the fact that both baseline and ECM lighting schedules depend entirely on modeler judgement. The model doesn't really do anything but process the modeler's assumptions. Secondary HVAC interactive effects are simulated, but the primary lighting savings are arbitrary!

Simulation software packages have other weaknesses. If modelers maintain awareness of these weaknesses, they can minimize some of the nastier consequences. First, most software packages do a relatively poor job of analyzing electrical demand in a building. This is because most utilities assign demand charges based on the maximum power draw during a 15 minute period. On the other hand, most software packages view peak demand as the concurrent average hourly maximum for the various end-uses.[1] Hourly simulation is somewhat more accurate in predicting the peak demand of a class of buildings (e.g., offices) because of the diversity of schedules and operation among the buildings.

In addition, most programs do a poor job of modeling morning warm-up. Where resistance heat is used, these programs tend to spread the actual spike over one or more hours. So, in most cases the simulation underestimates the demand.

This leads to a corollary weakness--using the model to size equipment. In general, energy simulation programs are not designed to size HVAC equipment. Equipment usually is designed to meet near peak loads. But, as stated above, the program addresses peak average loads.[2] This is not to say that the computer cannot be a useful tool for sizing HVAC equipment. The point is that there are programs specifically designed to analyze HVAC loads and to size equipment of adequate capacity to handle these loads. Having said this, we suggest though that the simulation package can sometimes be useful in calling attention to gross over or undersizing of equipment. If the simulation output equipment selection is sharply at odds with the designer's selection, the modeler should discuss this with the designer. Either the model or the design might have a serious error that

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[1] It is important to understand the concept of average hourly maximum power as applied to modeling. For a specific end-use, such as lighting, this is the installed wattage multiplied by the average percentage usage during the schedule hour of maximum usage. As an example, this hour might be 4 PM on weekdays, which is the average hourly power of all annual weekday 4 PMs.

[2] Some energy simulation programs can be used to size HVAC equipment providing the modeler has accurate design information, understands the actual mechanical system zoning, enters schedules that reflect peak load conditions, and runs a design day analysis. However, since design information is often incomplete during design-phase energy analysis, we advise modelers to leave equipment sizing to the HVAC designer.

cooperation may discover.

Another weakness lies in absolute predictions of building energy consumption. A Bonneville-sponsored study found that various model/modeler groupings estimated energy consumption for small offices to be between 66% and 127% of the utility billings (when the modelers had no feedback from utility bills). (See reference 3.) The range for large offices was 37% to 120% of the utility billings. Perhaps this degree of accuracy is acceptable to some users of the information. However, we have experienced several upset building owners who are shocked to see their utility bills coming in 50% higher than the model estimate. We recommend that the modeler clearly state that the simulation estimates are estimates only--generated with the best information available at the time.

Most commonly used simulation software packages do not do a good job of simulating the effect of thermal mass on building performance. Similarly, most packages do not address light-dimming controls in day-lit buildings well, if at all. Many modified bin method programs do not address solar gains very well. Some programs have very narrow limitations for the number of building zones that can be input. The modeler's task is to consider the specific building to be simulated and determine what building features are likely to be significant drivers of energy behavior. In addition, she must consider which ECMs are likely to be of particular interest. Having determined these things, she then must match the software package to these features and ECMs. If the modeler is not competent to use the selected level of software, she should not attempt to model the building.

Controls for HVAC and lighting can be a fertile ground for ECMs. However, the modeler must maintain great humility when simulating these ECMs. Most simulation packages are quite crude in their handling of controls. Controls that yield savings by shaving fractions of operational hours don't fit easily into the hourly structure of even the powerhouse programs. Other controls save energy with relatively complex, subtle, and infinitely variable logic. Simulation packages on the other hand are necessarily limited in the number of controls variations they can consider. Therefore, the modeler typically finds herself sculpting either the program or the ECM or both to fit each other. At best, such sculpting decreases the accuracy of the ECM analysis. At worst, it gives totally invalid and misleading results. In addition, most simulation packages assume ideal controls operation. Since as-built conditions are typically somewhat less than ideal, it is often difficult or impossible to simulate actual operation.

Energy management systems (EMSs) are often considered as ECMs. We lament this tendency. An ECM should describe specific control sequences, not an overall EMS. We suggest that the incremental control changes themselves should be considered as the relevant ECMs, rather than the entire control system. For example, since most energy codes now require an automatic means of setting back space temperature setpoints during unoccupied periods, this function of an EMS should not be considered as an ECM. On the other hand, complex control of multiple chillers serving primary cooling load and an ice storage system, with integrated waterside economizers, exceeds the capability of conventional control systems.[3] Such control--and the hardware, software, maintenance, and training that make it possible--should be considered as the ECM, not the entire control system.

A final weakness of energy simulation programs is that, like any computer program, they have very limited capabilities to compensate for bad assumptions or sloppy input.

We have highlighted many of the pimples in simulation programs. Having done this, we must point out that often there is no better alternative. Though the electrical demand estimates of a model may be faulty, there is usually no better tool for making these estimates. Though the thermal mass algorithms are imperfect, they certainly are better equipped to deal with this performance parameter than are hand calculations. We suggest that the modeler follow this procedure in dealing with these weaknesses:

1) Consider the specific building to be simulated and determine what building features are likely to be significant drivers of energy behavior. In addition, consider what ECMs are likely to be of particular interest.

2) Consider whether any of these features or ECMs can better be analyzed using other methods than conventional building energy simulation programs. Alternatives might include hand (or spreadsheet) calculations, other computer programs (such as daylighting or ice storage programs), manufacturer's analyses (be cautious here), and so forth. Sometimes a hybrid approach can be useful. For example, a daylighting analysis program could be used to generate lighting output that could be used as direct input for the energy simulation program. The energy simulation program then can be used to investigate the interactive HVAC effects of the daylighting controls.

3) Having determined these things, if energy simulation software is still indicated, select the software package that most clearly addresses these features and ECMs. Also, select a modeler who is competent with the selected software.

4) If possible, check the results of any analysis with another type of analysis. For example, coarse hand calculations might serve as a check on the reasonableness of the energy simulation results. We recommend some version of this with any modeling work. Later in these guidelines we will address the subject of reasonableness checks in much greater detail.

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[3] One can argue that, increasingly, EMSs are becoming common practice for large buildings. Insofar as this is true, it may be inappropriate to consider one as an ECM. However, even if they are common practice, using them to their full potential is certainly not common practice. Perhaps conservation programs should concentrate on this aspect of EMSs. This is a decision for conservation program managers.

1.2 QUALITY CONTROL

Part 2 of this report addresses things modelers can do to increase the quality of their work. In this section we address what program managers should do to ensure the reliability of the modeling tool. But before we can discuss reliability, we must consider what we mean by model accuracy and reliability.

The modeler always works with incomplete information. Usually she works with a standard weather file rather than with building-specific weather data. Usually she must guess at lighting and equipment usage schedules as well as equipment power densities. Eventual HVAC system operation is always unknown at the beginning of a modeling project. Also, no energy analysis software can exactly simulate the complexity of a real operating building.

With all of this missing or inaccurate information, and with imperfect software, the modeler cannot hope to precisely estimate building energy consumption. What can she expect? She, and the program managers who depend on her, can expect to get a reasonably accurate picture of building performance and ECM savings <u>under standard weather and ideal operating conditions</u>.

Quantifying "reasonable accuracy" is difficult, and varies depending on the complexity of the building and its ECMs. We believe it is normally possible--with some billing data, competent modeling, and a good choice of software--to estimate annual building energy consumption within about 10%, and seasonal consumption within about 25% of the actual measured consumption. Without the feedback of billing data, model estimates can easily vary by 50% or more from the eventual billed data. We cannot comment on the corresponding reliability of ECM savings estimates since we know of no research that has been done comparing estimates to actual measured ECM savings.[4]

Computer simulation of building energy performance uses an incredibly complex series of modeler inputs, software algorithms, and computer operations. Error is inescapable. But we can take steps to avoid or catch the most serious errors--those errors that can lead to wrong program decisions. Unreliable energy savings estimates (i.e. estimates that differ significantly from actual measured building performance) can come from several sources. Modeling error is only one of these sources. Others include:

- Different operating conditions
  - longer hours, more people, higher internal gains
  - different infiltration loads
  - different weather or indoor temperatures
  - different operating profiles

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[4] The Energy Edge project has gathered extensive building end-use data. But it has not attempted to directly measure individual ECM savings. The latter is a complex monitoring task that involves a variety of on-off, before-after, and other experimental approaches.

- different controls

- Funded ECMs not installed

- Improper ECM operation
  - hardware, software, or calibration problem
  - improper installation
  - inadequate design
  - poor controls

Modeling error generally comes from some level of inexperience or carelessness. Program managers can take steps to guard against these.

Inexperience is a relative term. Different software programs and different buildings require different levels of modeler experience. Bonneville has written qualifications to be required for the lead modeler in Energy Smart projects (reference 13). These should be enforced both in letter and intent. A word on intent: the qualifications state that, "The specific qualifications may be satisfied by several people possessing different skills and experiences which, when taken together, meet the intent of the 'lead' requirements." The intent of this statement is to not require superwoman modelers when all the required expertise is available <u>and used cooperatively</u> within one firm. A firm does not satisfy this intent if it has design personnel who have no contact with the modeling projects.

Carelessness is also a continuum. We are all careless to a greater or lesser extent. Every modeler makes mistakes, and even the best modelers sometimes make major errors. The single best antidote for this is to have a competent modeler (other than the project modeler herself) review every model. There is no substitute for subjecting a model input and output to a second pair of sharp eyes. Perhaps not all projects warrant the expense of such a review.[5] But we suggest that if a project is not worth the expense of a review, then it may not be worth the expense of modeling in the first place. Note that effective review of a model is difficult or impossible if the modeler has not prepared comprehensive documentation as described in part 2.

Finally, we have prepared the modeling guidelines in part 2 in order to improve the quality and consistency of modeling assumptions. Though these guidelines are not appropriate for all situations, they provide a framework that should be especially helpful to less experienced modelers. We believe that the active support of program managers for use of these guidelines will help make modeling a more reliable tool for conservation programs.

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[5] Review of a model normally takes from two to eight hours, depending on the simulation software, building complexity, and quality of the model and documentation.

1.3 RECOMMENDATIONS FOR FUTURE WORK

There is much we don't know about the reliability of computer simulation for ECM savings estimates. Modeling has been, and will likely continue to be, a major tool for design assistance and program evaluation. Therefore, we would do well to support future research into such basic questions as:

- Do better-tuned models give more accurate ECM savings estimates?
- How reliable are the ECM savings estimates at various phases of modeling?
- Does arithmetic adjustment of model estimates using billing data give reliable ECM savings estimates?
- Recent work with short-term energy measurements indicates that conventional theory may be defective in dealing with envelope thermal transmission (references 2 and 14). Is this work valid?
- What are realistic default assumptions for infiltration in different building types?
- Can simple arithmetic adjustments be used to account for the interactive HVAC effects of lighting ECMs? If so, can we dispense with modeling whenever only lighting ECMs are considered?
- What are the relative cost-to-benefit ratios of modeling and commissioning?
- Are certain classes of ECMs no longer cost-effective when the cost of modeling and commissioning are included? Which classes?

In addition, we note two questions that are specific to Bonneville Power Administration programs:

- How reliable are the ECM savings estimates of the Prescriptive Path?[6]
- Can the ELCAP End-Use Index (EUI) tables be expanded by either direct end-use measurement or tuned modeling to address other climatic areas and newer construction? (See references 5 and 15.)

We also recommend consideration of a possible follow-up step to aid consistency among modelers. This step is the creation of a library of annotated DOE2 input files for various commercial building types. Each input file would serve as a sort of check-list of relevant inputs with recommended defaults appropriate to that building type. The file would be

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[6] The Prescriptive Path was created for the Bonneville Power Administration Energy Smart project. Based on a series of prototype building computer simulations, it defined energy savings for a number of simple ECMs in small buildings.

liberally sprinkled with comments that explain the significance of the inputs. The file library could reside in magnetic form on the Electric Ideas Clearinghouse bulletin board.

2. THE PHILOSOPHY OF MODELING

2.1 THE PHILOSOPHY OF MODELING ASSUMPTIONS

"Assumptions" is not necessarily a dirty word. At every stage of modeling, the modeler must make assumptions. Even when the modeler tries to avoid making assumptions by letting a simulation program revert to default values, she is still making assumptions. In that case, the assumption is that the software authors were correct in their assumptions. Often the software default assumptions are poorly documented or inappropriate for the specific building at hand.

There are several issues here:

1) Assumptions are inevitable.

2) By avoiding the responsibility of making assumptions, the modeler may inadvertently incorporate poorer, hidden assumptions.

3) Assumptions range in quality from good to bad. Or, from another perspective, they range from believable to far-fetched.

4) The modeler's task is to identify when inadequate information forces some level of assumption. Having done this, she must use the best tools available to ensure that her assumptions are at the high end of the various scales of quality. These tools will include deductions from O&M audits, deductions from monitored data, data from other similar buildings, engineering rules-of-thumb, engineering judgement, and so forth. Somewhat obviously, the sharpest tools should be used in preference to the dullest ones. We would consider rules-of-thumb and engineering judgement to lie towards the duller end of the spectrum. However, for design-phase modeling these may be the only tools available.[7]

5) Assumptions have maximum credibility when they are supported by several of the above tools. We recommend that the modeler check the reasonableness of any significant assumption with a second method whenever possible. In a later section of this report, we will present guidelines for reasonableness for many of the more significant areas of assumption.

6) Assumptions may and should change as the level of knowledge about the building (new construction) increases. Information about HVAC operation, end-use schedules, etc. gains greater definition as the project progresses. Much more information is available for an as-built model than for the design model. Similarly, more is available late in the design phase than early in the design concept phase. Since the modeling work may span

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[7] When we refer to design-phase modeling throughout this document, we include the retrofit equivalent--ECM conceptual design modeling. Both of these are distinct from the modeling that occurs later in a project. These later models generally benefit from more accurate knowledge about the building and its operation.

several weeks, months, or even years, the modeler must use her judgement and maintain integrity when deciding what assumptions warrant adjustment.

7) Since the simulation results may say more about the assumptions than about the building, the modeler must clearly document all assumptions. She must clearly state the assumption. She must clearly state the source of the assumption--including whether it is a program default. She must include all relevant calculations, communications, measured data, etc. Complete documentation allows other analysts to develop a confidence-level in the simulation results. It may also serve as a basis for a second pair of eyes to discover a potentially significant modeling error.

2.2 THE PHILOSOPHY OF SIMULATION ERROR

There is a popular bumper sticker that says, in essence, unfortunate things happen. This observation applies to modeling. Errors happen. Every modeler makes mistakes. Every energy simulation program has bugs. Building information is often wrong. Error can arise from the mass of model input, from lack of understanding about the program or the building, from building changes, and from mis-tweaking (more about that in part 2). In sum, every model contains errors. This is true no matter how many times the model has been examined, massaged, and corrected. Every model contains errors.

Does this mean computer simulation is useless, or worse? No. Computer simulation is still the best tool available for many energy analysis tasks. However, it does mean that we should maintain humility and skepticism about simulation results. And it also means that we should carefully consider quality control procedures.

We cannot hope to catch all modeling errors. But we can certainly strive to eliminate the most significant ones. While it may not be important that an R-30 roof was input as R-28, it will be critical if a hydronic heating system was input without a boiler or other heating source. There are relatively straightforward quality control procedures that would catch the latter error. The most helpful procedures entail some level of investigation of model input and output reports and reasonableness comparisons of end-use output with typical values for these end-uses. We discuss these procedures in some detail in part 2 of this report.

One final dose of error philosophy: The yet-to-be-written book, "The Inner Game of Modeling", makes the point that since error is a fact of life, it is most constructive to just notice error and learn from it. Embarrassment, shame, cover-up are all counter-productive. This report is in fact partly an exercise in noting and learning from error. The Energy Edge project has been a generous teacher.

3. TECHNICAL OVERVIEW OF ENERGY EDGE MODELING

3.1 MODELING METHODOLOGIES

A wide variety of energy simulation software packages (and modelers) have been used in the Energy Edge project. These programs fall into two main groups--modified bin method and hourly analysis programs. Several of the Sponsors used bin method models for their initial screening of buildings. All of the Sponsors used hourly programs for the design model and subsequent models of buildings selected for Energy Edge participation. Not all of the models for a given building were necessarily run by the same modeler.

Selection of modeling programs was generally based on the following criteria:

1) SCREENING: Initial screening of multiple applicants for Energy Edge funding was done with quick, simple bin method programs. Though it was suspected that these programs are generally less accurate than the more complex hourly analysis programs, it was felt that they nevertheless provided a reasonable basis for comparison among buildings. In addition, it was felt that an hourly analysis simulation that is quickly and carelessly prepared would likely be more wildly inaccurate than a similarly careless bin simulation.

2) AS-DESIGNED MODEL: The as-designed model is the model that incorporates the building design information at whatever its level of completion. This level of completion might vary from concept design to complete construction documents. Once a project was selected for participation in Energy Edge (and sometimes before it was selected), an as-designed model with baseline was run. This model uses an hourly analysis program. Several different programs have been used. These include DOE2.1 (B, C, and D versions), TRACE, ADM2, and ESP. DOE2.1 was used most frequently.

3) AS-BUILT MODEL: After the building is constructed and has operated for a period of at least 6 months to a year, an as-built model is generated. The intent of this model is to capture the most up-to-date knowledge about the building and its operating systems. Data for the model are gathered from construction inspections, as-built building drawings, operations and maintenance (O&M) audits by the Sponsor, and occasionally from commissioning activities.

With only one exception, all Energy Edge as-built models used DOE2. The one exception involves a high-rise building with a complex ice storage system that cannot be adequately simulated with the present version of DOE2. (The "E" version, due to be released in the autumn of 1991, will address this type of system.) The as-built model for this project used the TRACE program, with some custom-written algorithms to deal with the complexities of the ice storage.

4) TUNED MODEL: Bonneville, in a quest for maximum analytical

reliability, has carried the Energy Edge modeling one step beyond the as-built model. Extensive operating end-use data are collected for each Energy Edge building. The model tuning adjusts the as-built model through a series of iterations to calibrate it to the monitored data. Though we have developed three different tuning methodologies (references 1 and 2), all three share the common approach of adjusting model input using monitored data until the simulation output matches monitored data within set tolerances.

The primary types of monitored input are site weather, end-use schedules and power densities for loads such as lighting and equipment, and operating schedules for HVAC equipment. The simulation output of greatest interest is HVAC end-use energy consumption. However, other end-uses must be tuned before HVAC tuning can be successful.

Model tuning relies on the hypothesis that if a model is calibrated such that its end-use energy consumption estimates approximate measured end-use consumption, then the model predictions of ECM and total building energy savings are more accurate than for an untuned model. We must point out that though this hypothesis seems intuitively correct, it has not been rigorously analyzed and tested.

A secondary purpose of the Energy Edge tuning work is to evaluate the program benefits of spending more time and money on the as-built and tuned models. Work to date indicates frequent and sometimes significant discrepancies among the energy consumption estimates of the four modeling stages (screening, as-designed, as-built, and tuned models).

3.2 COMPARISON OF MODEL SAVINGS ESTIMATES

Various studies have documented the variability among the predictions of different models and modelers. (References 3,4.) This document does not attempt to rehash this territory. The guidelines developed in this report focus on the input uncertainties identified in these assessments.

The Corson study (ref. 3) pursued two main research paths.[8] The first had 11 different modelers use five different software packages to model four different building types. The modeling was done in three cycles--each cycle giving the modelers more information about the building. The first cycle gives the modelers only basic building characteristics information. The second cycle gives utility billing data. The third cycle gives end-use monitored data. The tentative conclusions of this portion of the study are:

1) The billing data feedback generally resulted in simulations that more nearly match each other and more closely approach measured data. Cycle 1 annual energy as modeled by DOE2 ranges from 56% to 148% of the

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[8] Note that this is a massive study. We do not claim to do it justice with our interpretation of the results as presented here. One of the main conclusions of the study is that much further work is required to add meaning and certainty to the study results.

respective billing data. (These are larger differences than with some of the bin method software packages studied.) Cycle 2 percentages of billing data for the DOE2 models range from 93% to 106%.

2) The end-use data feedback also resulted in an improvement in simulation results (for most programs tested) relative to the simulations done with billing data feedback. However, these cycle 3 results are not nearly as marked as the cycle 2 results. Also, the DOE2 annual kWh differences increased for three of the four buildings modeled.

3) There is great variability in results among the different software packages and among modelers.

The second main research path involved running multiple building simulations for two of the building types to test model sensitivity to 25 different input parameters.[9] The tentative conclusions of this portion are:

1) The tested parameter that is the strongest driver of energy consumption in the two buildings is the HVAC system selected. There is great variability among the software packages as to the significance of HVAC system selection.

2) Parameters of secondary importance include:
- wall insulation in the small building (R11 increase)
- supply fan operating mode during unoccupied hours
- internal load schedules (2 hour increase in lighting, equipment, and occupancy)
- building location (mild versus severe climate).

3) Tested parameters of minimal sensitivity generally include:
- building orientation (rotated 90 degrees)
- floor insulation (R-value increased 30%)
- roof insulation (R-value increased by R-19)
- south wall glazing area (small retail--convert 30% of opaque wall area to glass; large office--reduce 30%)
- glazing R-value (increase 30%)
- glazing shading coefficient (decrease 30%)
- outside air CFM (increase 50%)
- interior lighting power density (decrease 30%)
- interior lighting heat to space (decrease 30%)
- hot water usage (increase 100%)

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[9] Experience from our work does not always agree with the results of this study. We have found that some of the parameters shown in this study to be of minimal significance as energy drivers have sometimes been of major significance with specific buildings. Also, starting values for the parameters may have a strong role in determining importance. For instance, a change in wall insulation R-value from 0 to 11 could be critical, whereas a change from 11 to 19 could be insignificant. Thus we warn against offhandedly ignoring the effect of any of these parameters. Experience and informed judgement are always valuable tools.

- economizer operation (turn off)
- supply air volume (increase 30%, holding outside air CFM constant)
- cooling COP (increase 30%)
- space setpoint temperature (increase winter occupied setpoint by 5 F degrees)
- cooling equipment part load performance (increase specified capacity 50%)
- number of occupants (increase 50%)
- vacation period, unoccupied (add July)
- building mass (change from medium to heaviest category)

In addition to the conclusions from the two main research paths, the study called into question the common modeling rule-of-thumb that though estimates of base building consumption may vary widely among different models and modelers, the ECM energy savings estimates will show little variation. The Corson study saw results that are totally opposed to this rule-of-thumb. The study results indicate that the ECM savings estimates vary more widely than do the widely-varying base building estimates. In our Energy Edge work, we have seen some results that also support this conclusion. This is of global significance! If valid, it means that we modelers can no longer find solace in the belief that a sloppy base model can nevertheless yield accurate ECM savings data. And if we modelers can't find solace in this belief, then the program administrators who routinely base financial decisions on our simulations must feel some unease also.

3.3 ENERGY EDGE COMPARISONS

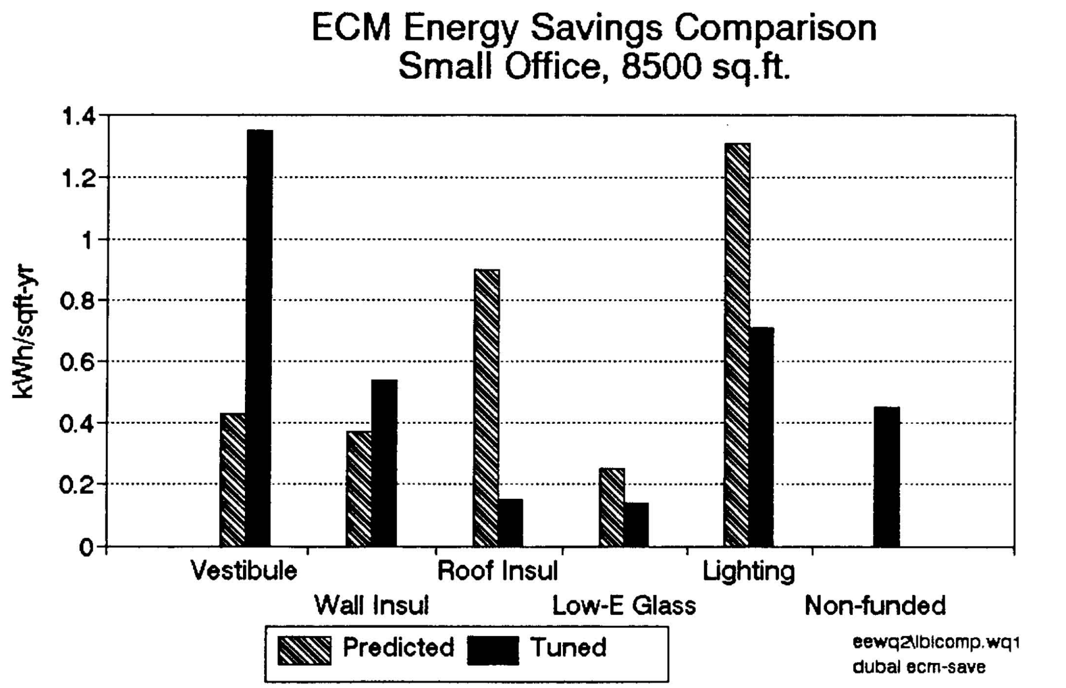
Lawrence Berkeley Laboratory (LBL) is responsible for impact analysis of the Energy Edge program. Part of their work has involved comparing the design-phase computer models to the tuned models. This report section owes much to an unpublished LBL memorandum that summarizes the early results of this analysis.

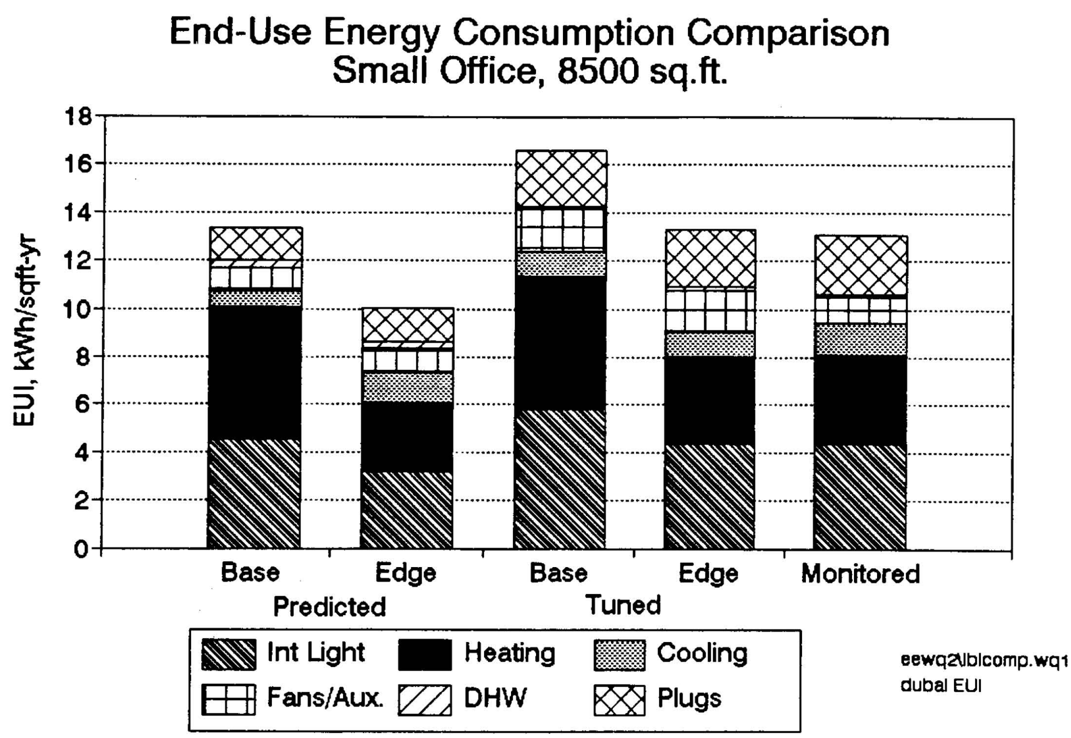
As the Energy Edge program has progressed, LBL has found substantial differences in the building systems and operating conditions between early design intentions and actual occupied buildings. Part of LBL's evaluation efforts has included tracking these changes. Although this task is hampered by lack of data, such as clear reference to original modeling assumptions, LBL has identified and compared key building characteristics (ref. 16).

The main finding of the analysis is that the early design predictions and the tuned model estimates show tremendous variation in the estimated energy savings of the ECMs. We see, for example, in an 8500 ft^2 office building that the total energy use of the tuned model is about the same as the design-phase baseline model, but the total savings by the ECMs were similar to the design-phase model. However, the savings of individual ECMs differ by as much as a factor of five between the two models. (See Figure 1.)

There appear to be several reasons for these differences. At least two (and to some extent, all) of the ECMs owe their differences to the dissimilarity in baseline assumptions in the two models.

Figure 1


ECM Energy Savings Comparison
Small Office, 8500 sq.ft.
kWh/sqft-yr
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Vestibule
Wall Insul
Roof Insul
Low-E Glass
Lighting
Non-funded
Predicted
Tuned
eewq2\lblcomp.wq1
dubal ecm-save


End-Use Energy Consumption Comparison
Small Office, 8500 sq.ft.
EUI, kWh/sqft-yr
18
16
14
12
10
8
6
4
2
0
Base
Edge
Predicted
Base
Edge
Tuned
Monitored
Int Light
Heating
Cooling
Fans/Aux.
DHW
Plugs
eewq2\lblcomp.wq1
dubal EUI

In a 4100 ft^2 fast food restaurant, we see significant differences between the ECM savings estimates for four of the five ECMs. (See figure 2.)
In this building the difference in the savings estimates for the lighting ECM is primarily due to differences in baseline assumptions. The difference for the hot water heat pump ("ht pump DHW") is due to a mistaken assumption in the design-phase model regarding hot water usage. The monitored data allowed us to improve this assumption in the tuned model.

In a 3025 ft^2 medical office, we see relatively small differences between the ECM savings estimates for three of the four ECMs. The fourth ECM shows a tremendous difference between the two estimates. (See figure 3.)
In this case the difference appears to be due to the fact that the funded lighting controls (occupancy sensors and daylighting controls) are not working. The tuned model simulates this as-operating condition, whereas the design-phase model assumes proper operation.

Each difference between the performance of the ECMs in the design-phase versus tuned models can be assigned to one or more of the following four categories:

1) Improper or different ECM operation (hardware, software, or calibration problem, incorrect installation, poor design, poor control, different controls, etc.)

2) ECM not installed (or new ECM installed)

3) Different assumptions about operating conditions of ECM or building (operating profiles, weather, infiltration, occupancy, etc.)

4) Modeling technique differed (error, different software, different baseline assumptions, etc.)

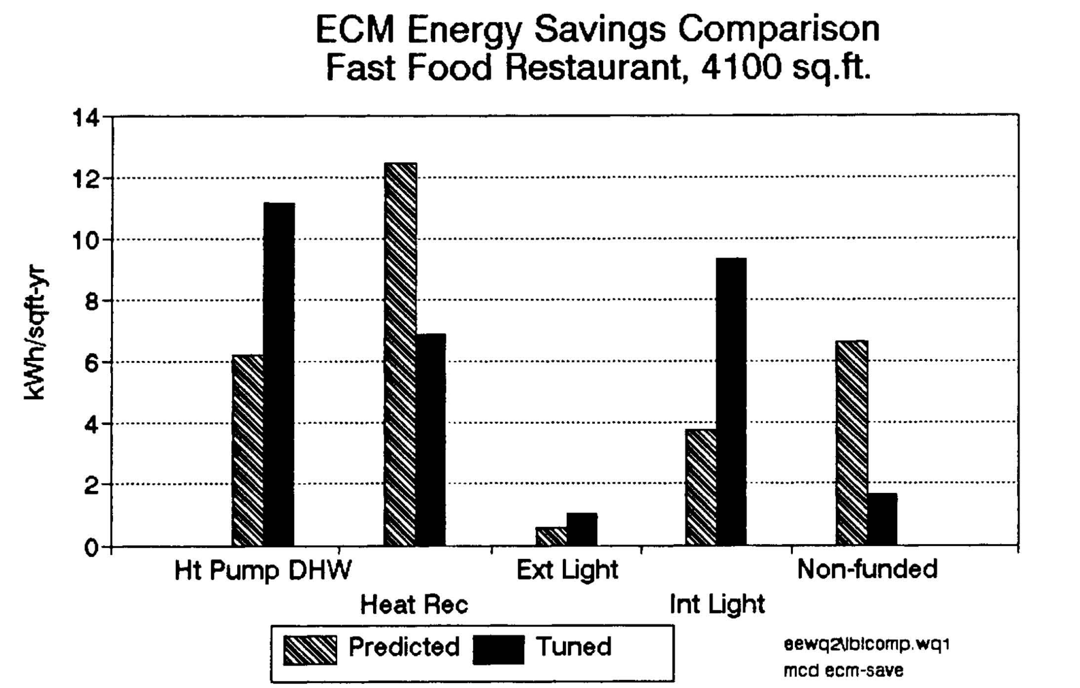
From the analysis of the three buildings described above, it appears that categories 1 and 4 are the main causes of differences in ECM savings estimates between the two modeling phases. However, we also see examples of the other two categories.

3.4 LESSONS LEARNED FROM MODEL CALIBRATION

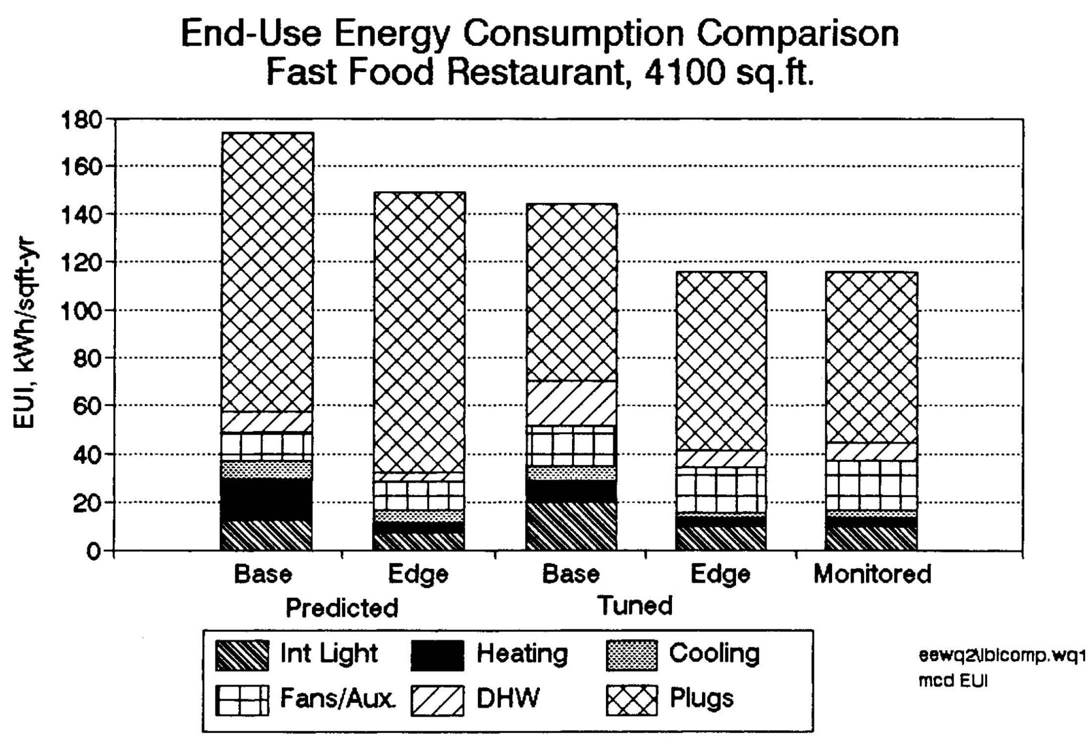
The Energy Edge project has required us to examine a small number of building models in exhaustive detail. For most buildings we have had the benefit of well analyzed end-use monitored data, and sometimes supplementary measurements of ECM or system behavior.

For most buildings we are charged with calibrating the model end-use monthly, seasonal, and annual energy consumption to the monitored data. The extent of this activity is unique in the annals of energy modeling, and has enabled us to catch a glimpse of certain inalienable modeling truths. We have already alluded to some of these in the appropriate sections. But we shall summarize all of these truths in this section.

Figure 2

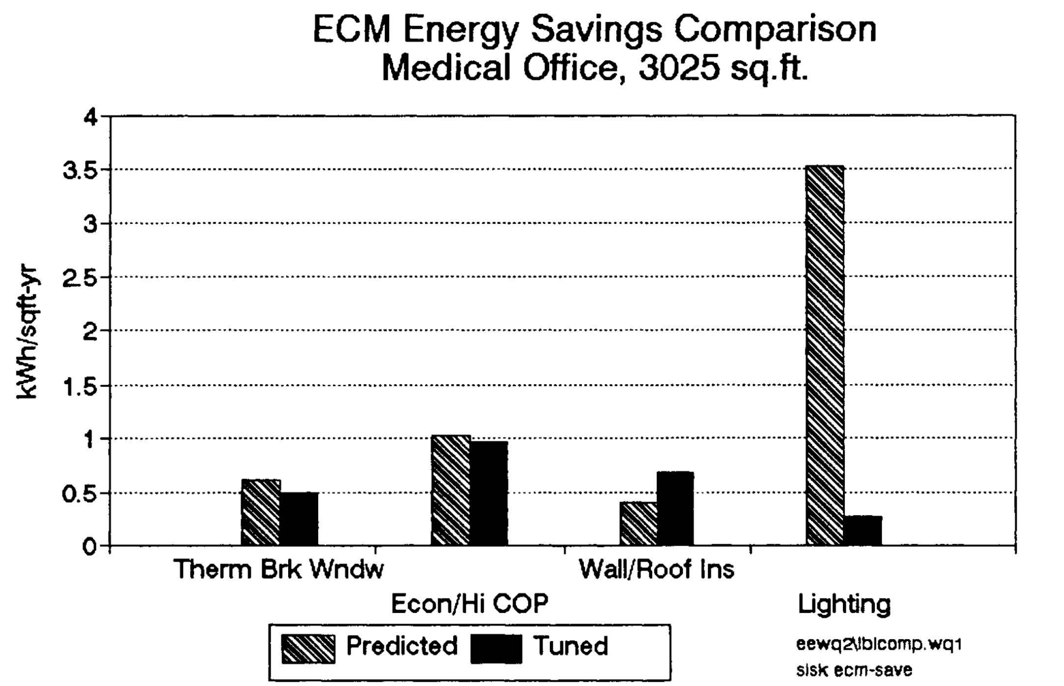


ECM Energy Savings Comparison
Fast Food Restaurant, 4100 sq.ft.
kWh/sqft-yr
0
2
4
6
8
10
12
14
Ht Pump DHW
Heat Rec
Ext Light
Int Light
Non-funded
Predicted
Tuned
eewq2\lblcomp.wq1
mcd ecm-save

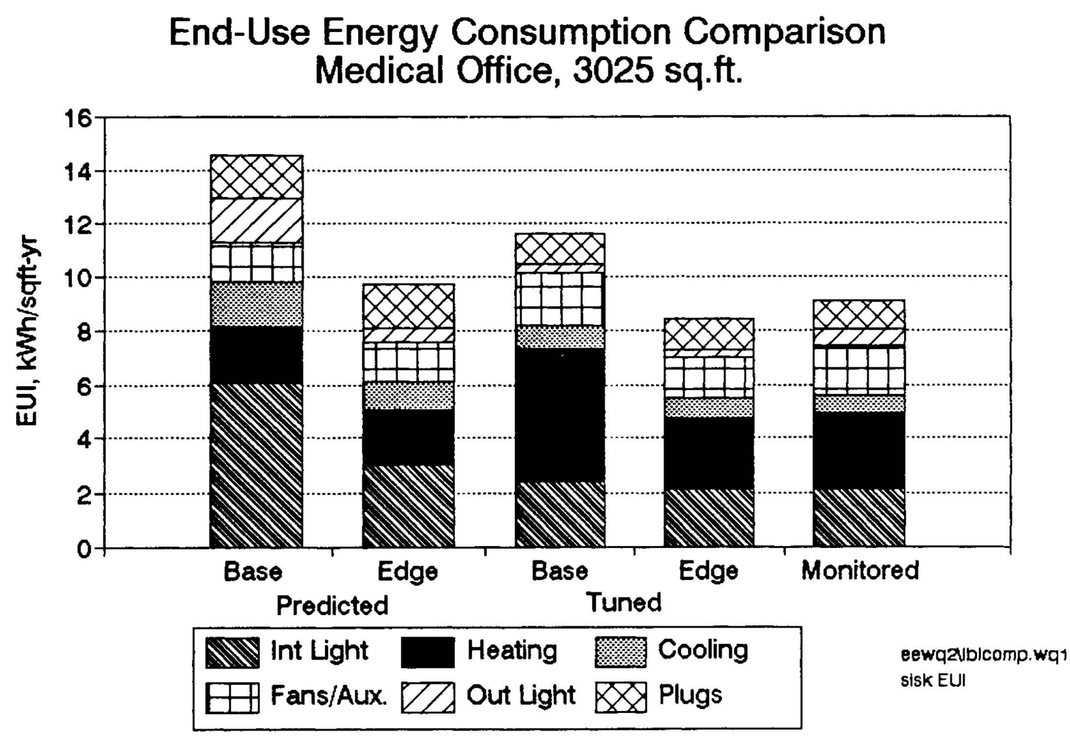


End-Use Energy Consumption Comparison
Fast Food Restaurant, 4100 sq.ft.
EUI, kWh/sqft-yr
0
20
40
60
80
100
120
140
160
180
Base
Edge
Base
Edge
Monitored
Predicted
Tuned
Int Light
Heating
Cooling
Fans/Aux.
DHW
Plugs
eewq2\lblcomp.wq1
mcd EUI

Figure 3



ECM Energy Savings Comparison
Medical Office, 3025 sq.ft.
kWh/sqft-yr
4
3.5
3
2.5
2
1.5
1
0.5
0
Therm Brk Wndw
Econ/Hi COP
Wall/Roof Ins
Lighting
Predicted
Tuned
eewq2\lblcomp.wq1
sisk ecm-save



End-Use Energy Consumption Comparison
Medical Office, 3025 sq.ft.
EUI, kWh/sqft-yr
16
14
12
10
8
6
4
2
0
Base
Edge
Predicted
Base
Edge
Tuned
Monitored
Int Light
Heating
Cooling
Fans/Aux.
Out Light
Plugs
eewq2\lblcomp.wq1
sisk EUI

1) One cannot overemphasize the importance of the baseline definition. We have seen that differences in baseline assumptions were responsible for most of the greatest differences in ECM savings estimates between the three design-phase and tuned models discussed in the previous section. Codes simply do not address all the aspects of model input. Therefore modeler judgement is unavoidable.

Program managers must realize that there is often some degree of unavoidable arbitrariness in the definition of the baseline model. Different competent and ethical modelers may make different assumptions about various baseline parameters. This becomes particularly significant when these parameters are affected by an ECM. The implication of this is that the ECM savings estimates must then also have a degree of arbitrariness.

In part 2 of this report we discuss baseline derivation in some detail. Both modelers and program managers should read that section.

2) Many of the most significant energy drivers can be quantified only by educated guess--even with extensive monitored data. This is especially true during design-phase modeling and for new construction. The most obvious example of this is infiltration, though ventilation air volume and schedule, internal equipment loads and schedules, and HVAC system control are also significant. Infiltration and ventilation air assumptions can overshadow most other inputs for buildings that are subject to a significant heating load. These assumptions can greatly affect ECM savings estimates, especially when directly addressed by an ECM.

Often, parametric analysis of the extremes of reasonable values can give the modeler insight into the importance of these uncertain energy drivers. Parametric analysis is also helpful in establishing the error bounds related to specific inputs.

In part 2 we provide some guidelines for these assumptions. However, both modelers and program managers should realize that the science of infiltration is crude, and that savings reliability can often be diminished by this. When a modeler analyzes an ECM that relies heavily on infiltration assumptions, she should clearly document the assumptions and the degree of uncertainty about them.

3) Small buildings are often disproportionately affected by occupant intervention. We found that it is sometimes impossible to calibrate the models for small buildings. Occupant manipulation of a single thermostat or a single window in a one or two zone building can completely mask the known input parameters. We know of nothing that can be done in the design-phase models to address this issue. (Though, again, parametric analysis of the impact of thermostat setting variability may be useful in establishing the error bounds.) The lesson here is not a solution. The lesson is one of awareness. End-use and ECM savings estimates from design-phase models of small buildings may differ significantly from the actual end-use consumption and ECM savings due to such occupant intervention.

4) Choice of tuning methodology can strongly influence ECM savings estimates. We recently completed a model tuning study of a small credit union in Idaho. In analyzing this building, we used two different methodologies. One of these methodologies drew on work by the National Renewable Energy Laboratory (NREL, formerly Solar Energy Research Institute, SERI) involving short-term energy monitoring (STEM). This approach directly measured the building load coefficient and, indirectly, the envelope overall U-value. The startling conclusion of these tests was that the measured envelope U-value is about 40% of the value as calculated by ASHRAE methods! Yes, this means that STEM believes the envelope behaves more efficiently than as predicted by conventional theory. Assuming that the methodology is valid, one possible explanation for this is that the envelope operates as a heat exchanger--heating infiltration air as it filters through.

Much work remains to validate this methodology, but these results should certainly give modelers pause. We are not at this time recommending that modelers depart from conventional methods for U-value calculation. However, one should note that, depending on which theory is embraced, the savings estimates for any ECM related to envelope performance may differ widely.

5) Errors happen, happen. The modeler should never assume her model to be correct. Part 2 deals at length with error checking and model debugging. Suffice it to say here that models are never correct. They are only less incorrect as the modeler takes greater care.

6) ECMs often do not operate as intended. Another Energy Edge project lesson is that ECMs (and, for that matter, buildings) often do not work as intended by the original design. Dynamic systems (lighting controls, economizers, energy management systems, other HVAC controls) are the most frequent examples of this.

Several conclusions can be drawn from this lesson. The first is that design-phase models that assume proper ECM operation will often not be indicative of actual ECM savings or building energy consumption. The second is that, if program managers are serious about procuring ECM savings, then the programs must include commissioning of the ECMs and related systems. They must also support intelligent operations and maintenance procedures for the life of the measures. The third is that HVAC tuning can be complicated by unintended operation.

7) Simplified analysis can bear useful results. Sometimes a model can be used for analysis of only a part of a building or for certain ECMs only. This can greatly simplify the modeling task when appropriate. An Energy Edge project example of this was an existing large office/retail building with a complex glass facade and massive construction. We wished to approximate the potential savings due to air-side economizers and night flushing. As a first cut, we modeled only interior zones. This was based on the assumption that since the installed capacity of interior HVAC units grossly exceeded that of perimeter units, and since the building appeared to be satisfying heating and cooling loads, then the interior zones represented the vast

majority of heating and cooling energy consumption.

From this crude analysis we found that the ECM savings were not at all close to the cost-effective criteria. Therefore further analysis was not warranted, and we had avoided significant modeling effort and expense. The lesson is that model complexity is not an end in itself. The modeler should always be alert to the potential for simplified modeling.

PART 2 TECHNICAL GUIDELINES

1. GENERAL MODELING STRATEGIES

1.1 THE ROLE OF THE ANALYST

Conserving energy requires living on the edge. Excessive amenity levels are avoided, but so is deprivation. HVAC systems are sized with adequate capacity but little margin for error. New, relatively complicated and untested technologies are introduced where the tried and true once reigned. Designers, manufacturers, installers and building operators and administrators are forced up against a learning curve.

Energy savings analysis increases investment in conservation by offering building owners the information needed to weigh first cost against reduction in annual operating costs. Savings calculations also serve as the basis for utility funding in demand side management programs. Nevertheless, it is important that energy conservation not be confused with energy analysis.

Analysis is only a small link in the chain of activities that leads to a successful ECM. Once estimated savings have been used to select an ECM, it is effective manufacturing, design, installation and operation that determine actual savings. The analyst's role is not only to predict typical energy savings but also to promote actual savings through all phases of the project.[10]

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

Ideally, an ECM description should include, from an early stage, a written consensus between the designer, customer and analyst of how the success of the ECM is to be evaluated after installation. For HVAC and controls, check-out trend logs should be planned in advance wherever possible. The analyst can also promote clear labelling of equipment, training of the building operators, and good user manuals. To last, an ECM must be reliable, convenient and understandable.

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[10] We use the terms "analyst" and "modeler" somewhat interchangeably in this report. Insofar as we intend a difference, it lies in usage of "modeler" in a more restricted sense of "one who models". The analyst, on the other hand, is the modeler who also provides design assistance, encourages commissioning, does hand calculations, etc.

1.2 BALANCING DETAIL WORK WITH TIME FOR CRITICAL THOUGHT

Computer simulations require so many detailed inputs there may be little time to sit back and look at the overall picture and still turn a profit. Be sure to simplify the simulation to an extent that there's time to think about the results from a distance. Analysis requires judgement, which requires time for calm reflection.

At first it is tempting to model each schedule, each system, each strange wall, each unconditioned space and each wall layer with intricate detail. But the inputs and outputs can easily become unmanageable. Checking inputs and outputs for reasonableness and careless errors takes time. A huge number of detailed inputs full of errors is of no advantage to anyone.

The ultimate goal in simulation is to focus any desire for detail on inputs that make a big difference. To some degree, the critical inputs vary from one building or ECM to the next. However, the following guidelines may be generally useful in reducing the amount of time spent on detail work. Most of the points that are summarized here are discussed in greater detail later in this report.

- Interior Walls. Do not model interior walls between air spaces that are roughly the same temperature unless they are needed to properly simulate thermal mass or light-dimming controls in day-lit buildings. However, the modeler must take care that she allow some path for heat transfer from interior zones with significant internal gains.

- Utility Rooms. In general, don't model mechanical (or electrical) rooms or mechanical room walls. The heat loss from the equipment usually keeps the rooms warm, and that energy is already accounted for in the HVAC model as equipment inefficiency.

- Permanently Shaded Glazing. Treat windows that are permanently shaded as north-facing without shade, or as unshaded with a low shading coefficient.

- Schedules. Since schedules are highly uncertain in any case, don't create two schedules that are only off by 10% unless that difference is the specific goal of a control ECM.

- Roof and Ground Losses. With tall buildings, pay little attention to the roof, doorway and ground heat loss characteristics unless they are directly involved in an ECM.

- Hand Calculations. Calculate consumption by domestic hot water, exterior lights, and equipment located in unconditioned space by hand (i.e. with a spreadsheet). That way you can change those calculations without rerunning the program.

- Sensitivity studies. We highly recommend the modeling practice of running parametric simulations of parameters in question to test their significance in a specific building. If changing the values within the range of uncertainty has little effect on the output, then the modeler can arbitrarily select a mid-range value and move on.

- Lighting Inputs. If lighting is fairly evenly distributed, calculate a watts per square foot input to use throughout, even for retrofit baseline simulations.

- Spreadsheets. Some modelers find it helpful to develop the envelope and internal gain inputs on a computer spreadsheet. (See appendix VI.) Some modelers even go so far as to use a spreadsheet to help generate their DOE2 BDL files.

- Pre-simulation Review. If possible, check the level of detail in zoning and schedules with any reviewers before you get started.

- Preserving Carefully Done Work. If you perform a careful detailed calculation to create an input, file the calculation carefully so that you don't have to redo it a month later when checking your work.

- Focus on ECMs. Even with the baseline inputs, focus on the inputs that will be directly affected by the ECMs to be modelled.

Caution: The net heating and cooling loads on a zone are sacred. The modeler should not move walls, lights, equipment, etc between zones. Multiple spaces can be joined into a single zone, but the respective lights, walls, floor area, etc should be manipulated together, and not capriciously assigned to different zones.

1.3 NEGOTIATIONS BETWEEN THE MODELER AND THE COMPUTER SIMULATION

The good modeler knows how to negotiate profitably with her software.

Part of successful negotiation is arriving at the table with an opinion about what the results should be. The modeler should have access to information about typical:

- Btu per square foot per year total consumption by building type,

- end-use breakdown fractions,

- seasonal variation of end-use consumptions, and

- a reasonable range of inside space temperatures.

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.

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

1) Careless Errors in the Inputs. Look for careless errors in the inputs. Examine both the actual input and the simulation program input echo reports.

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 you've understood the simulation properly, and correct any errors resulting from such misunderstandings.

4) Understanding of the Building or the Design. Think about the physical process being modelled and whether the model - as described in the user's manual - has captured the major elements. If not, consider a change in the inputs or a hand calculated correction to the outputs.

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

6) 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 answers you expected. (This is a complex and dangerous topic. "Responsible tweaking" requires modeler experience, judgement, and integrity.)

If the results are still mysterious, the modeler may try a parametric run or two to make sure she understands how the simulation works on algorithms related to the source of disagreement. As an example, she might input infiltration at two different values during unoccupied hours--say, 0.2 and 0.5 air changes/hour. Or she might try two runs--one with 5% minimum outdoor air ventilation and one with 20%.

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. If the simulation has been around for over 10 years, most of the bugs have probably been worked out. To distinguish between a bug and a sober lesson in reality, it may be helpful to talk with someone who is familiar with the software and talk with people knowledgeable about the technology in question. For unexpected ECM savings, try hand calculations to see whether the same results can be approached manually.

Do not tweak all of the uncertain inputs before checking for careless errors. Otherwise you may find yourself in the humbling and inefficient activity of tweaking back to center after careless errors have been found.

If the modeler doesn't start each simulation with an idea of the reasonable range of outcomes, she 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. <u>It is important to know when to stop arguing and to start listening.</u>

Computer analysis is helpful not only in fine-tuning ECM savings calculations within the range of typical values but also in identifying overly optimistic ECM expectations.

Simulations may also help dislodge outdated notions of energy use indexes and end-use breakdowns. As design fashions shift, so do building consumption patterns.

2. SOURCES OF MODEL DISCREPANCIES

There is a growing body of knowledge that identifies recurring modelers' biases in constructing building models. End-use monitoring through the ELCAP and Energy Edge programs has lead to surprising new information about equipment power densities and lighting and equipment use during unoccupied hours. Review of design phase modeling for Energy Edge buildings has also revealed some typical errors resulting from modeler oversight or misunderstanding of how simulations use input data.

Since these findings may be particularly helpful to modelers, they are summarized here. Each of these topics is also covered in greater detail later in this report.

2.1 EQUIPMENT POWER DENSITY

We identify two significant biases that relate to equipment power density:

1) Underestimates from using rules of thumb. Equipment loads (also referred to as plug-loads and receptacles), tend to be vastly underestimated. The time-worn rule-of-thumb for office spaces has been 0.5 W/ft^2, not including large main-frame computers. Recent studies indicate that a power density of 1.0 to 2.0 W/ft^2 is more appropriate.

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. Many pieces of equipment, like photocopying machines and printers, draw power in varying amounts through their operation cycle. The peak, or nameplate consumption, is only experienced for a fraction of the time the machines are on. 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 electronic office equipment.[11]

2.2 UNOCCUPIED EQUIPMENT AND LIGHTING SCHEDULES

Modelers often assume that the lighting and equipment loads go to zero during unoccupied periods. Monitoring data have shown that in fact 10% to 30% of the lighting and at least 30% of equipment loads are on during

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[11] There is much variation among different types of electronic equipment in the ratio of average to rated power. Personal computers tend to be constant load machines with average power at 25% to 40% of rated power. Copiers and printers have ratios that can vary widely, and that are primarily a function of the duty cycle of the machines. Average power for such machines is generally between 15% and 30% of rated power. Because of the preponderance of personal computers in the receptacles load of the typical office, the 1/3 rule of thumb is a reasonable approximation. (Reference 21, Harris et al, and reference 22, Piette.)

unoccupied hours in typical office buildings.[12] Similar values apply to other commercial building types.

2.3 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. Often this occurs either as a simple oversight or because the modeler has no information on which to base assumptions. Existence and use of curtains are the norm rather than the exception since glare and overheating tend to occur in direct sunlight. The modeler should 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.

Computer simulations vary widely in their ability to model internal and external shading. Compromises often need to be made. For example, curtains or shading by adjacent buildings can be modeled by input of an artificial shading coefficient. The modeler is encouraged to model shading accurately within the limits of the program, and in no case to ignore shading just because it is uncertain or difficult to model.

2.4 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.

2.5 HEAT LOSS TO GROUND

Some computer models overestimate heat loss to ground from floors in contact with the soil. Heat loss to ground from floors occurs primarily at the perimeter. Calculations based on the entire floor area are likely to overestimate heat loss. If a simulation calculates heat loss from floor to ground based on a floor area input, the modeler is encouraged to input the floor perimeter in linear feet or to input an artificially low U-value. The artificially low U-value is more convenient if the floor area is used to calculate infiltration or equipment loads as well as conduction losses. (See reference 11, p. III.118.)

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[12] The unoccupied fractions of peak lighting and equipment power appear to be somewhat dependent on building size. Small offices tend to have lower unoccupied fractions than do large offices.

2.6 OPERATION ASSUMPTIONS

Modelers typically assume that both the baseline and the as-designed building operate according to design intent. Commissioning and auditing experience constantly screams to 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 the modeler be aware of this issue and be humble about her simulation estimates.

Commissioning work in the Energy Edge project and other northwest energy conservation programs is providing much anecdotal evidence that certain ECMs frequently do not work according to the designers' intent. Controls-related ECMs are probably the most common example. For instance, we have <u>never</u> seen economizer controls on packaged equipment to operate properly as-installed. Energy management systems typically are only partially utilized--in direct contrast to the designer's fantasies. Such 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.

We recommend that the modeler, in her role as a provider of design assistance, make herself and the building owner aware of these issues. She should especially emphasize that model predictions presume proper installation and operation of the relevant building systems. 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.

3. FOCUSING ON THE INPUTS THAT HAVE A SIGNIFICANT IMPACT

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 and shading coefficient, infiltration, ventilation, fan schedules, lighting and equipment watts per square foot, and thermostat settings are always important. The risk of significant error for other inputs depends to some degree on the size of the building and whether or not it is new construction.

3.1 SMALL BUILDINGS

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.

3.2 LARGE BUILDINGS

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.

3.3 RETROFIT PROJECTS

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. Air flow rates and fan and pump consumption may also be difficult to determine if the original system was dramatically oversized and the system is being operated at flow rates much lower than were intended.

When applying ECMs to the simulation of an existing building, it is critical to input non-default values for important HVAC parameters. Supply CFMs, and chiller and heat pump capacities should be input by the modeler for the post-ECM run (i.e. carried from the baseline to the post-ECM run) even if they were allowed to default for the baseline, because otherwise the addition of any ECM affecting peak heating and cooling loads will cause the entire HVAC system to be resized.

Occupant discomfort in an existing building may be related to a reduction in energy consumption. Burned out light bulbs that haven't been replaced, inadequate ventilation, or undersized cooling equipment may save energy while reducing the quality of the space being served. For such cases, the baseline simulation may tend to overestimate baseline consumption if it models normal operating conditions. If the comfort problem is corrected as part of the ECM installations, modeled ECM savings may be incorrect. For that reason, it is important in retrofit projects to discuss with the owner any needs to improve amenity levels beyond the existing condition and to consider the implication of such needs on ECM savings.

4. SIMULATION INPUT

Proper selection of simulation inputs requires understanding of building technologies as well as computer models. In this section, recommendations are made for developing simulation inputs. When an understanding of the physical process being modeled is critical to developing the appropriate model inputs, that process is described.

4.1 ZONING

This section paraphrases extensively from an article in the BLAST News (reference 9), and blends in our own opinions. We therefore take full responsibility for any faults in the material, but take only partial credit for its successes.

4.1.1 The Basics

The 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.

Aggregation of loads into zones, systems, and plants can have a significant impact on energy consumption, particularly for large buildings and buildings served by multiple-zone heating and cooling systems.[13]

Zoning in simulation models is based on, but is not identical to, HVAC zoning. An HVAC zone is defined by an individual thermostat and that part of the air distribution system that responds to that thermostat. A designer will often give individual thermostatic control to several different groups of occupants in an area that can be expected to have a relatively homogenous heat balance. A model zone, on the other hand, represents simply a mass of air on which a heat balance is performed. 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:

> A zone represents a mass of air on which a heat balance is performed.
>
> Surfaces, scheduled loads, and controls provide mechanisms for energy

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[13] We frequently refer to "multiple-zone systems" in this report. This nomenclature is not to be confused with the more common term, "multi-zone system". A multiple-zone system as used here is an HVAC system that serves more than one zone and responds on some level to multiple thermostats. A multi-zone is one example of a multiple-zone system; VAV, dual duct, VVT, and so forth are other examples.

flow into and out of a zone.

This means, for the model, that the entire zone has one mass of air at a single temperature. Any surfaces which are assigned to a given zone exchange energy with the zone air mass and with the other surfaces of the zone. Any scheduled loads and controls which are assigned to a given zone exchange energy with the zone air mass and with the zone surfaces.

Before discussing ways to zone a building, there are some common myths about zones which must be dispelled:

Myth 1:
A zone must represent an enclosed volume.
This is not necessary... If a zone has a hole in it, it will not let in masses of outside air. Surfaces, controls, and scheduled loads are the only means by which energy can enter or leave a space. Many zones may be completely described with a single exterior wall and a piece of internal mass.

Myth 2:
A zone must represent a continuous volume.
This is not necessary. It is possible to have a single zone consist of several spaces which are far removed from each other. For example, all of the bathrooms in an entire building might be combined into a single zone.

Myth 3:
A zone must all be on one floor.
This is not necessary. Very often, it is useful to have a single zone include rooms on several different floors.

Remember that a model zone is a somewhat abstract thing--it is not limited by the geometry of specific rooms or of the HVAC distribution system. However, since buildings are divided into rooms, a zone will typically be a collection of rooms.

Start With One Zone

One approach to zoning a building is to start with the entire building as one zone and then subdivide that zone as needed. Any building may be modeled as one zone, if desired. This would be a very simple model, but it can be done. 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, controls type, 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.

1) Zoning by Usage. Rooms which differ greatly in usage typically need

to be described in separate zones. All rooms which are included in a zone should have similar internal loads.

Example A
A kitchen with high internal loads should not be grouped into the same zone as a storage room with low internal loads. If both of these rooms were modeled in a single zone, the kitchen loads would be distributed evenly throughout both rooms; it would be as though there was no wall between the kitchen and the storage room. The modeler may, however, decide that this distinction is trivial to the major energy patterns of the building. In this case, the zones could be combined.

Example B
Ten offices with similar lighting levels and controls, occupancy rates, and equipment loads may be described with a single zone. These offices may even be on different floors, and they do not necessarily have to be adjacent to each other. Since all of the rooms will essentially behave the same, nothing is lost by combining them into a single zone.

2) Zoning by Controls Type. Rooms with different temperature control strategies or thermostat schedules (or thermostat setpoints) typically need to be described in separate zones. A zone can only have one control profile which is active for any given hour, so all rooms which are included in a zone will be controlled the same way.

Example A
Fifteen classrooms are heated/cooled from 8am to 5pm and are set back from 5pm to 8am. All of these rooms may be included in a single zone.

Example B
A hospital office area is occupied from 7am to 7pm and is set back from 7pm to 7am. The hospital patient rooms are never set back. The offices and the patient rooms should be placed in at least two different zones to model the setback periods properly.

3) Zoning by Solar Gains. Rooms which have greatly differing solar gains should not be included in the same zone, because the effects of the solar gains will be diluted throughout the entire zone.

Perimeter zones with windows should be assigned at least one zone for each direction of the compass. Otherwise multiple zone system controls are difficult to model accurately, and solar overheating of one zone is likely to be misrepresented in the simulation as free heat in another area of the building.

For further simplification (and somewhat less accuracy) the perimeter zones can combine north and east sides, and south and west sides. Zones with unglazed exterior surfaces or extensive heat loss through interior walls can also be lumped in a single zone if they are otherwise similar.

Example A
A north-facing zone should not be combined with a south-facing zone.

Example B
A core of interior offices should not be combined with an atrium unless a single thermostat controls the HVAC for both.

4) Zoning by Perimeter or Interior Location. For large buildings, careful attention should be paid to separation of interior and perimeter spaces when breaking the building down into zones. Ignore the location of interior walls in this case. Interior spaces with no exterior walls, roofs, or floors are cooled year round. Perimeter areas stretching from exterior walls with windows inward to about 12 to 15 feet from the wall are often heated. If these perimeter spaces and interior spaces are lumped into common zones, the simulation will dramatically underestimate winter heating and non-economizer cooling consumption.

5) Zoning by Fan System Type. Rooms which are served by different types of fan systems should not be included in the same zone, since a single zone may be served by only one type of fan system.

Example A
A room which is served by a fan coil system should not be combined with a room which is served by a variable air volume (VAV) system.

Special Considerations:

There will often be special conditions in a building which require additional zoning in order to model the building conditions accurately. The modeler must always analyze the thermal aspects of the building to determine whether the zoning will be sufficient. Here are a few things to watch for.

Shading
When zoning is based on solar gains, remember to consider shading effects.

Large Open Spaces
Models generally assume that all zones are well-mixed. If there is reason to believe that different parts of a large space may experience different conditions, then the space may be divided into more than one zone. Remember, though, to provide some means for heat transfer between these zones. This may be accomplished with mixing or interzone surfaces.

Unconditioned Spaces
When describing unconditioned spaces, such as attics and crawlspaces, consider the boundaries carefully. For example, if the attic is separated into more than one section, so that the sections will not always be at the same temperature, then it may be necessary to use more than one zone to describe the attic.

It is important when combining spaces into a single zone that all of the elements of each space are included. Do not move, for example, the lighting or a window from one zone into another without moving also the respective floor area, equipment and any associated exterior surfaces.

4.1.2 Assignment of Zones to Systems

In computer simulations, once the net heating and cooling loads have been calculated for a zone (usually on an hourly basis), the loads are combined with any loads due to ventilation or change in thermostat setpoint and passed to the simulation of the air distribution system, which we refer to simply as the "system".

Zoning of Single Zone Systems:

Zone assignment is not particularly critical for single zone systems, except that the following two conditions should be met.

1) If some of the building is heated or cooled by a different system type, different fuel, or at a significantly different efficiency level than another part of the building, that distinction needs to be made by assigning the respective zones to separate systems.

2) If multiple zones are assigned in a computer simulation to a single-zone air distribution system, some simulations will assume that each zone is served by a separate air distribution system, while other simulations will add reheat and serve all of the zones with a single system. Since the latter strategy is far less efficient, the modeler needs to make sure that the strategy taken reflects the actual design or building.

In existing buildings, single zone systems as installed are sometimes serving incompatible spaces, such as interior and perimeter areas, without much success. Discomfort caused by improper zoning is difficult to model. The simulation is likely to overestimate consumption if proper zoning is modeled.

Conversely, extensive use of baseboards to offset inadequate air distribution system zoning in existing buildings can introduce an inefficiency that isn't reflected in a simulation of a single zone system serving the same area. In such cases, greater simulation accuracy may be achieved by modeling the single zone system as a multiple-zone system with reheat or baseboard heat.

Zoning of Multiple-Zone Systems:

For multiple-zone systems, it can be important to assign zones to air distribution systems accurately. In general, it takes more energy for an air distribution system to serve zones with diverse simultaneous (i.e. at any given time) heating and cooling needs than it takes to serve zones with similar loading patterns. Two extreme examples will illustrate the case.

Fans Schedules. If a building contains 4 zones that are occupied 12 hours a day and one zone that is occupied 24 hours a day, the energy consumption for heating and fans is going to be higher if the 24 hour zone is served by the same air distribution system as the other zones.

Cold (and hot) duct central supply temperatures. If a building contains some zones that require 52 F supply air for cooling year round and other zones that are in heating during cold weather, energy consumption for heating (and possibly cooling) is likely to be higher if all zones are on the same air distribution system.

If a computer room or a 24 hour part of the building is served by its own air supply system, adding those zones to a multiple-zone system serving the rest of the building will result in a significant overestimate of energy consumption.

4.1.3 Assignment of Systems to Plants

Where one or more air distribution systems is served by one or several boilers and chillers, the heating and cooling loads on the respective air distribution systems are passed to a separate "plant" section of the program. Unitary systems, which include the supply fan and all heating and cooling equipment within a single enclosure, are modeled without a "plant" simulation.

Plant assignments (the assignment of one or more air distribution systems to a specific group of boilers and chillers) can be important if different fuels or efficiency levels characterize different boilers and chillers in the building. Plant assignments are also important because they affect where on the part load curve the boiler or chiller is operating.

Building energy simulation software generally offer limited capability for assigning different air distribution systems within the same simulation to different boilers and chillers. Inaccuracies that might result from this limitation should be considered qualitatively by the modeler in presenting the simulation results.

Sometimes software limitations may make it advisable for the modeler to simulate a particular building in two or three separate parts (i.e. independent models). This, of course, adds to the complexity of the modeler's work, and requires careful accounting to not lose track of any of the parts. Software limitations that could make this necessary might include:

- inability to assign different air distribution systems to different plant equipment,
- insufficient allowance for required number of zones,
- inability to accept multiple occupancy or operating schedules for different building sections.

4.2 ENVELOPE LOADS

4.2.1 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 poorest information. For these reasons, modelers often view infiltration with mixed feelings. On the one hand, it is frustrating to have to guess at such an influential parameter. On the other hand, because the truth is safely hidden, the modeler often feels free to adjust ("tweak") this parameter within the wide bounds of reasonableness in order to match measured data.

The ASHRAE Standard 90.1 recommends procedures for model input of infiltration (reference 8):

> "Infiltration shall impact only perimeter zones. When the HVAC system is ON, no infiltration shall be assumed to occur. When the HVAC system is OFF, the infiltration rate for buildings with or without operable windows shall be assumed to be 0.038 CFM/ft^2 of gross exterior wall."

An exception is provided for hotels and motels. For these buildings, the above infiltration rate is to be assumed for all hours.

Though we have little data to support this contention, we believe that the above guidance is somewhat simplistic. The assumption of zero infiltration during hours of HVAC system operation 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 her infiltration input.

Similarly, the mandated value for infiltration during hours of no HVAC operation is restrictive and simplistic. Though the value may be generally appropriate, the standard gives no guidance as to when this value applies. Is it wind-dependent or independent? Is it temperature dependent? **We recommend that 0.038 CFM/ft^2 is a reasonable beginning assumption, but that the modeler 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 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.

4.2.2 Window Unit U-Values and Shading Coefficients

Modelers commonly assume that the winter U-value of a single-glazed window is 1.1, and that the U-value of a double-glazed window is 0.49. However, these values do not consider the effect of the window frame. An aluminum frame with no insulating "thermal break" can degrade these U-values to 1.23 and 0.78, respectively (reference 6). Given the high U-values of glazing relative to walls and roofs, this bias can have a disproportionately large effect on the building model. The opaque frame can also have a significant effect on the overall window unit shading coefficient.

Typically, the design-phase modeler will not have accurate information about the window units to be installed. **We recommend that, unless the design specifically includes an ECM relating to glazing and frame type, the modeler assume a double-glazed window with a non-thermal-break aluminum frame. If the modeler does have knowledge of the specific window types to be installed, then we recommend that she use the manufacturer's rated <u>window unit</u> 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. The modeler should also adjust shading coefficients to account for opaque portions.**

DOE2 modelers should note that the input for glazing heat transfer is GLASS-CONDUCTANCE, not U-VALUE. The former parameter adjusts the U-value for outside film coefficient and wind speed. The DOE2 reference manual provides a formula for making this conversion.

4.2.3 Wall U-Values

One cannot assume the U-value of a wall (or roof or floor section) to be the same as the U-value of the insulation it contains. In some cases the U-value of the wall-section may be less than that of the insulation due to other layers, air-spaces, etc. And in some cases the U-value may be substantially higher than that of the insulation due to wall construction. Metal stud construction is a prime example of the latter. (See Reference 8, Appendix E, for a thorough technical treatment of this issue.) In general, though, stud spacing, thickness, and type all influence the wall U-value.

The State of Oregon Energy Code Compliance Manual (reference 7) presents a useful set of tables for dealing with this issue. We recommend that the modeler uses these tables where appropriate. These tables can be found in appendix I.

Sometimes insulation is installed in such a manner that it's theoretical U-value is not realized. This can occur when batt insulation is compressed in a wall space or installed with major gaps. The as-built modeler should be aware of such deficiencies and adjust nominal U-values to reflect the as-installed conditions.

Architectural features of a building sometimes make it unusually difficult to calculate an appropriate U-value. When the modeler encounters such features, she should first evaluate whether they are likely to have a significant effect on building energy behavior. If the features affect only a small portion of the building, then the modeler may decide that quick-and-dirty calculations may be adequate.

If the features may have a significant effect, the modeler should take more care in these calculations. Sometimes, this may involve adding zones to the model--for instance, to model an unheated area above the top floor ceiling, or an attic. Sometimes, it could involve modeling the feature with a high and a low in a range of possible U-values. This would bracket the effect of assumptions about this feature on the model.

Recent work at the National Renewable Energy Laboratory suggests that effective U-values may actually be 60% lower than those calculated using the standard ASHRAE methods. One project measured a small building's overall U-value on the basis of heating consumption and outside air temperatures.[14] Until the SERI methodology and results have been closely examined and duplicated, it would be premature to revise the recommendations given above. It will be interesting however, to follow the outcome of further investigation.

4.2.4 Shading and Solar Gain

When a building has significant areas of glazing, solar gain through that glazing can be a major driver of building energy performance. Accurate solar gain calculations must take into account the building latitude, the time of year, the time of day, the orientation of the building surface, the physical characteristics of the surface, and shading. Hourly computer simulations are generally equipped to accurately take care of all of these factors except shading, without much inconvenience to the user.

Exterior shading is usually uncontrolled by the occupants, and exerts a seasonal effect on building energy behavior. Ground-based shading such as trees may block the low winter sun more than the high summer sun. Or they may loose their leaves in winter--leading to the opposite effect. Ignoring this may lead to gross miscalculation of heating energy, cooling energy, or both.

If a building is to be located in an urban area amidst multiple high-rise buildings, then those buildings will offer exterior shading. Most software programs have some means of entering such shading. For new construction, if the design drawings include landscaping plans, then the modeler should input major shading features from these plans. If the building involves architectural features such as fins or overhangs that will shade the windows, these features must be input.

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[14] This project was done cooperatively with Bonneville. It applied the STEM techniques to an Energy Edge small office. The results of this study are reported in reference 17.

Another commonly overlooked type of exterior shading is the building itself. Often one wall of a building may shade other walls. Again, this can have a significant effect on the simulated performance.

Occupant-controlled interior shading can be a more difficult, but equally important, energy driver. Usually the type and usage of interior shading devices is not known until well after the design-phase model is required. However, it is reasonable for the modeler to assume that some form of interior shading will be installed if there is a significant area of untinted glazing--especially on the south and west sides of a building. Lacking guidance from the owner and architect, we typically assume shading by venetian blinds. As for scheduling of usage, we typically assume that west-side blinds will be shut from 3pm to 8am the following morning, and that south-side blinds will be shut from 11am to 3pm. Sometimes we adjust these schedules seasonally.

ASHRAE Standard 90.1 (reference 8) requires that glazing be assumed to be internally shaded by medium-weight draperies closed one-half time. It further requires that the shading be calculated as effective over one-half the glazed area in each zone. Though we see this requirement as more arbitrary than our normal assumptions, we recommend that the modeler use whichever she feels most comfortable with.

It's important to remember that shade will tend to increase heating consumption in the winter and reduce cooling consumption in the summer. Similarly, solar gain that occurs in the early morning is likely to reduce heating consumption, while solar gain in the afternoon will more often increase cooling loads. A shading coefficient, which applies equally year round, is therefore not going to properly represent operation of curtains, deciduous trees, or external structures that result in varying degrees of shading.

Window setback and overhangs are generally easy to input into simulations. Movable curtains can be modelled in DOE2, but cannot be modelled in many programs. Shading by adjacent buildings and other parts of the same building tends to be time-consuming, even when possible. It's advisable for that reason to model windows that are in almost permanent shade as either north-facing or with a very low shading coefficient.

Keep in mind that for most simulations, each zone floats in space, with no designated geometrical shape or relationship to the other zones. The simulation has no idea if one part of the building shades another unless that information is input explicitly.

4.2.5 Daylighting

Installation of additional glazing and controls to automatically reduce electric lighting during sunlit periods is referred to as daylighting. The HVAC effects of glazing are easy to model in simulations; the reduction of electric lighting in response to varying levels of natural light is much more difficult to simulate. Even lighting design programs that model only daylighting make some serious simplifying assumptions, such as zero direct beam (versus diffuse) solar radiation.

In most building energy simulations, the only way to model the lighting effects of daylighting is to input a reduction in the peak lighting load, or a change in the lighting schedule.

Unfortunately, this method tends to underestimate the energy savings from daylighting controls. Natural light is usually brightest during warm weather, so daylighting reduces cooling energy requirements while having little effect on heating. Simulations that can only model daylighting controls by a change in the average lighting levels year round will tend to overestimate both heating and cooling.

For this reason, the modeler is advised to model a daylighting ECM with daylighting algorithms if they are available in the simulation being used for overall analysis.

DOE2.1 (versions C and later) does offer a daylighting program. All sunlight entering the space is assumed to be split in half, with half being evenly distributed over the ceiling and the upper half of the walls, and half being evenly distributed over the floor and the lower half of the wall area. The modeler inputs the minimum foot-candle requirement, and the location it is required. Specific architectural daylighting elements, such as light shelves, cannot be directly simulated by the program, so their attenuation of light entering the space may be evaluated by the modeler and included in the shading coefficient.[15]

4.2.6 Thermal Mass

The well known equation for heat loss (or gain),

$$Q = \text{U-value} * \text{Area} * (T_{in} - T_{out})$$

fails to account for solar gain or thermal lag. While such an equation is useful for sizing equipment, using worst case (design) conditions, it is less accurate for calculations of annual energy consumption. The strength of computer programs as tools to estimate annual energy consumption lies largely in their ability to account for solar gain and thermal lag, two factors which are not easy to model in hand calculations.

When the outside temperature and/or inside temperature is varying with time, the above equation is no longer correct for any given moment, because the heat loss or gain by the space is affected not only by current temperatures, but also by the history of previous temperatures. Given dynamic, (non-steady state) outside or inside temperatures, heat is stored in the walls and roofs, creating a thermal lag. The rate at which a change of

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[15] DOE2 function commands can be used to input the effects of various architectural elements. In buildings where daylighting control is a significant ECM, an architectural scale model can be created to generate data for the function commands.

outside temperature is registered inside the building is a function of the insulation value, and even more importantly, the weight of the wall or roof through which the heat is passing.

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.

Heavy buildings are likely to show higher savings from night flushing than light buildings. Heat absorbed by heavy walls during hot days is released to the atmosphere and to the interior of the building at night. Cool night air can be used to cool the building at night, displacing use of mechanical cooling that would otherwise be needed the following day.

The amount of energy required for morning warm-up or cool-down is greater in heavy buildings than in light buildings (unless the building is permitted to warm up or cool down after occupancy). Heat transfer decreases as the difference between the inside temperature and the outside temperature decreases. In a light building, the inside temperature approaches the outside temperature (during setback, setup, or night shut off) faster than in a heavy building with the same configuration and envelope U-values.

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, once again, if the modeler declines to select a method, she has, by default selected one. Quoting from the DOE2 Reference Manual, p.III.143 (reference 11),

> "To aid the user in deciding which of the above methods to use for HVAC calculations, the following can be stated. The <u>Precalculated Weighting Factor</u> method requires the least computer time and produces the least accurate results. The <u>Custom Weighting Factor</u> method is more accurate than the Precalculated Weighting Factor method, but requires more user-input effort and slightly more computer time. In the following cases use of the <u>Custom Weighting Factors</u> is suggested:
>
> - Buildings with thermostat set-back and/or set-up
> - All passive solar buildings
> - Masonry buildings
> - Heavy construction buildings
> - Any building in which it is necessary to define the distribution of the solar radiation within the building
> - 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. Other modelers have also noted a significant difference. **The modeler should follow the DOE2 reference manual recommendations concerning when to use custom weighting factors.**

In our work, we have found that switching from precalculated to custom weighting factors generally makes a more significant difference than changing the values of the keywords in the custom weighting input. Though we have not researched the question exhaustively, it appears that the most critical custom weighting input is the area and construction of interior walls (including floors and ceilings). As long as the modeler takes some care in her input of actual interior wall characteristics (area, construction, U-value, and location), her input for the remaining custom weighting keywords (FURNITURE-TYPE, FURN-FRACTION, AND FURN-WEIGHT) will have relatively little effect. She may find it convenient to enter an adiabatic wall rather than standard interior walls to adequately simulate the mass without affecting the inter-zonal heat transfer. She must also use layer-type input for exterior walls as opposed to the "quick" U-value input.

To use custom weighting factors, the modeler must input a FLOOR-WEIGHT of zero under the appropriate zone SPACE-CONDITIONS command. Reasonable input for the FURNITURE-TYPE keyword is HEAVY for a predominance of file cabinets, bookshelves, etc., and LIGHT for a predominance of chairs, softwood furniture, etc. Reasonable input for the FURN-FRACTION keyword is 0.2 to 0.3 for a typical office layout. Reasonable input for the FURN-WEIGHT keyword is 2 to 5 (lb/ft^2) for the typical office. Extensive file storage, heavy equipment pallets, library stacks, and so forth would prompt a higher input value.

DOE2 also provides a keyword for description of the portion of the solar radiation coming through the glazings in the space that is absorbed by the particular interior wall, floor, or ceiling under which the keyword is input. Generally, the DOE2 defaults for this keyword, SOLAR-FRACTION, are adequate. These defaults are: 60% of the incoming solar radiation is absorbed by the floor; the remaining 40% is distributed to the other named surfaces in the space, according to their surface areas. The modeler should override these defaults only when they are a clear misrepresentation of the actual geometry of the space.

4.2.7 Unconditioned Spaces

Heat transferred through surfaces (wall, floor or ceiling) between conditioned and unconditioned spaces can be modeled in either of two ways.

Method 1: The unconditioned space is input as a zone in the program, and the surface between the two zones is input as an interior surface.

Method 2: The surface between the two zones is input as an exterior surface, with provisions made to see that solar gain and the additional thermal lag of the adjacent space are roughly accounted for.

The advantage of the second method is speed: it doesn't require descriptions of the exterior surfaces or conditions of the unconditioned space.

The disadvantage of the second method is that it is difficult to model the thermal lag and solar gain characteristics of an unconditioned space as a simple surface. If, for example, an office is adjacent to an unheated warehouse, the effects of outside temperature changes will be transmitted through the warehouse to the office at a slower pace than they would be through a light exterior wall. There probably is some sort of exterior wall which the user could input which would approximate the same insulation value, thermal lag and solar gain characteristics as an attached warehouse, but it is not obvious what that surface would be like. The best that one can do when forced to use such a procedure is to make the interior surface which is modeled as an exterior surface heavy enough to roughly cover the effects of the thermal mass of the unconditioned space.

If there is a liberal flow of outside air through the unconditioned space, (as in most commercial garages), it is advisable to model the interior surface as an exterior surface, because the temperature of the conditioned space will be similar to the outside temperature. The surfaces should be described as north walls, or horizontal surfaces facing down (with a 180 degree tilt in DOE2), to minimize solar gain.

Do not model mechanical rooms, or the walls of such rooms. They are heated for free by the waste heat from HVAC equipment.

In small buildings, heat loss and heat gain between conditioned and unconditioned spaces can have a significant impact on the overall building energy consumption. In those cases, it may be worth modeling unconditioned spaces as zones. For large buildings, where the overall effect of the unconditioned space is small, the added detail work involved in modeling unconditioned spaces as separate zones is usually not worth the effort.

4.2.8 Interior Walls

It is often unnecessary to model an interior wall if the thermostat schedules for the zones on either side of the wall have identical setpoints and hourly profiles. Heat transfer does not occur unless there is a temperature difference.

However, there are two important exceptions to this recommendation. First, the modeler must take care that an interior zone with high internal heat gains during periods of HVAC non-operation has some means of transferring this heat to adjoining perimeter zones. Otherwise, these interior zones may see unoccupied period temperatures float absurdly high. This in turn can lead to improper morning pick-up loads and generally overestimated occupied period cooling loads.

Second, when thermal mass is important to a building's energy behavior, the modeler should elect to calculate custom weighting factors. She can simulate the mass of an interior zone by entering an adiabatic wall with surface area equal to that of the actual interior walls.

If there is a significant temperature difference across an interior wall for a significant period of time, the wall should be described in the model. There are typically two ways to describe an interior wall in a building simulation. Either the modeler is asked to identify the zone on the other side of the wall or to give the average temperature of the air on the other side of the wall.

Be sure not to input an interior wall under both adjacent zones. That would result in duplicating the heat transfer.

In a large building, very often the heat transfer between the conditioned spaces and an adjoining massive unconditioned space (such as a parking garage) will be insignificant relative to the other heat balances in the building. If the modeler decides not to model such a massive unconditioned space as a separate zone(s), the simplest approximation is to input under the adjacent zone an interior surface, and give the temperature on the other side of the wall as the average annual temperature.

Summarizing our recommendations, **model interior walls only if:**

> **(1) the thermostat schedules and setpoints for the zones on either side of the wall are not identical, or**
>
> **(2) the zone has significant internal gains during periods when the HVAC system is not operating, or**
>
> **(3) an adiabatic wall is needed to properly simulate thermal mass.**

4.2.9 Above-Ceiling Spaces

Most commercial buildings have spaces several feet high located between the ceiling of each conditioned space and the floor (or roof) above it. Such a space is unique in several respects. It gains heat from recessed fluorescent fixtures, loses and gains heat through the exterior plenum walls, and loses and gains heat from heating and cooling supply air ducts. In some buildings, HVAC return air travels unducted through these spaces. In these cases, the spaces are termed ceiling plenums. The temperature of the ceiling plenums is not thermostatically controlled.

Heat losses and gains which occur in a ceiling air plenum affect the amount of energy consumed for HVAC because they affect how much heat is lost or gained by the return air between the conditioned space and the supply fan. The above-ceiling space temperature also affects heat loss or gain through the ceilings of the space below and any floor above, and the amount of heat loss or gain from supply air ducts.

In most cases the walls of the above-ceiling space can be included in the zone directly below it. The walls, and heat from lights would be included in the inputs for that zone. The greatest inaccuracy of such an approach occurs for true return air plenums, and only when economizer cooling is operating or a high minimum outdoor air percentage is in effect. During these conditions, the heat of lights and heat gain through the plenum walls would still be modeled as entering the space rather than being dumped outside before entering the supply fan and coils. Energy consumption for cooling tends to be low during periods of economizer cooling, so this inaccuracy is not large. However, the inaccuracy may be significant in the case of a high minimum outdoor air percentage since this condition occurs during all hours of HVAC operation.[16]

4.2.10 Heat Loss to Ground

Heat loss through surfaces in contact with the ground is only a very small part of the overall heat loss for a multiple story commercial building. For such a building, accuracy is not very important, though care should be taken to avoid gross overestimates. In single-story commercial buildings, heat loss to ground can be a significant portion of the building's total heat load.

The temperature of the ground is more stable than temperature of the air, particularly as depth increases. But the temperature of the soil is significantly affected by the presence of the building. One cannot simply say that the ground temperature is usually around 50°F so the underground wall or floor heat loss can be modeled as,

$$Q = U \times A \times (T_{in} - 50 \text{ degrees})$$

because in fact, during the heating season, the soil under a heated building and around underground walls is warmer than the normal ground temperature. Use of this type of calculation, though, is common in the more simple software packages, and tends to overestimate heat loss to ground.

According to the ASHRAE Handbook of Fundamentals (1989, page 25.6), heat loss through underground floors and walls is best understood as flowing from the building interior, through the ground to the outside air. The ground acts as thermal mass and insulation. The longer the path through the soil from the building to the outside air, the lower the heat loss. Heat loss therefore decreases with depth and distance from the building's perimeter.

If a simulation uses the full floor area to calculate heat loss from a floor in contact with the soil, it is best to either input the linear footage of the floor's perimeter where the simulation asks for area, or to input an artificially low U-value. The low U-value is the better approach if the floor

[16] If the DOE2 modeler feels that for a specific building it is important to account for the heat exchange between the return air stream and the plenum walls, she can model the plenum as ZONE-TYPE=PLENUM and, in the SYSTEM command for the adjacent conditioned zone, model the RETURN-AIR-PATH=PLENUM-ZONES.

is likely to be important to the building thermal mass behavior or if the floor area input is also used for calculating other information such as infiltration or zone equipment loads. The DOE2 modeler should use the actual floor construction for calculation of the custom weighting factor parameters. The artificial U-value can be calculated as,

$$U\text{-}EFF = U_{actual} \times (\text{length of perimeter/floor area})$$

4.2.11 Weather

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. Edge put a lot of time and money into monitoring actual weather at the building sites. However, in our modeling we have found that it rarely made a significant difference in annual end-use energy consumption whether we used the site-gathered weather file or the Typical Meteorological Year (TMY) weather file for the closest available site. Typically we would find about a 5% or less annual difference between simulations using the two types of weather files. Monthly differences were, of course, more noticeable. But for design-phase modeling, monthly energy consumption is usually not of prime importance.[17]

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. 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.

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[17] The Corson report (reference 3) also generally backs up our experience. In the sensitivity study phase of that work, Corson found that, depending on the software used, switching the weather file between Eugene, Oregon (a site with relatively moderate summers and winters), and Richland, Washington (a site with relatively extreme summers and winters), usually resulted in less than a 10% difference in the estimates for annual energy use. (However, most of this difference is in the heating end-use.)

4.3 INTERNAL LOADS

The modeler must estimate end-uses such as equipment (also referred to as "plug-loads" and "receptacles") and lighting both to account for the power consumed by the end-use and for the cooling (or in the case of refrigeration, heating) load imposed on the space by the end-use. In general, there are three types of input parameters associated with such end-uses. These are peak power consumed, a profile (schedule) of fraction of peak power used in any given hour, and a fraction of hourly energy consumed that results in a load to the space in which the equipment is located. Following is a generic discussion of these three parameters. Section 4.3.1 begins a more detailed discussion of these parameters as they apply to plug-loads, computers, lighting, refrigeration, and cooking.

1) Peak Values

Rated, or peak, consumption rarely occurs on most pieces of equipment. **The modeler should only give the rated equipment capacities if the simulation offers a load factor (average/peak load fraction), or calculates the equipment load input hourly using an operating schedule profile that permits fractional amounts.** Note that even the peak consumption in a weekly equipment schedule is generally not equal to the rated equipment capacity, because the weekly peak used in computer simulations represents only the maximum hourly average that occurs in a typical week. For copiers and printers, the equipment peaks may occur for only a half a minute at a time and may far exceed the average during any hour.

2) Schedules

We recommend that the modeler use Table 13-3, Building Schedule Percentage Multipliers, in ASHRAE Standard 90.1-1989 (reference 8) as the first source for building schedules. This is reproduced in appendix III for the modeler's convenience. However, we further recommend that these multipliers be modified in certain circumstances--as discussed in sections 4.3.1 through 4.3.3. The modeler must use good judgement in application of recommended multipliers in the table. For instance, the warehouse schedules are not appropriate in general to refrigerated warehouses. Similarly, the retail schedules are not appropriate to refrigeration in grocery stores.

If believable information concerning schedules is available from the owner or design team, the modeler should consider this information. For instance, the owner of a grocery store may intend 24 hour operation, but the Table 13-3 schedule states 12 hour operation. In this case it is appropriate to input the owner's intended schedules.

For new construction, the modeler should be aware that, even if the input makes reasonable assumptions about load schedules, the simulation results may be far from actual building energy consumption when the building is only partially occupied. Partial occupancy is the normal state for buildings that are not owner-occupied during their first months or years. So, unless the modeler specifically attempts to model this start-up period, she should not expect the simulation estimate to match billing data during this period.

3) Percent of Heat to Space

The objects located in a building may affect the energy consumption of the building in two ways: they may consume energy directly, and 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 generally affects both. This section addresses internal gains by such equipment, including office equipment, computers, refrigeration, and task (not ceiling) lighting.

If a piece of equipment is completely enclosed by the building and has no exhaust stack or vent, the equipment heats the building at the same rate it consumes energy to run, even if the equipment (such as a typewriter) has a primary purpose other than heating the building. Energy is conserved, and any machine ultimately dissipates mechanical energy in the form of heat as a result of friction.

If equipment has an exhaust hood or vent, some of the energy consumed directly by the equipment escapes up the stack, and the amount of heat contributed to the space is less than the amount of energy consumed directly by the equipment.

The modeler needs to find out how the simulation addresses internal gains. Some programs assume that the heat to space equals the energy consumed by the equipment, other programs ask for the percent heat to space. Some programs ask for two inputs: one to cover electric consumption by equipment, the other to give the amount of heat to space. Most programs offer an input for equipment that has no effect on the HVAC. If a program assumes the heat to space for internal equipment equals the electricity or other fuel consumed, the portion of the equipment load that is vented directly by exhaust hoods can be entered under the program's option for modeling external equipment. Such artificial inputs are difficult to track and should therefore be used only for important loads.

Chapter 26 of the ASHRAE Handbook of Fundamentals, 1989, is a good source of information concerning the amount of energy consumed by various sorts of equipment, and their effect on HVAC requirements.

4.3.1 General Plug Loads

Peak, or Connected, Load:

As the connected load for lighting drops, the connected load for office equipment and computer is rising dramatically. Old rules of thumb, such as .5 watts per square foot for plug in loads are no longer even approximately correct. Information about current use patterns are available from several end-use studies.

These studies indicate that, given no actual building data, an operating

power density of 1.0 to 1.5 W/ft^2 for office equipment and personal computers is appropriate.

One study (ref. 4) suggests that the actual plug usage in six large office buildings was over five times higher than predicted. Modelers' estimates ranged from 0.64 to 1.73 Kwh/ft^2-yr, but sub-metered data indicate 7.2 to 10.7 Kwh/ft^2-yr. Most of this discrepancy apparently was due to the assumption for peak power density.

Schedules:

According to recent end-use monitoring studies, power consumption by office equipment during occupied hours far exceeds what has generally been assumed by energy analysts. **Results of the ELCAP study suggest that, as a general rule of thumb, equipment consumption during unoccupied hours should be set at no less than 30% of the peak load.**

Monitoring data from the Energy Edge Program, and ELCAP data (reference 5) indicate that unoccupied equipment usage in some building types lies in the range of 40 to 70% of occupied usage. ELCAP data gives the following ratios of unoccupied to occupied (peak) weekday equipment usage:[18]

BUILDING TYPE	UNOCCUPIED/ PEAK RATIO	PEAK W/FT^2
Office	**0.40**	**1.50**
Retail	**0.30**	**0.76**
Grocery	**0.67**	**1.04**
Restaurant	**0.36**	**2.13**
Warehouse	**0.50**	**0.35**

We recommend that these values for unoccupied equipment fraction be used during design phase modeling unless there is specific design information to support a different assumption. The modeler may also wish to use the ELCAP values for peak power density when she lacks more detailed design information.

[18] The ELCAP "other loads" end-use does not include refrigeration or food preparation equipment. Also note that ELCAP data represent an average among all monitored buildings in a given building type. Thus the data for groceries are an average of stores that may operate for anywhere from 12 to 24 hours.

4.3.2 Computer Rooms

In office building simulations, personal computers must be distinguished from large computers. Large computers are usually on 24 hours a day, served by their own HVAC systems. On the other hand, personal computers are often shut off during unoccupied hours, and are served by general HVAC building systems that cycle supply fans at night.

If internal gains from mainframe computers are averaged into the general equipment watts per square foot, the building heating loads are likely to be underestimated, and the 24 hour operation of the computer HVAC will not be well represented unless the entire building is operating on a 24 hour schedule.

The modeler is advised to distinguish between large computers and small computers when developing equipment load inputs, and to create a separate zone and air distribution system in the simulation for any significant computer rooms.

As with any attention to accuracy, this precaution can be ignored if the load in question is too small to warrant detailed treatment. Also, in new construction, a computer room that has no interactions with the rest of the building can be completely left out of the model if it is unaffected by any ECMs.

The effects of large computers relative to general office equipment and personal computers can be assessed by examining the following ELCAP end-use data.

End-Use	Annual Consumption, kWh/ft^2-yr	Equipment Power Density, W/ft^2
Large Offices (>30,000ft^2):		
General Office Equipment	0.84	0.66
Personal Computers	1.07	0.64
Large Computers	1.98	0.23
Small Offices (<30,000ft^2):		
General Office Equipment	0.93	0.73
Personal Computers	0.46	0.27
Large Computers	1.58	0.18

In most other building types examined, consumption by large computers was negligible.

4.3.3 Lighting

Schedules:

ELCAP monitoring studies show that lighting loads, like equipment loads, are higher during unoccupied hours than has generally been assumed by modelers. The ELCAP results (reference 5) indicate that **the following ratios of unoccupied to occupied (peak) weekday lighting usage should be used unless building-specific data are available:**

BUILDING TYPE	UNOCCUPIED/ PEAK RATIO	PEAK W/FT^2
Office	**0.29**	**1.56**
Retail	**0.10**	**1.44**
Grocery	**0.58**	**2.00**
Restaurant	**0.14**	**1.67**
Warehouse	**0.06**	**0.68**

The modeler may also wish to use the ELCAP values for peak power density when she lacks more detailed design information.

Heat to Space:

Building simulations track both the direct electric lighting consumption, and the indirect effect of lighting on HVAC requirements. The direct electric consumption is input either as watts per square foot, or watts per zone.

For surface mounted or suspended fixtures, the electricity which is used by the lights ends up as heat in the conditioned space, increasing the cooling load or decreasing the heating load accordingly. Recessed fixtures may loose heat to an unconditioned attic in small buildings, or to an unconditioned air plenum in large buildings. If the attic is well vented, or if the HVAC system in the large building uses an air plenum return, part of the heat generated by lighting may escape from the building without contributing to HVAC loads. For that reason, most computer programs ask for the fraction of the heat from the lights that goes into the space. Other programs ask whether or not the lighting is "vented".

The most common method of cooling fluorescent fixtures is to pass the return air through them to an air plenum above the ceiling tiles. In some cases the air is passed through slots on the side of the fixture; in other cases the air is passed though the interior of the fixture to a ducted return. The percent of heat from the lights which goes to the space is a strong function of the fixture design, the air flow rate through each fixture, and whether or not there is ducted return. With a VAV system, the air flow rate varies. Some fixtures experience a greater air flow than others due to their location relative to the fans.

For these reasons, the percent of heat from the lights which goes to the space is a rough estimate for vented light fixtures. It is generally assumed that somewhere between 35% (for some ducted return air fixtures) and 80% (for plenum return) of the heat goes to the space from fixtures with vented return. A 1988 study by S.J. Treado and J.W. Bean gives extensive estimates of space heat gain for various configurations of fluorescent lighting fixtures (reference 17). For incandescent light fixtures and fixtures vented to supply air, the fraction of heat to the space is roughly one.

4.3.4 Refrigeration

Refrigeration is the largest energy end-use in grocery stores and refrigerated warehouses. It can also be a significant end-use in other building types. According to ELCAP data, central refrigeration equipment in grocery stores consumes, on an average, 43 kWh/ft^2-yr.

Most software packages either do not simulate commercial refrigeration, or simulate it poorly. DOE2.1 (versions C and later) is an exception, offering the capability to simulate many characteristics of commercial refrigeration systems and to investigate many possible refrigeration ECMs.

Modeling Refrigeration with DOE2:

We used DOE2 to analyze a large grocery in the Energy Edge program. The DOE2 estimate of the refrigeration end-use consumption was within 5% of the estimate of the refrigeration system manufacturer, who used software designed for and tested against their equipment. We know of no other comprehensive energy simulation software that can claim this flexibility or accuracy.

For this reason, we recommend that modelers use the DOE2 program for modeling any building that contains a significant amount of commercial refrigeration equipment. The input for this end-use can be quite complex. It typically requires a large amount of supporting hand calculations. The modeler should carefully calculate case loads, auxiliary loads (anti-condensate heaters, evaporator fans, and case lights), and zone loads. Controls must also be carefully considered. Carelessness in any of these inputs can invalidate not only the refrigeration simulation, but also the simulation results for the entire building since refrigeration systems usually interact strongly with the building HVAC.

We offer a few specific tips concerning DOE2 refrigeration input:

- Anti-condensate heaters - Split the rated heater kW between the refrigerated case and the space in which the case is located. Based on manufacturer recommendation, we have directed 85% of the kW to the case and 15% to the space. This accounts for the full heater wattage, but attributes a more reasonable amount to a refrigeration load to the case.

- Case lights - Split between case and space. Based on manufacturer recommendation, we have directed 80% of the kW to the case and 20%

to the space.

- Condenser type - The default is water. If you don't want this, be sure to enter air.

- Heat recovery - Consider how heat recovery interacts with floating head pressure control. Both control strategies are common practice in large refrigeration systems. In some systems, the condensing temperature may be elevated to permit heat recovery. In others, the savings of floating head pressure control take precedence. DOE2 simulates only the former case. In either case, if there is no heating load in the space, then the head pressure usually is allowed to float down to about 10 degrees F above the ambient temperature (minimum, about 60°F).

- System definition - The modeler should try to obtain the manufacturer's R/S sheet (refrigeration schedule) to aid her in defining the system input. Information is also often available from case manufacturers about electricity consumption and heat gain per linear foot of case. Hand calculations can also be performed using the compressor capacities, assumed load factors, and standard COP's as a function of case temperature.

  Whenever possible, the types and linear footage of refrigeration display cases, and capacity and location of compressors should be obtained from audit data or design drawings for use in the hand calculations necessary to develop refrigeration inputs.

  Sometimes though it is not possible to obtain actual design or as-built information. Architectural Energy Corporation has prepared a draft handbook for analysis of ECMs (reference 18). In this handbook they have provided some very useful tables for analysis of commercial refrigeration. Included are typical case design loads per lineal foot, energy consumption by auxiliaries per lineal foot of case, and default compressor EERs for different temperature cases.

  Since DOE2 allows only three refrigeration systems per zone, it is often necessary to combine the actual systems to meet the three system limitation. Case (or walk-in) location and evaporator temperature should be the main considerations for system combination.

- Pull-down loads - Sometimes grocery walk-in coolers are stocked with warm product. The refrigeration load related to bringing the temperature of this product down to the desired temperature is called the "pull-down load". This load can represent a major portion of the total refrigeration load in some extreme situations. Therefore, it is important that the modeler try to determine whether, and to what degree, such a situation exists. She may do this through audits of existing buildings or through interview of the operators of new buildings.

  DOE2 has no capability for direct simulation of pull-down loads. If the modeler has determined that a specific building will have a significant pull-down load, she should use hand calculations to determine the load. She should then add the load to the appropriate REFG-ZONE-LOAD and input an offsetting SOURCE-BTU/HR in the loads section.

Modeling Refrigeration with Other Software Packages:

The analyst should use DOE2 whenever simulating any building in which commercial refrigeration can be expected to be a major energy end-use or where refrigeration ECMs are considered. This would include, at a minimum, all grocery stores and refrigerated warehouses. But sometimes the analyst encounters buildings such as restaurants or hotels in which refrigeration is a relatively minor end-use. In these cases it is permissible to use another simulation program.

When using a simulation that doesn't model food refrigeration equipment as such, the modeler has to manipulate other inputs to approximate direct consumption by refrigeration equipment and its effects on HVAC. HVAC effects can be the most difficult to represent.

Refrigeration equipment generates heat at the condenser, but it produces a cooling effect next to the refrigeration case.

If the condenser is not attached to the body of the refrigerator (and the condenser is located outside the zone where the refrigeration case is located), the space heat contribution at the condenser will be greater than the value of the electricity consumed by the equipment, and the space cooling contribution at the body of the refrigerator will also be greater than the value of the electricity consumed by the equipment. If the compressor is located in an unconditioned area, heat from the compressor can be ignored except when considering heat recovery options.

Self-contained refrigeration equipment is relatively simple to model because the net effect on the space will be a heating effect equal to the electricity consumed by the unit. Where most of the compressors and condensers are located outside the conditioned space and heat recovery is performed mechanically rather than via air flow through the compressor room, the net effect of the refrigeration cases on the spaces they are in is a negative internal gain.

When the analyst must resort to hand calculations, the direct energy consumption by the compressor, and the effect on the HVAC energy balances can be roughly calculated as follows:

1) Electricity consumed by the compressor, hourly =

   (rated capacity in kW / COP) x load factor.

2) Heat removed from the space around the refrigeration case, hourly =

   (rated capacity x load factor) - E_{aux}

3) Heat rejected at the condenser, hourly =

rated capacity + electricity consumed by the compressor ≈

rated capacity x (1 + 1/COP) x load factor.

where E_{aux} is the electricity consumed each hour by strip heaters and display lights in the refrigeration cases served by the compressor; and the load factor is the average actual load on the compressor divided by its rated capacity.

These load factors are useful for general reference, but may not be accurate if refrigeration ECMs are being considered, or if an existing building has already undergone extensive refrigeration remodel. The loads on compressors are decreased by decreasing the store ambient temperature and humidity, reducing the amount of energy consumed for case lights and defrost, the existence of case doors or strip curtains, or the orientation of the case (tub vs vertical shelves). Floating head pressure controls and parallel piping of multiple compressors also dramatically lower compressor loading.

If any of these features has been retrofitted into an existing building, the use of the standard compressor load factors may overestimate consumption. For that reason, on retrofit projects, it is helpful to discuss with the store operator a rough history of the refrigeration systems, and use low load factors if it seems appropriate.

According to a study done by Seton, Johnson and Odell for the Oregon Department of Energy, a load factor of 0.8 is typical of compressors under normal operation. A load factor of 0.6 is typical of compressors working on a refrigeration case which was originally designed to be open, but has been retrofitted with a cover to save energy.

The same study gives the following COPs as typical:

1.0, for ice cream cases (-20 to -15 degrees F)
1.2, for low temperature cases (-5 to 0 degrees F)
1.75, for medium temperature cases (30 to 45 degrees F)

However, if manufacturer's COP ratings are available for a specific installation, these should be used.

Inputs to the simulation will depend on the type of inputs permitted by the simulation. If the program accepts negative internal gains, the heat removed from the space by refrigeration can be easily described once the above hand calculation has been performed. Otherwise, a negative internal gain is most easily modeled by creating a fake internal wall next to an air space of fixed temperature, with a UA delta-T equal to the hourly heat loss to the refrigeration cases.

Inputs for the direct electric consumption of food refrigeration equipment also depend on the types of inputs offered by the program. Many simulations assume that any internal equipment loads create an internal HVAC heat load equal to the direct equipment consumption. Description of equipment that actually causes a net cooling effect on the space needs to be performed carefully in such models. Once the cooling effect has been described, as recommended in the above paragraph, the direct electric consumption for refrigeration can be calculated by hand and added to the simulation results, or can be input to the simulation as equipment outside the building conditioned space.

If a simulation does not offer refrigeration models, ECM savings can be sometimes approximated by hand, and the resulting impacts on equipment consumption HVAC can be input to the simulation. As an example, savings from reduction in case lighting or electric strip heaters can be calculated as:

> Savings = (change in direct consumption by the lighting or electric strip heaters) x (1 + 1/COP).

4.3.5 Cooking

Cooking equipment consumes a significant percentage of the total building consumption in restaurants. According to ELCAP data (reference 10), food preparation equipment in restaurants has an average power density of 9.6 watts per square foot (continuously operated, plus 1.89 watts per square foot of intermittently operated) and consumes on the average 9.16 kwh/yr per square foot. These figures cover only electric equipment. Gas cooking was also in use in many of the buildings examined.

Note that the electric consumption by cooking equipment is generally less than the rated capacity, because the electric consumption is regulated by the cooking requirements at any given time. Note also that the cooling load imposed by the cooking equipment is less than the electricity or other fuel consumed directly if it is vented to an exhaust hood.

Page 26.10 of the 1989 ASHRAE Handbook of Fundamentals gives recommended values for heat gain to space from various types of cooking equipment, with and without an exhaust hood.

In dining areas, a significant amount of latent and sensible heat are given off by the food served. ASHRAE recommends assigning 50 Btu/hr of internal load (25% latent and 75% sensible) for each meal served (Fundamentals, 1989, page 26.9).

5. HVAC SYSTEM SIMULATION

5.1 SYSTEM SELECTION FOR SIMULATIONS

All energy simulation programs offer the modeler some latitude in HVAC system selection. The modeler will be offered a menu including systems such as variable air volume (VAV) with reheat, fan-powered VAV, single zone packaged rooftop, multi-zone, dual-duct, heating and ventilating only, two-pipe hydronic with fan coils, and so forth.

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. Remember that the Corson study showed that choice of system type was the single most important driver of energy consumption.

The modeler should carefully question the default simulation of system type. What control options are available for each system type? Is reheat being assigned automatically if multiple zones are assigned to a "single" zone system, or does the model assign a separate single zone system assigned to each zone? Does the default dual duct system have the same number of supply fans as the actual system? Is the default dual duct system supplying a constant total flow to each zone or a variable total flow? Are the supply fans continuously on, on during occupied hours, or cycling on at all times? Is the reheat source electric or gas? Does the system type allow outside air ventilation? And so forth, ad infinitum.

5.2 HOW AIR DISTRIBUTION FITS INTO THE OVERALL SIMULATION

In a computerized building energy analysis, the amount of heating and cooling required by a space is typically calculated by a section of the program called "loads". The space loads account for envelope heat transfer, solar gains, and internal gains.

Once the loads section of the program is completed, the results are sent to a section of the program that models the HVAC air distribution systems. In this program section the ventilation air load, the coil heating and cooling loads, the zone reheat and mixing loads, the supply air flow rate, and fan energy consumption are calculated. (Reheat and mixing loads refer to loads which may occur as a result of the need to serve several zones at once, either by reheating mechanically cooled air or by mixing heated and cooled air. They are loads which would not occur if single zone systems served the same space loads.) If the HVAC equipment is packaged (i.e. not served by a central plant hot and chilled water system), then HVAC energy consumption will also be calculated in the systems section of the program.

However, if the HVAC equipment is not packaged, then the "system loads" are sent on to a section of the program that models the boilers, chillers, pumps, cooling towers, and so forth. That section of the program includes central plant equipment efficiencies and part load curves, and calculates the total HVAC energy consumption.

5.3 CAPACITY, LOAD FACTORS AND PART LOAD EFFICIENCIES

5.3.1 User inputs

When entering capacity, power, or efficiency for equipment it is important to know what the simulation is going to do with it. Is a fan kW going to be applied to a part load curve, cycled on or off, or taken at face value for the entire time the fan schedule says "on"? Is a lighting or equipment kW going to be multiplied by a load factor or an hourly fraction in a schedule somewhere? Is a chiller model going to take a straight user-input average efficiency, or is the loading going to be compared to the capacity and used to find the part-load efficiency?

Constant volume fans and pumps are usually sized to run at about 80% of the nameplate hp. In existing buildings the fans and pumps may be running well below capacity. For a constant volume supply fan or pump, the modeler should input a kW roughly equal to what the fan or pump is actually consuming since the simulation will use that input as the average (constant) consumption.

Boiler and chiller capacity inputs should reflect the nameplate rating, not the actual average consumption since the simulation will in most cases apply a part load multiplier to the rated power. This is particularly important for retrofit projects where the chillers are significantly oversized.

5.3.2 Default Capacities

If the modeler has access to the actual designed HVAC equipment capacities, it is always better to use these capacities than to let the program size the equipment.

In modeling existing buildings, use of default values for sizing HVAC equipment may lead to inaccuracy in modeling existing buildings if the system is oversized or undersized for the current application. However, sometimes the modeler may have inadequate knowledge about the existing building equipment, and thus must resort to auto-sizing of equipment (i.e. program defaults). If she does this with the baseline (existing) building model, it is important that she not continue the use of autosizing when analyzing ECMs. Once the program has selected equipment size for the baseline building, these sizes should be input as the equipment sizes for succeeding ECM simulations (unless an ECM specifically addresses equipment size). Use of defaults for ECM runs in retrofit projects will result in simulation of a comprehensive HVAC redesign that is not occurring in reality.

5.3.3 Sizing Factors

In existing buildings, the capacity of equipment generally has been selected on the basis of design outside temperatures dictated by code. Additional capacity for morning warm-up and severe weather is accounted for by heating and cooling sizing (or safety) factors. Most computer simulations allow the modeler to input the sizing factors and the design conditions.

These sizing factor inputs can be important when the modeler allows the program to auto-size equipment. If the modeler inputs equipment capacities, however, the sizing factors are irrelevant. In our experience, designers use heating equipment sizing factors of 1.1 to 1.5, depending on the type of equipment and control, severity of climate, and inclination of the client for legal adventures. Generally cooling equipment sizing factors are 1.0 to 1.2, since warm-up is not a consideration.

The DOE2 modeler has access to another input that affects auto-sizing of HVAC equipment. This is the SIZING-OPTION keyword in the systems module ZONE command. DOE2 defaults to a FROM-LOADS value for this keyword. This default uses the LOADS single space temperature input for both heating and cooling modes, resulting in an overestimate of peak loads. It also assumes unconditioned spaces and plenums to be at a constant temperature. If the modeler is depending on the program to size her equipment, she should generally override the default with the ADJUST-LOADS value.

5.3.4 Part Load Curves

Most energy simulation software uses part load curves to determine HVAC equipment input power at those times when the equipment experiences a load less than its rated capacity. Most equipment operates in a part load condition most of the time. Chillers, fans, boilers, packaged air conditioning equipment, refrigeration equipment, and so forth are all affected by part load operation. In most cases, the equipment efficiency is different at the various degrees of part load than at full load. Sometimes the equipment is more efficient at part load than at full load; but in most instances, it is less efficient.

Energy simulation can be strongly affected by part load curves. The energy consumption of a piece of equipment at a given part load is a function of three numbers: the full load or rated capacity of the equipment, the part load (i.e. the percent of full load), and the efficiency multiplier for that specific part load. We have already discussed rated capacities. Sometimes these are input by the modeler based on design or audit information, and sometimes these are automatically calculated by the program to satisfy the calculated peak loads plus a specified or default safety factor. The accuracy of the part load function depends on the accuracy of the rated capacity input.

Most simulation programs do a competent job of calculating part load fraction. This is simply the equipment load (directly or indirectly related to heating or cooling load) at a given time divided by the full load capacity. However, not all programs competently simulate part load performance. Some programs hide their assumptions about part load performance. In others, including DOE2, the modeler can directly input part load performance.

Part load curves vary significantly depending on the type of equipment and control. The curves can be linear, quadratic, cubic, and so forth. If an ECM directly affects a part load curve, the modeler should ensure that the affected equipment is described properly in the simulation. She should carefully examine the output reports and use hand calculations as an adjunct to check the simulation and to analyze part load efficiencies that can't be easily simulated. Condenser water reset, chilled water reset, and variable-pitch axial vane fans will create part load consumption patterns that are likely to be lower than those calculated in simulation unless artificial inputs are used.

5.4 CONTROLS

Controls are one of the most important factors in determining energy consumption. Theoretical savings for controls ECMs are easily overestimated. Accurate predictions of energy savings can only be achieved if controls 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.

5.4.1 Sequence of Operations

The action of a set of controls is best defined by a sequence of operations. (See the example in appendix IV.) 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, either by the analyst or by another party in the project.

Unfortunately, it is often very difficult to get manufacturers to document how their controls work. Sometimes the information is viewed as proprietary. Other times the manufacturer's representatives don't themselves understand the control logic being used. Designers and building owners are also sometimes vague about what the functions of a proposed control system will be.

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 contract drawings or from the controls contractor.

5.4.2 Role of the Analyst

Communications between the analyst and the other parties in any project involving controls are important to achieving consistency between estimated and actual ECM savings. We note here several of the activities that are critical to successful controls ECMs. Some of these activities are typically the responsibility of one of the project contractors. But if the analyst sees that a critical task is not being done, she or someone on the energy team should step in.

1) Promote Development of a Clear Sequence of Operations.
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. In these communications, the analyst will need to find out from the designers and manufacturers what is being proposed, and may also need to inform the other parties involved in the project which aspects of the controls are most critical to 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 analyst.[19] These specifications should include sequences of operations to be performed by the new controls. The sequence of operations should not be left up to the contractor developing the controls

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[19] A performance specification differs from a full design specification in that the performance specification gives enough design information to thoroughly define the design intent. This should include a general description of equipment required, functions to be performed, efficiency requirements, general controls sequence of operation, start-up scope, and general requirements for documentation and training. The full specification goes well beyond this, giving complete details of equipment to be purchased, codes to be followed, start-up procedures, submittal requirements, and so forth. See appendix V for several examples of performance specifications.

software, to be uncovered by the owner for the first time after installation.

2) 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, a description of 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 customer needs to understand from the start that the controls cannot operate effectively unless the setpoints and schedules fed to it are good. User-friendliness of controls also is extremely important. Unfriendly controls are ignored, bypassed, or otherwise improperly used.

3) Post Installation Evaluation.
For expensive control ECMs projects, the analyst should meet with the owner and the designer during the design phase and discuss how the building owner will be able to tell whether or not the controls system is working after it has been installed. It also may be worth adding a few monitoring points if necessary to assure that the performance of the new controls can be evaluated after it is in (e.g., trend log capability for flow, duct static pressure, and fan consumption to evaluate VSD control on large motors).

5.4.3 The Building Operator's Effect

The computer simulation is not equipped to model the building operator's mind. This is a serious shortcoming. Building controls include an automatic component and a manual component. The two are linked by the mind of the building operator.

Where sophisticated controls are installed, the actual building operation will usually be limited by the ability of the building operator to understand the controls and the building. For these cases, a computer simulation will often underestimate consumption.

On the other hand, the baseline run for a large building with few automated controls will tend to overestimate the HVAC consumption since the building operator often will be much smarter than the automatic control logic at his disposal. He or she will be constantly manipulating the controls according to a higher order of understanding than any of the formal logic they can offer. Most building operators will perform manual mixed air and supply air temperature resets seasonally if possible, and will turn off the boilers and chillers in a pattern that minimizes reheat, even where there is some compromise in comfort. This is particularly true of existing buildings with older, simpler control systems.

This tendency to underestimate the efficiency levels achieved using simple automatic controls and overestimate the efficiency levels achieved with complex automatic controls can result in excessive estimates of savings for controls ECMs.

To minimize inaccuracy for retrofit projects, the analyst should visit the building at night to see what equipment is on (lights, fans, pumps, etc.). She should also interview the building operator.

Malfunction:

Computer simulations are poorly equipped to model malfunctions. Inaccurate sensors, controls wired in backwards, and malfunctioning dampers and valves all can have a dramatic effect on the accuracy of baselines for retrofit projects, and actual ECM savings in both new and existing buildings.

5.4.4 Specific Control Operations

Warm-up Controls:

The amount of time it takes for the space to come up to the occupied setpoint depends in the simulation, as it does in real life, on the thermal mass of the building, the capacity of the heating system, and the difference between the temperature of the space prior to occupancy, and the occupied setpoint.

Most programs begin to simulate warm-up at the hour that the thermostat setpoint changes from the unoccupied to the occupied value. If the space does not reach the occupied setpoint in the first hour of occupancy, the simulation will generally begin to keep track of "hours of loads not met". Loads not met during other parts of the day are cause for concern, but one or two hours a day of loads not met during winter morning warm-up is usually not a concern.

If a building warm-up begins either via manual or automatic controls before occupancy, the "occupied" setpoint should not be assigned to occupied hours only. The computer simulation that waits until the change from setback thermostat setpoints to occupied heating space temperature setpoints will tend to underestimate heating consumption.

Unless a simulation is explicitly modeling optimum start, either (1) input a change in thermostat setpoint an hour or two prior to occupancy or (2) input a thermostat setting schedule that ramps up the heating setpoints prior to occupancy. A ramp of 3 F per hour is typical for heat pumps, 5 F for other heating equipment. The ramp brings on the fans and the heat earlier on cold days than warm days, as does optimum start, but without the fine tuning afforded by optimum start self-correction capabilities.

DOE2 offers an optimum start option, but many programs do not.

Heat Pump Setback:

Heat pump back-up heat (typically electric resistance) is usually staged to come on when the actual space temperature drops more than about 4 degrees below setpoint (or a lesser temperature difference over a protracted period of time, if integral controls are used). Use of a simple setback thermostat would thus bring on the back-up heat on every winter morning as soon as the thermostat setpoint changed back to its occupied setpoint.

Some of the "intelligent recovery heat pump thermostats" create a thermostat setpoint ramp with a slope of 3 degrees per hour so the heat pump may have a chance to meet the warm-up load during mild weather without use of back-up heat. (Other intelligent recovery thermostats alter the slope of the ramp somewhat on the basis of historical data, or apply a more complicated algorithm. In general, it is difficult to obtain information on the more complex methods.)

Computer simulations can be programmed with a thermostat setpoint ramp, if the simulation offers a thermostat setpoint schedule. Some of the simpler programs limit the heat and cooling setpoints to one set during unoccupied hours and one during occupied. These programs generally do a poor job of simulating heat pump setback.

Perimeter Heat:

Perimeter heat is a wild card in computer simulations since the relationship between air distribution system zoning and perimeter heat is often complex and difficult to quantify.

Air distribution system perimeter zones are usually 12 to 15 feet deep. In a computer simulation, the heat gain from lights and equipment for that full 12 foot depth is subtracted from winter heat losses through the windows and exterior walls when the HVAC load is calculated. By contrast, perimeter heating systems - hot water, steam, and electric baseboards - are designed to meet the window losses right at the inside window surface. A properly operated perimeter heating system will in this way tend to increase comfort while reducing efficiency (assuming the baseboard heat source is less efficient than the air system source). Simulations add the envelope heat losses to the lighting heat gains for the perimeter zones. Thus simulations tend to underestimate heating consumption by canceling window heat losses with internal gain from lights.

Perimeter heating systems in large existing buildings are often controlled as a function of outside air temperatures. In many cases, the air distribution system may actually be cooling air that is overheated by the perimeter heat. When that occurs, the computer simulation will dramatically underestimate heating consumption. During mild weather the net heat load on a 12 foot perimeter may be zero (heat loss through the glass being compensated by heat gain from the lights), while the heat loss through the glass is still significant.

In most software packages, baseboards are modelled more or less like reheat. Since nothing can be done about the inaccuracies mentioned above, it is only necessary to differentiate baseboards from reheat if they are served by a different fuel, if they have outdoor air reset, or if they are controlled to provide heat when the fan system is not on.

Economizer controls:

Computer simulations of economizers generally ask for the high limit shut-off temperature and whether the control is based on dry bulb or enthalpy sensors. Humidity sensors are notoriously unreliable, and humidity generally is not an important economizer performance parameter in the northwest. Therefore, there is reason to promote use and simulation of dry bulb economizer controls. The modeler should note that simple non-differential dry bulb and enthalpy controls open the outdoor air damper when the outdoor air temperature or enthalpy is less than the control setpoint. To simulate such control, the modeler must enter that setpoint. Otherwise the program may default to differential control, comparing outdoor air to return air. This usually results in an underestimate of cooling energy consumption.

In some large buildings, the building operator closes the outside air dampers when the chiller is on during mild weather, because the chiller does not operate well at low loads. Thus the analyst should address chiller part load operation in conjunction with economizer controls as part of the audit of existing buildings and as part of the design phase of new buildings. If a chiller has a minimum allowable loading level, that can be reflected in the simulation by designation of a low "high limit shut-off temperature" for the economizer.

Energy Monitoring and Controls Systems (EMCSs):

A building owner may be interested in an EMCS for a number of reasons, including less maintenance than pneumatics, flexibility, responsiveness, alarm or avoidance of environmental problems, and reliability.

Within the simulation, by contrast, an EMCS is simply a set of independent control functions, such as cold deck reset and optimum start, that are modeled the same way for an EMCSs as for discrete controls.

As with any control savings estimate, the estimate of savings for an EMCS must start with a list of the intended control functions (e.g. optimum start, condenser water reset, cycling of the fan during unoccupied hours). To make an accurate analysis of savings, the analyst will then want to know the specific sequence of operations to be employed. (See appendix V.)

After the installation, an EMCS may be more likely to save the estimated amount of energy than discrete controls because use of monitoring points and trend logs permit the owner, building operator, or building commissioner to evaluate the performance of the new control system relative to the intended sequence of operations.

Simulation of ECMs that involve EMCSs requires careful consideration of the baseline condition. With existing buildings, the baseline is simply the existing set of controls sequences as operating. With new buildings, the baseline must include code-required controls sequences such as unoccupied setpoint setback and reset and/or VAV control in multiple-zone systems.

5.5 SIMULATION OF MULTIPLE ZONE SYSTEMS

5.5.1 General System Characteristics

Most commercial buildings simultaneously require perimeter zone heating and interior zone cooling during cold weather. Many commercial buildings are served by multiple-zone HVAC air distribution systems that serve both interior zones and perimeter zones. A multiple-zone system has to provide simultaneously for the various conditions in all of the zones it serves. To do so at a reasonable first cost, multiple-zone systems most often cool supply air (either mechanically or with outside air) centrally and then heat up some portion of that cooled air at those zones that require heating. Depending on the design and health of the governing control system, this can be a highly efficient or highly inefficient process.

Constant volume reheat systems and constant volume dual duct or multi-zone systems without hot and cold deck reset have similar potential for inefficiency since they all mix heated and cooled air when neither heating nor cooling is needed. Dual duct and multi-zone systems have additional inefficiencies introduced by duct leakage and zone damper leakage.

Today, multiple-zone systems have become more efficient by using hot and cold deck reset and variable air flow rates for both reheat and dual duct type systems. Nevertheless, the modeler still needs to produce accurate simulations of reheat and mixing controls because,

1) baseline runs for existing buildings may be dominated by reheating or mixing, and

2) mixing and reheat continue to play a lesser, but still significant, role in new multiple-zone systems.

When a zone load varies, it can be met by varying the zone supply CFM or the zone supply air temperature. Zone supply CFM can be varied in a straightforward manner within certain limits if the system is VAV. If a system is constant volume, variation of the zone supply temperature is the only way to meet the varying zone loads.

Since supply air is cooled centrally it must be available at the coldest temperature needed by any zone to meet the zonal cooling load. During times when <u>no</u> zone requires 55 degree air, the central supply air temperature can (and usually should) be raised to the highest temperature that will still cool the zone requiring the most cooling (the "critical zone"). This automatic control is called central supply air temperature reset, and is a common strategy for energy efficiency in multiple-zone buildings.[20]

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[20] Cold air reset may or may not save energy in a VAV system. The increased cold air temperature at cooling part loads requires greater zonal air flow than would be required without reset. This in turn increases fan consumption, decreasing the savings of reset control. The net savings can be determined using some of the more powerful simulation programs.

Since zone loads can vary independently from one another, every multiple-zone system has some means of raising the zone supply air temperature for one zone while lowering it for another. Central supply air reset is not sufficient to provide this service. For all but the "critical zones", the central cold supply air to each zone has to be heated even if the system has reset. Each non-critical zone therefore has a "reheat" heating coil, or a set of mixing dampers which mix the central supply cold air with central supply hot air. In addition, depending on the system type, each zone may have a damper for throttling the central supply air (VAV) and sometimes a fan for introducing a secondary air stream consisting of warm ceiling plenum air to the zone.

Simulations generally offer three hot and cold deck temperature controls: constant, reset based on outside air temperature, and reset based on the needs of the coldest and warmest zones. The modeler should be careful in making this selection to pick the option that most closely matches the existing building or proposed design. If reset based on outside air temperatures is selected, the modeler usually has the option of determining the exact reset schedule.

To the extent that heating and cooling loads in the critical zones are a linear function of the outside air temperature for a certain range of outside air temperatures, outside air reset can work well. To the extent that solar gain is not directly linked to outside temperature, or that occupancy and internal gain schedules vary during occupied hours, outside air reset may not satisfactorily track zonal cooling loads. When modeling outside air reset controls in a computer simulation, the modeler often must input the proportionality relationship between the supply air temperature and the outside temperature.

It is important to note that reset of the cold duct supply air temperatures should ideally affect both control of the central cooling coil valve and control of the outside air/return air mixing dampers. In other words, the mixed air setpoint and the supply air setpoint should be reset together. Otherwise the advantages of cold deck reset will be seen on reducing the cooling consumption but not for reducing the heat consumption. On dual duct systems that have a separate set of outside air mixing dampers for the hot duct, the same issue applies.

5.5.2 Multi-Zone and Dual Duct Systems

Multi-zone and dual duct systems generally have very similar models in energy simulations. The only actual difference between the systems as-installed is the location of the zone mixing dampers. In a multi-zone system, the zone mixing dampers are located together near the supply fan. In a dual duct system, the zone mixing dampers are located near each zone at the end of the ductwork. However, a given program may have significantly different defaults for equipment or operation depending on whether the multi-zone or the dual duct option is selected. Therefore, the modeler must be alert (as always) to the defaults in the program.

Some multi-zone and dual duct systems have been retrofitted to VAV operation either by conversion to a VAV reheat system or by changing the zone mixing dampers so that they may alter the total (sum of hot and cold) air flow rates to the zones. If a program doesn't offer a VAV multi-zone or dual duct option, the most accurate simulation to use is probably a VAV reheat simulation.

5.5.3 Variable Air Volume Systems

Variable air volume systems vary the heating and cooling delivered to each zone by varying the amount of air supplied to the zone. By reducing the amount of reheat (or mixing, as in multi-zone and dual duct systems), VAV systems reduce the energy required for heating and cooling. By reducing the total amount of air, VAV systems reduce the energy required for fan operation.

VAV systems have central mixing dampers for outside air and recirculated air, a central cooling coil, and, often, central supply air temperature reset based on the critical zone. Some VAV systems have both supply and return fans. The VAV volume damper for a zone reduces the cold central supply air CFM rate to the zone below the design (maximum) flow rate when the cooling load is low or heating is required.

From the point of view of energy efficiency it would often be desirable to temporarily eliminate air supply to a zone. For several reasons, there is a limit to how much the air flow rate to a zone can be reduced.

1) Ventilation requirements. The amount of outside air delivered to a zone at any given time depends on both the position of the outside air mixing dampers and the amount of central supply air delivered to the zone. During cold weather, if the outside air mixing dampers are set at a minimum, the amount of central supply air required for adequate zone ventilation can be relatively high. In any case, during occupied hours, a minimum amount of central supply air is required during occupied hours to provide ventilation.

2) Air distribution. A certain air flow rate is required to operate zone heating coils and VAV terminal units, and to adequately distribute the conditioned air through a space.

3) Fan limitations. Fans are unable to operate at less than a certain fraction of their design air flow rate. This limit is a function of the fan type and the type of air flow control.

The minimum zone supply CFMs required for air distribution can be met without use of centrally cooled air by providing a zone fan to recirculate air directly from the conditioned space over the reheat coil and back into the space. Such VAV systems, called "fan powered terminal unit VAV" reduce the amount of reheat by reducing the minimum zone supply CFM.

If the system being modelled is a fan-powered VAV, the minimum zone flow rate is set by ventilation requirements during occupied hours. During unoccupied hours, it is zero.

Air flow to each zone is never dropped to zero during occupancy in VAV systems. In actual systems, the zone dampers and fan controls have minimum settings which take all of the above criteria into account. In computer simulations, the user is required to input the minimum air flow rates for VAV systems, as a percentage of the maximum. Such information can sometimes be found in specifications or on the mechanical drawings, but would be difficult to measure on-site because there may be many zones, and the minimum air flow rate for each only occurs under certain zone conditions.

The modeler should input a minimum supply air CFM of no less than 0.3 CFM/ft^2 and a design supply air CFM of no less than 0.8 CFM/ft^2 unless she has audit or design information that states otherwise.

The efficiency of VAV systems in saving fan energy depends on the type of VAV control. Reduction of zone supply air volume is accomplished by a VAV air damper, which closes or opens to alter the air flow to the zone. As the zone dampers close to varying degrees, the pressure drop through the duct system increases, which increases the pressure drop across the central supply fan, which in turn reduces the central supply CFM and the horsepower consumed by the fan by one of the following methods.[21]

1) Riding the fan curve (a simple increase in pressure drop through the fan, resulting from closing volume dampers in the distribution system). Note that this method often results in high air leakage losses through ducts and dampers as a result of the high pressure in the duct system.

2) Discharge damper. Discharge dampers increase the pressure drop across a fan without increasing the pressure in the ductwork.

3) Inlet vanes.

4) Variable speed fan drive.

Some VAV systems actually have a constant air flow through the fan but reduce reheat by dumping unneeded supply air directly back to the return air without passing it through the zone. If a computer simulation doesn't offer this bypass option, the VAV simulation will underestimate fan energy consumption for such systems.

5.5.4 Water-Loop Heat Pump Systems

Most simulation software programs do a mediocre job (at best) of modeling

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[21] Some designers are using an alternative control logic called terminal regulated variable air volume (TRVAV). With TRVAV, the EMCS sums sensed air flow at each of the terminal units and sets fan air flow accordingly. This theoretically decreases fan energy consumption by allowing the fan to operate in part load conditions at a lower static pressure. Simulation of this type of fan control requires a program that allows input of a user-defined fan curve.

water-loop heat pump systems. And few programs can directly simulate the added complexity of a ground-water source. It is important that the modeler seek a complete understanding of the specific software algorithms related to the simulation as well as of the actual system to be simulated.

In many cases the defaults of the water-loop heat pump system algorithm cannot be overridden by the modeler. This happens even with powerful programs such as DOE2. DOE2 does not allow different operating schedules for the individual zone heat pumps, and does not allow economizer operation. When the modeler encounters limitations such as these, she should ask herself whether an artificial input will more accurately simulate the actual system performance.

The simplest artificial input for a ground-water source loop heat pump system is to input individual packaged single zone units with hydronic heating and cooling coils for each zone. Then input a central plant with chiller, boiler, and tower COPs calculated to simulate the heat pump COPs at the normal water loop temperature. Circulation pump power can either be manually calculated or calculated with program pump algorithms. This approach can also be used for water-loop systems that do not have a ground-water source. However, the accuracy will be poorer for this application since the actual heat pump COPs will vary with the wider range of loop water temperatures.

If the modeler chooses to use default program algorithms to simulate ground-water source systems, she should be careful in her accounting of tower and boiler power. We recommend that she input a very high COP (or low energy-input-ratio) for this equipment. She may also wish to input a non-electric fuel for the boiler to aid with accounting. If the program does not allow user input for the maximum and minimum loop temperatures, she should either use a different program or resort to the artificial input described above.

5.6 VENTILATION

Ventilation and infiltration are powerful drivers of energy consumption in northwest buildings. All simulation programs allow separate inputs for ventilation and infiltration. However, programs vary widely in the ways they combine ventilation and infiltration loads to calculate the total outside air flow into the building.

Many programs assume zero infiltration whenever the fan is on, based on the theory that the outside air being introduced to the building through the ventilation system will pressurize the building, creating a net outflow of conditioned air.

In reality, homogenous pressurization of a building is difficult. Wind patterns, air balance, thermal buoyancy of warm air in a tall building on a cold day, volume dampers, dirty and clean air filters, and control of return fans off of building pressure sensors all affect the building pressurization. In small buildings, entry and egress, and occupant operation of doors and windows add to these factors. Even with the fans on, there is likely to be infiltration is some parts of a building.

While it may be optimistic to simulate no infiltration when the fans are on, DOE2 handles this differently. It adds the infiltration load to the ventilation load when the fans are running. Thus if the modeler thinks infiltration is likely to diminish when the supply fans are running (a likely supposition), she must adjust the infiltration and ventilation schedules to reflect reduction of infiltration during fan operation. This can greatly increase modeling complexity, particularly if any ECMs affect fan schedules.

Some simulation programs compare the infiltration and the ventilation, and take the larger of the two. One program cuts the infiltration to zero when fans are running only if the fan static pressure is above a certain threshold.

Since ventilation and infiltration are often large loads, it is important for the modeler to find out how the simulation does handle infiltration when the fans are and are not running. The modeler should also convert ventilation and infiltration into a common unit of measure so she can compare their magnitudes. Otherwise, it is difficult to gauge the significance of fan operation and outside air damper positions.

If the simulation does not automatically reduce infiltration when the fans are on, and the modeler feels that the building is successfully pressurized, she should decrease the ventilation rate input to compensate for the greater infiltration rate.

Even when the program does permit input of an occupied infiltration schedule, the modeler may wish to avoid the complexity of coordinating the infiltration and ventilation schedules. She can do this with input of a constant infiltration value equal to unoccupied infiltration, and input of a ventilation volume equal to the actual ventilation volume plus the change in infiltration due to fan operation. She must also input a ventilation schedule.

For existing buildings, the analyst should consider the condition of the outside air dampers before deciding on the minimum outside air setting for the simulation inputs. Dampers that haven't been properly maintained tend to have a high leakage rate when they are at the minimum setting.

If infiltration is input in air changes per hour, the modeler should be careful not to overestimate infiltration loads in zones with high ceilings and no windows. If minimum outside air is input as a percent of the supply CFM, she should input accurate supply CFM, especially in simulations of existing buildings.

Some simulations permit the modeler to input an hourly schedule of minimum outside air settings. This is particularly helpful for modeling controls that set the minimum outside air at zero during unoccupied hours to prevent unnecessary heating for ventilation when ventilation is not needed. It is important when using an hourly schedule for minimum outside air settings to remember that the leakage rate through closed dampers is not zero. For existing dampers, visual inspection of the position of the blades in the "closed" position is warranted. For new construction, a 5 to 10% leakage rate can be assumed, or the modeler can ask the designer what leakage rate is going to be specified.

Indoor air quality questions are being pursued through lawsuits and academic studies. Standard ventilation rates are increasing, so this component of the energy simulation is likely to become even more critical. Use of low leakage outside air dampers for 100% recirculation during warm-up, minimum supply air volumes in VAV systems, and reduction in fan operating hours may be limited in some cases by concerns for indoor air quality.

5.7 FAN SCHEDULES AND SUPPLY CFM

Fan schedules and supply CFM are important in determining heating and cooling consumption because they are closely linked to outside air ventilation HVAC loads, to the amount of reheat or mixing of hot and cold air that takes place in multiple-zone systems, to central plant equipment operation, and, of course, to 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. The amount of time the fan is off has a dramatic effect on energy consumption.

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 a dual duct system, or a system with central cooling and zone heating, high supply CFMs and extended fan schedules increase the amount of air that is centrally cooled and then reheated. In large buildings, it is common during mild weather to turn on fans during unoccupied hours when the boilers and chillers are still off. Simulations may for that reason tend to overestimate heating and cooling during unoccupied periods unless the boiler and chiller schedules can be, and are, input accurately.

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 work, the existing supply CFM may be more than what is required to satisfy current loads. If that is the case, allowing the simulation to assign supply CFMs may underestimate heating, and to a lesser extent, cooling loads. The original design CFM should be read 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, very rough rules of thumb can be outlined as follows:

For constant volume systems:

perimeter areas, South, East and West: 0.5 to 3.0 CFM/ft^2

perimeter areas, North: 0.5 to 2.0 CFM/ft^2

interior areas: 0.75 to 2.0 CFM/ft^2

For Variable Air Volume Systems:

all areas: 0.5 to 1.5 CFM/ft^2

5.8 FAN HEAT

The supply fan itself can impose a significant cooling load. The temperature rise of the air across the fan is typically 1 to 3 degrees F. The temperature rise across the space, when it is being cooled, is roughly (78°F - 55°F) = 23°F. The fan heat therefore can be roughly 10% of the cooling load.

If the motor is located in the air stream, the temperature rise across the fan is higher than for motors located outside the ductwork. Heat gain from typical electric motors is given on page 26.8 of the 1989 ASHRAE Handbook of Fundamentals.

Most simulations will automatically calculate the temperature differential (delta-T) across the fan on the basis of air flow rates, fan energy consumption, fan and motor efficiency, and fan motor placement (assumed or input), so this is not an input the modeler normally needs to worry about. It is however helpful to note its importance in case the modeler decides for any reason to input the fan delta-t rather than using the default value. The modeler also should remain alert to programs that do not automatically calculate the fan delta-T. Should she encounter such a program, she can add a zone load equivalent to the effect of the fan delta-T.

6. OTHER ENERGY CONSUMPTION

6.1 EXTERIOR AND "HIDDEN" ENERGY USERS

This is a loose category that includes both energy loads external to the building and easily-missed loads within the building that do not contribute to HVAC heating or cooling loads. External loads might include car washes, exterior lighting, swimming pools, gas pumps, water pumps, sidewalk heating systems, and so forth. Non-HVAC driving interior loads might include elevators, laundries, 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.

There is at least one internal load that is easily missed but that can strongly drive building energy use and HVAC performance--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 (reference 10). To put this in perspective, this is the largest contributor to the equipment end-use for both large and small offices, as determined by the ELCAP study. 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 AC 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.

7. THE BASELINE BUILDING

7.1 GENERAL DISCUSSION

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 sloppy in their generation 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. Energy Edge selected the following hierarchy (starting with the highest source):

1. Model Conservation Standards Equivalent Code (February, 1985)
2. Common Practice Matrix. PECI convened a group of architects and engineers to define baseline glazing area and HVAC system type for a broad range of commercial building types.
3. Modeler judgement when neither source 1 nor 2 directly addresses an issue.

In addition to these sources, Energy Edge provided modelers with a list of "parameters held constant". Quoting from the Energy Edge Technical Requirements:

> "The following building parameters shall be held constant between the MCS Design and the .7 MCS Design building.
>
> 1. Weather - hourly ambient wet and dry bulb temperature, wind speed and direction, and solar weather data. The data should be representative of the construction site.
>
> 2. Occupancy and Function - Number of people, schedule(s) of occupancy, and sensible and latent heat gains.
>
> 3. Usage schedules of installed interior and exterior lighting. This means the schedule for which lighting is made available either through daylighting or electrical lighting.
>
> 4. Zoning of Building Area - At a minimum, each different occupancy located in the building (e.g. office space, cafeteria, etc.) shall be modeled with a separate set of zones. Perimeter zones shall be between 8 and 20 feet deep for the MCS Design.
>
> 5. Internal Equipment (e.g., elevators, computers, office machines, refrigeration, etc.) - Operating schedules and internal heat sources to conditioned spaces.

6. Ventilation Air - Fan operating schedules and minimum amounts (in CFM) of outside air.

7. Heating and cooling system schedules - Months of the year, days of the week, and hours of the day when heating and/or cooling are available from the primary and secondary system equipment (except where thermal storage and/or night flushing and/or EMS controls are shown to save energy).

8. Thermostats - Space conditioning set points and their related schedules of operation (except where variable space temperature techniques can be shown to save energy).

9. Floor area and wall area.

10. Energy Sources - Energy source for each end-use (no fuel switching). Heat recovery is not precluded.

11. External shading from existing buildings and vegetation located at the construction site."

Energy Edge abandoned the Common Practice Matrix relatively early in the program. Instead it treated both glazing percentage and HVAC system as parameters held constant (PHC)--unless either is directly affected by an ECM. (As an example, skylights might be considered an ECM when tied to a daylighting lighting control system. Similarly, a water-loop heat pump system might replace the baseline air-to-air heat pumps.)

The MCS generally held its position in the baseline source hierarchy throughout Energy Edge. Similarly, the PHC held its position. However, interpretations were required of both in numerous instances. The most common requirement for interpretation of the PHC related to exceptions when a parameter was affected by an ECM. For instance, lighting, HVAC, or equipment schedules could be changed between the baseline and as-designed buildings if an ECM specifically provides automatic controls to make that possible. Item numbers 3,5,6,7,8, and 11 each has the potential for ECM exceptions.

The MCS is Swiss cheese when it comes to defining baseline. We have already mentioned that it doesn't address a host of parameters. In addition, when it does address a parameter, it sometimes does so with a laxity that defies common-sense. An example of this are the MCS requirements for wall U-value. The maximum acceptable U-value for most commercial building walls is 0.25. Though glazing typically elevates the overall U-value of a wall area, the MCS requirement often leads to a calculated insulation value on the order of R-5 to R-7. This is not common installation practice! **The modeler should input for the baseline the minimum insulation value that both satisfies MCS and represents common construction practice.**

Carrying this one step further, we recommend that the modeler be given the option of using the building that the program applicant submits as his/her non-program proposed design for the baseline, providing that that proposed design at least satisfies MCS.

7.2 BASELINE ISSUES

Generation of a baseline model can raise some interesting technical issues. We have already dealt with several of the code-related issues. Now we turn our attention to some others.

HVAC equipment downsizing is one issue that often arises when baseline derivation is discussed. This relates to the concept that a more efficient building (lower lighting loads, lower solar gains, lower heat loss, etc.) should be designed with HVAC equipment of a smaller capacity than the less efficient baseline building. Our Energy Edge experience (primarily with small to medium size offices so far) indicates that equipment downsizing usually had little effect on estimated ECM savings or ECM ranking.

Also, it is our observation that designers tend to ignore or distrust the potential downsizing benefits of ECMs and therefore size HVAC for efficient buildings much as they would for the hypothetical baseline. Designers are especially cautious about potential future increases in equipment and lighting power density. Finally, incorporating downsizing in the modeling process adds considerable complexity. Therefore, to simplify our modeling, we generally ignore downsizing as an issue. **In design-phase modeling, the modeler should use the designer's selection for the HVAC equipment capacity for as-designed building. She should use the same equipment for the baseline building unless the output indicates that increased capacity is necessary to meet loads. In the latter case she should let the software program select the capacity required, being alert to possible unrealistic sizing by the program.**

We have previously alluded to the issue of lighting controls. What is the appropriate baseline for such ECMs? If a daylighting ECM has been modeled by enabling a program switch for daylighting, then the baseline model simply turns off that switch. In the case of occupancy sensor controls, the modeler should resort to ASHRAE Standard 90.1 requirements. **The modeler should simulate the effect of occupancy sensor lighting control by multiplying the relevant baseline lighting power densities by 0.7.** Note, though, that this factor should be used only for modeling the ECM, not for increasing the allowed baseline lighting power density.

Infiltration is discussed in some detail in section 4.2.1 of this report. **The modeler should consider infiltration as a parameter to be held constant between the as-designed and baseline buildings unless an ECM is designed to directly decrease infiltration in a predictable manner.**

Another baseline-related issue that seems to confuse some modelers is whether the baseline and as-designed model should have different assumptions concerning proper operation.

One could argue that since, statistically, most building occupants cannot program programmable thermostats, then the modeler should simulate such buildings without night-time setbacks. This arguer might continue with the proposal that an energy management system (EMS) be considered an ECM. We counter that it is unreasonable to assume improper operation for a baseline technology and proper operation for an ECM that is at least as complex. Since design-phase modeling generally assumes proper building operation for the as-designed model, it is appropriate to assume the same for the baseline model. **For new construction, the modeler should assume proper operation of all building systems in both the baseline and as-designed models. For existing buildings, the modeler should assume actual operation for the baseline model.**

8. ERROR CHECKING AND DEBUGGING

8.1 GENERAL ERROR CHECKING APPROACH

At the same time the modeler is keeping track of how the software works and assessing its accuracy, she also needs to keep a vigilant eye on her own contributions to the simulation.

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 inputs that information into the computer without careless errors. Patience with detail is an important part of good simulation work.

For accuracy:

- Check calculation of inputs for errors prior to keyboard input.
- Check to make sure the units of measure (e.g. kW, hp, feet, Btu) agree with instructions in the simulation manual.
- Check inputs for typographical errors before running the model.
- Check output to see whether end use consumption and hourly and monthly profiles are reasonable. (Include comparison of actual and simulated consumption where possible.)
- Do not "tweak" uncertain inputs before the previous steps have been taken.

Early detection of errors reduces the amount of time spent on reruns; and careless input errors are sometimes more easily detected by examining the input than by working backwards from the output. Results in the output which appear abnormal may be due to any number of causes, including software glitches or influences on actual consumption which have not been explained to the modeler by the occupants.

8.2 INPUT CHECK

Most simulation software packages provide some form of report that echoes the modeler's input. Some programs will change the modeler's input under certain circumstances (if the input is viewed within the simulation as falling outside the realm of reason). But the echo reports typically document the adjusted input. Careful inspection of the input echo reports is thus useful for two purposes--to see what the program thinks the modeler input, and to see how the program changed what the modeler input.

What should the modeler specifically look for? We recommend the following checks, as a minimum:

- building orientation
- zone definitions

- wall, roof, floor, and window definitions (orientation, area, zonal affiliation, construction, U-value, glazing shading coefficient)
- lighting and equipment power densities
- operating schedules (for lighting, equipment, fans, thermostat setpoints, plant equipment, occupancy, etc.)
- HVAC definition (CFM, input power, zones served, minimum outside air percentage, system type, heating and cooling capacities, fan schedule)
- plant equipment definition (equipment type, capacities, rated efficiency, part load efficiencies)
- utility rate schedules if economic analysis used

8.3 OUTPUT CHECK

It is not at all unusual that a model will appear to be correct even though it is correct for the wrong reasons. Offsetting errors do not make a successful model. Though the model may accurately estimate annual energy use, if it does so for the wrong reasons, then the ECM savings analysis may be wildly inaccurate. The modeler must ensure that her model adequately simulates actual building operation even before she checks whether the end-use EUI results are "reasonable".

As a minimum, we suggest that the modeler check for the following in the output reports (not all software packages include all appropriate reports):

- Loads not met. Do the HVAC systems and plant as input satisfy the building heating and cooling loads? If they do not, it could signify improper loads, systems equipment, or controls input. It also could signify an inadequate design. Or it might signify several other things (including reasonable operation, as in morning warm-up). In any case, a significant value of loads not met is a serious warning signal. In DOE2, we find a "% of hours any system zone outside of throttling range" (in the BEPS report) greater than about 5-7% to be of concern. The SS-F reports provide further information for trouble-shooting.

- Fan schedule. This is the source of many common modeling errors. Many software programs have different fan schedule defaults for different HVAC systems. Fan schedule error contributes to model inaccuracy primarily through incorrect fan power and ventilation air simulation.

  The modeler can guard against fan schedule error by investigating whatever relevant report the software provides. In DOE2, both the SS-C and the hourly reports can be useful for this investigation. In other programs there may be similar reports, or the modeler may have to deduce fan operation from total monthly fan consumption.

  Note that this is a critical input, and one that is often in error. We are not recommending that it be checked through an input echo report! The input echo may not be a true indication of how the schedule is actually used by the software. We strongly recommend that this input be checked through the program output--either directly or with manual calculations.

- Ventilation air. Like fan schedule, this input is a frequent source of model error. Ventilation air is a direct contributor to heating and cooling load through the equation,

  $$\text{Btu/hr} = 1.08 \times \text{CFM} \times (T_o - T_r).$$ [22]

  Error can arise from either the ventilation CFM or from the ventilation schedule. Software programs often tie the ventilation schedule to the fan schedule. We discussed this effect and how to troubleshoot it in the previous item. But some software programs allow input of a distinct ventilation schedule. When this is the case, the modeler should check whatever output report gives an indication of the ventilation simulation. In DOE2, the most direct indicator of simulated ventilation schedule is the systems hourly report #39, "OUTSIDE/TOT CFM".

  There is another reason for debugging ventilation air simulation--economizers. The effect of an economizer is the variation of the ventilation air volume as a function of several temperature or enthalpy conditions. We have often found that when we think we have input a certain economizer logic, the program simulates something else. We recommend that the modeler take advantage of whatever output report is available to verify the economizer simulation. Again, in DOE2, the systems hourly report #39 along with the appropriate outside air temperature (or enthalpy) are the most direct reports for verifying this simulation.

- Simultaneous heating and cooling. This is a less frequent source of error than the previous two items. And sometimes simultaneous heating and cooling is representative of how the building will actually operate.

  Nevertheless, the modeler should check the output reports to ensure that the software program simulated the HVAC system operation in a way consistent with her (and the designer's) intention. If the HVAC system or control system modeled does not allow simultaneous heating and cooling, then the output should show none. Conversely, if the systems modeled are based on simultaneous heating and cooling (e.g. variable air volume--VAV--with reheat), then the output should show some. Note that not all programs provide output that will enable the modeler to determine whether simultaneous heating and cooling occurs.

- Errors due to conflicting inputs. Some programs allow conflicting

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[22] where Btu/hr is the heating or cooling load imposed by ventilation air, CFM is the volume rate of the outside air, T_o is the outside air temperature, and T_r is the return air temperature.

inputs. Conflicts may be resolved internally without notifying the modeler. Inspection of hourly reports for selected seasonal conditions (hot, cold, and swing) is an excellent way of assuring that the program works as intended.

- HVAC system and plant COPs or EERs. Once again, what the modeler inputs is not always what the program simulates. What a devious world we model in! Simulation programs sometimes recalculate the efficiency input using hidden defaults, auxiliary energy consumption, and so forth. Only by investigating the relevant output reports can the modeler ascertain that her intent was honored.

  We recommend that, at a minimum, the modeler use the output reports to calculate seasonal heating and cooling COPs. She can do this by dividing the total cooling (or heating) output for a given time period by the relevant equipment input for the same period (all units in Btu). For vapor compression air conditioning or heat pump equipment, one would expect seasonal COPs ranging from about 2 to 3.5. Chillers could range from 2 to 5. Values much higher or much lower should prompt further investigation.

- HVAC system operation. The algorithms for simulation of HVAC system operation are complex. Various software programs simulate HVAC with varying degrees of success. And various modelers of course simulate HVAC with varying degrees of success. Simulated HVAC controls are never an exact representation of actual building controls. Some system types--such as variable air volume (VAV), water loop heat pumps, ground source heat pumps, and thermal energy storage--are especially difficult to model. Some control sequences--such as night flush cooling, heat pump morning warm-up, and refrigeration heat recovery--are especially difficult to model.

  Because of the capacity for error, the modeler should check output to verify that design intent was simulated correctly. Sometimes when the simulation and the design intent are not in agreement, this may be a red flag for design error. Or it may be a red flag for simulation error or inadequacy. In either case, the modeler should notice the flag and act accordingly.

  When debugging the model for HVAC simulation error, it is often necessary for the modeler to refer to the software documentation. Energy simulation software uses various synthetic algorithms to model HVAC systems. These algorithms incorporate assumptions, simplifications, and sometimes errors. It is frequently essential for the modeler to understand these algorithms in order to understand the simulation input and results.

8.4 EUI CHECKS

In many cases the software package used does not provide the input or output reports alluded to in the previous subsection. For this reason, and for an additional safeguard of model reliability, we recommend that the modeler compare the baseline building simulation results to independently collected data for a similar building type. For the use of northwest energy conservation programs, the Lawrence Berkeley Laboratory has compiled data from three sources: ELCAP monitored end-use data, the Northwest Power Planning Council 1991 forecast (reference 19), and the SBW Consulting Inc. prototypes study (reference 20). These data are combined in a single table with statistically derived EUI ranges for each major end-use and for a variety of building types (see appendix II).

The baseline model should be used for this comparison since, as a code-based building, it is more likely to be similar to the ELCAP new commercial construction buildings than the more efficient as-designed building. Since the baseline model is derived from the as-designed model, if the baseline end-use EUIs are similar to the statistical data, this implies that the as-designed model shares the same validity.

Discrepancies between the simulation results and the statistical data do not necessarily indicate an erroneous model. These discrepancies may be due to justifiable differences between the modeled building and the average building represented in the data. Such justifiable differences might include weather files, operation, schedules, equipment power densities, and so forth. Nevertheless, statistical data are a good indication of typical end-use EUIs for commercial buildings in the northwest.

The modeler should compare the end-use EUIs in the building baseline simulation to the data in appendix II. The modeler should troubleshoot the simulation input whenever a simulated end-use EUI differs from the corresponding EUI high or low range value by more than ±35%. If the troubleshooting convinces the modeler that the input and the simulation are correct, she should discuss and justify any such discrepancies.

9. DOCUMENTATION

9.1 PURPOSE OF 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 for the building owner, developer, design professionals, facility personnel, and program decision-makers. Beyond this, the as-designed and baseline models may be used as the basis for a future as-built model, or even a tuned and calibrated model. They also may be subjected to expert review. Finally, they may serve the modeler herself as a basis for other building simulation projects.

<u>In all cases, proper technical use can be made of the models only if the modeler has thoroughly documented the assumptions, calculations, sources, and so forth that she 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.

Note that the model documentation package as discussed here may overlap with, but is not the same as, the building design assistance report. That report addresses the primary modeling purpose only--to estimate ECM savings for the building owner's team and program decision-makers. The model documentation package, on the other hand, is a technical document that addresses everything a reader would have to know to fully understand the building model.

9.2 DOCUMENTATION REQUIREMENTS

In this subsection we present the general requirements for model documentation for Bonneville's Energy Smart program and associated programs. Though these requirements may seem to some to be excessive, we have found that this extent of documentation generally saves much time in the long run--not only for other parties, but for the modeler herself.

The modeler should document for both the as-designed and the baseline building the following:

- **State company names, contact names, addresses, and phone numbers for as many of the following as available:**
  - **architect**
  - **mechanical engineer**
  - **electrical engineer**
  - **lighting designer**
  - **owner**
  - **general contractor**
  - **mechanical subcontractor**
  - **electrical subcontractor**
  - **modeler**

- **State software package selected and reasons for selection.**

- List information sources available to and used by the modeler (e.g. O&M audits--give dates and auditor names, building drawings, specifications, phone conversations with designers, job conferences, etc.).

- General building description. Include building area, location, proposed usages and occupancies, number of floors, number and allocation of electricity meters, and so forth.

- Envelope construction description. Include both actual proposed construction details (materials, layers, R-values, stud type and spacing, etc.) as well as how the construction is represented in the models.

- HVAC system description. Include actual proposed equipment specifications as well as how the systems are modeled. Include manufacturer's data where these are needed to support calculations. Explain model departures from specifications. Describe assumptions regarding fan control, minimum outside air volume and control, setback, warmup, reset, and so forth. Describe central plant equipment and control. State design criteria, if known.

- Lighting description. Describe lighting fixture, lamp, and ballast types and installed power density for main building areas. Describe switching and other controls. Describe exterior lighting and controls.

- Base electrical loads description. State power density assumptions (and sources of assumptions) for office equipment and other base (not to be confused with baseline) loads. Differentiate between different building areas where appropriate (e.g. cafeteria, office, warehouse). State assumptions and sources for other base loads such as elevators, refrigeration equipment, process equipment, and cooking equipment.

- Operating schedule assumptions. Include all relevant zonal schedules for each scheduled end-use. State sources of schedules. (It's acceptable to state that an assumption is the result of the modeler's best guess.)

- Clearly define building zoning as modeled. Describe the rationale of zoning if it departs from actual installed HVAC zones. Include floor plans with modeled zones clearly marked.

- Include code compliance check calculations for both models. Clearly state all relevant assumptions.

- Describe fully each ECM that has been analyzed. Follow a format that includes:
    - **ECM name**
    - **short description**
    - **baseline description as relates to the ECM**
    - **specifically how the ECM differs from baseline**
    - **cost estimates for baseline and ECM--include by item, materials, labor, contractors' overhead and profit, design**

fees, contingency, commissioning, and annual maintenance. State sources for all values.
    - incremental ECM cost

- Provide a table showing a summary of the modeling results. This table should include electricity usage and demand, fossil fuel usage, electricity energy use index (EUI) in kWh/ft^2-yr, and total fuel EUI in Btu/ft^2-yr for the baseline model, for each ECM, and for the package of all recommended ECMs.

- Provide a table showing the annual end-use EUIs (electric, fossil, and both) of the baseline model. Also show the ELCAP end-use EUIs for the relevant building type and calculate percentage differences between the two. In the text of the documentation explain any percentage differences greater than 35%.

- Provide a table summary of all recommended ECMs. This table should include for each ECM:
    - ECM description
    - electricity demand savings
    - electricity consumption savings
    - other fuel savings
    - total incremental cost
    - estimated measure life (from Bonneville Technical Requirements)
    - levelized cost (from requirements of specific program)
    - baseline basis for savings estimates (i.e. MCS, MCS code equivalent, proposed building, etc.)

- Describe any software package limitations that might affect these specific models. Does the model provide direct simulation of the actual systems and operation? If not, describe how this was handled.

- Describe any known bugs, errors, discrepancies, conundrums, etc. in the models. Describe any unusual insights into the energy behavior of the building that may have been gained during the course of modeling. These might include discovery of parameters to which the building consumption is particularly sensitive.

- Provide <u>all</u> backup calculations and assumption sources. This is critical. These would include, but not be limited to, infiltration values, U-values, lighting and equipment power density, equipment and plant operation curves, glazing parameters, and other calculated inputs.

- Provide hard copies of the model input and output. If the models used DOE2, the output should include reports LV-C, LV-D, SV-A, SS-D (if there is a central plant), PV-A, PS-B, PS-C (if there is a central plant), and BEPS. Also include ES-D if the economics module was run. Finally, include any other reports that are necessary for the reader to understand important results of the modeling.

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21. Harris, J., J. Roturier, L.K. Norford, and A. Rabl. November, 1988. *Technology Assessment: Electronic Office Equipment.* LBL-25558 Rev., Lawrence Berkeley Laboratory, Berkeley, California.

22. Piette, M.A., 1992. Personal communication.

SUMMARY OF MODELING RECOMMENDATIONS

Glazing (discussed on page 42):
We recommend that, unless the design specifically includes an ECM relating to glazing and frame type, the modeler assume a double-glazed window with a non-thermal-break aluminum frame. If the modeler does have knowledge of the specific window types to be installed, then we recommend that she 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. The modeler should also adjust shading coefficients to account for opaque portions.

HVAC Equipment Capacity (page 82):
In design-phase modeling, the modeler should use the designer's selection for the HVAC equipment capacity for as-designed building. She should use the same equipment for the baseline building unless the output indicates that increased capacity is necessary to meet loads. In the latter case she should let the software program select the capacity required, being alert to possible unrealistic sizing by the program.

Infiltration (page 41, 82):
The modeler should consider infiltration as a parameter to be held constant between the as-designed and baseline buildings unless an ECM is designed to directly decrease infiltration in a predictable manner.

We recommend that 0.038 CFM/ft^2 is a reasonable beginning assumption for infiltration, but that the modeler 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.

Insulation (page 81):
The modeler should input for the baseline the minimum insulation value that both satisfies MCS and represents common construction practice.

Interior Lighting (page 56):
The following ratios of unoccupied to occupied weekday lighting usage should be used unless building-specific data is available:

BUILDING TYPE	UNOCCUPIED/ PEAK RATIO	PEAK W/FT^2
Office	0.29	1.56
Retail	0.10	1.44
Grocery	0.58	2.00
Restaurant	0.14	1.67
Warehouse	0.06	0.68

The modeler may also wish to use the ELCAP values for peak power density when she lacks more detailed design information.

Interior Walls (page 48):

Model interior walls only if:

(1) the thermostat schedules and setpoints for the zones on either side of the wall are not identical, or

(2) the zone has significant internal gains during periods when the HVAC system is not operating, or

(3) an adiabatic wall is needed to properly simulate thermal mass.Do 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.

Be sure not to input an interior wall under both adjacent zones. That would result in duplicating the heat transfer.

Miscellaneous Equipment (page 53):
The modeler should only give the rated equipment capacities if the simulation offers a load factor (average/peak load fraction), or calculates the equipment load input hourly using an operating schedule profile that permits fractional amounts.

An operating power density of 1.0 to 1.5 W/ft^2 for office equipment and personal computers is generally appropriate.

Results of the ELCAP study suggest that, as a general rule of thumb, equipment consumption during unoccupied hours should be set at no less than 30% of the peak load.

We recommend that the following values for unoccupied equipment fraction be used during design phase modeling unless there is specific design information to support a different assumption:

BUILDING TYPE	UNOCCUPIED/ PEAK RATIO	PEAK W/FT^2
Office	0.40	1.50
Retail	0.30	0.76
Grocery	0.67	1.04
Restaurant	0.36	2.13
Warehouse	0.50	0.35

The modeler may also wish to use the ELCAP values for peak power density when she lacks more detailed design information.

The modeler is advised to distinguish between large computers and small computers when developing equipment load inputs, and to create a separate zone and air distribution system in the simulation for any significant computer rooms.

Occupancy Sensors (page 82):
The modeler should simulate the effect of occupancy sensor lighting control by multiplying the relevant baseline lighting power densities by 0.7.

Operating Assumptions (page 83):
For new construction, the modeler should assume proper operation of all building systems in both the baseline and as-designed models. For existing buildings, the modeler should assume actual operation for the baseline model.

Optimum Start (page 68):
Unless a simulation is explicitly modeling optimum start, either (1) input a change in thermostat setpoint an hour or two prior to occupancy or (2) input a thermostat setting schedule that ramps up the heating setpoints prior to occupancy.

Reality Checks (page 88):
The modeler should compare the end-use EUIs in the building baseline simulation to the data in appendix II. The modeler should troubleshoot the simulation input whenever a simulated end-use EUI differs from the corresponding EUI high or low range value by more than ±35%. If the troubleshooting convinces the modeler that the input and the simulation are correct, she should discuss and justify any such discrepancies.

Schedules (page 52):
We recommend that the modeler use the Building Schedule Percentage Multipliers (appendix III) as the first source for building schedules. However, these should be modified per the following recommendations.

Supply Air CFM/ft^2 (page 74):
The modeler should input a minimum supply air CFM of no less than 0.3 CFM/ft^2 and a design supply air CFM of no less than 0.8 CFM/ft^2 unless she has audit or design information that states otherwise.

Thermal Mass (page 47):
The modeler should follow the DOE2 reference manual recommendations concerning when to use custom weighting factors.

Tweaking (page 29):
Do not tweak any of the uncertain inputs before checking for careless errors.

Unconditioned Spaces (page 48):
If there is a liberal flow of outside air through the unconditioned space, (as in most commercial garages), it is advisable to model the interior surface as an exterior surface.

APPENDICES

APPENDIX I U-VALUES

Table 3a
FRAMING R-VALUES

Wall Framing

This table can be used to find the R-Value for framing and framing cavity in a wall. The values from this table can be added to the R-Values of other layers to calculate the Rt of the wall.

Wood framing values are based on 20% and 15% framing factors for 16 inches and 24 inches spacing.

Metal framing values are based on Department of Energy, 10 CFR Part 435.

If the insulation is compressed, adjusted the insulation R-Value in accordance with manufactures recommendations. Use the adjusted insulation R-Value in this table.

Type of Framing	Spacing	Insulation R-Value	Correction Factor	Effective R-Value
Wood, 2 x 2	16" o.c.	0.90 (Air Space)	112%	1.01
		5	75%	3.75
		7	65%	4.55
		9	57%	5.13
	24" o.c.	0.90 (Air Space)	109%	0.98
		5	80%	4.00
		7	71%	4.97
		9	64%	5.76
Wood, 2 x 4	16" o.c.	0.90 (Air Space)	116%	1.05
		9	82%	7.38
		11	77%	8.47
		13	72%	9.36
		19	60%	11.40
	24" o.c.	0.90 (Air Space)	112%	1.01
		9	86%	7.74
		11	81%	8.91
		13	77%	10.01
		19	66%	12.54
Wood, 2 x 6	16" o.c.	0.91 (Air Space)	121%	1.10
		11	89%	9.79
		19	74%	14.06
		22	68%	14.96
		30	60%	18.00
	24" o.c.	0.91 (Air Space)	115%	1.05
		11	92%	10.12
		19	79%	15.01
		22	74%	16.28
		30	66%	19.80
Metal, 2 x 4	16" o.c.	0.90 (Air Space)	100%	0.90
		9	56%	5.04
		11	50%	5.50
		13	45%	5.85
		19	35%	6.65
	24" o.c.	0.90 (Air Space)	100%	0.90
		9	66%	5.94
		11	60%	6.60
		13	55%	7.15
		19	44%	8.36
Metal, 2 x 6	16" o.c.	0.91 (Air Space)	100%	0.91
		11	56%	6.16
		13	51%	6.63
		19	40%	7.60
		22	35%	7.70
	24" o.c.	0.91 (Air Space)	100%	0.91
		11	61%	6.71
		13	56%	7.28
		19	45%	8.55
		22	40%	8.80

Source: State of Oregon Code Compliance Manual

FRAMING R-VALUES

Roof/ Ceiling and Floor Framing

This table can be used to find the R-Value for framing and framing cavity in a roof/ceiling or floor. The values from this table can be added to the R-Values of other layers to calculate the Rt of the roof/ ceiling or floor.

Wood framing values are based on 10%, and 6% framing factor for 16 inches and 24 inches spacing without air spaces or compression of insulation. R-Value for wood is based on fir, pine, and similiar softwood.

If the insulation is compressed, adjust the insulation R-Value in accordance with manufactures recommendations.

Metal truss values are based upon metal trusses with 4 ft spacing that penetrate the insulation, and 0.66 in diameter crossmembers every 1 ft.

Type of Framing	Spacing	Insulation R-Value	Correction Factor	Effective R-Value
Wood, 2 x 6	16" o.c.	11	94%	10.34
		13	92%	11.96
		19	85%	16.15
		22	81%	17.82
	24" o.c.	11	97%	10.67
		13	95%	12.35
		19	90%	17.10
		22	88%	19.36
Wood, 2 x 8	16" o.c.	13	96%	12.45
		19	90%	17.10
		22	87%	19.14
	24" o.c.	13	97%	12.61
		19	94%	17.66
		22	92%	20.24
Wood, 2 x 10	16" o.c.	19	94%	17.85
		22	92%	20.17
		30	86%	25.87
	24" o.c.	19	96%	18.29
		22	95%	20.87
		30	91%	27.37
Wood, 2 x 12	16" o.c.	22	95%	20.82
		30	90%	26.94
		38	85%	32.47
	24" o.c.	22	97%	21.28
		30	94%	28.09
		38	91%	34.47
Wood, 2 x 14	16" o.c.	22	97%	21.35
		30	93%	27.83
		38	89%	33.77
	24" o.c.	22	98%	21.60
		30	96%	28.67
		38	93%	35.35
Metal truss	4'-0" o.c.	3	98%	2.94
		5	96%	4.80
		7	94%	6.58
		9	93%	8.37
		11	91%	10.01
		13	90%	11.70
		19	86%	16.34
		22	83%	19.09
		30	79%	23.70
		38	74%	28.12

APPENDIX II ENERGY USE INDICES

NEW COMMERCIAL BUILDINGS IN THE PACIFIC NORTHWEST
Electricity Consumption by End-Use (kBTU/sq.ft.-yr)

ENDUSE	OFFICE	RETAIL	GROCERY	RESTAURANT	WAREHOUSE	SCHOOL
Heating	11-27	4-11	7	4-72	8-9	1-31
Cooling	2-10	2-13	1-8	11-13	1-2	-
Fans/aux	6-15	3-17	13-14	14-37	1-2	4-8
Hot water	1-2	1	1-13	9-30	1	5-8
Int. light	16-27	13-43	36-44	35-40	8-10	8-16
Ext. light	1-5	1-8	6-10	8-18	1	0-2
Vert. Transp.	0-2	0-2	-	-	-	-
Food Preparation	-	-	36	26	-	-
Refrigeration	-	-	148	19-52	2	-
Other	10-12	2-8	7-18	20-196	2-4	3-4
HVAC	26-44	12-41	22-27	29-122	11-12	5-39
INT. LIGHTING	16-27	13-43	36-44	35-40	8-10	8-16
OTHER	13-18	6-13	172-213	82-295	4-8	11-12
Total	66-83	42-70	238-277	145-457	24-28	24-66

NOTES:

- **Based on prototype simulations and measured data for samples of 2 to 17 buildings per building type.**
- **The totals are not the sum of the high and low EUIs, but are based on the totals from individual data sources.**

SOURCES:

(1) Northwest Power Planning Council, "Northwest Conservation and Electric Power Plan", Volume II-Part I, p. 356, May 1991. Data are from forecasts of 1989 construction based on all-electric buildings only.

(2) SBW Consulting Inc., "Analysis of Commercial Model Conservation Standards Study. Conservation Analysis Summary", Final Report, Vol. 1, November 1990. Simulated data from prototypical buildings. All electric with resistance space heating and Seattle weather.

(3) Taylor Z.T., Pratt R.G., "Description of Electric Energy Use in Commercial Buildings in the Pacific Northwest. End-Use Load and Consumer Assessment Program (ELCAP)", Pacific Northwest Laboratory, DOE/BP-13795-22, p. 356, December 1989. End-use metered data from Post-1980 buildings. Electric use only; not corrected for gas use in some buildings.

NOTES ON ENERGY CONSUMPTION BY END-USE TABLE.

The table shows the range of electric energy use intensities (EUIs) by end-use for new commercial buildings in the Pacific Northwest. The values shown are based both on simulations of prototypical buildings with characteristics typical of new buildings and on measured data (for samples of 2 to 17 buildings per building type).

End-use EUIs vary greatly from building to building, even with buildings of the same type. This variation can be explained by climate building characteristics (such as size, shell, and types of lighting and HVAC), occupancy, and type of activities. Most of the data are based on all-electric buildings although some gas and steam use was reported for some of the buildings. There are some unique charateristics of the data for several building types:

Office. Data are from sources (1) (n=7 for the ELCAP data) and (2). Variations in the HVAC EUIs are explained by differences such as climate, occupancy, building size, and equipment type. Differences in heating are explained by differences among data sources. Prototypical buildings represent resistance heat while the ELCAP sample and the forecast have a fraction of buildings that use heat pumps (heat pumps are more efficient than electric resistance).

Retail. Data are from sources (1) and (2). As reflected in the table, the most important end-use in retail space is lighting. Lighting use affects HVAC related end-uses. The range in heating EUIs also reflect the fact that 7 of the buildings in the sample uses gas as their primary heating source.

Grocery. Data are from sources (2) and (3) (n=6). The high values for cooling (8 kBTU/sq.ft-yr) and hot water (13 kBTU/sq.ft.-yr) end-use EUIs are from the ELCAP measured data. The low values are from simulations (cooling had a value of 0.34 kBTU/sq.ft.-yr that was rounded up to 1.0 kBTU/sq.ft.-yr). The large difference in the hot water EUI may be due to differences in kitchen use within groceries.

Restaurant. Data are from sources (2) and (3) (n=6). The wide range for some of the end-use EUIs in restaurants is explained by the mix of fast-food and sit-down restaurants. Fast-food restaurants tend to be more energy intensive due to relatively smaller seating area. The high value in heating EUI is from simulations while the low value is from metered data (where half of the buildings had gas as their primary heating source).

Warehouse. Data are from sources (2) and (3) (n=12). The range in warehouses end-use EUIs is small.

School. Data are from sources (2) (n=2) and (3) (n=2). The low heating EUI comes from metered data and is explained by the fact that both buildings in the ELCAP sample use gas as their primary heating fuel.

Data for the table came from the following sources:

(1) Northwest Power Planning Council, "Northwest Conservation and Electric Power Plan", Vol. II-Part 1, p. 356, May 1991. Data are from forecasts of 1989 construction and from a subset of ELCAP buildings (post-1979) obtained from source (3). ELCAP EUIs have been adjusted to account for non-electric heating. Forecasts are based on all-electric buildings only and on data from public utilities.

(2) SBW Consulting Inc., "Analysis of Commercial Model Conservation Standards. Conservation Analysis Summary", Final Report, Vol. 1, November 1990. Simulated data from prototypical buildings. All electric with resistance space heating and Seattle weather.

(3) Taylor Z.T., Pratt R.G., "Description of Electric Energy Use in Commercial Buildings in the Pacific Northwest. End-Use Load and Consumer Assessment Program (ELCAP)", Pacific Northwest Labortatory, DOE/BP-13795-22, p. 356, December 1989. End-use metered data from Post-1980 buildings. Both all-electric and fossil-fuel heated buildings are included in ELCAP. The EUIs have not been adjusted to account for non-electric heating. Office buildings average less than 50,000 square feet.

APPENDIX III ASHRAE OCCUPANCY SCHEDULES

Table A3-1
Building Schedule Percentage Multipliers

		Hour 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Assembly Occupancy	Weekday	0	0	0	0	0	0	0	0	20	20	20	80	80	80	80	80	80	80	20	20	20	20	10	0
	Saturday	0	0	0	0	0	0	0	0	20	20	20	60	60	60	60	60	60	60	60	60	60	80	10	0
	Sunday	0	0	0	0	0	0	0	0	10	10	10	10	10	70	70	70	70	70	70	70	70	70	20	0
Assembly Lighting & Receptacle	Weekday	0	0	0	0	0	0	40	40	40	75	75	75	75	75	75	75	75	75	75	75	75	75	25	0
	Saturday	0	0	0	0	0	0	0	30	30	50	50	50	50	50	50	50	50	50	50	50	50	50	0	0
	Sunday	0	0	0	0	0	0	0	30	30	30	30	30	65	65	65	65	65	65	65	65	65	65	0	0
Assembly HVAC	Weekday	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	Saturday	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
	Sunday	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off
Assembly SWH	Weekday	0	0	0	0	0	0	0	0	0	5	5	35	5	5	5	5	5	0	0	0	0	0	0	0
	Saturday	0	0	0	0	0	0	0	0	0	5	5	20	0	0	0	0	0	0	0	65	30	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	5	5	10	0	0	0	0	0	0	0	65	30	0	0	0
Office Occupancy	Weekday	0	0	0	0	0	0	0	10	20	95	95	45	45	95	95	95	95	95	30	10	10	10	0	0
	Saturday	0	0	0	0	0	0	0	10	10	30	30	30	30	10	10	10	10	10	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Office Lighting & Receptacle	Weekday	0	0	0	0	0	0	10	30	90	90	90	90	80	90	90	90	90	50	30	30	20	20	0	0
	Saturday	0	0	0	0	0	0	10	10	30	30	30	30	15	15	15	15	15	0	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Office HVAC	Weekday	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Saturday	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	off	off	off	off	off	off
	Sunday	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off
Office SWH	Weekday	0	0	0	0	0	0	0	15	30	35	35	45	55	50	30	30	40	20	20	10	15	5	0	0
	Saturday	0	0	0	0	0	0	0	10	10	20	15	20	15	15	10	10	10	0	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Retail Occupancy	Weekday	0	0	0	0	0	0	0	10	20	50	50	70	70	70	70	80	70	50	50	30	30	0	0	0
	Saturday	0	0	0	0	0	0	0	10	20	50	60	80	80	80	80	80	80	60	20	20	20	10	0	0
	Sunday	0	0	0	0	0	0	0	0	0	10	20	20	40	40	40	40	40	20	10	0	0	0	0	0

Table A3-1 (cont.)
Building Schedule Percentage Multipliers

		Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Retail Lighting & Receptacle	Weekday	0	0	0	0	0	0	0	20	50	90	90	90	90	90	90	90	90	90	60	60	50	0	0	0
	Saturday	0	0	0	0	0	0	0	10	30	60	90	90	90	90	90	90	90	90	50	30	30	10	0	0
	Sunday	0	0	0	0	0	0	0	0	0	10	40	40	60	60	60	60	60	40	20	0	0	0	0	0
Retail HVAC	Weekday	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off	off
	Saturday	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Sunday	off	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	off	off	off	off	off
Retail SWH	Weekday	0	0	0	0	0	0	0	10	20	30	40	55	60	60	45	40	45	45	40	30	30	0	0	0
	Saturday	0	0	0	0	0	0	0	15	20	25	40	50	55	55	45	45	45	45	40	35	25	20	0	0
	Sunday	0	0	0	0	0	0	0	0	0	10	25	30	35	35	30	30	35	30	20	0	0	0	0	0
Warehouse Occupancy	Weekday	0	0	0	0	0	0	0	15	70	90	90	90	50	85	85	85	20	0	0	0	0	0	0	0
	Saturday	0	0	0	0	0	0	0	0	20	20	20	20	10	10	10	10	0	0	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Warehouse Lighting & Receptacle	Weekdays	0	0	0	0	0	0	0	40	70	90	90	90	90	90	90	90	90	0	0	0	0	0	0	0
	Saturday	0	0	0	0	0	0	0	0	10	25	25	25	10	10	10	10	0	0	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Warehouse HVAC	Weekday	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	off	off	off	off	off	off	off
	Saturday	off	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	off	off	off	off	off	off	off	off
	Sunday	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off
Warehouse SWH	Weekday	0	0	0	0	0	0	0	5	25	35	35	45	55	40	35	40	15	0	0	0	0	0	0	0
	Saturday	0	0	0	0	0	0	0	0	0	10	10	15	0	0	0	0	0	0	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School Occupancy	Weekday	0	0	0	0	0	0	0	5	75	90	90	80	80	80	80	45	15	5	15	20	20	10	0	0
	Saturday	0	0	0	0	0	0	0	0	10	10	10	10	10	0	0	0	0	0	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
School Lighting	Weekday	0	0	0	0	0	0	0	30	85	95	95	95	80	80	80	70	50	50	35	35	30	30	0	0
	Saturday	0	0	0	0	0	0	0	0	15	15	15	15	15	0	0	0	0	0	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A3-1 (cont.)
Building Schedule Percentage Multipliers

		Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
School HVAC	Weekday	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	off	off
	Saturday	off	off	off	off	off	off	off	off	on	on	on	on	on	off	off	off	off	off	off	off	off	off	off	off
	Sunday	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off	off
School SWH	Weekday	0	0	0	0	0	0	0	5	30	55	60	70	75	80	60	60	5	5	15	20	20	20	0	0
	Saturday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hotel/Motel Occupancy	Weekday	90	90	90	90	90	90	70	40	40	20	20	20	20	20	20	30	50	50	50	70	70	80	90	90
	Saturday	90	90	90	90	90	90	70	50	50	30	30	30	30	30	30	30	30	50	60	60	60	70	70	70
	Sunday	70	70	70	70	70	70	70	70	50	50	50	30	30	20	20	20	30	40	40	60	60	80	80	80
Hotel/Motel Lighting & Receptacle	Weekday	20	15	10	10	10	20	40	50	40	40	25	25	25	25	25	25	25	25	60	80	90	80	60	30
	Saturday	20	20	10	10	10	10	30	30	40	40	30	25	25	25	25	25	25	25	60	70	70	70	60	30
	Sunday	30	30	20	20	20	20	30	40	40	30	30	30	30	20	20	20	20	20	50	70	80	60	50	30
Hotel/Motel HVAC	Weekday	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
	Saturday	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
	Sunday	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
Hotel/Motel SWH	Weekday	20	15	15	15	20	25	50	60	55	45	40	45	40	35	30	30	30	40	55	60	50	55	45	25
	Saturday	20	15	15	15	20	25	40	50	50	50	45	50	50	45	40	40	35	40	55	55	50	55	40	30
	Sunday	25	20	20	20	20	30	50	50	50	55	50	50	40	40	30	30	30	40	50	50	40	50	40	20
Restaurant Occupancy	Weekday	15	15	5	0	0	0	0	5	5	5	20	50	80	70	40	20	25	50	80	80	80	50	35	20
	Saturday	30	25	5	0	0	0	0	0	0	5	20	45	50	50	35	30	30	30	70	90	70	65	55	35
	Sunday	20	20	5	0	0	0	0	0	0	0	10	20	25	25	15	20	25	35	55	65	70	35	20	20
Restaurant Lighting & Receptacle	Weekday	15	15	15	15	15	20	40	40	60	60	90	90	90	90	90	90	90	90	90	90	90	90	50	30
	Saturday	20	15	15	15	15	15	30	30	60	60	80	80	80	80	80	80	80	90	90	90	90	90	50	30
	Sunday	20	15	15	15	15	15	30	30	50	50	70	70	70	70	70	70	60	60	60	60	60	60	50	30
Restaurant HVAC	Weekday	on	on	on	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
	Saturday	on	on	on	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
	Sunday	on	on	on	off	off	off	off	off	off	off	on	on	on	on	on	on	on	on	on	on	on	on	on	on

Table A3-1 (cont.)
Building Schedule Percentage Multipliers

		Hour																							
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Restaurant SWH	Weekday	20	15	15	0	0	0	0	60	55	45	40	45	40	35	30	30	30	40	55	60	50	55	45	25
	Saturday	20	15	15	0	0	0	0	0	0	50	45	50	50	45	40	40	35	40	55	55	50	55	40	30
	Sunday	25	20	20	0	0	0	0	0	0	0	50	50	40	40	30	30	30	40	50	50	40	50	40	20
Health Occupancy	Weekday	0	0	0	0	0	0	0	10	50	80	80	80	80	80	80	80	80	50	30	30	20	20	0	0
	Saturday	0	0	0	0	0	0	0	10	30	40	40	40	40	40	40	40	40	10	10	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	5	5	5	5	5	5	5	5	0	0	0	0	0	0	0	0
Heath Lighting & Receptacle	Weekday	0	0	0	0	0	0	0	50	90	90	90	90	90	90	90	90	90	30	30	30	30	30	0	0
	Saturday	0	0	0	0	0	0	0	20	40	40	40	40	40	40	40	40	40	40	10	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	10	10	10	10	10	10	10	10	0	0	0	0	0	0	0	0
Health HVAC	Weekday	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
	Saturday	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
	Sunday	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on	on
Health SWH	Weekday	0	0	0	0	0	0	0	15	55	65	75	80	70	80	75	70	60	40	15	15	15	5	0	0
	Saturday	0	0	0	0	0	0	0	0	15	25	25	25	20	20	20	20	20	5	0	0	0	0	0	0
	Sunday	0	0	0	0	0	0	0	0	0	15	15	15	15	15	15	0	0	0	0	0	0	0	0	0

(a) Reference: ASHRAE/IES Standard 90.1-1989, Table 13-3.

(b) Table A3-1 contains multipliers for converting the nominal values for building occupancy, receptacle power density, service hot water, and lighting energy into time series data for estimating building loads under the standard calculation procedures.

For each standard building profile there are three series - one each for weekdays, Saturdays, and Sunday. There are 24 elements per series. These represent the multiplier that should be use to estimate building loads from 12 a.m. to 1 a.m. (series #1) through 11 p.m. to 12 a.m. (series element #24). The estimated load for any hour is simply the multiplier from the appropriate standard profile multiplied by the appropriate value from the tables cited above.

(c) The building HVAC system schedule listed in Table A3-1 lists the hours when the HVAC system shall be considered ON or OFF in accordance with Section 13.7.3.2 of ASHRAE 90.1-1989.

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APPENDIX IV SAMPLE CONTROLS SEQUENCE OF OPERATIONS

ECONOMIZER SEQUENCE OF OPERATIONS
(For a Rooftop Packaged HVAC Unit)

This control sequence is more elaborate than most that are written. However, we believe that this level of detail is necessary in order to tightly specify the ECM as funded. Also, a commissioning agent could easily take this control sequence and write a detailed functional test plan aimed at performance verification.

Intended operation:

The purpose of the economizer is to use outside air for cooling whenever possible to minimize compressor operating time. When Stage 1 of the space thermostat calls for cooling and the outside air enthalpy is below the controller setpoint, the outside air damper will move toward the open position. Simultaneously, the return air damper will move toward the closed position. The outside air damper will admit a proportionate amount of air necessary to satisfy the mixed air temperature setting of 55°F. If Stage 2 of the space thermostat calls for cooling, second stage mechanical cooling will cycle.

On a call for cooling from the space thermostat, if the outside enthalpy is above the setting on the controller, the outside air damper will remain in the minimum open position. In this event, the space thermostat will cycle the mechanical cooling equipment.

With power on the economizer motor, the outside air damper will always be in the minimum air position during the heating season and whenever the space cooling demand is satisfied. With no power on the economizer motor, the spring in the motor will completely close the outside air damper.

The minimum outside air setting is determined by the adjustment of the minimum position potentiometer located on the economizer motor.

During the night setback cycle, the outside air damper is completely closed.

Check-out:

The check-out procedure is intended to ensure: 1) that the economizer controls and motor function properly; 2) that the dampers perform as intended without binding; 3) that the mechanical cooling system is locked out during Stage 1 cooling.

APPENDIX V SAMPLE PERFORMANCE SPECIFICATIONS

This specification is intended to be representative of a reasonable level of detail in a typical performance specification. However, it does not contain all hardware, software, and execution direction that might be required for a specific building project.

PERFORMANCE SPECIFICATION FOR ENERGY MANAGEMENT AND CONTROL SYSTEM

1. SCOPE OF WORK

Install a DDC energy management and control system (EMCS) to provide night setback and optimum start for each of the building's hydronic heat pumps.

The system shall control operation of each heat pump's supply fan, compressor, and reversing valve as well as the central electric boilers, building supply and exhaust fans, cooling tower and hydronic loop valves and water pumps. Each heat pump shall be controlled on the basis of a user-input occupancy schedule, user-input heating and cooling space temperature setpoints for occupied and unoccupied periods, actual space temperatures, and manual override status. Each of these inputs shall be tracked separately for each heat pump.

2. HARDWARE

The EMCS shall include:

a central processing unit (CPU) capable of running all software and functions listed in these specifications, and

a central Man-Machine Interface, with CRT, keyboard and dot matrix printer, to permit input of schedules and setpoints, and to permit review of actual conditions at each point or create a trend log (history) of setpoints, schedules and actual conditions at any point on the system, and

a manual override for each heat pump, located in the space conditioned by that heat pump.

3. SOFTWARE

The software shall offer the option of assigning a unique occupancy schedule and optimum start calculation for each heat pump. In addition, the software shall be programmed as follows:

3.1 Occupied Mode. In the occupied mode, the heat pump supply fans shall be run continuously to provide ventilation, and the heat pump shall be operated to meet the occupied heating and cooling space temperature setpoints for the space served.

3.2 Unoccupied Mode. During the periods a space is scheduled as unoccupied, the EMCS shall operate the heat pump in the unoccupied mode, unless it is in the Override Mode, Optimum Start Mode, or Heat Recovery Mode, as described below. In the unoccupied mode, the heat pump supply fans shall be on only as necessary to meet the unoccupied heating and cooling space temperature setpoints.

3.3 Override Mode. Each heat pump shall have a manual override switch located in the area it serves. If the manual override switch is activated during a period that the space is selected to be unoccupied, the heat pump operation will go into the occupied mode. The length of the manual override interval shall not exceed 2 hours.

3.4 Optimum Start Mode. It shall be the intent of the optimum start calculations to bring the heat pumps into warm-up, heat pump by heat pump, at the latest possible time on a day-to-day basis, while still meeting the occupied setpoints by the beginning of the scheduled occupancy period, and while minimizing use of the boilers. Warm-up shall begin no more than 5 hours before occupancy (except on Monday mornings). In the Optimum Start Mode, the heat pump shall be operated to take the space temperature from the unoccupied temperature setpoint range to the occupied temperature setpoint range.

3.5 Heat Recovery Mode. If the hydronic loop return temperature drops below 65 degrees, the controls shall scan the heat pumps to see if any of the zones is in the unoccupied mode and has an actual space temperature higher than the occupied space temperature setpoint range. If so, all such heat pumps shall be brought on in the cooling mode until the occupied setpoint(s) is (are) reached. Only then shall the boilers come on, if still necessary.

4. USER-INPUTS

The occupancy schedules input into the EMCS shall agree with the attached list except where tenant occupancy schedules have changed.

The heating setpoint shall, in all cases, be no more than 63°F for unoccupied periods, and no more than 70°F for occupied periods.

The cooling setpoint, for occupied periods, shall be no less than 75°F.

5. DESIGN DOCUMENTS

A full point list and specifications shall be drawn up prior to installation and updated after installation to reflect as-built conditions. The specifications shall give, at least, the control sequences for the boilers, cooling towers, loop controls, and the heat pumps. A copy of the design documents shall be provided to <utility name> (1) after a contract has been awarded and prior to installation, and (2) after they have been edited to reflect as-built conditions.

6. OPERATOR'S MANUALS AND MANUFACTURER'S LITERATURE

The customer shall receive from the manufacturer a complete set of manuals to permit new staff to learn how to operate the system properly, and a full set of cut sheets describing the installed hardware.

7. TRAINING

The controls contractor shall provide two days of training to the building operator(s). If the contractor does not have the expertise to conduct the training himself, he shall subcontract to the manufacturer's representative to conduct the training. The training shall be provided in two separate one-day periods. The 1st period shall be conducted when the EMCS is fully programmed and ready for normal operation. The 2nd period shall be at least several days later, and shall be arranged per the operator's request.

8. COST PROPOSAL

To receive a <utility name> contract for this project, the customer must send the <utility name> analyst a Cost Proposal containing at least the following elements:

> a description of the proposed system, including the total number of points, a list of points for each heat pump, the number of heat pumps served, and itemization of major components, with model numbers,
>
> the controls sequence of operations,
>
> the total installed cost, broken down into equipment, design, labor, training, and overhead and profit, and a statement "This cost covers an installation meeting all of the requirements of the <utility name> Work Orders for this project, dated ______________", and
>
> cut sheets for the proposed equipment.

(The point count shall only include physical points where either a physical condition is measured, or the EMCS operates a physical device. The point count shall not include calculated values.)

9. CODE COMPLIANCE

This project shall comply with all applicable codes. Where permits are required, the installation shall be approved by appropriate building officials. The building owner agrees to maintain compliance documents in their files and have them available to review if requested.

10. PROJECT COMPLETION

<Utility name> payment is made after the <utility name> analyst has confirmed, via documentation review and on-site inspection, that the project meets these Work Orders.

10.1 Documentation.

Prior to inspection, the customer shall send the <utility name> analyst:

a signed, approved copy of any permit(s) required for the project,

an invoice for the full amount of the installation,

a one-week trend log demonstrating that the system is operating per Work Order,

cut sheets for the installed equipment (if different from cut sheets in Cost Proposal), and

Work Orders signed by the installer and the customer and edited by them to reflect as-built conditions.

10.2 On-site Inspection.

The <utility name> analyst will visit the site and confirm that (a) at least one member of the customer's staff has a full understanding of the system so that it can be operated properly, and (b) the installed equipment meets the requirements of these Work Orders.

10.3 Changes.

If the installed project does not meet these Work Order requirements, delays in payment may be introduced, and the funding level may change. Approval for a change to the Work Orders is valid only if it is made in writing by the <utility name> analyst.

This specification is significantly more detailed than the EMCS specification. This sometimes is warranted, especially with relatively new technology, where potential project pitfalls are numerous.

Electronic Ballast Specifications

BIDS

Bids shall give the number of units, the manufacturer and model number, as well as a description of the number and type of lamps served (e.g., "2 each F96T12 slimlines").

Bids shall include cut sheets.

EQUIPMENT

The ballasts shall be electronic.

Each ballast shall have a rated input wattage of no more than 75% of their standard electromagnetic counterparts.

Each ballast shall be listed as U.L. Class P, or be equipped with an internal fuse.

Each ballast shall have at least a 3 year warranty covering both equipment and labor costs.

Total harmonic distortion (THD) of the input current shall be no more than 30% of the total input current. The 3rd harmonic shall be no more than 25% of the total input current.

Each ballast shall be able to withstand input power line transients as defined in ANSI C62.41 (or IEEE Publication 587 Category A) without damage.

Each ballast shall tolerate line voltage variations plus or minus 10 percent.

The power factors shall be no less than 90%.

The ballasts shall be able to start and operate properly with the respective lamps down to 50°F ambient air temperature.

Each ballast type shall be approved by the ballast manufacturer for use with the number and type of lamps it is serving. That approval shall be indicated by the presence of rated input wattage data (for the respective lamp/ballast combination) in the manufacturer's standard literature.

A list of the compatible lamp combinations, and a wiring diagram, shall be given on each ballast.

The ballasts shall be compatible with all controls controlling the new ballasts at the time of the installation and inspection.

INSTALLATION

Each ballast shall be installed in accordance with the manufacturer's written instructions.

The installer shall assure that the neutral wires serving the new ballasts are large enough to carry the ballasts' triple (3rd, 9th, 15th, etc) harmonics without creating unreasonable voltage drops.

PAYMENT

The <utility name> inspector will inspect the installation after receiving the following paperwork:

> an itemized invoice (giving number of ballasts and their manufacturers and model numbers),
>
> an as-built sketch or drawing showing where the ballasts have been installed,
>
> a copy of the approved electrical permit, and
>
> cut sheets for any ballasts that were installed but not bid.

If the installation does not agree with the bid, funding levels may be affected. <Utility name> change order approvals are only valid if made in writing.

APPENDIX VI SAMPLE CALCULATION SPREADSHEET

HAND CALCULATIONS FOR LOADS NOT INCLUDED IN SIMULATION
SAMPLE OFFICE BUILDING

DOMESTIC HOT WATER		
(1 gal/person-day x 260 days x 333,056sf/150sf/person x 8.33 x (110-50 deg F)) / 3412 Btuh/kW		84,564
EXHAUST FAN		
30 hp x .746 x 0.8x	3120 hrs =	55,860
GARAGE EXHAUST		
20 hp x .746 x 0.8x	8760 hrs =	104,559
TOILET EXHAUST		
0.25 hp x .746 x 0.8x	8760 hrs =	1,307
HYDRONIC LOOP PUMPS		
40 hp x .746 x 0.7x	8760 hrs =	182,979
DHW PRESSURE PUMPS		
4 hp x .746 x 0.7x	8760 hrs =	18,298
GARAGE LIGHTS		
35.088 kw x	8760 hrs =	307,371
EXTERIOR LIGHTS		
6.25 kw x	4380 hrs =	27,375
4.5 kw x	8760 hrs =	39,420
ELEVATORS:		
10,272,000 kwh/yr total bldg x	2% =	205,440

TOTAL		1,027,174
	% of total bldg energy	10.00%

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